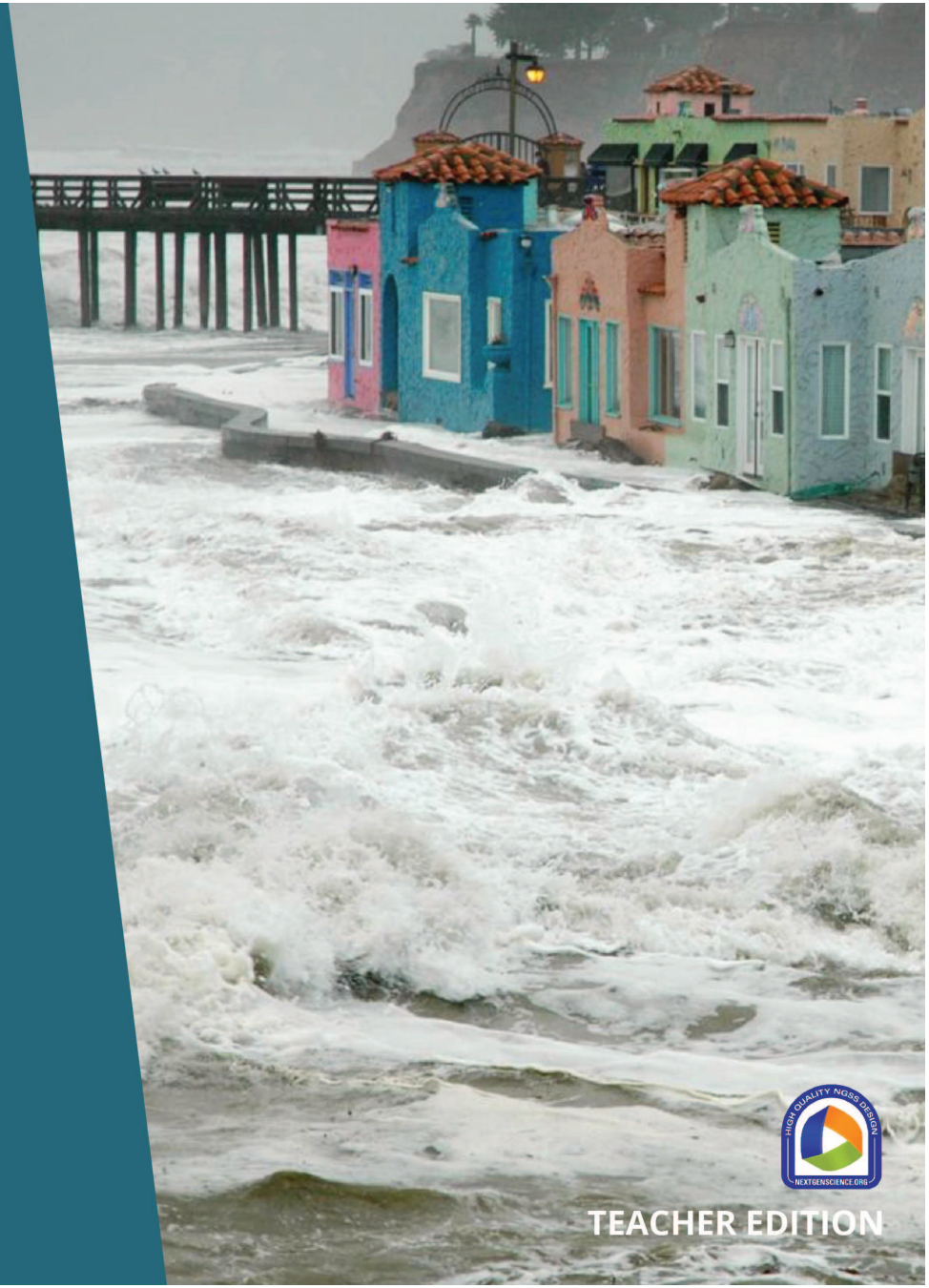
CHEMISTRY

Thermodynamics in Earth's Systems

How can we slow the flow of energy on Earth to protect vulnerable coastal communities?



OpenSciEd

HIGH SCHOOL SCIENCE

HIGH QUALITY NGSS DESIGN NEXTGENSCIENCE.ORG

TEACHER EDITION

How can we slow the flow of energy on Earth to protect vulnerable coastal communities?

Thermodynamics in Earth's Systems: Polar Ice

OpenSciEd Unit C.1

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UNIT OVERVIEW

How can we slow the flow of energy on Earth to protect vulnerable coastal communities?

This unit is anchored by students exploring coastal communities that are affected by rising sea levels, which are forcing some communities to move. Students analyze data that show how sea level rise is historically connected to polar ice melt and temperature increases, and thorough data and investigation determine that the temperature increase is caused by humans releasing excess carbon dioxide into the atmosphere. They are introduced to two possible solutions and figure out how these solutions, along with decreasing carbon dioxide emissions, could help slow sea level rise. Students figure out how energy transfers on the molecular level as well as on the Earth-systems level through radiation, convection, and conduction.

Throughout the unit, students will do the following:

- Develop an energy transfer model based on evidence to illustrate how atmospheric carbon dioxide, more than any other factor, causes global temperature increases, polar ice melt, and sea level rise.
- Use mathematical and computational thinking and investigation to predict and explain the likely impact of matter transfer from the cryosphere to the hydrosphere.
- Apply scientific ideas to examine, explain, and ask questions about two design solutions for polar ice melt.
- Develop an energy transfer model that shows how microbeads could interrupt the feedback loop in which areas with melting polar ice reradiate more infrared light, which is absorbed by carbon dioxide, causing even greater temperatures and more polar ice melt.
- Consider and ask questions about the many feedback loops in and between Earth's systems.
- Evaluate complementary information about glacier melt from Inuit hunters and fishers and NASA scientists.
- Use mathematical thinking to derive and compare densities for water at different temperatures and salinities.
- Collaboratively design and plan an investigation using a computer model to produce simulated data as evidence to figure out what is happening at a particle level when two pieces of matter come in contact that are at different temperatures.
- Use digital tools to computationally analyze data to determine and predict the amount of ice melt when we know the mass and temperature of the water that's in contact with the ice.
- Develop and use particle and energy transfer models to provide mechanistic accounts for how the berm geoengineering solution can help reduce glacier melt.
- Develop the outlines of and use a computational climate model that reflects all the main ideas from the unit, in order to answer questions about the impacts of human activities.

Building Toward NGSS 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.

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.

HS-ESS2-7:
Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.

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.

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.

HS-ESS3-6:

Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

HS-PS3-1:
Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-4:
Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

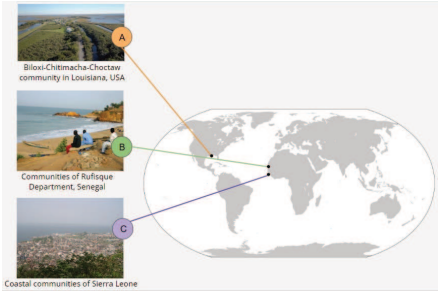
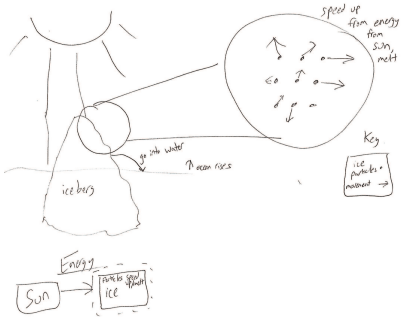
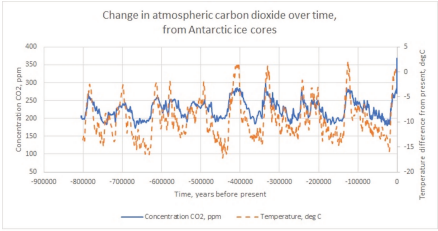
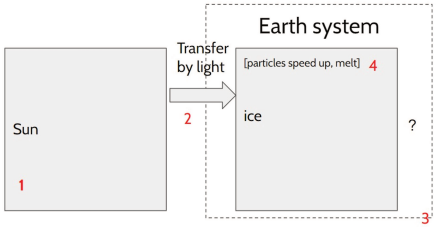
UNIT STORYLINE

Unit Question: How can we slow the flow of energy on Earth to protect vulnerable coastal communities?

How students will engage with each of the phenomena

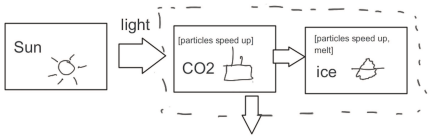
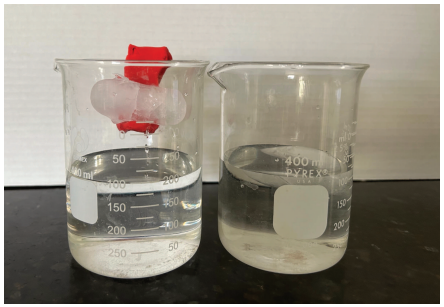
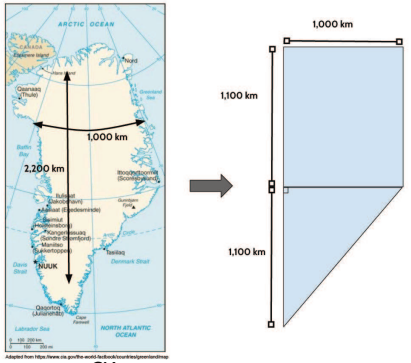
HANDS-ON/ LAB ACTIVITIES | VIDEOS OR IMAGES | DATA SETS | READINGS | COMPUTER INTERACTIVES

Lesson Set 1: Why and how is the sea level rising?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 1 Lesson Set 1 3 days **How are sea levels rising and forcing people to move?** Anchoring Phenomenon	 *Coastal locations are noticing sea level rise due to local and global causes, which are forcing some communities to move.*	We explore coastal communities that are affected by rising sea levels, which is a recent global problem that deeply affects people. We develop community agreements, a class consensus model, a Driving Question Board, and ideas for investigation. We figure out: • Sea levels are rising--some causes we find are local like storms and erosion, but something is affecting sea levels globally. Scientists predict that this will continue. • In chemistry we use ideas about energy and matter to explain confusing things that we see in the world. • Polar ice melt due to climate change is one explanation for why the sea level is rising.	
LESSON 2 Lesson Set 1 3 days **What can the past help us figure out about what is causing sea level rise in the present?** Anchoring Phenomenon, Investigation	 *Sea level tends to increase as temperature increases and polar ice melts. Various factors can affect Earth's climate, but only carbon dioxide can impact it at the timescales we observe.*	We look at historical data of temperature, polar ice volume, sea level, and different possible causes. We discuss and model the likely cause of current ice melt and sea level rise. We figure out: • Over the last million years, global temperatures seem to increase around the same time that ice volumes decrease and sea levels increase. • Scientists have to use indirect sources of evidence to figure out what Earth's climate was like in the past. • Changes in the sunlight that reaches Earth's surface can affect climate. • Changes in carbon dioxide due to plant growth or human activity can affect climate and can help explain current temperature increases.	

⇓ **Navigation to Next Lesson:** We have a lot of questions, but we would like to start by figuring out what is causing the current changes in sea levels and if people have ever encountered something similar before.

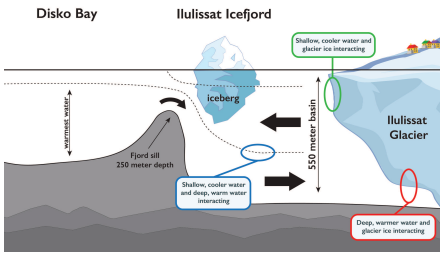
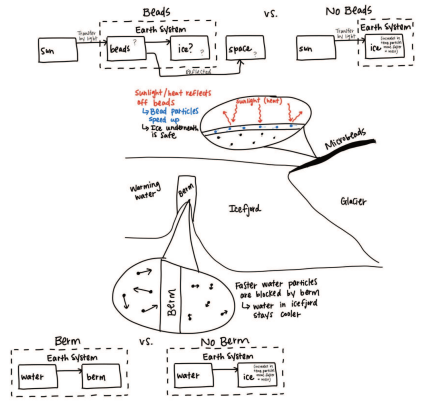
⇓ **Navigation to Next Lesson:** We have evidence that carbon dioxide is likely causing the current temperature increases and therefore sea level rise, but we do not know how that would work. We want to figure it out.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 3 Lesson Set 1 3 days **How does carbon dioxide contribute to climate change?** Investigation	 *In the closed water bottle system, bottles containing more CO2 see a greater increase in temperature under a heat lamp.*	We investigate, model, and read about how increased CO_2 in the atmosphere causes warmer temperatures. We figure out: • The presence of carbon dioxide somehow enhances the rate of warming in a closed water bottle system, which we can use to model Earth's atmosphere. • Energy that enters a system with more carbon dioxide is less likely to exit that system compared to a system with less carbon dioxide. • Earth's atmosphere is a mixture of many different types of gases, including carbon dioxide. • The concentration of carbon dioxide in Earth's atmosphere has increased rapidly over time. Because it can last in the atmosphere for a very long time, we need to find another way to address sea level rise besides reducing CO_2 emissions.	
LESSON 4 Lesson Set 1 3 days **What would happen if the Earth's ice melted?** Investigation, Putting Pieces Together	 *Data about Greenland's and Antarctica's size allow us to calculate how much water the melting ice would add to the world's oceans and we investigate whether both land ice and sea ice raise sea levels.*	We develop a mathematical model to figure out the impact on sea level if Greenland and Antarctica's ice melted. We evaluate our answer using a simulation of sea levels and notice that the ice in the Arctic Ocean is not represented. We wonder if this ice affects sea levels, so we plan and carry out an investigation to see if ice in water affects the water level when it melts. We figure out: • We estimate that if all of Greenland's land ice melted, Earth's sea levels would rise by almost 7 meters. If all of Antarctica's land ice melted, Earth's sea levels would rise by about 55 meters. • A sea level rise of 7 or 55 meters, or even 0.5 meter, would cause many major cities and other places to be covered by water for at least part of the year. • Earth's sea levels would not rise if Earth's sea ice melted, because this ice is already in the ocean. • We have initial ideas about ways that ice sheets could be prevented from melting.	 *Data source: CIA*

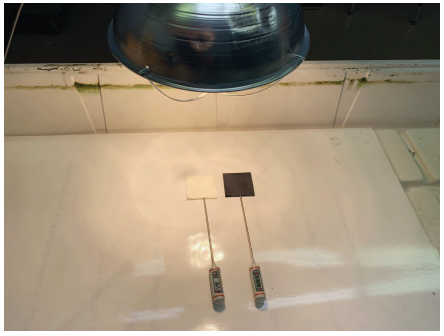
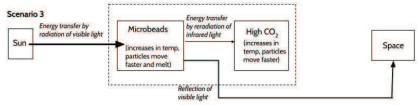
⇓ **Navigation to Next Lesson:** We figure out that carbon dioxide has a substantial impact on atmospheric temperatures and sea level rise, both in terms of the amount of warming and how long Earth will continue to warm up. We wonder how we can address the reality of rising sea levels in the short term.

⇓ **Navigation to Next Lesson:** We brainstormed some possible solutions to mitigate the rising sea levels. Now we are wondering if scientists, engineers, or policymakers have already come up with some solutions, and it sounds to us like a solution that goes to the source of the sea level rise is a good place to start.

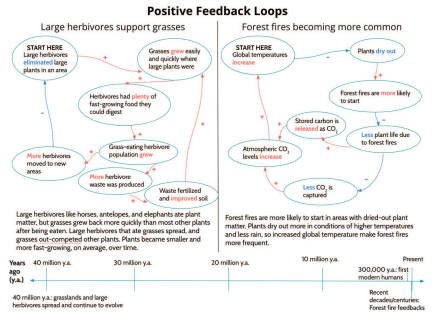
Lesson Set 2: What solutions could help slow polar ice melt?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 5 Lesson Set 2 2 days **How can we best slow or stop the land ice melt?** Problematizing	 *The Ilulissat Glacier has lost a lot of ice mass and has visibly retreated over the past few decades. Scientists have proposed two potential geoengineering solutions to slow the rate of melting at this location — building an underwater berm, or spreading thin layers of microbeads on ice during the summer.*	We use satellite images and modern design ideas to consider possible mitigations for glacier melt. We figure out: • The Ilulissat Glacier is the single largest flow of melt in Greenland. The front edge of the glacier has been receding over many decades. • There are two proposed solutions. One is to build a huge underwater barrier between Disko Bay and Ilulissat Icefjord to prevent warm salty ocean water from coming into contact with the Ilulissat Glacier. The other is to spread thin layers of microbeads on Arctic ice in the summer months. • Rights holders have concerns about the suitability of these designs and their potential impacts.	

⇓ **Navigation to Next Lesson:** We have a lot of new questions about these proposed solutions. We are wondering how they would work and if we should build them. We prioritize figuring out the microbeads first and decide to come back to the berm later.

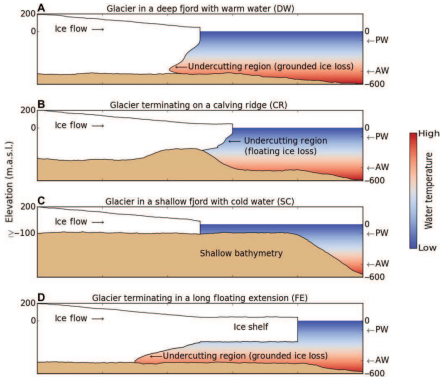
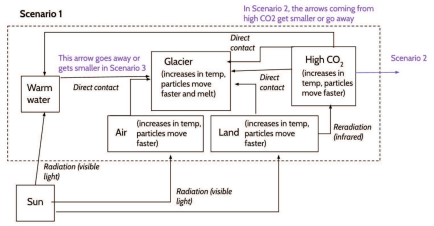
LESSON 6 Lesson Set 2 2 days **Why would some engineers want to sprinkle glass microbeads on the Arctic?** Investigation	 *Different colors of construction paper increase in temperature differently under a heat lamp.*	We plan an investigation to test our ideas about how microbeads prevent ice melt. We read about light energy and discuss how what we read can explain both how carbon dioxide causes temperature increases and how the beads can help prevent melt. We reflect on who should get to decide to use microbeads. We figure out: • Different materials absorb and reflect light energy differently. More reflective materials, like fresh ice or snow, have a high albedo. • When dark materials absorb visible light, their particles speed up and re-emit infrared light over time. • Carbon dioxide and other greenhouse gases transmit visible light, but absorb infrared light, trapping it in the Earth system. • A feedback loop could occur as additional carbon dioxide causes increased temperatures.	

⇓ **Navigation to Next Lesson:** We figure out that microbeads work because they reflect light energy from the Sun and that carbon dioxide absorbs reradiated infrared energy. We are wondering if microbeads really are a good solution to prevent polar ice melt, or if cost, complicated feedback loops, and unintended consequences could hurt their effectiveness.

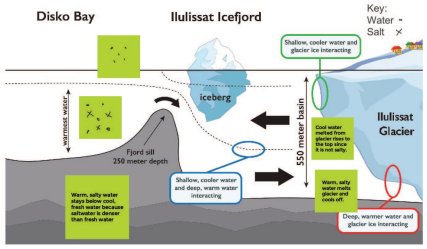
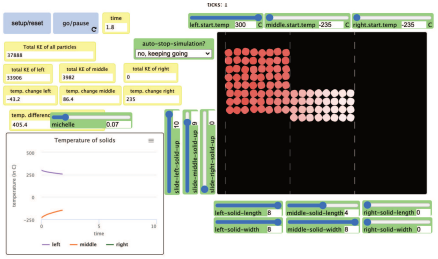
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 7 Lesson Set 2 1 day **How do feedback loops affect Earth's systems?** Putting Pieces Together	 *Many changes in Earth systems, like increased warming due to melting ice and permafrost releasing CO2 that speeds warming, are due to feedback loops.*	We discuss who should decide whether microbeads should be used to slow polar ice melt. We read about feedback loops. We engage with a short mid-unit assessment and check in on our Driving Question Board. We figure out: • Earth's atmosphere and surface have changed significantly over time due to changes in living things, and changes in these systems impact living things in a feedback loop. • A positive feedback loop is one where effects end up reinforcing the original cause, driving more change. A negative feedback loop is one where effects end up counteracting the original cause and limiting its impact. • One feedback loop is thawing permafrost releasing carbon dioxide, which can cause additional warming and permafrost thaw.	

⇓ **Navigation to Next Lesson:** After revisiting the Driving Question Board, we wonder how the berm solution actually works and if there are any feedback loops that could be related to it.

Lesson Set 3: How well would the berm solution work in the context of Earth systems?

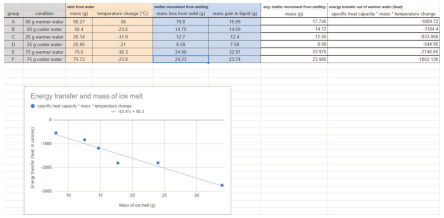
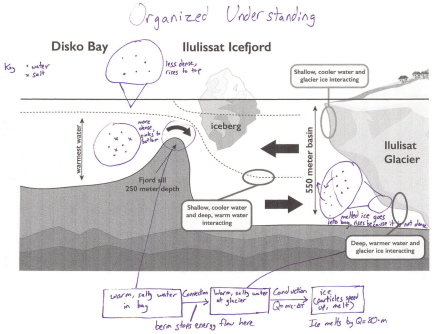
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 8 Lesson Set 3 1 day **What is going on where the ice meets the water?** Investigation, Problematizing	 *Data from Inuit hunters and fishers and NASA scientists suggest that warming oceans contribute to glacial melt*	We pose questions about the interface where glacial ice meets ocean water, and learn from Inuit and NASA experts to frame hypotheses about how proposed solutions would affect energy flows in the area. We figure out: • Some questions are best answered by evidence gathered in the field. • Indigenous Knowledge is a systematic way of thinking. • Both the berm solution and cutting carbon emissions could slow the transfer of energy at the interface.	

⇓ **Navigation to Next Lesson:** We are puzzled that the warmest water is at the bottom of the bay and decide we need to figure out why the warm salty water sinks.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 9 Lesson Set 3 3 days **Why does warm salty water sink to melt a glacier?** Investigation	 *Samples of water of different temperatures and amounts of salt form layers when they first come into contact with one another.*	We create models of water at different conditions. We investigate the mass and volume of water under these conditions, graph our results, and calculate densities. We figure out: • Density of a substance (or a sample) is its mass per unit volume. • When denser fluids are added above less dense fluids, the denser fluids sink. • When denser fluids are moved beneath less dense fluids, they tend to remain separated and flow independently of each other. • Changes in energy and matter happen together, including in convection, when energy transfers as substances move.	
LESSON 10 Lesson Set 3 3 days **How can we measure the energy transfer a berm prevents?** Investigation	 *Two computer simulations help model how energy transfers from a warmer object to a cooler one.*	We use an investigation, simulations, and mathematical modeling to examine energy transfer when substances are in direct contact. We figure out that when two objects/samples at different temperatures are in contact with one another, this is what happens: • Energy transfer between two objects/samples initially at different temperatures will cause both to eventually reach the same final temperature, which will be between the initial temperatures. • The mass of each sample affects where the final temperature stabilizes (ΔT depends on m). • Energy is conserved. It flows between objects but is not created or destroyed. • Conduction is the transfer of energy through direct contact as particles collide. • The specific heat (c) of a substance or mixture tells us how much energy in calories is needed to change 1 gram of it by 1 °C. • Heat transfer Q into or out of a substance can be found by multiplying the specific heat, mass, and temperature change.	$Q = c_p \cdot m \cdot \Delta T$ Energy transferred = c_p · mass · temperature change (calories) (grams) (°C) **Substance or Mixture** / **Specific heat, c_p calories / (g · °C)** Dry air — 0.24 Limestone — 0.22 Sand — 0.20 Copper — 0.09 Water — 1.00

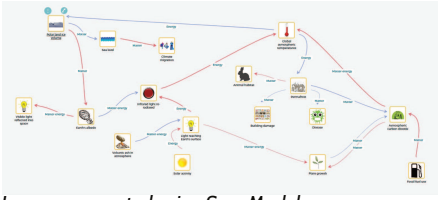
⇓ **Navigation to Next Lesson:** Though we now see how creating a barrier at the bottom of the ocean would prevent warmer saltwater from coming into contact with the bottom of Ilulissat Glacier, we are unsure about how this melting process works.

⇓ **Navigation to Next Lesson:** We have an equation to calculate the heat transfer to a glacier from warm water, but we may not have the information we need to apply this equation in the context of Ilulissat Glacier.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 11 Lesson Set 3 1 day **How does heat affect the amount of ice melt?** Investigation	 *The mass of ice melt varies with the surrounding water temperature.*	We reflect on where our new heat equation fits into our energy transfer model. We realize that we do not know what affects the amount of ice melt other than incoming heat, so we plan and conduct an investigation in which we measure both the temperature change of the water and the mass change of the melting ice. We figure out from the slope of the best-fit line of the data that 80 calories of energy are required to melt 1 gram of ice. We consider how this understanding might help us in addressing glacier melt and sea level rise. We figure out: • Because energy is conserved, the heat that transfers out of the water in our investigation flows to the ice. • 80 calories of energy are required to melt 1 gram of ice ($Q = 80 \cdot m$). • We can use our mathematical model to predict the amount of ice melt when we know the mass and temperature of the water it is in contact with.	
LESSON 12 Lesson Set 3 2 days **How can we slow the flow of energy on Earth to protect vulnerable coastal communities?** Putting Pieces Together, Problematizing	 *We can predict how a berm might affect the ice melt at Ilulissat Glacier.*	We develop a model that can help us further evaluate the berm solution. We develop this mathematical model, then use it to calculate the berm's impact on ice melt. We brainstorm ideas for an expanded computational model that includes the Earth system beyond the glacier. We figure out: • We can build a mathematical model that will allow us to figure out how much ice melt the berm can prevent. • About 5 x 10^{18} calories of annual energy flow into the Ilulissat Glacier system could be prevented by the proposed berm solution, so the berm could theoretically stop glacier melt at that location. • We can expand our model to include a larger system (i.e., on the global scale, rather than the scale of a particular glacier).	

⇓ **Navigation to Next Lesson:** We have the information we need to figure out how much energy transfer a berm prevents as we consider this proposed solution.

⇓ **Navigation to Next Lesson:** We figured out what impact the berm has, but we want an extended computational model that can help us consider the many impacts that humans have had or could have on the environment.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 13 Lesson Set 3 3 days **How can we model what will happen to Earth's climate if humans make changes?** Putting Pieces Together 	 *We can build models that help us predict how different human actions will affect climate.*	We read about how scientists carry out and use climate modeling. We use this understanding to develop questions we can ask of our computational model, then test them. We discuss our results and reflect on how they make us feel. We close out our Driving Question Board and complete a transfer task focused on indoor heating in a changing climate. We figure out: • Climate models work using equations for energy and matter transfer like those we developed. • They are based on assumptions and are therefore not perfectly predictive. • Models are improved as scientists get new information. • Climate models agree that Earth will continue to warm significantly if no changes are made. • Our computational model shows that solutions that decrease carbon dioxide in the atmosphere or energy reaching Earth's surface could prevent some sea level rise and its negative impacts on people. • Heat pumps provide a possible solution to help limit carbon dioxide emissions while keeping homes safe and comfortable.	 *Images generated using SageModeler (https://sagemodeler.concord.org/), developed at the Concord Consortium and Michigan State University.*

⇓ **Navigation to Next Lesson:** This is the last lesson of the unit.

LESSONS 1-13

30 days total

TEACHER BACKGROUND KNOWLEDGE

Lab Safety Requirements for Science Investigations

It is important to adopt and follow appropriate safety practices when conducting hands-on science investigations and demonstrations, whether in an instructional space (traditional laboratory or classroom) or in the field. To this end, teachers must be aware of any school or district safety policies, legal safety standards, and better professional safety practices that are applicable to the activities being undertaken.

Science safety practices in instructional spaces require engineering controls and personal protective equipment (e.g., sanitized safety goggles or safety glasses with side shields as appropriate, non-latex aprons and gloves, eyewash/shower station, fume hood, appropriate ventilation, and fire extinguishers). **Science investigations should always be directly supervised by qualified adults, who should review safety procedures annually, and also before initiating any hands-on activities or demonstrations.** Prior to each investigation, students should be reminded of the specific safety procedures they must follow. Each lesson within the OpenSciEd units includes teacher guidelines for applicable safety procedures for setting up and running an investigation, as well as disassembling, disposing of, and storing materials.

Prior to the first investigation of the year, a safety acknowledgement form for students and parents/guardians should be provided and signed. You can access a model safety acknowledgement form for high school activities here: https://static.nsta.org/pdfs/SafetyAcknowledgmentForm-HighSchool.pdf

Disclaimer: The safety precautions provided for each activity are based in part on use of the specifically recommended materials and instructions, as well as legal safety standards and better professional safety practices. Be aware that selecting alternative materials or procedures for these activities may affect the activity's level of safety, and is therefore at the user's own risk.

Please follow these lab safety recommendations for any science investigation:

1. Wear sanitized safety goggles (specifically, indirectly vented chemical splash goggles) or safety glasses with side shields, as appropriate, a non-latex apron, and non-latex gloves during the set-up, hands-on investigation, and take-down segments of the activity.
2. Safety goggles are required when working with liquid biological or chemical hazards (e.g., microbes, acids, bases, etc.). Safety glasses with side shields or safety goggles may be used when working with physical hazards (sharps, springs, glass, projectiles, etc.).
3. Immediately wipe up any spilled liquid (e.g., water) and/or granules on the floor, as this is a slip-and-fall hazard.
4. Follow your *Teacher Guide* for instructions on disassembling and storing materials and disposing of waste materials.
5. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
6. Wash your hands with soap and water immediately after completing the activity.
7. Never eat any food items used in a lab activity.
8. Never taste any substance or chemical in the lab.
9. Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
10. Use caution when working with glassware, which can shatter if dropped and cut skin.
11. Use caution when using sharp [tools/materials], which can cut or puncture skin.
12. Never pour chemicals, either used or unused, back into their original container. Dispose of chemicals according to your teacher's instructions.
13. If you get a hazardous chemical on your clothing or have a clothing fire, use the emergency shower.
14. If you get a chemical in your eye, use an eyewash station immediately.
15. Point the test tubes, beakers, or other vessels away from yourself and other people when the vessels contain reactants or other substances.
16. When diluting acids or bases, the acid or base should be added to water and not water to the acid or base.
17. Projective trajectory zones must be well defined and free of any obstacles. No participant is to be in the zone during operation of the projectile..
18. Make sure the ventilation system meets the needs relative to removal of flammable vapors produced. Also make sure there are no active flames or sparks in the work zone.

Specific safety precautions are called out within the lesson using this icon and a call-out box.

Where does this unit fall within the OpenSciEd Scope and Sequence?

This unit is the first in the OpenSciEd High School Chemistry course sequence. In OpenSciEd High School Biology, students built proficiency with crosscutting concepts and science and engineering practices that are leveraged throughout this unit. They also began to build understandings of speciation and the role of human activity in Earth systems, which they build on in this unit. Several of the Performance Expectations (PEs) in this unit are shared across other units and across OpenSciEd High School courses. HS-PS3-1 is shared with *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*, *OpenSciEd Unit P.1: How can we design more*

reliable systems to meet our communities' energy needs? (Electricity Unit), and *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*. HS-ESS2-7 is shared with *OpenSciEd Unit B.5: What will happen to Arctic bear populations as their environment changes?(Speciation Unit)*. HS-ESS3-1 is shared with *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*. HS-ESS3-6 is shared with *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*. HS-PS3-4, HS-ESS2-2, HS-ESS2-4, and HS-ESS3-5 are addressed in this unit alone in the OpenSciEd course sequence.

As this unit is intended as the first in the OpenSciEd High School Chemistry course, it intentionally incorporates, in the moment, a number of activities that would typically take place in a "Unit 0." These include co-construction of Community Agreements, investigation planning, use of some simple laboratory equipment, lab safety guidelines, measurement, scientific notation, and unit conversions. We recommend that you begin this unit at the start of the school year, following any requirements in your school or district. In addition, students may benefit from a collaborative hands-on activity prior to the start of this unit. This will help prepare students to talk with each other, work together, and ask questions about phenomena throughout the unit and course.

What is the anchoring phenomenon and why was it chosen?

For the anchoring phenomenon, students explore stories of and data about communities that are impacted by and responding to sea-level rise. These responses often involve human migration away from rising sea levels. Students consider where water is found on Earth and develop models about this phenomenon that share initial ideas about how and why the sea level is rising. Because this phenomenon of sea-level rise is driven in significant part by polar ice melt, it provides a meaningful context in which students can consider not only anthropogenic climate change and its impacts, but also physical science ideas around energy transfer. This phenomenon also generated high student interest across racial and gender identities and locations (rural/urban) in a national survey. Furthermore, it successfully garnered student interest in the unit field test.

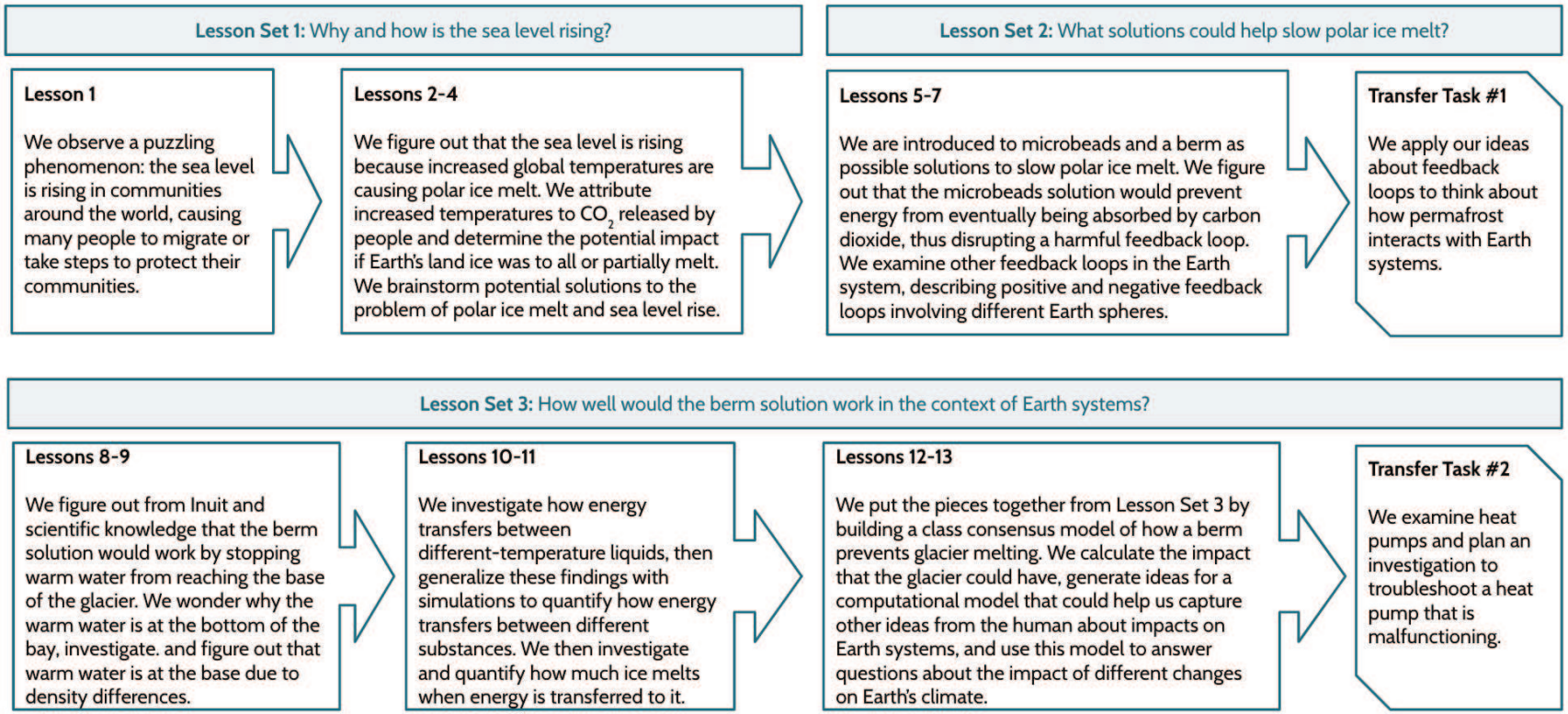
This anchoring phenomenon was chosen from a group of phenomena aligned with the target performance expectations based on the results of a survey administered to students from across the country and in consultation with external advisory panels that include teachers, subject matter experts, and state science administrators. The anchor was chosen for the following reasons:

- Teachers and administrators saw high relevance to students' everyday experiences.
- Explaining how global warming affects sea-level addresses all the DCIs in the bundle at a high-school level.
- Students have the opportunity to apply their ideas to a real-world scenario that they are likely to encounter in the future.

This anchoring phenomenon provides a compelling example of the effects of human-caused climate change. Students will explicitly return to issues related to climate change in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)* (ocean acidification), *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)* (replacing fossil fuels in transportation), and *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)* (improving the electricity grid). There will also be implicit connections in the remaining chemistry units, *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)* (as students think about the dangers of lightning as extreme storms become more frequent due to climate change) and *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)* (as students consider whether human beings could survive off of Earth).

How is the unit structured?

The unit is organized into three lesson sets. Lesson Set 1 (Lessons 1-4) focuses on explaining sea-level rise with science ideas about how increased energy in Earth's systems causes polar ice melt. Lesson Set 2 (Lessons 5-7) emphasizes how spreading microbeads on polar ice or reducing carbon dioxide emissions could reduce polar ice melt, and therefore sea-level rise, by disrupting harmful feedback loops. This lesson set also introduces a berm as another possible solution to slow sea-level rise. Lesson Set 3 (Lessons 8-13) supports students as they figure out how the berm solution works and quantify its impact. Students bring these ideas together in a climate model in Lesson 13, then apply them in a transfer task.


Lesson Set 1: Why and how is the sea level rising?
Lesson 1
We observe a puzzling phenomenon: the sea level is rising in communities around the world, causing many people to migrate or take steps to protect their communities.
Lessons 2-4
We figure out that the sea level is rising because increased global temperatures are causing polar ice melt. We attribute increased temperatures to CO_2 released by people and determine the potential impact if Earth's land ice was to all or partially melt. We brainstorm potential solutions to the problem of polar ice melt and sea level rise.
Lesson Set 2: What solutions could help slow polar ice melt?
Lessons 5-7
We are introduced to microbeads and a berm as possible solutions to slow polar ice melt. We figure out that the microbeads solution would prevent energy from eventually being absorbed by carbon dioxide, thus disrupting a harmful feedback loop. We examine other feedback loops in the Earth system, describing positive and negative feedback loops involving different Earth spheres.
Transfer Task #1
We apply our ideas about feedback loops to think about how permafrost interacts with Earth systems.
Lesson Set 3: How well would the berm solution work in the context of Earth systems?
Lessons 8-9
We figure out from Inuit and scientific knowledge that the berm solution would work by stopping warm water from reaching the base of the glacier. We wonder why the warm water is at the bottom of the bay, investigate. and figure out that warm water is at the base due to density differences.
Lessons 10-11
We investigate how energy transfers between different-temperature liquids, then generalize these findings with simulations to quantify how energy transfers between different substances. We then investigate and quantify how much ice melts when energy is transferred to it.
Lessons 12-13
We put the pieces together from Lesson Set 3 by building a class consensus model of how a berm prevents glacier melting. We calculate the impact that the glacier could have, generate ideas for a computational model that could help us capture other ideas from the human about impacts on Earth systems, and use this model to answer questions about the impact of different changes on Earth's climate.
Transfer Task #2
We examine heat pumps and plan an investigation to troubleshoot a heat pump that is malfunctioning.

What elements of the NGSS three dimensions are developed in this unit?

It should be noted that this unit leverages different elements of Analyzing and Interpreting Data than those articulated in HS-ESS2-2 and HS-ESS3-5. Although students use spreadsheets as a technology to analyze data, the focus is on developing mathematical models rather than making claims. This was done to best support student sensemaking around the anchoring phenomenon and the whole bundle or performance expectations, rather than around individual, disconnected performance expectations. This particular SEP element (4.1) will be intentionally developed in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*.

This unit is designed to introduce students to ideas about energy transfer and human impacts on the climate in a meaningful setting with human implications. Because this unit begins the course, **asking questions is intentionally developed across the unit**, beginning in Lesson 1 with the Driving Question Board and continuing throughout the unit. In Lessons 3, 5, 7, and 11, students ask questions arising from particular contexts. In Lesson 9 they think more deeply about the best questions to use in an investigation. This practice culminates with asking questions of a computational model in Lesson 13 that are not necessarily drawn from the prior activity. Many of the students' questions involve tracking **energy and matter** or clarifying ideas about **energy transfer** in **Earth systems that are being modified by humans**.

We should note that "defining problems" is intentionally not referenced above. Sea-level rise certainly represents a problem, and to show that this problem is not hopeless students engage with engineering solutions throughout the unit. The presented solutions provide a context for figuring out science ideas, but students are not intentionally engaged in defining problems or developing solutions, as engineering is systematically developed in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)* and *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*.

Energy and matter is **intentionally developed** across this unit. From Lesson 1, these two ideas are framed as central to the way that we use chemistry to explain the world. In Lesson 2, the class begins to formally develop **energy transfer** models, as described in *Energy Anchor Chart* (which also details how the "Rules for Energy Transfer" anchor chart is used to track student thinking). Students consider energy and matter **conservation** in Lesson 3 and practice with their energy transfer models in Lessons 3, 5, and 6. Students annotate a particularly complex energy transfer model in Lesson 8 and complete one again as a class in Lesson 9 before finally developing their own in Lesson 10. Students also **quantify** energy in Lesson Set 3 and figure out that energy and matter are intimately connected. In Lesson 9, the Matter-Energy-Forces triangle (M-E-F triangle) is first introduced, and will be returned to in subsequent chemistry and physics units.

Systems and system models is also **intentionally developed** across this unit. Systems are first defined as a class in Lesson 1, then developed in every subsequent lesson as students develop an energy transfer model and explicitly indicate how energy transfers among the systems under consideration. Lesson 8 highlights system thinking in particular as students compare how Inuit fishers and hunters and NASA scientists think about systems in complementary ways. This thinking culminates in Lesson 12 as students describe the boundaries of the Earth system so that they can engage with a computational model in Lesson 13. Students also consider ideas about the reliability of models in Lessons 9 and 13.

The actual modeling piece is heavily scaffolded in this unit through the use of energy transfer models, but **developing and using models** is **key to the sensemaking** in this unit. This practice was already developed at the high school level in OpenSciEd High School Biology and will be further developed in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*.

To familiarize students with the chemistry classroom and its particular requirements and affordances, **planning and carrying out investigations** is **intentionally developed** in this unit. Students collaboratively plan relatively simple investigations in Lessons 3-6 before moving on to more complex investigations, or investigations with individual planning in Lessons 9-11. These latter investigations involve **quantification of energy** and other ideas for use in mathematical **models** of **energy transfer**. Students' thinking around planning investigations is recorded on an anchor chart as described in *Investigation Anchor Chart*.

Because of the unit's heavy emphasis on mathematical modeling, the use of **mathematics and computational thinking** is **intentionally developed** in this unit. Students begin this modeling in Lesson 4 as they try to track the movement of water through Earth's **systems** and consider the impact on **human migrations.** They recognize that humans can **model and predict changes in Earth systems** and do so using unit conversions. Students have an opportunity to practice unit conversions in Lesson 6. They then mathematically model energy transfers in Lessons 10 and 11, before compiling their different mathematical models in Lesson 12. Students then develop a computational model of climate for use in Lesson 13, having also engaged with computational models or simulations in Lessons 4 and 10. Tools used for mathematical and computational thinking are recorded on an anchor chart as described in *Mathematical Anchor Chart*.

Analyzing and interpreting data is **key to the sensemaking** in this unit, particularly in the context of developing mathematical **models** of **energy transfer** in Lesson 9. This activity is done primarily as a class so that students who have never worked with lines of best fit do not get lost. However, students also analyze data in a much simpler form in Lesson 2 as they try to determine which **changes in energy flows in Earth systems cause increases in global temperature.**

Stability and change is **key to the sensemaking** in this unit. Students apply ideas about stability and change at global scales, as done in OpenSciEd High School Biology. They consider amounts and rates of changes to sea level and polar ice and figure out that feedback loops are present in Earth's systems as students develop energy transfer models in Lesson 6. Although students should be familiar with feedback loops from biology, these are introduced in a somewhat more chemistry-oriented context here as they are important to sensemaking about stability and change at the particle level students will further develop in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*. Students also develop the idea of equilibrium in Lesson 10 as they observe that particles in a simulation are moving, but the overall system is not changing significantly.

This unit builds toward these performance expectations:

HS-PS3-1† Create a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flow in and out of the system are known.
HS-PS3-4 Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperatures are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).
HS-ESS2-2 Analyze geoscience data to make the claim that one change to Earth's surface can create feedback that causes changes to other Earth systems.
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.
HS-ESS2-7† Construct an argument based on evidence about the simultaneous coevolution of Earth's systems and life on Earth.
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.
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 on Earth systems.
HS-ESS3-6† Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified due to human activity.

*This performance expectation is developed across multiple units.
†This performance expectation is developed across multiple courses.

Science and Engineering Practices	Disciplinary Core Ideas*	Crosscutting Concepts
Asking Questions and Defining Problems: This unit **intentionally develops** students' engagement in these practice elements: • Ask questions that arise from careful observation of phenomena, or unexpected results, to clarify and/or seek additional information. • Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships. • Ask questions to determine relationships, including quantitative relationships, between independent and dependent variables. • Ask questions to clarify and refine a model, ~~an explanation,~~ or an engineering problem. • 1.5 Evaluate a question to determine if it is testable and relevant. • Ask questions that can be investigated within the scope of the ~~school laboratory, research facilities, or~~ field (e.g., outdoor environment) with available resources and, when appropriate, frame a hypothesis based on a model or theory. • Ask ~~and/or evaluate~~ questions that challenge the ~~premise(s) of an argument, the interpretation of a data set, or the~~ suitability of a design.	**PS3.A: Definitions of Energy** • Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another ~~and between its various possible forms~~. (HS-PS3-1, HS-PS3-2) **PS3.B: Conservation of Energy and Energy Transfer** • Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (HS-PS3-1) • Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-1, HS-PS3-4) • Mathematical expressions, which quantify how the stored energy in a system depends on ~~its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and~~ speed, allow the concept of conservation of energy to be used to predict and describe system behavior. (HS-PS3-1) • Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., ~~water flows downhill~~, objects hotter than their surrounding environment cool down). (HS-PS3-4)	**Systems and Systems Models:** This unit **intentionally develops** students' engagement in these crosscutting concept elements: • Systems can be designed to do specific tasks. • When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. • Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions—including energy, matter, ~~and information~~ flows—within and between systems at different scales. • Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models.

Science and Engineering Practices	Disciplinary Core Ideas*	Crosscutting Concepts
Planning and Carrying Out Investigations: This unit **intentionally develops** students' engagement in these practice elements: • Plan an investigation ~~or test a design individually and~~ collaboratively to produce data to serve as the basis for evidence as part of ~~building and~~ revising models, ~~supporting explanations for phenomena, or testing solutions to problems~~. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. • Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, ~~risk~~, time), ~~and refine the design accordingly~~. • Plan and conduct an investigation or test a design solution in a safe ~~and ethical~~ manner including considerations of ~~environmental, social, and~~ personal impacts. • Select appropriate tools to collect, ~~record, analyze, and evaluate~~ data. • Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated. **Using Mathematics and Computational Thinking:** This unit **intentionally develops** students' engagement in these practice elements: • Create ~~and/or revise~~ a computational model or simulation of a ~~phenomenon, designed device, process, or~~ system. • Use mathematical, computational, ~~and/or algorithmic~~ representations of phenomena or design solutions to ~~describe and/or~~ support claims ~~and/or explanations~~. • Apply techniques of algebra and functions to represent ~~and solve~~ scientific ~~and engineering~~ problems. • Use simple limit cases to test ~~mathematical expressions, computer programs, algorithms, or~~ simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world. • Apply ratios, ~~rates, percentages~~, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m^3, acre-feet, etc.).	**PS3.D: Energy in Chemical Processes** • Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-3, HS-PS3-4) **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. (secondary to HS-ESS2-4) **ESS2.A: Earth Materials and System** • Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes. (HS-ESS2-1, HS-ESS2-2) • The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. (HS-ESS2-4) **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. (HS-ESS2-4) • Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. (HS-ESS2-6, HS-ESS2-7) • Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. (HS-ESS2-4, HS-ESS2-6) • Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and by the ways in which these gases are absorbed by the ocean and biosphere. (secondary to HS-ESS3-6)	**Energy and Matter:** This unit **intentionally develops** students' engagement in these crosscutting concept elements: • The total amount of energy and matter in closed systems is conserved. • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. • Energy cannot be created or destroyed—only moves between one place and another place, between objects ~~and/or fields~~, or between systems. • Energy drives the cycling of matter within and between systems. The following crosscutting concepts are also **key to the sensemaking** in this unit: • Stability and Change • Scale, Proportion, and Quantity

Focal Science and Engineering Practices	Focal Disciplinary Core Ideas*	Focal Crosscutting Concepts
The following practices are also **key to the sensemaking** in this unit: • Developing and Using Models • Analyzing and Interpreting Data	**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. (HS-ESS2-7) **ESS3.A: Natural Resources** • Resource availability has guided ~~the development of~~ human society. (HS-ESS3-1) **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. (HS-ESS3-1) **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. (HS-ESS3-5) • Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities. (HS-ESS3-6)	

*"Disciplinary Core Ideas" are reproduced verbatim from A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. DOI: https://doi.org/10.17226/13165. National Research Council; Division of Behavioral and Social Sciences and Education; Board on Science Education; Committee on a Conceptual Framework for New K-12 Science Education Standards. National Academies Press, Washington, DC. This material may be reproduced and used by other parties with this attribution. If the original material is altered in any way, the attribution must state that the material is adapted from the original.

Connections to the Nature of Science (NOS) and Engineering, Technology, and Applications of Science (ETS)

Connections to the Nature of Science (NOS)	
Which elements of NOS are developed in the unit?	How are they developed?
Scientific Investigations Use a Variety of Methods. Science investigations use diverse methods and do not always use the same set of procedures to obtain data.	Students engage with a variety of investigations throughout the unit.
Scientific Investigations Use a Variety of Methods. Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings.	Students are encouraged to be precise in data collection, honest about their results, and appropriately skeptical of ideas.

Scientific Knowledge is Based on Empirical Evidence. Science arguments are strengthened by multiple lines of evidence supporting a single explanation.	Students gather multiple types of evidence (e.g., historical and experimental data, or experimental and simulation-based data) to support their ideas.

Connections to the Nature of Science (NOS)	
Which elements of NOS are developed in the unit?	How are they developed?
Scientific Knowledge is Open to Revision in Light of New Evidence. Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.	Students read about how scientists change their climate models based on updated assumptions or new data.
Science Models, Laws, Mechanisms, and Theories Explain Natural Phenomena. Scientists often use hypotheses to develop and test theories and explanations.	Students develop their own hypotheses based on prior understanding and test these hypotheses.
Science is a Way of Knowing. Science is a unique way of knowing and there are other ways of knowing.	Students explicitly compare the ways of knowing of Inuit hunters and fishers and NASA scientists.
Science Addresses Questions About the Natural and Material World. Science and technology may raise ethical issues for which science, by itself, does not provide answers and solutions.	Students consider aspects of the Learning in Places Ethical Deliberation and Decision-Making in Socio-Ecological Systems Framework as they consider the implications of potential solutions to polar ice melt.
Science Addresses Questions About the Natural and Material World. Many decisions are not made using science alone, but rely on social and cultural contexts to resolve issues.	Students hear from a variety of perspectives as they consider whether the proposed solutions would have a positive impact.

Connections to Engineering, Technology, and Applications of Science (ETS)	
Which elements of ETS are developed in the unit?	How are they developed?
Influence of Engineering, Technology, and Science and Society and the Natural World. New technologies can have deep impacts on society and the environment, including some that were not anticipated.	Students consider aspects of the Learning in Places Ethical Deliberation and Decision-Making in Socio-Ecological Systems Framework as they consider the implications of potential solutions to polar ice melt.

How does the unit build three-dimensional progressions across the course and the program?

OpenSciEd units support students in integrated development and use of the three dimensions. No one dimension can be developed in isolation from the others, as reflected in three-dimensional Lesson-Level Performance Expectations (LLPEs) which detail the specific dimensions and elements used and assessed in each lesson. However, some practices and crosscutting concepts are more productive for investigating particular anchoring phenomena, so focal practices and crosscutting concepts are articulated in each unit. All 46 SEP and 29 CCC elements are developed at some point in the high school OpenSciEd program, so all elements of a given SEP or CCC may not be present even in a unit that emphasizes developing that SEP or CCC.

This unit uses and builds upon **disciplinary core ideas (DCIs)** and other science ideas that students should have previously developed in OpenSciEd High School Biology.

- 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. (*OpenSciEd Unit B.5: What will happen to Arctic bear populations as their environment changes?(Speciation Unit)*)
- Carbon dioxide cycles into Earth's atmosphere and is at high levels right now due to human activity. This results in relatively high global temperatures, as we can show by modeling energy and matter flows between Earth systems. (*OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*)

Although students should be familiar with the second point from *Fires Unit*, in this unit it is further emphasized, along with debunking of other "alternate explanations" for climate change on Earth, to ensure that students are engaging with the rest of the unit from the same set of base assumptions. This unit expands on the work done in *Fires Unit* by expanding the mechanism for the enhanced greenhouse effect and comparing the role of carbon dioxide to other factors that can impact energy flows on Earth and therefore global climate.

This unit reinforces and builds from the following **disciplinary core ideas (DCIs)** and other science ideas from the OpenSciEd Middle School sequence:

- Energy flows through Earth's systems. (*OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*)
- Global movements of water and its changes in form are propelled by sunlight and gravity. Variations in density due to variations in temperature and salinity drive a global pattern of interconnected ocean currents. (*Storms Unit*)
- gases and liquids are made of molecules or inert atoms that are moving about relative to each other. (*OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*)
- When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light. (*OpenSciEd Unit 6.1: Why do we sometimes see different things when looking at the same object? (One-way Mirror Unit)*, *Cup Design Unit*)
- The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment. (*Cup Design Unit*)
- Energy is spontaneously transferred out of hotter regions or objects and into colder ones. (*Cup Design Unit*)
- The term "heat" as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects. (*Cup Design Unit*)
- Temperature is not a measure of energy; the relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present. (*Cup Design Unit*)
- Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present. (*Cup Design Unit*)
- In a liquid, the molecules are constantly in contact with others; in a gas, they are widely spaced except when they happen to collide. In a solid, atoms are closely spaced and may vibrate in position but do not change relative locations. (*Cup Design Unit*)
- The changes of state that occur with variations in temperature or pressure can be described and predicted using these models of matter. (*Cup Design Unit*)

Although students developed a strong mechanism for climate change in *OpenSciEd Unit 7.6: How do changes in Earth's system impact our communities and what can we do about it? (Droughts and Floods Unit)* and returned to these ideas in OpenSciEd High School Biology in *Fires Unit*, students rebuild these ideas at a high school level in this unit due to their centrality of understanding the urgency of the sea-level rise problem, its mechanism compared to natural mechanisms of energy transfer throughout Earth systems, and the importance of finding solutions.
In this unit, students also have the opportunity to build on thinking about energy conservation first introduced in *Fires Unit*. These prior experiences involved tracing energy transfer and conservation in ecosystems, with this unit more explicitly quantifying energy and tracking its transfer and conservation in physical systems.

This unit begins the development of **disciplinary core ideas (DCIs)** and other science ideas that students will utilize and continue building in subsequent units in the OpenSciEd Chemistry and Physics courses:

- Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (*OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*)
- Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system. (*Electricity Unit*)
- Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (*Electricity Unit*)
- Mathematical expressions, which quantify how the stored energy in a system depends on its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and speed, allow the concept of conservation of energy to be used to predict and describe system behavior. (*Electricity Unit*)
- The availability of energy limits what can occur in any system. (*Electricity Unit*)
- 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. (*OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*)
- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. (*Microwave Unit*)
- 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. (*Microwave Unit*)
- Resource availability has guided the development of human society. (*OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*)

- 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. ([material: ce.n])

This unit uses and builds upon high school level **Science and Engineering Practices (SEPs)** and **Crosscutting Concepts (CCCs)** that students should have previously developed in **OpenSciEd High School Biology** and will continue to build in future units in **OpenSciEd High School Chemistry and Physics**. The progression of these practices and concepts across the program are as follows:

	Questions	Models	Investigations	Data	Math	Explanation	Argument	Obtaining
Biology	*Cancer Unit*	*Serengeti Unit, Fires Unit*	*Fires Unit, Natural Selection Unit*	*Natural Selection Unit, Cancer Unit*	*Serengeti Unit*	*Fires Unit, Cancer Unit, Natural Selection Unit*	*Speciation Unit*	*Cancer Unit, Speciation Unit*
Chemistry	*Polar Ice Unit, Oysters Unit*	*Electrostatics Unit, Space Survival Unit*	*Polar Ice Unit*	*Fuels Unit*	*Polar Ice Unit, Oysters Unit*	*Fuels Unit*	*Fuels Unit*	*Electrostatics Unit, Space Survival Unit*
Physics	*Electricity Unit, Cosmology Unit*	*Electricity Unit, Microwave Unit*	*Microwave Unit*	*Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit, Meteors Unit*	*Vehicle Collisions Unit, Meteors Unit*	*Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit*	*Vehicle Collisions Unit*	*Cosmology Unit, Microwave Unit*

	Patterns	Cause/Effect	Scale	Systems/Models	Energy/Matter	Structure/Function	Stability/Change
Biology	*Natural Selection Unit, Speciation Unit*	*Cancer Unit, Natural Selection Unit, Speciation Unit, Serengeti Unit*	*Serengeti Unit*	*Fires Unit, Cancer Unit, Serengeti Unit*	*Fires Unit, Serengeti Unit*	*Cancer Unit*	*Speciation Unit, Serengeti Unit*
Chemistry	*Electrostatics Unit, Space Survival Unit*	*Oysters Unit, Fuels Unit*	*Electrostatics Unit, Oysters Unit*	*Polar Ice Unit*	*Polar Ice Unit, Fuels Unit*	*Space Survival Unit*	*Oysters Unit*
Physics	*Cosmology Unit, Vehicle Collisions Unit, Earth's Interior Unit*	*Vehicle Collisions Unit, Earth's Interior Unit*	*Meteors Unit, Earth's Interior Unit*	*Electricity Unit, Vehicle Collisions Unit, Microwave Unit*	*Electricity Unit, Earth's Interior Unit*	*Earth's Interior Unit, Vehicle Collisions Unit*	*Electricity Unit, Cosmology Unit*

What are some common ideas that students might have?

Students will come into the unit with many ideas about energy and climate derived from previous classroom experiences, intuitive understanding of the way the world works, everyday experiences with ice, and the conversations they have had with parents, friends, and family members.

Some relevant ideas about climate that students may come into the unit with include:

- Climate and weather are the same thing.
- Climate change is NOT occurring.
- A warming climate means warmer weather across the board, which is not what we have observed.
- Climate change IS occurring, but it is NOT human caused.
- Climate change IS occurring because carbon dioxide itself is warm and is heating the planet.
- Climate change IS occurring and IS human-caused, but there is nothing people can do to slow or stop it.
- Climate change is caused by ozone in the atmosphere or holes in the Earth's ozone layer.

- Climate change will not affect people significantly, or will not affect people where I live.
- Climate change is caused by long-term natural processes like changes in the Sun or in Earth's orbit.
- The greenhouse effect is only associated with climate change and does not occur to a certain extent naturally.

Some relevant ideas about energy and physical science generally that students may come into the unit with include:

- Melting of polar ice must be solely from warm air temperatures.
- Energy has distinct forms that are fundamentally different from one another (e.g., electrical, thermal, kinetic, sound, chemical).
- Something that is cold is giving off a distinct type of energy from something that is hot (i.e., that coldness transfers energy just as heat does).
- Energy is a property only of living things (e.g., a rock has no energy).
- Energy is a thing or stuff.
- Energy can be created and destroyed (e.g., when an object gets cold it is because its energy disappears).
- Ice seemingly disappears when it melts.
- Density is the same thing as weight.
- Water added to a specific location of Earth will only affect that local area.

It is valuable to think of ideas like these not as misconceptions that need to be erased but as productive ideas that can be used to build understanding. Not only does this help some students feel more comfortable talking about science and build a scientific identity, it improves science learning across the board. For example, in Lesson 1 students are asked to identify related phenomena where they have seen water levels change, and in Lesson 10 they compare the functioning of the simulation to what they expect from phenomena at home.

What modifications will I need to make if this unit is taught out of sequence?

This is the first unit of the High School Chemistry Course in the OpenSciEd Scope and Sequence. Given this placement, several modifications would need to be made if teaching chemistry first or teaching this unit later in the Chemistry course. These include the following adjustments:

- Early units spend considerable time developing Community Agreements. If taught out of sequence, later units will need additional time for developing the Community Agreements.
- If taught before OpenSciEd High School Biology, supplemental modeling of energy flow within and between systems may be required. Students will also need more explicit callbacks to middle school understandings of evolution as they consider the feedback loops that occur between the biosphere and other spheres over long periods of time.
- If you are using this unit to address the topics for "Unit 9 - Global Change" as organized by College Board in the Course and Exam Description for AP Environmental Science 2020, be prepared to supplement with materials about other greenhouse gases besides carbon dioxide, impacts of climate change besides increased temperature including ocean acidification (as in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*), changes in oceanic currents, changes in where species of animals live, and explicit consideration of the importance of ozone in the atmosphere.
- Major modifications would be needed to this unit to address the topics for the College Board's 2022 AP Chemistry "Unit 6 - Thermodynamics" or its 2020 AP Physics 2 "Unit 2 - Thermodynamics" because these courses divide the thermodynamics ideas built in this unit while adding many other ideas. Carefully consult the course and exam descriptions.

How do I shorten or condense the unit if needed? How can I extend the unit if needed?

The following are example options to shorten or condense parts of the unit without eliminating important sensemaking for students:

- Lesson 3: Planning the investigation is important, but actually collecting the data is less vital. If tight on time, students may be presented with sample data after planning the investigation. Although a simpler version of this investigation is also included in *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)* with a different emphasis, this activity may also go more quickly if students have also experienced that unit.
- Lesson 4: Once again, the investigation plan is more important to sensemaking than the actual investigation. If you believe ice melting will have to take place during class, prepare a "before and after" set of samples ahead of time so that students can see the change without having to collect data themselves.
- Lesson 9: Students should conduct the first investigation themselves so they have experience using scales. However, the demonstration may be done with the provided videos instead.
- Lessons 10 and 11: Students should plan the investigations and use the first simulation in Lesson 10, but may use provided data for developing conclusions in one of the lessons if necessary for time purposes.

- Lesson 12: Students' computations may be reduced or done partially as a class, as long as students have the opportunity to show some calculations and make a claim based on this work.

To extend or enhance the unit, consider the following:

- Lesson 1: Give students opportunities to consider how their own ancestors have migrated in the past and how their experiences might have been similar to or different from those of climate migrants. Guidance is also provided to support students in thinking about whether species that move or spread because of climate change should be labeled by people as "invasive."
- Lesson 2: Give students time to analyze geological and historical data from your own region in addition to the global data provided in the lesson.
- Lesson 5: Share the provided resource for value mapping with students. This will provide students ideas of what they are looking for in the solutions throughout Lesson Sets 2 and 3.
- Lesson 6: Assign students to research solutions that leverage albedo to decrease the "urban heat island" effect.
- Lesson 9: If students proposed thermal expansion of water as a cause of sea-level rise, establish this second correct mechanism and a volume-temperature relationship by placing a capped syringe in warm water and watching it expand, as done in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*. Introduce different types of glassware beyond those included in the lesson, if you believe it is important for students to be familiar with all equipment in the chemistry lab.
- Lesson 10: Encourage students to collect data on the related phenomenon they identify in the lesson. Give students time to graph by hand if you think this will support their understanding of graphs.
- Lesson 11: Help students generalize their understanding of the energy to melt a mass of ice to all substances by assigning and discussing *Other Substances*.
- Lesson 13: Return to climate models from throughout the course. Have students explore these models in more depth, paying particular attention to the background information accessible in each.
- All lessons: Remove scaffolds provided with Science and Engineering Practices as a way to give students more independent work with the elements of these practices.

What mathematics concepts will students engage with in the unit?

This unit requires students to use unit conversions, reason about equations that they collaboratively build from data, and mathematically model these using tools. Note that modeling is best interpreted not as a collection of isolated topics but in relation to other standards. Making mathematical models is a Standard for Mathematical Practice, and specific modeling standards appear throughout the high school standards.

This unit does not assume students are fluent with the mathematical practices listed below, but that students develop these practices as part of the sensemaking. Thus these standards are not so much prerequisites, as co-requisites. If students are simultaneously developing the skills and vocabulary in math class, you can help by making explicit connections to the mathematical standards below.

Talk with the math teacher(s) to identify the strategies students are familiar with for breaking down linear functions, conducting unit conversions, and using different equations in sequence to solve a complex problem.

Category	Code	Domain and Heading	Standard	Lesson
Number and Quantity	CCSS.MATH.CONTENT.HS.N-Q.1	**Quantities:** Reason quantitatively and use units to solve problems.	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays	4, 6, 9, 11, 12
	CCSS.MATH.CONTENT.HS.N-Q.2	**Quantities:** Reason quantitatively and use units to solve problems.	Define appropriate quantities for the purpose of descriptive modeling.	4, 9, 10, 11, 12
Functions	CCSS.MATH.CONTENT.HS.F-LE.2	**Linear, Quadratic, and Exponential Models:** Construct and compare linear, quadratic, and exponential models and solve problems	Construct linear ~~and exponential~~ functions, ~~including arithmetic and geometric sequences,~~ given a graph, ~~a description of a relationship~~, or two input-output pairs (include reading these from a table).	9, 10, 11
	CCSS.MATH.CONTENT.HS.F-IF.6	**Interpreting Functions:** Interpret functions that arise in applications in terms of the context	Calculate and interpret the average rate of change of a function (presented symbolically or as a table) over a specified interval. Estimate the rate of change from a graph.	9, 10

Geometry	CCSS.MATH.CONTENT.HS.G-GMD.3	**Geometric Measurement and Dimension** Explain volume formulas and use them to solve problems	Use volume formulas for cylinders, ~~pyramids, cones, and spheres~~ to solve problems.	4

Category	Code	Domain and Heading	Standard	Lesson
Statistics and Probability	CCSS.MATH.CONTENT.HS.S-ID.6b	**Interpreting Categorical and Quantitative data:** Summarize, represent, and interpret data on two categorical and quantitative variables	Represent data on two quantitative variables on a scatter plot, and describe how the variables are related: Informally assess the fit of a function by plotting and analyzing residuals.	9, 10, 11
	CCSS.MATH.CONTENT.HS.S-ID.6c	**Interpreting Categorical and Quantitative data:** Summarize, represent, and interpret data on two categorical and quantitative variables	Represent data on two quantitative variables on a scatter plot, and describe how the variables are related: Fit a linear function for a scatter plot that suggests a linear association.	9, 10, 11
	CCSS.MATH.CONTENT.HS.S-ID.7	**Interpreting Categorical and Quantitative data:** Interpret linear models	Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of the data.	9, 10, 11

What strategies are available to support equitable science learning in this unit?

OpenSciEd units are designed to promote equitable access to high-quality science learning experiences for all students. Each unit includes strategies which are integrated throughout the OpenSciEd routines and are intended to increase relevance and provide access to science learning for all students. OpenSciEd units support these equity goals through several specific strategies such as: 1) integrating Universal Design for Learning (UDL) Principles during the unit design process to reduce potential barriers and increase accessibility for students to engage in learning experiences; 2) developing and supporting Community Agreements that encourage a safe learning culture; 3) supporting classroom discourse to promote students in developing, sharing, and revising their ideas; and 4) specific strategies for supporting emerging multilingual students in science classrooms.

Many of these strategies are highlighted in the teacher guides in sidebar or in-line callout boxes with the headings of:

- Attending to Equity
- Supporting Emerging Multilingual Learners
- Supporting Universal Design for Learning
- Additional Guidance
- Alternate Activity
- Key Ideas
- Discussion callouts

The example callout below highlights how an activity can be modified to support a wider variety of learners.

ALTERNATE ACTIVITY: For students who benefit from additional reading comprehension support, the Coherent Reading Protocol is well-suited for *Atmospheric Carbon Dioxide*. The Coherent Reading Protocol guides students to monitor their understanding after each chunk of text, identify the main idea, and connect the information in the reading to the lesson question. The Coherent Reading Protocol can be found in the *OpenSciEd Teacher Handbook: High School Science*.

What are recommended adult-level learning resources for the science concepts in this unit?

The OpenSciEd instructional model focuses on the teacher being a member of the classroom community, supporting students to figure out scientific ideas motivated by their questions about phenomena. Students iteratively build their understanding of phenomena as the unit unfolds. To match the incremental build of a full scientific model across the unit, the science content background necessary for you to teach individual lessons incrementally builds too. Throughout the unit, we provide just-in-time science content background for you that is specific to the Disciplinary Core Ideas (DCIs) that will be figured out in a lesson. Places to look for this guidance include the "Where we are going" and "Where we are not going" sections for each lesson. Also, the expected student responses, keys, and rubrics illustrate important science ideas that should be developed in each lesson. The K-12 Science Framework is another great resource to learn more about the DCIs in this unit (**PS3.A: Definitions of Energy, PS3.B: Conservation of Energy and Energy Transfer, PS3.D: Energy in Chemical Processes and Everyday Life, 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.B: Natural Hazards, and ESS3.D: Global Climate Change**), including what students have learned previously and where they are headed in high school. In addition to the science content background information embedded in the lesson resources, below we provide recommended resources that can help build your understanding of phenomena and Performance Expectations bundle for this unit:

- To learn more about sea level, polar ice melt, and climate change:
    - Sea-level rise: https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level
    - Data and information about other aspects of climate change: https://www.climate.gov/climatedashboard
    - Common misconceptions about climate change: https://theconversation.com/five-climate-change-science-misconceptions-debunked-122570
    - Feedback loops: https://climate.nasa.gov/nasa_science/science/
- To learn more about proposed solutions to protect polar ice and implementation:
    - Inuit knowledge and engagement: https://www.inuitcircumpolar.com/
    - Microbeads: https://www.arcticiceproject.org/
    - Berm: https://tc.copernicus.org/articles/12/2955/2018/
    - CO_2 emissions: https://www.unep.org/interactive/six-sector-solution-climate-change/
- To learn more about energy transfer and modeling:
    - Energy transfer: https://www.physicsclassroom.com/class/thermalP
    - Energy transfer models: https://onlinelibrary.wiley.com/doi/epdf/10.1002/tea.21556

How do I support students' emotional needs?

In this unit, students explore the problem of polar ice melt and sea-level rise, its causes, and how potential solutions work. Students may have emotional needs related to two main issues:

- climate anxiety
- status or identification as a refugee, asylum-seeker, or migrant from human-caused or natural disasters.

Before beginning this unit, be sure to reach out to the counselor at your school for student-specific support and strategies that might be needed with regard to the students in your classroom. Consider asking the counselor to join you in the classroom at key moments, such as the discussion on climate migrants in **Lesson 1**. Also consider planning follow-up check-ins with the counselor for any students who may need additional emotional support.

Educate yourself on the phenomenon of climate anxiety. More than two-thirds of Americans, including 84% of those aged 16 to 25, are at least moderately worried about climate change. This brief piece from Harvard Medical School provides an excellent starting point: https://www.health.harvard.edu/blog/is-climate-change-keeping-you-up-at-night-you-may-have-climate-anxiety-202206132761. Other online resources, such as the *Emotional Resilience Toolkit for Climate Work (Version 1.5)* https://static1.squarespace.com/static/5f74c9f17e186b15c051629e/t/5fadc42316947a58febe7782/1605223460375/Copy+of+Copy+of+Emotional-Resilience-Toolkit-for-Climate-Work-v1.5-04Oct19-2.pdf, also offer other tools to help students manage their emotions when studying climate change (Climate Therapy Alliance - Pacific Northwest, 2019).

Reach out to students' support system at home prior to the unit using *Example Home Communication*. This letter is a way to communicate with trusted adults and make them aware of the content of the unit. The letter also provides an opportunity for trusted adults to share important context with you about students' experiences and background that might be relevant.

Be aware that students who are struggling may demonstrate a variety of behaviors including, but not limited to: fidgeting, withdrawal, disruption or distraction, rapid breathing, holding of breath, and change in body language or tonation. If you notice a student might be struggling, share what you are observing and ask if they need some help.

Often in science classrooms, we are focused on evidence and data. When addressing a phenomenon or design solution that straddles the nature-culture divide, like this one, supporting students in using an empathy or socio-emotional lens will also be important. Make space for students to process, and validate their feelings and reactions. These opportunities were built in throughout the unit.

Furthermore, an important part of addressing climate anxiety is recognizing that there is hope. Lesson Sets 2 and 3 focus on helping students understand how people can work together to address the problem that humanity created by reducing carbon dioxide emissions and considering novel solutions that protect particular stretches of polar ice.

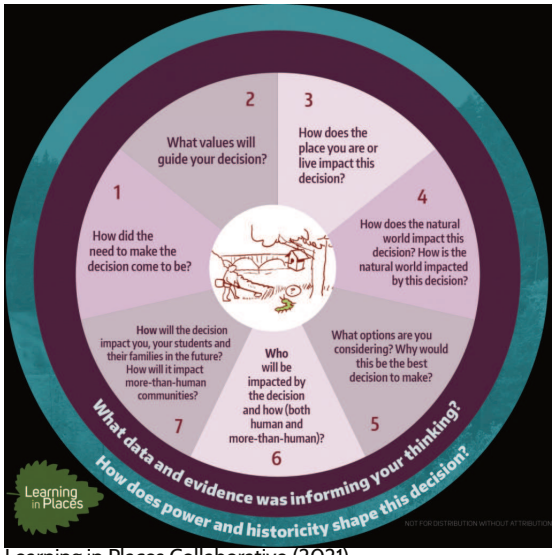
What is the Learning in Places socio-ecological deliberation and decision-making framework?

This unit is informed by the Learning in Places socio-ecological deliberation and decision-making framework. This framework involves sensemaking across seven dimensions. These dimensions include making sense of both human and other-than-human values, needs, and behaviors across multiple temporal and spatial scales. The framework guides learners towards designing actions or making decisions for making change in adaptive and resilient ways.

Socio-ecological decisions are those made by individuals, communities, organizations, and institutions that are informed by and impact the natural world. These decisions are affected by relationships between humans and the natural world, what is called "nature-culture relations". Nature-culture relations often vary by culture, context, and society, and affect which socio-ecological decisions are made and enacted. Understanding the connections between humans and the natural world is imperative for creating and sustaining socially and environmentally just decisions.

In this unit, students are faced with the need to prevent sea-level rise to the extent possible. In Lesson 1, it is clear that coastal communities will be heavily impacted by this decision and support is provided to help students see how they could be affected personally. In Lessons 2 and 3, students dig into historical and experimental data to understand the mechanism behind climate change. In Lesson 4, students gain a sense of the ways in which many people are likely to be affected and begin to consider options that could slow polar ice melt and sea-level rise. Options are presented in Lesson 5, and students consider the needs of people who live in the Arctic and would be directly impacted by some proposed solutions. Students consider how the complex systems in our natural world would relate to the microbeads solution in Lessons 6 and 7 and the berm solution in Lesson 8. They determine the potential impact of the berm in Lesson 12, and consider the impacts of different changes in the Earth system at home and throughout the world in Lesson 13.

For more about socio-ecological deliberation and decision-making, please visit http://learninginplaces.org/.



Learning in Places Collaborative (2021)

Text and image courtesy of Learning in Places Collaborative (2021). Ethical Deliberation and Decision-Making in Socio-Ecological Systems Framework. Learning in Places website. http://learninginplaces.org/frameworks/ethical-deliberation-and-decision-making-in-socio-ecological-systems-framework/.

Guidance for Developing Your Personal Glossaries

This unit refers to two categories of academic language (i.e., vocabulary). Most often in this unit, students will have experiences with and discussions about science ideas before they know the specific vocabulary word that names that idea. After students have developed a deep understanding of a science idea through these experiences, and sometimes because they are looking for a more efficient way to express that idea, they have co-constructed that definition and can add the specific term to a personal glossary at the back of their notebooks. These "definitions we co-construct" should be recorded using the students' own words whenever possible. On the other hand, "definitions we encounter" are "given" to students in the course of a reading, video, or other activity, often with a definition clearly stated in the text. Sometimes, definitions we encounter are helpful just in that lesson and need not be recorded in students' personal glossaries. However, if a word we encounter will be frequently referred to throughout the unit, it should be added.

It is best for students if you create consensus definitions in the moment, using phrases and pictorial representations that the class develops together as they discuss their experiences in the lesson. When they co-create the meaning of the word, students "own" the word—it honors their use of language and connects their specific experiences to the vocabulary of science beyond their classroom. It is especially important for emergent multilingual students to have a reference for this important vocabulary, which includes an accessible definition and visual support. Sometimes defining a word is a challenge. The *Teacher Guide* provides a suggested definition for each term to support you in helping your class develop a student-friendly definition that is also scientifically accurate.

The definitions we co-construct and encounter in this unit are listed in this document and in each lesson to help prepare and to avoid introducing a word before students have earned it. They are not intended as a vocabulary list for students to study before a lesson, as that would undermine the authentic and lasting connection students can make with these words when they are allowed to experience them first as ideas they're trying to figure out.

Lesson	Words with meanings we co-construct	Words with meanings we encounter
L1	climate migrant	consensus, glacier, energy, matter, model, system
L2		
L3	independent variable, dependent variable, controlled variables, greenhouse effect	concentration, mixture, solution, greenhouse gases, input, output
L4		cryosphere, unit conversion, assumptions, land and sea ice
L5		microbeads, berm
L6	albedo, feedback loop	infrared light, radiation
L7		positive and negative feedback loops
L8	system, input, output	Indigenous Knowledge
L9	density, convection	significant figures, meniscus
L10	equilibrium, conduction, heat, specific heat	
L11		
L12		
L13		climate model

HOME COMMUNICATION

Dear Guardian,

Your child's high school chemistry class is starting a unit called *How can we slow the flow of energy on Earth to protect vulnerable coastal communities?*, as part of the OpenSciEd high school science curriculum. This unit develops science ideas around how sea levels are rising due to polar ice melt, how energy moves between Earth systems, and how energy moves between objects at the particle level. Throughout the unit, students will draw on their own experiences and everyday understandings to help them figure out complex science ideas.

In the first few lessons of the unit, students will figure out two important facts:

1. Many people in coastal communities around the world are currently migrating or will soon need to migrate due to rising sea levels.
2. Sea levels are rising because of polar ice melt due to human-caused climate change.

Students figure out these ideas using data from our world and from their own investigations.

You can learn more about sea-level rise and polar ice melt due to climate change at https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level, and more about climate change generally at https://theconversation.com/five-climate-change-science-misconceptions-debunked-122570.

These facts may be disconcerting to your child. They or your family may have experiences migrating from human-caused or natural disasters. Or they may be one of 84% of Americans ages 16 to 25 who are at least moderately worried about climate change (as are the majority of American adults). You can learn more about *climate anxiety* and ways to support your child at https://www.health.harvard.edu/blog/is-climate-change-keeping-you-up-at-night-you-may-have-climate-anxiety-202206132761.

If your child or someone close to your child has been heavily impacted by climate change, please contact me at __(contact information here)__, if you are comfortable doing so. You can also contact the school counselor at __(contact information here)__. By knowing about these experiences in advance we can be sensitive to students' needs and provide support for students who may experience strong emotions during this unit.

Having conversations about science in our world:

- Encourage your child's curiosity through talking about their own noticings and wonderings.
- Acknowledge any emotions around climate change.
- Ask your child to explain how we know that sea-level rise and polar ice melt are caused by climate change, and discuss what we can do about it.

Emphasize that we can take action on climate change. Have honest conversations with your child about what they, personally, can do, while taking into consideration the needs of those who would be most affected (people in coastal,Arctic, and desert communities, and in other areas experiencing the greatest effects).

Helping your student make sense of their learning:

- There is no need to teach your child vocabulary before the unit because words often have multiple meanings, and are often easier to remember once students have some experience with them.
- Encourage your child to expand and clarify their own thinking by asking your child for examples, saying more about their ideas, and repeating what your child said back to them.
- Ask how they might have arrived at a particular conclusion.
- Ask your child to recall what other students have said in class, and what parts of their ideas your child agreed or disagreed with.
- Rephrase what your child is saying to check your own understanding. For example, say, "If I hear you right, you are telling me that..."

Best,
(Your name or signature here)

Querido guardián,

La clase de química de la escuela secundaria de su hijo está comenzando una unidad llamada *¿Cómo podemos frenar el flujo de energía en la Tierra para proteger a las comunidades costeras vulnerables?*, como parte del plan de estudios de ciencias de la escuela secundaria de OpenSciEd. Esta unidad desarrolla ideas científicas sobre cómo aumentan los niveles del mar debido al derretimiento del hielo polar, cómo se mueve la energía entre los sistemas de la Tierra y cómo se mueve la energía entre objetos a nivel de partículas. A lo largo de la unidad, los estudiantes aprovecharán sus propias experiencias y conocimientos cotidianos para ayudarlos a descubrir ideas científicas complejas.

En las primeras lecciones de la unidad, los estudiantes descubrirán dos hechos importantes:

1. Muchas personas de comunidades costeras de todo el mundo están migrando actualmente o pronto necesitarán migrar debido al aumento del nivel del mar.
2. El nivel del mar está aumentando debido al derretimiento del hielo polar debido al cambio climático causado por el hombre.

Los estudiantes descubren estas ideas utilizando datos de nuestro mundo y de sus propias investigaciones.

Puede obtener más información sobre el aumento del nivel del mar y el derretimiento del hielo polar debido al cambio climático en https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level, y más sobre el clima. cambios generales en https://theconversation.com/five-climate-change-science-misconceptions-debunked-122570.

Estos hechos pueden resultar desconcertantes para su hijo. Ellos o su familia pueden tener experiencias de migración debido a desastres naturales o causados por humanos. O pueden ser uno del 84% de los estadounidenses de entre 16 y 25 años que están al menos moderadamente preocupados por el cambio climático (al igual que la mayoría de los adultos estadounidenses). Puede obtener más información sobre la ansiedad climática y las formas de apoyar a su hijo en https://www.health.harvard.edu/blog/is-climate-change-keeping-you-up-at-night-you-may-have-climate-anxiety-202206132761.

Si su hijo o alguien cercano a él se ha visto gravemente afectado por el cambio climático, comuníquese conmigo al __(información de contacto aquí)__, si se siente cómodo haciéndolo. También puede comunicarse con el consejero escolar al __(información de contacto aquí)__. Al conocer estas experiencias de antemano, podemos ser sensibles a las necesidades de los estudiantes y brindarles apoyo a los estudiantes que puedan experimentar emociones fuertes durante esta unidad.

Tener conversaciones sobre la ciencia en nuestro mundo:

- Fomente la curiosidad de su hijo hablándole sobre sus propias observaciones y dudas.
- Reconozca cualquier emoción en torno al cambio climático.
- Pídale a su hijo que le explique cómo sabemos que el aumento del nivel del mar y el derretimiento del hielo polar son causados por el cambio climático, y analice qué podemos hacer al respecto.
- Enfatizar que podemos tomar medidas sobre el cambio climático. Tenga conversaciones honestas con su hijo sobre lo que él, personalmente, puede hacer, teniendo en cuenta las necesidades de quienes se verían más afectados (personas en comunidades costeras, árticas y desérticas, y en otras áreas que experimentan los mayores efectos).

Ayudar a su estudiante a darle sentido a su aprendizaje:

- No es necesario enseñarle vocabulario a su hijo antes de la unidad porque las palabras suelen tener múltiples significados y suelen ser más fáciles de recordar una vez que los estudiantes tienen algo de experiencia con ellas.
- Anime a su hijo a ampliar y aclarar su propio pensamiento pidiéndole ejemplos, diciéndole más sobre sus ideas y repitiendo lo que le dijo.
- Pregúnteles cómo pudieron haber llegado a una conclusión particular.
- Pídale a su hijo que recuerde lo que otros estudiantes han dicho en clase y con qué partes de sus ideas estuvo de acuerdo o en desacuerdo.
- Reformule lo que su hijo dice para comprobar su propia comprensión. Por ejemplo, diga: "Si te escuché bien, me estás diciendo que..."

Sinceramente,
(Su nombre o firma aquí)

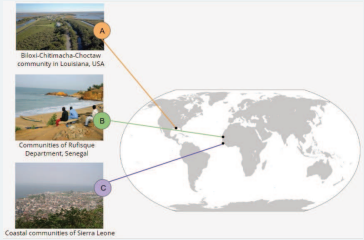
LESSON 1: How are sea levels rising and forcing people to move?

PREVIOUS LESSON *There is no previous lesson.*

THIS LESSON

ANCHORING PHENOMENON

3 days



We explore three coastal communities that are affected by rising sea levels. We identify that this is a global problem, with communities responding in different ways. People in some places have to move. We recognize that sea levels have been rising for over a hundred years and model ideas about the matter and energy changes that are causing sea levels to rise. We develop community agreements and a class consensus model. We build a Driving Question Board and gather ideas for investigation.

NEXT LESSON *We will look at historical data on sea level rise, temperature, ice volume, and potential causes of climate change. We will analyze this data to determine that carbon dioxide is the most likely cause of current ice melt and will model how all the potential causes could affect climate.*

BUILDING TOWARD NGSS

HS-PS3-1, HS-PS3-4, HS-ESS2-2, HS-ESS2-4, HS-ESS3-1, HS-ESS3-5, HS-ESS3-6, HS-ESS2-7

WHAT STUDENTS WILL DO

1.A Ask questions that arise from examining models to clarify and seek additional information about changes and rates of change in sea levels and the resulting impact on human migration. (SEP: 1.2; DCI: ESS3.B.1; CCC: 7.2)

1.B Develop a model based on evidence to illustrate energy and matter flows in the Earth system that result in changes in human migration. (SEP: 2.3; DCI: ESS3.B.1; CCC: 5.2, 4.2)

WHAT STUDENTS WILL FIGURE OUT

- Sea levels are rising--some causes we find are local like storms and erosion, but something is affecting sea levels globally. Scientists predict that this will continue.
- Some communities are able to build infrastructure to protect themselves, but in other places people who live near the coast need to move.
- In chemistry we use ideas about energy and matter to explain confusing things that we see in the world.
- Polar ice melt due to climate change is one explanation for why the sea level is rising.

Lesson 1 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	14 min	✓	**INTRODUCE A PHENOMENON AFFECTING DIFFERENT COMMUNITIES AROUND THE WORLD** Share a phenomenon affecting different communities around the world.	A-D	https://youtu.be/Ju9BGj5OUL8, https://youtu.be/HNSoX4_czzE, https://youtu.be/qWx3-9TREDU, chart paper, markers
2	6 min	✓	**ANALYZE SEA LEVEL GRAPH** Analyze a sea level graph to establish a clear trend.	E-F	Clear plastic ruler (optional)
3	13 min		**EXAMINE SEA LEVEL RISE AROUND THE WORLD** Establish that sea level rise is occurring around the world and will deeply impact many communities.	G-I	*Community Responses*, https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool, Notice and Wonder chart, markers
4	12 min		**DEFINE THE PROBLEM** Pull students together in a whole-group discussion about respect and how to refer to people who have been forced to move from their homes.	J-K	*Climate Change Terminology*
					End of day 1
5	7 min		**RELATED PHENOMENA** Consider causes of water level rise in everyday life and where water is located on Earth.	L-M	Earth squeeze ball
6	9 min	✓	**DEVELOP AN INITIAL MODEL** Develop a model to explain changes in sea level.	N-O	*Initial Model*
7	6 min		**SHARE INITIAL MODELS WITH PARTNERS** Compare similarities and differences in initial models with multiple partners using Concentric Circles.	P	*Initial Model*
8	10 min		**CO-CONSTRUCT COMMUNITY AGREEMENTS** Co-construct initial classroom community agreements.	Q-R	chart paper
9	13 min		**DEVELOP AN INITIAL CONSENSUS MODEL** Co-construct an initial consensus model.	S	*Initial Model*, chart paper, markers
					End of day 2
10	8 min	✓	**NAVIGATE** Revisit the class consensus model and emphasize system thinking.	T-U	Community Agreements, initial consensus model
11	18 min	✓	**DEVELOP THE DRIVING QUESTION BOARD** Create questions that will help drive our next steps.	V-W	sticky notes, initial consensus model
12	8 min		**GENERATE IDEAS FOR INVESTIGATIONS** Brainstorm with a partner how we could find answers to our questions.	X-Z	Driving Question Board, chart paper

Part	Duration		Summary	Slide	Materials
13	6 min		**REFLECT ON OUR USE OF COMMUNITY AGREEMENTS** Gather students in a Scientists Circle to reflect on how we are doing as a class with our community agreements.	AA-BB	1 green and 1 yellow sticky note or dot sticker, Community Agreements
14	5 min		**SET UP SCIENCE NOTEBOOKS** Set up Progress Tracker and organize notebooks	CC	dividers

End of day 3

Lesson 1 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Community Responses* • *Climate Change Terminology* • *Initial Model* • sticky notes • 1 green and 1 yellow sticky note or dot sticker • dividers	• Earth squeeze ball	• https://youtu.be/Ju9BGj5OUL8 • https://youtu.be/HNSoX4_czzE • https://youtu.be/qWx3-9TREDU • chart paper • markers • Clear plastic ruler (optional) • https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool • Notice and Wonder chart • Community Agreements • initial consensus model • Driving Question Board

Materials preparation (30 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Test the videos to be sure they play correctly:
- https://youtu.be/Ju9BGj5OUL8
- https://youtu.be/HNSoX4_czzE
- https://youtu.be/qWx3-9TREDU

You may instead choose to use https://youtu.be/w9GpyEZOm6U, which is the same as https://youtu.be/qWx3-9TREDU but in the Krio language, with English subtitles.

Ensure that all students who would like a transcript of the anchoring phenomena videos have access to one: *Transcript: Biloxi-Chitimacha-Choctaw*, *Transcript: Rufisque*, *Transcript: Rising Sea Levels in Sierra Leone*

Make copies of at least one of the following for each of your students: *Community Responses*, *Climate Change Terminology*, *Initial Model*. You may wish to modify *Community Responses* to include examples of people addressing sea level rise (or other problems related to climate change) that are closer to your community.

Prepare pieces of chart paper for what students "Notice and Wonder" (day 1), for the class consensus model (day 2, labeled "What is causing the sea level to rise?"), and for students' Ideas for Investigations (day 3).

If your community agreements (which you will build on day 2) are posted on chart paper, students can reflect on them on day 3 by marking them with green and yellow dot stickers or sticky notes. Alternatively, you might create a virtual representation of the community agreements so your students can mark green and yellow "stickies" or dots on them for reflection. You might use Google Jamboard (set an image of your community agreements as the background and have students add stickies) or a shared slide of the community agreements with a green dot and a yellow dot for students to copy/paste and drag to where they want them. An example of the completed activity is shown in this teacher guide.

Make sure you have materials ready for students to add sticky notes with their questions to the Driving Question Board (DQB).

Lesson 1 • Where We Are Going and NOT Going

Where We Are Going

This lesson (and this unit) invites students to figure out how and why sea levels are rising, causing residents of some coastal communities to move. The targeted disciplinary core idea that we are beginning to develop is:

- **ESS3.B.1: 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.

Students determine that sea levels are rising due to human activity, likely related to climate change, and may or may not come to complete agreement on a cause based on the understanding that sea levels are rising everywhere, meaning a local cause like increased rainfall is unlikely. By the end of the lesson, students should have some initial ideas that melting polar ice is a likely source of water to cause sea level rise.

Students practice asking questions in this lesson (SEP: 1.2) as they seek to learn more about different aspects of the phenomenon of sea level rise and human migration and ultimately clarify their initial models of how and why sea level rise is occurring. These models utilize evidence about sea levels rising everywhere around the world at increasing rates (CCC: 7.2) to support which components are included (SEP: 2.3). The models also push students to think about energy and matter flows (CCC: 5.2). Students are supported in defining the system that interests them (CCC: 4.2). Energy and matter, and to a lesser extent systems and system models, are tracked throughout the course on *Energy Anchor Chart*.

The questions that students ask throughout the lesson are added to a Driving Question Board on day 3. This Driving Question Board, along with related ideas for investigation that students generate, will drive the work students do in the unit.

In this lesson, students' use of *asking questions* builds on their work in this practice in biology, particularly in *OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*. Students have prior experience in *developing and using models* from *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*, *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*, and *OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*. They developed the crosscutting concept of *stability and change* in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*, *energy and matter* in *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*, and *systems and system models* in *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*.

You may notice that energy is referred to primarily as "energy" throughout the unit. All the energy in this unit is kinetic energy at the particle level, commonly called thermal energy. However, with no other energy storage modes (such as in the field) to compare it to, we stick with the term "energy" to emphasize its ties to particle motion and lay a foundation for the introduction of energy in the field as equivalent to kinetic energy in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*.

This lesson also incorporates a number of supports to build an equitable classroom community. These pieces and other components of this anchor lesson are not just "extras." Instead, they lay the foundation for the intellectual and collaborative work students will do throughout the unit and course. In order to figure out how and why sea levels are rising and what can be done about it, students must have a common experience from which to draw questions and ideas as well as a strong community in which they feel comfortable sharing their thinking.

In this lesson, students will co-construct a definition for the following word, which they should add to their personal glossaries: *climate migrant*. **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

While students will notice in the readings and videos that climate change is a cause of the displacement of coastal communities, students are not expected to know specific details of climate change. In Lesson 2, they will determine the relationship between sea level rise, increased temperature, polar ice melt, and atmospheric carbon dioxide, and then in Lessons 3 and 6 they will develop a mechanism for how increased atmospheric carbon dioxide causes temperature increase.

Students will not have the evidence to fully support the idea that sea levels are rising due to polar ice melt until Lesson 2 and will re-develop and extend middle school mechanisms for energy transfer in Lessons 3 and 6 (radiation), 9 (convection), and 10-11 (conduction). However, in this lesson students should begin to recognize polar ice melt as a possible cause and ideate how energy flows could be causing changes in the number of water particles in the ocean or the space that they take up. Students do not have to know the molecular structure of water in order to do this thinking. Molecular structures and terminology for different categories of substances (pure substance vs. mixture) are introduced in Lesson 3.

Students may have questions about what, if anything, can be done to prevent sea level rise. Lesson 1 introduces some local solutions to protect communities, but other questions should be added to the DQB. Students will be introduced to solutions to directly protect stretches of ice in Lesson 5 and explore these solutions throughout Lesson Sets 2 and 3. In Lesson 13 students will have an opportunity to model the effects of other solution ideas they generate (such as reducing carbon dioxide emissions). Solutions to address climate change at the source, by reducing greenhouse gas emissions, will be explored somewhat more in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)* and extensively in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*.

In this lesson, some students may identify an alternate, but accurate, model for sea level rise in which increased global temperatures cause thermal expansion of water. This mechanism is intentionally de-emphasized in the unit to ensure a focus on energy transfer, but an extension is provided in Lesson 9 if you wish to emphasize this additional mechanism or it is brought up by students.

Students will continue developing their thinking about natural hazards in Lesson 4 as they calculate how many people would be affected by sea level rise. They will further reflect on the role of other geological events (specifically, fossil fuel development and use) in human history in *Fuels Unit*. In this lesson or unit they do not consider the idea that some system changes are irreversible, an idea that is explicitly addressed in *Oysters Unit*.

LEARNING PLAN for LESSON 1

1 · INTRODUCE A PHENOMENON AFFECTING DIFFERENT COMMUNITIES AROUND THE WORLD

14 min

MATERIALS: science notebook, https://youtu.be/Ju9BGj5OUL8, https://youtu.be/HNSoX4_czzE, https://youtu.be/qWx3-9TREDU, chart paper, markers

Introduce the idea of phenomenon based learning.✱ Say, *Our work in class this year is going to center on our questions about phenomena--events or things we can observe but not yet completely explain. Each unit will be anchored by a phenomenon, and the questions you all have about it will drive our work in this class for weeks to come as we try to figure them out. This may be different than in other classes where you started out by learning new ideas. But because your questions will drive the direction of our work in this class, we are going to spend a few periods exploring a phenomenon, trying to develop initial explanations about it, and considering other experiences we have had that could be related to it. This will help us pull different ideas and perspectives in and develop questions that reflect what we are all curious about.*

ALTERNATE ACTIVITY

Students may already have some conception of what a "phenomenon" is. Instead of introducing this term and explaining what it means, you may want to consider opening by saying, *Our work in class this year might look a little different from what you experience in other classes. We will focus our attention on trying to explain different phenomena.* Then ask students where they have heard the word "phenomenon," and what it means to them.

Explore a phenomenon affecting different communities around the world. Display **slide A**. Say, *Let's get ready to explore a phenomenon that is affecting different communities around the world. We have three different communities we will look at first. Before we dive in, let's orient ourselves to where these communities are located. Location A is the Biloxi-Chitimacha-Choctaw* (Buh-LUCK-see Chi-tee-MAA-chuh CHAAK-taa) *community in Louisiana, USA. Location B marks the communities of Rufisque Department in the African nation of Senegal, and Location C marks coastal communities of the African country of Sierra Leone.*

Set up a Notice and Wonder chart. Display **slide B**. Direct students to create a T-chart on the first clean page of their science notebooks to record their noticings and wonderings while watching the videos.✱

SCIENCE NOTEBOOK

Keeping a science notebook allows students a space where they can reflect and communicate their developing understandings about science ideas and track changes in their understandings. This course uses a 3-ring binder as the science notebook and the layout of most handouts has been adapted to allow students to add these materials to a 3-ring binder, but you may choose another format based on what works best in your context.

If your students have not yet set up their notebooks, ask them to begin by using loose-leaf paper at the front of a 3-ring binder. Time is set aside at the end of this lesson (**slide CC**) for students to further organize their notebooks, and students will keep notes and handouts there throughout the course.

Watch the videos about three locations affected by sea-level changes. Watch the videos as a class and have students record observations and questions in their notebooks.

ADDITIONAL GUIDANCE

In this unit, students are faced with the problem of sea level rise due to climate change, and must consider how we respond to it. Here, students learn information related to two questions in the Learning in Places Ethical Deliberation and Decision-Making Framework (http://learninginplaces.org/frameworks/ethical-deliberation-and-decision-making-in-socio-ecological-systems-framework/): "How did the need to make the decision come to be?" and "Who will be impacted by the decision and how (both human and more-than-human?"

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Making sense of phenomena or designing solutions to problems is a key and necessary component to three-dimensional learning. Among other places, this is emphasized in the National Research Council report, *Science and Engineering for Grades 6-12: Investigation and Design at the Center.*

National Academies of Sciences, Engineering, and Medicine 2019. Science and Engineering for Grades 6-12: Investigation and Design at the Center. Washington, DC: The National Academies Press. https://doi.org/10.17226/25216

✱ ATTENDING TO EQUITY

Social and Emotional Learning: Some students may be more susceptible to climate change anxiety. There has been research on climate change anxiety on young people that can have lasting mental health consequences. For example, see https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(20)30223-0/fulltext. Symptoms associated with climate anxiety include panic attacks, insomnia, and obsessive thinking. It is important to be delicate in the way you discuss climate change with young people because evidence shows that worrying about climate change can have serious negative overall mental health effects, potentially leading to increases in stress-related problems such as substance use disorders, anxiety disorders, and depression. If you suspect any of your students are experiencing anxiety, refer them to appropriate student mental health services.

ADDITIONAL GUIDANCE

You will notice that many places have two names in this unit. In all of these cases, one name is an Indigenous name, and the other name is a settler name. Throughout the unit, OpenSciEd has made an effort to use the Indigenous names of places. We will use callouts to highlight the history of these places and names. If you are trying to search for the locations on the Internet, you may need to use the settler name.

In this lesson, you will notice the particular band of Biloxi-Chitimacha-Choctaw use the French settler name for their island, Isle de Jean Charles. This band of Biloxi-Chitimacha-Choctaw fled to the island from their original homelands to escape the Indian Removal Act in 1830.

The Rufisque Department of Senegal is named after the city of Rufisque, which was known as Tëngeéj until it was forcibly annexed by the French in 1859.

The Sierra Leone video mentions the capital, Freetown. Recent establishment of the city began in 1787 when 400 formerly enslaved people, mostly of African descent but from around the world, settled there. The land where Freetown sits had been purchased by British abolitionists from the Kingdom of Koya, although it is unclear if the agreement was properly explained to Koya leaders.

Facilitate an Initial Ideas Discussion✱ and record observations as a whole class. Display **slide C** and develop a whole-class record. Invite students to share some of the things they have noticed or questions they have wondered about while you record them on the chart. It is not necessary to have an exhaustive list at this point, but do keep the discussion going until you have the following ideas on the list (which will be helpful in the next activities and used again on day 3 for the Driving Question Board).

KEY IDEAS

Purpose of this discussion: To collect students' observations and questions about sea level rise so that we can motivate further exploration of the phenomenon. The role of early Initial Ideas Discussions is also to build momentum and excitement in the class. This is not the time to critique ideas or push for evidence. Being explicit about your role in facilitating each type of discussion will help students feel comfortable as you help them work with each other's ideas.

Listen for these ideas:

- Sea levels are rising.
- Rising sea levels negatively affect people, and some have to move.
- Human activity (climate change) is the cause of rising sea levels.✱
- Local issues, like coastal erosion and storms, work with rising sea levels to cause problems for communities.

✱ STRATEGIES FOR THIS INITIAL IDEAS DISCUSSION

For each discussion type, the teacher takes on a slightly different stance in facilitation. Be explicit with students about your role in this discussion. Your role is to capture all student ideas (whether "right" or "wrong"), build excitement, and encourage as many students to participate as possible. Meanwhile, emphasize to students that they should share as many ideas as possible.

Make space for all students to share their ideas (possibly connected to experiences they have had outside school as well). Encourage student-to-student talk with a focus on raising questions, clarifying, or adding on to what someone has said, rather than debating or arguing. Students might also use head nods or hand signals to show that they had a similar idea to a classmate's. Keep a class record of these initial ideas (such as on chart paper, a slide, or a shared digital document) for students to refer to later in the lesson–for example, when creating questions for the DQB. More guidance on Initial Ideas discussion may be found in the *OpenSciEd Teacher Handbook: High School Science*.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING CAUSE AND EFFECT

Although cause and effect is not an intentionally developed CCC in this unit, this lesson presents a good opportunity to support students in thinking about the causal claim made in the videos (that human-caused climate change is behind sea level rise) and consider what we might need to figure out to explain what that would be the case.

Suggested prompt	Sample student response
What did we notice?	People are being affected by increasing sea levels. Some of the people that are being affected by increasing sea levels live in warm climates. Some governments are helping the people that live in affected areas. Some people have to move. Flooding and coastal erosion might be issues in some cases. The third video said that people are the cause of rising sea levels.
What did we wonder?	Is this sea level rise happening everywhere? What is really causing it? Why are some people moving? Is that happening everywhere? How can we help people?

Identify local causes for the changes in sea level rise and the reason people have to move.
Say, *So the people in these communities are already being affected by sea level rise! If we know what is causing it, maybe we can understand how to stop it. The videos stated that there are some local reasons for why sea levels are rising. What are the local reasons for the Biloxi-Chitimacha-Choctaw community to have to move? What about coastal communities in Senegal or Sierra Leone?* Add the answers to these questions to the Notice and Wonder chart. Student answers might include tropical cyclones/hurricanes, rainfall, and coastal erosion.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
- Students ask questions that consider why changes in sea level rise are occurring. (SEP: 1.2; CCC: 7.2)
- Students ask questions that consider how sea level rise is impacting human migration. (SEP: 1.2; DCI: ESS3.B.1)

What to do: If students are struggling to connect their wonderings and questions to the videos, they can reread or annotate the video transcript. You can prompt them to consider specifically why people have to move by asking, "What did the video say is the reason why people have to move?"

Building toward: 1.A.1 Ask questions that arise from examining models to clarify and seek additional information about changes and rates of change in sea levels and the resulting impact on human migration. (SEP: 1.2; DCI: ESS3.B.1; CCC: 7.2)

Turn and talk to predict whether these three communities share common challenges with other communities around the world. Display **slide D.** Direct students to talk with a neighbor about the questions on the slide, then briefly discuss as a class.

Suggested prompt	Sample student response
In what ways might the challenges these communities are facing be shared by other communities around the world?	Maybe the sea level is rising in other places. Lots of people live on coasts, so they would be affected. Some people might be affected more than others because of differences in how their communities are protected.
Do you think other coastal communities might be experiencing sea level changes? Why or why not?	Yes, because if the sea level rises in one place it has to go up everywhere. No, because there were some local causes mentioned.

2 · ANALYZE SEA LEVEL GRAPH

6 min

MATERIALS: Clear plastic ruler (optional)

Consider how sea levels have changed overall. *Say, So we know sea levels have been changing and that has affected people living in these local areas, and we had some concerns about whether this is a general pattern in other areas. Scientists have been measuring sea levels around the world since about 1900. Let's take a look at how these measurements compare over time.*

Show **slide E.** Say, *The first hundred years of those measurements have come from tide gauges, which are used to measure the height of the water at a given location. Average sea level heights have been recorded in many places around the world using these gauges. From 1982 onward we have been able to collect this data using satellites.*

Analyze a graph of sea levels since 1900 with a partner.✱ Display **slide F**. Invite students to discuss with a partner for 5 minutes what they notice about the graph and make predictions about the data for the next 20 years. Remind students to focus on the trends of the graph.

Suggested prompt	Sample student response
What do you notice about the data in the graph?	We notice that from 1900 to 2020, the sea level increased by about 200 mm. (Highlight to students that this is 20 cm, or almost 8 inches. You may wish to pull out a clear plastic ruler to show this length to students.)
What do you predict the data will look like in 20 years?	We predict that this pattern will continue, that in the next 20 years the sea level will increase another 2 inches.
Do you think the rate of sea level rise is increasing, decreasing, or staying the same?	It seems to be increasing because the slope is getting steeper.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Students will have opportunities in Lessons 2 and 9 to more systematically consider how to analyze and interpret data. Here, keep the focus on identifying simple patterns from the graph, particularly as related to the rate of change of the data.

Suggested prompt	Sample student response
How will this affect people?	Sea levels would threaten more communities. Even more people would have to move, even sooner.

Say, *Those are interesting observations. Scientists are also trying to make projections for different locations around the world. Let's see what they think is going to happen even farther out.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
Students indicate that sea levels are rising and the rate of sea level rise is increasing, and this will increase rates of human migration. (DCI: ESS3.B.1; CCC: 7.2)

What to do: If students are challenged by thinking about changes in the rate of sea level rise, ask, "Would we say that the sea level is rising more quickly if the line is steeper, or less steep?" Then use a clear plastic ruler to help students see that the rate of change is increasing.

Building toward: 1.A.2 Ask questions that arise from examining models to clarify and seek additional information about changes and rates of change in sea levels and the resulting impact on human migration. (SEP: 1.2; DCI: ESS3.B.1; CCC: 7.2)

3 · EXAMINE SEA LEVEL RISE AROUND THE WORLD

13 min

MATERIALS: science notebook, *Community Responses*, https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool, Notice and Wonder chart, markers

Examine global sea level rise.✱ Show **slide G** and tell students to get ready to add to their Notice and Wonder chart. Go to https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool and start with Total Sea Level, 2100, SSP3-7.0. Click "Update Map". Explain how this map shows likely sea level rise in 2100 compared to 1995-2014. Choose several locations and ask students to show the numbers with their hands (for example, if the rise is 0.80 m, or 80 cm, students place their hands 2-3 feet apart).

Ask students to share observations and questions as you show different locations. They may say:

- A couple feet does not sound like that much, but some places are really close to sea level.
- It looks like in 2100 different parts of the world will face sea level rise.
- This looks like it could be a problem everywhere.
- Will people on ALL the coasts have to move?
- Is this a new problem? If so, why?
- Is there anything we can do to stop it? Or to prevent cities from being flooded?

Show how communities would be impacted. Say, *Even a few feet may not sound like much, but scientists have developed a tool to show how different places would be affected.* Display **slide H** and explain that these images show how different places would be affected by about 3 feet of sea level rise. Note that even places that are not permanently flooded might be more vulnerable to flooding from storms.

Examine community responses. Say, *I have some information here on how different communities around the world are responding.* Show **slide I.** Distribute *Community Responses* and have students look over the data and discuss it with a partner for 2-3 minutes. Then lead a short Building Understandings Discussion. Show locations using a map site as needed.✱

✱ ATTENDING TO EQUITY

Work to ensure that students who do not live near the coast build connections to the communities examined here. Besides the humanity of those who are affected and the importance of their culture, if necessary also bring in ideas about fishing and other economic services these communities provide and the financial and social consequences of many people having to move to another place in a short period of time.

✱ STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

Be explicit with students about your role in this type of discussion, which is different from your role in an Initial Ideas Discussion. Your role here is to press students for

KEY IDEAS

Purpose of this discussion: To use evidence to conclude that sea level rise is global and that some of the most affected communities and people are not at fault.

The factors that we think influence how sea level rises, who is impacted, and how they are impacted, will inform parts of our initial models, so it is important that students begin learning to defend their ideas with evidence.

Listen for these ideas:

- Community responses vary greatly between places, without much evidence that sea level rise in each location is the cause.
- There may be differences in communities' abilities to afford expensive solutions.
- Because the sea level is rising all over the world, the cause must be global, not local.
- The people who have to move are not primarily at fault.

Suggested prompt	Sample student response
What do you notice in the data?	Some communities are spending billions of dollars to build walls and even raise land. Others are planning to move some or all of their people. There does not seem to be much of a relationship between the places where people are most at risk and where people are being protected. 17 to 72 million people might have to move because of rising sea levels–that is a lot of people who have to do something difficult. Where will they go?
Why do you think different communities respond in different ways?	The differences do not seem to be due to which places will be most affected. Bigger communities might have more resources to build structures. Some communities may not be able to afford expensive solutions, and it is cheaper (although not cheap) to move people.
What could be causing sea level rise to happen in so many different places?	It must be a global cause, not just storms. Something big, like polar ice melting or water not evaporating as much.
Are the people who are forced to move at fault?	No, because it is happening everywhere. No, the video said that the cause is greenhouse gases from wealthy countries.

evidence when they bring up patterns they notice about sea level rise and its impact on people.

Tell students explicitly, *My role in this discussion is to press for evidence, whether the ideas are right or wrong. So you might hear me ask, "Where did you see that?" or "Can you sketch what you mean?" It is my job to push us as a class to articulate the evidence we have to support our ideas.*

Make clear to students that they should share their ideas and the evidence that led them to these ideas. When someone names a pattern you might ask, *"Can you tell us where you saw that pattern?"* You can also go back to any data sources and have students point to what they are trying to communicate.

Say, *According to this data, a lot of people will be negatively affected by sea level rise. A lot of people will have to move. We will spend time thinking about these people throughout the unit.*

4 · DEFINE THE PROBLEM

12 min

MATERIALS: *Climate Change Terminology*

Turn and Talk to discuss initial ideas about terms for people in these communities. ✱ Display **slide J.** *Say, There are different terms used to describe people who are displaced by climate change. It may be useful to have a way to refer to anyone that has to move because of climate change.*

Direct students to turn and talk with a neighbor about the following question: What initial ideas do you have about why we should have a common term to describe people who are displaced by climate change?

Listen to partner discussions.

Define the problem. Display **slide K** and say, *I heard many of you consider some great ideas about how we can be respectful when talking about people who have been forced to move. Others have attempted to think about this question too, and there are different terms proposed for this. Let's take a look at some short excerpts from various sources of information so we can consider some different possibilities for how else we may want to refer to people who have been displaced by climate change.*

Invite students to independently read the article *Climate Change Terminology*.

ALTERNATE ACTIVITY

For students who benefit from additional reading support, you can prompt them to highlight specific parts of the text in different colors, e.g., highlight the "*who*" in yellow, the "*why*" in blue, and the "*where*" in orange. This will provide a focus for reading and clarify similarities and differences between the terms.
Who = refugee, migrant, climate migrant; *Why* = fear of persecution for various reasons, any reason, displaced by the effects of climate change; *Where* = outside of their own country or residence

Debrief the article in a whole-group discussion. Develop a class consensus for the term students decide to use.

KEY IDEAS

Purpose of this discussion: The goal of this discussion is to use evidence to create a general class agreement on the terminology we will use to describe people displaced due to climate change. While not all students may agree on the terminology, it is important to identify a common term to use throughout the unit so that students are clear about who they are referring to in later lessons.

Listen for these ideas:

- There are different terms used to describe people who need to move from their homes.
- Climate refugees

ALTERNATE ACTIVITY

Extension opportunity: Ask students to reflect back on why people, including their own ancestors, have migrated in the past. How were these experiences similar to or different from those of climate migrants? How might climate migration cause there to be different patterns of where people live than we see today?

You may additionally assign students to read https://ensia.com/features/climate-change-nonnative-invasive-species/ as home learning and begin the next class with a discussion of whether people should label non-human animals and other organisms that have moved or spread because of climate change as "invasive."

✱ ATTENDING TO EQUITY

Social and Emotional Learning: Discussion around the terminology used to describe people displaced by climate change is especially important if you have students who are considered refugees. The term *refugee* can have negative connotations. As you facilitate this discussion with students, remind them that as they share their ideas they should be considerate and mindful of the possible struggles of others. *Climate refugee* will be the term used throughout the unit to describe people who are displaced due to climate change. If your class decides on a different term, be sure to substitute it whenever you see climate refugees referenced in materials. This could be an SEL connection to the CASEL core competency, Social Awareness.

End of day 1

5 · RELATED PHENOMENA

7 min

MATERIALS: Earth squeeze ball

ADDITIONAL GUIDANCE

Discussing related phenomena "broadens questioning and sensemaking from the anchor and connects what students investigate to their own experiences" (https://www.tandfonline.com/doi/full/10.1080/1046560X.2021.1884784). Here, students use their collective experience to share expertise that they can all use in their models and identify situations (like melting ice on roofs or interconnected bodies of water around the world) into which this unit might provide insight.

Turn and talk about related phenomena. Welcome students back to class. Display **slide L**. Direct students to talk with a neighbor about the questions on the slide. Then after 2 minutes, discuss the prompts as a class.✱

Suggested prompt	Sample student response
What other examples have you encountered where the level of water changed over time?	My sink in the kitchen has changed in water when we filled it. One time, my bathtub filled too much and water went all over my bathroom. The lake (reservoir) increased in water or flooded when it rained too much. Ice melting off the roof of a nearby building floods its gutters every spring.
What do you think caused those changes?	The sink and bathtub increased in water (overfilled) because we added too much water. The lake increased due to rain adding water. The ice added to the amount of water in the gutter.
Do you think people have encountered sea level rise before?	(Accept all responses.)
How much of Earth is water? Where is all the water located?	A lot is in the oceans. I heard 75% of our Earth is water. Isn't water around the continents? Rivers, lakes. I don't exactly know. Some might be frozen in ice.

Show where water is located on Earth. Distribute Earth squeeze balls and give students 30 seconds to explore the ball. *Say, This ball is a model of the Earth and some parts may not be to the correct scale.*

✱ ATTENDING TO EQUITY

Universal Design for Learning: Reinforce that students have multiple options for *expressing* their ideas. Encourage the use of gestures, drawings, and physical representations, especially as students describe their ideas about where water is on Earth and how water levels rise in different situations. Use the language(s) and terminology your students use to describe and explain their ideas, especially during this first lesson. There will be appropriate points later in the unit to name specific vocabulary. More guidance on supporting students in this work may be found in the *OpenSciEd Teacher Handbook: High School Science*.

Suggested prompt	Sample student response
Where do you see water on your squeeze ball of Earth?	Water is all around Earth and apparently connected.
Do you think that all water is shown on our squeeze balls?	No, water is also found in rivers and lakes.
Are there any other important features of Earth that are missing?	The squeeze balls do not show mountains, deserts, or areas covered in ice.

Show different places on Earth that have water. Display **slide M** and ask students, *Where can we see these types of features on Earth?* Students should note that lakes and rivers are found all over and ice and snow are found year-round at the poles and high mountains. You may wish to help students point to the specific locations of the images, as well. You do not have to fully define the terms "glacier" and "sea ice," but highlight that the glacier ice is on land, while the sea ice is floating in the ocean.

Collect the Earth squeeze balls unless you wish to have students refer to them as they develop the initial models.

6 · DEVELOP AN INITIAL MODEL

9 min

MATERIALS: *Initial Model*, science notebook

Prepare to create initial models. Show **slide N.** Say, *We have figured out a lot about the problem of sea level rise, so it is a good time to try to think about what all that information means. We will draw models that explain why we think the sea level is rising. But first, let's think about how we explain things in chemistry.* Lead a brief discussion using the prompts on the slide.

Suggested prompt	Sample student response
What types of things have you learned about chemistry in prior classes?	Stuff (matter) is made of particles, or atoms and molecules. Chemical reactions happen. Sometimes, matter explodes during a reaction.
What types of things do you expect to learn more about in this class?	Different elements on the periodic table Why some things are reactive and others are not

Say, *I heard ideas about some different concepts. Many of them are related to changes in matter. Chemistry is the study of matter, or stuff. Sometimes we also think about how energy flows between matter, as in an explosion.* If students have not said that stuff is made of some type of particles, ask them what matter is made of.

Tell students that in chemistry, it is important that we try to figure out what is going on at the microscopic level, so our models should always talk about particles of matter or energy.

Create initial models. Display **slide O** and distribute *Initial Model*. Direct students to develop an initial model to explain why they think the sea level is rising, including what they think is happening at a scale too small to see. Remind students to use pictures, words, symbols, labels, etc., to document their thinking in quiet independent work time. If students think of more questions while they are working, encourage them to record these questions on their handout or in their notebooks.

Example models are included on the key for *Initial Model Key*.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' models are supported by evidence for the components that were included. (SEP: 2.3)
- Students' models show changes in and flows of energy and matter. (SEP: 2.3; CCC: 5.2)
- Students' models explain how changes in sea level that cause human migration could occur. (SEP: 2.3; DCI: ESS3.B.1)

What to do: Because this is the first lesson in the unit, this is a pre-assessment opportunity to see where students are in the progression for the three dimensions targeted here. Collect these models if you do not have time to look at them in the lesson and use them to gauge how students are using models to show three-dimensional thinking; that is, that they are able to model changes in matter and energy to explain the mechanisms behind and impacts of natural hazards like sea level rise. Feedback around these dimensions can also help support student thinking as they begin to use energy transfer models in subsequent lessons.

Students often struggle with their initial attempts at modeling. Remind students that this is an opportunity to share initial ideas and that you do not expect perfection. Also, encourage students to think about how the related phenomena can be explained and if sea level is rising for similar reasons.

Building toward: 1.B.1 Develop a model based on evidence to illustrate energy and matter flows in the Earth system that result in changes in human migration. (SEP: 2.3; DCI: ESS3.B.1; CCC: 5.2, 4.2)

7 · SHARE INITIAL MODELS WITH PARTNERS

6 min

MATERIALS: *Initial Model*, science notebook

Compare similarities and differences in initial models with partners. Display **slide P**. Say, *Last class we came up with initial models on our own to attempt to explain the patterns we saw in the polar ice data. Now, let's take a few minutes to share our ideas with others.*

Direct students to create a T-chart on the next clean page of their science notebook to record similarities and differences while participating in Concentric Circles. Briefly explain the instructions for this discussion strategy. Give students about 5 minutes to compare models with several different partners (students do not need to share their models with every student). Students should record similarities and differences in their T-charts while they are talking with different partners. If other questions come up during their conversations, students should record those questions in their science notebooks too.

COLLABORATION

Concentric Circles is a discussion strategy that invites every student in the class to participate as an active listener and as a speaker. Students stand in two concentric circles facing one another and discuss the similarities and differences in their initial models. Encourage students to write down the similarities and differences before moving in the circle. When prompted by the teacher, the inner circle moves to the left or right so that each student now faces a new partner with whom they compare their models.

8 · CO-CONSTRUCT COMMUNITY AGREEMENTS

10 min

MATERIALS: science notebook, chart paper

Consider why we should establish community agreements.✱ Navigate to this work with community agreements by saying something like, *We have already been working as scientists these past couple of days: analyzing data, asking questions, developing models to explain our ideas. Over the course of the unit (and school year), we will also communicate our ideas with others, argue from evidence, and plan investigations. Those can be difficult tasks, and we will need to practice them together. We cannot do science work alone, so our goal for this class is to have us build a community where we can figure things out together.*

Display **slide Q.** Direct students to stop and jot their responses to these prompts in their notebooks:

- What are you hoping to get out of this class?
- How can working together help us get farther than we would on our own?
- What barriers have you encountered in other classes or groups that would:
    - prevent us from building a community?
    - prevent us from accomplishing our goals, both as individuals and as a class?

After a minute or two of silent writing time, invite volunteers to share if they would like to. If no one volunteers to share, that is fine -- just tell students to keep those ideas in their heads as we continue this conversation.

Form a Scientists Circle for the first time. Ask students to assemble their chairs in a circle and to bring their science notebooks and something to write with.

SCIENTISTS CIRCLE

You will form a Scientists Circle in many future lessons as well. Setting up the community agreements and logistics for forming, equitably participating in, and breaking down that space is important to do if this is your first time forming such a space. Having students sit in a circle so they can see and face one another can help build a sense of shared mission and a community of learners working together. Returning to this Scientists Circle throughout the course of the unit to take stock of what the class has figured out and where they need to go next will be an important tool in helping the class take on greater agency in steering the direction of their learning. This circle will also help students build a sense of pride in their work. You may want to inform students that professional scientists also collaborate with one another to brainstorm, discuss, and review their work.

Co-construct community agreements as a class. Display **slide R.** Say, *Scientists have a lot in common, especially in our ways of thinking and habits of mind: scientists value new ideas, are open to hearing questions and comments from others, and are respectfully skeptical when they are trying to figure something out. Before we talk about our models, we need to have agreements in place that can help us do these things.*

The agreements on the slide are a starting point for the class. It is important to talk through each category with students and ask them to provide an example or paraphrase the agreement. The purpose of this is to develop a shared understanding of each agreement. Also provide opportunities for students to clarify an agreement, ask for a modification, or develop a new agreement. It is fine if there are not an equal number of agreements in each box at the end.✱

The table below includes example community agreements as a reference; your version of the agreements should use wording and ideas co-constructed with your class.

✱ ATTENDING TO EQUITY

Building classroom culture: The purpose of introducing the consensus task before establishing community agreements is to get students thinking about how it may be difficult to hear from all members of the learning community during this discussion and model development. Our agreements can help us be sure that everyone's ideas are included.

✱ ATTENDING TO EQUITY

Building classroom culture: Especially this early in the year/unit, frame your community agreements as a work in progress. Several lessons in this unit include opportunities for students (and you) to reflect on these community agreements, and revising them as needed is encouraged.

Respectful Our classroom is a safe space to share.	• We provide each other with support and encouragement. • We share our time to talk. We do this by giving others time to think and share. • We critique the *ideas* we are working with, but not the *people* we are working with.
Equitable Everyone's participation and ideas are valuable.	• We monitor our own time spent talking. • We encourage others' voices whom we have not heard from yet. • We recognize and value that people think, share, and represent their ideas in different ways.
Committed to our community We learn together.	• We come prepared to work toward a common goal. • We share our own thinking to help us all learn. • We listen carefully and ask questions to help us understand everyone's ideas. • We speak clearly and loud enough so everyone can hear.
Moving our science thinking forward We work together to figure things out.	• We use and build on others' ideas. • We use evidence to support our ideas, ask for evidence from others, and suggest ways to get additional evidence. • We are open to changing our minds. • We challenge ourselves to think in new ways.

ALTERNATE ACTIVITY

When setting up learning community agreements, students should understand how agreements help everyone in the community to know what is expected of them. Here are two approaches to setting up community agreements:

- Co-construct agreements with students (the default approach). Explain what agreements are and why we need them for productive science talk and classroom culture. Have students co-construct agreements. As the teacher, you can add agreements that may be missing from the list. Be sure to explain to students how you think the agreement you added is helpful so that they are clear about why you are adding it to the list.
- Give students a set of agreements as a starting point (the alternate approach). Share a set of community agreements with students and provide space for students to edit or add to the agreements if they believe something is missing.

Consider the following questions, which can help you determine which approach is best for your situation:

- Do you want students to participate in co-constructing the agreements?
- Do you want the same set of agreements for every section of science you teach?
- Do you want to work with your team teachers to establish a shared set of agreements for students across all your classes?
- What kinds of consequences will you enforce if students do not follow the agreements?

9 · DEVELOP AN INITIAL CONSENSUS MODEL

13 min

MATERIALS: *Initial Model*, science notebook, chart paper, markers

Debrief similarities and differences of the initial models. Display **slide S**. Invite students to share the similarities and differences they wrote in their science notebook. Begin with writing the similarities on the chart paper, then the differences.

Represent areas of agreement and disagreement in a consensus model. Facilitate a Consensus Discussion while you record the initial consensus model on a piece of chart paper titled, "What is causing the sea level to rise?"✱ Throughout the discussion, encourage students to identify their evidence and reasoning. Also prompt students to identify what might have caused the phenomenon that is causing sea level rise. *Energy Anchor Chart* details how the energy portion of this model is built throughout the unit.

KEY IDEAS

Purpose of this discussion: To develop an initial consensus model to capture the ideas we agree on, disagree with, or are uncertain about regarding the causes of sea level rise. For example, students will not be certain that ice is actually the cause of sea level rise, or what it is that is causing ice to melt. Use question marks to help show that we have some different ideas about this. In other words, we all agree that we are not in agreement on X parts of the model.

There are three goals of this discussion:

1. Capture "melting polar ice" and any other initial ideas about large-scale changes in and flows of matter and energy that could be causing sea level rise. Help students consider that models that explain sea level rise everywhere, like polar ice melt, are more likely.
2. Re-establish a middle school-level model for representing changes that would occur in particles that make up a solid as energy is transferred into it.
3. Scope out the territory of what the class is uncertain about or has competing ideas about in order to problematize what the group needs to investigate. As such, it is again important to accept all student responses and to encourage students to share their ideas. Furthermore, it is important to highlight areas of disagreement and help students clearly explain their thinking in these areas.

Listen for these ideas:
Specific responses to each prompt are in the next table, and two sample initial consensus models are below. The first represents a situation where students mostly agree that polar ice melt is the most likely cause. The second represents a situation where some students think polar ice melt is the most likely cause, while others think there is more rain.

In either case, the teacher should represent students' ideas about energy on the side. Tell students that using these boxes can help us keep thinking about energy separate from thinking about particles. When developing these models, you do not yet have to draw a dotted line to define the system. This will be done at the beginning of day 3.

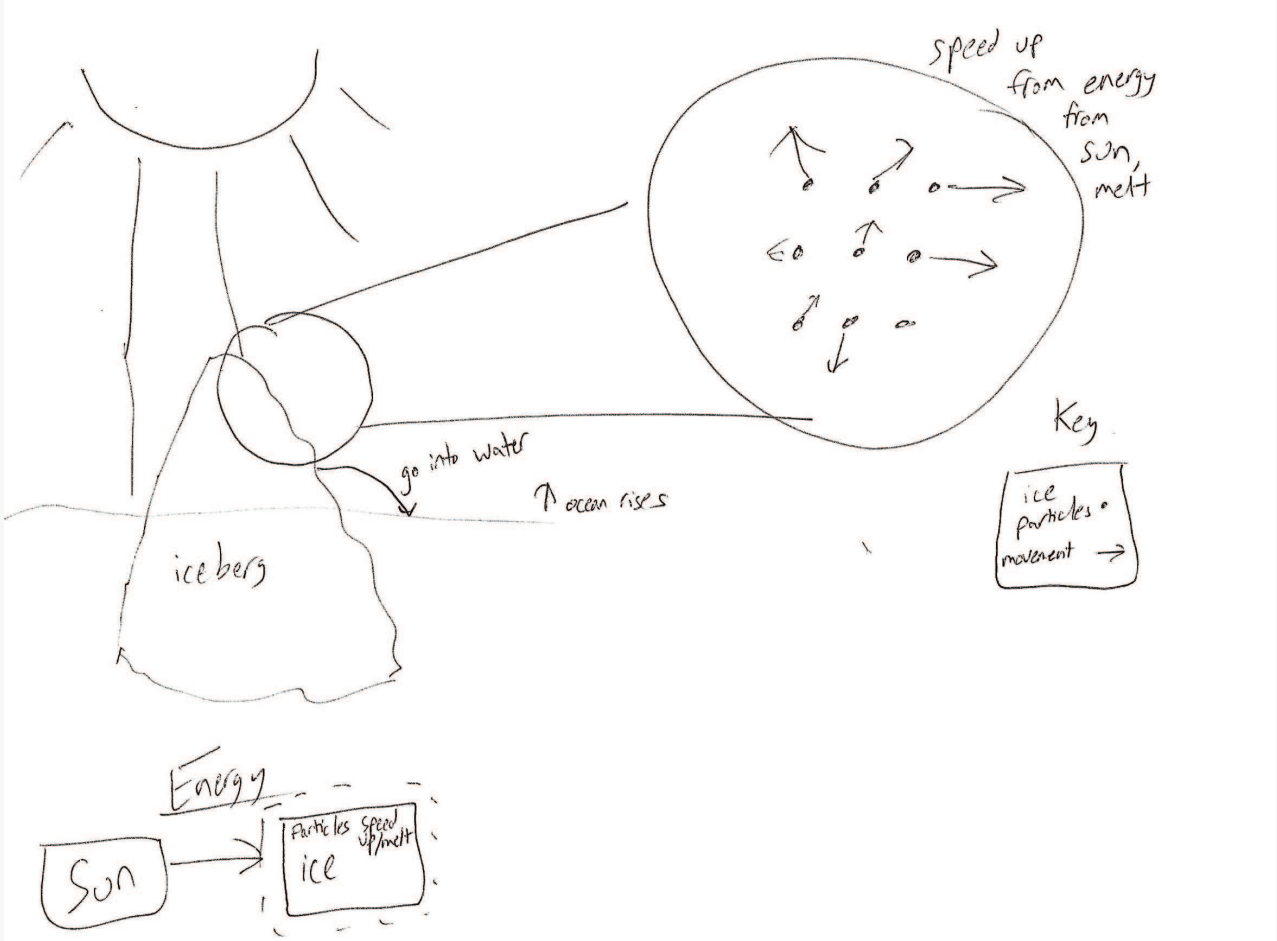
In Lessons 2 and 3, students will engage with evidence that supports the almost universally accepted model among scientists that sea level rise is at least in part caused by polar ice melt, which is caused by increased temperatures due to anthropogenic emissions of carbon dioxide and other greenhouse gases.

✱ STRATEGIES FOR THIS CONSENSUS DISCUSSION

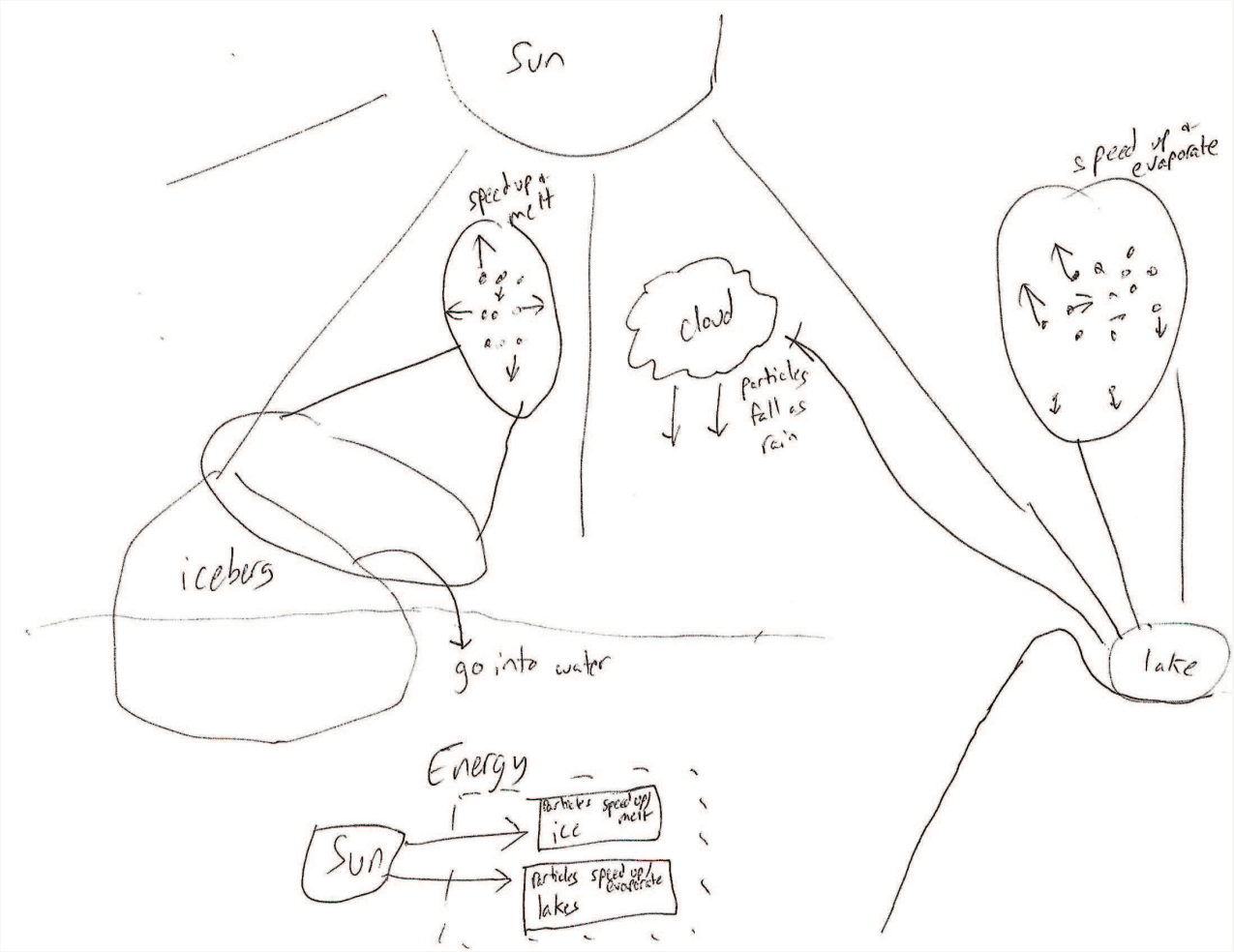
Your role as a facilitator in a Consensus Discussion is to motivate students to take stock of where the class agrees and where the class disagrees. Tell students explicitly that you will not write down everything they say. Say, *My role here is to put ideas back into the public classroom arena so we can debate them and clarify where we stand as a class, even if that means we agree that we have a few areas of disagreement. So you might hear me say,* What do others think of that idea? With a show of hands, how many students agree with the idea, and how many disagree? *I will only write something down when we have taken stock of it as a class.*

Encourage as many students as possible to contribute to this discussion because consensus should represent the whole class, not just a few students. It may be helpful to explicitly say this to the class at the start. Say that you might invite others who have not yet contributed to the conversation by asking, *[Student's name], what do you think of that?*

Canonical Model - Polar Ice Melt as Primary Cause



Alternate Model - Rain as a Possible Cause



Suggested prompt	Sample student response
Where do you think the water is coming from to cause sea level rise all around the world?	The change in sea levels must be due to something big, like polar ice melting, ocean water expanding, or increased rainfall.
How do you think the water that causes sea level rise gets to the ocean?	Answers will vary depending on the proposed source. The most common answer will be melted ice that flows directly into the ocean.

Suggested prompt	Sample student response
Draw a model that explains why the sea level is rising all around the world.	We can draw the source of the water and how water moves to the ocean. We can use arrows and other symbols to show different movements and changes.
Develop a model to show what you think is happening at the particle level to cause the sea level to rise. Make sure your model shows any changes or flows of matter (particles) and energy.	At the particle level, ice melts because energy is transferred to it and the molecules speed up until they become liquid. This energy might come from the Sun or the surrounding air or water. Alternate but accurate model not addressed in this unit: Water particles in the ocean speed up as they are heated by energy from the Sun or atmosphere and take up more space, causing the ocean to expand and rise. Alternate but inaccurate model: Energy from the atmosphere causes water particles on the land to speed up and evaporate into the air and then fall into the ocean, causing it to rise.
Explain why you included the components in your models that you did.	Because the sea level is rising in a lot of places, the cause has to be something global like ice melt instead of local like rain. Temperatures are getting higher with climate change, so there is less ice at the North and South Poles.
Could your model explain how the sea level is rising everywhere?	(Push students to reflect on whether an alternative model, like localized storms and rainfall, could really do so. This should help tilt the scales toward polar ice melt as the most likely cause.)

ADDITIONAL GUIDANCE	It is okay to use this discussion to guide students to recall ideas that they already figured out in middle school, but otherwise be careful not to favorably respond to any one idea over others so as not to give away what might be going on in the phenomenon. The class will return to this model and evaluate their initial competing ideas as they gather more evidence throughout the unit.

Close class. Thank students for their thoughtful consideration of what should go into our class consensus model.

End of day 2

10 · NAVIGATE

8 min

MATERIALS: Community Agreements, initial consensus model

Choose focal Community Agreements for today. Say, *Yesterday we had some really productive discussions around our consensus model.* Highlight a way in which you thought students engaged with each other in alignment with the community agreements. Then say, *We want to make sure we are each continuing to work to build this community using the agreements we developed.* Display **slide T**. Have students individually choose a community agreement they will focus on today. Then, have students tell a partner why they chose that agreement and how they plan to work on it. ✱

Direct students' attention to the initial consensus model. Display **slide U** and give students a couple of minutes to turn and talk about the prompts before discussing them as a class.

Suggested prompt	Sample student response
Where is matter flowing from and to in our consensus model?	Water is going from the polar ice (or other source) to the ocean.
Where is energy flowing from and to in our consensus model?	Energy is going from the Sun to the atmosphere/water or to the ice.
What object or systems do we care about when thinking about sea level rise?	We care about what is happening on Earth, since it is what affects people and other organisms. We also care about the Sun, since it is indirectly affecting Earth's systems.

As students come to agreement on what to define as the system, make a dotted outline around it on the class consensus model. You may need to do this separately on the matter and energy-focused portions of the model, depending on how you set it up. Label this system so that students remember what it is referring to (e.g., "Earth", "Earth-Sun System", or "Ocean").

Follow up by considering the energy and matter flows. Have students turn and talk around the question, *Do you think these same types of matter and energy flows have always been affecting sea level, long before we have records or there were even people to observe it?* Listen for these ideas:

- Yes, because the Sun is not affected by what people do.
- It is impossible to know, because there would not be data for it.
- No, because some of the changes are related to climate change, which involves people somehow.

Say, *When we built this model we had a lot of ideas about what might be causing sea level rise, but we also had lots of questions. Let's take some time to capture those.*

✱ ATTENDING TO EQUITY

Building classroom culture: Identifying a specific focal agreement to work on in concert with introducing the purpose of protocols, talk moves, and discourse strategies to support advancing that agreement serves two purposes. It can give students practice with new ways to interact with the members of their learning community, as well giving them experience using strategies that can help them engage in science and engineering practices more deeply over time.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students present an accurate description of changes in and flows of energy and matter using the model. (SEP: 2.3; CCC: 5.2)
- Students identify their system of interest on the model. (SEP: 2.3; CCC: 4.2)

What to do: Students are new to system thinking so they may struggle to identify the system of interest. In this case, begin at a small scale and zoom out, asking students each time if that is part of what they care about in this case. For example, begin by asking if we care about one water particle, then zoom out to the water around Louisiana, then zoom out to the ocean, the ocean/atmosphere/ice, the whole Earth, and the Sun.

Building toward: 1.B.2 Develop a model based on evidence to illustrate energy and matter flows in the Earth system that result in changes in human migration. (SEP: 2.3; DCI: ESS3.B.1; CCC: 5.2, 4.2)

11 · DEVELOP THE DRIVING QUESTION BOARD

18 min

MATERIALS: science notebook, sticky notes, initial consensus model

Generate questions.✱ Display **slide V**. Say, *Let's take a few minutes to write down our questions so that they will be clear to others when we are ready to get them organized. Look back at the questions you had in your Notice and Wonder chart, the questions you recorded during our modeling, and consider the related phenomena, too. Write down at least two new questions that you now have about the phenomenon we have been exploring.*

Remember to write one question per sticky note, write in marker to make it big and bold, and put your initials on the back in pencil.

Give students a few minutes to generate their questions and record them on sticky notes.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students ask questions that consider why changes in sea level rise are occurring and whether they can be prevented or reversed. (SEP: 1.2; CCC: 7.2)
- Students ask questions that consider how sea level rise is impacting human migration. (SEP: 1.2; DCI: ESS3.B.1)
- Students' questions should seek to clarify confusing portions of their models. (SEP: 1.2)

What to do: If students struggle to identify questions, encourage them to revisit their notes from the lesson and the initial consensus model. You may also elicit from students what they have done in the lesson so far in order to refresh their memories about parts that may have been more or less clear. Although students may ask a variety of questions, use this opportunity to assess students' use of crosscutting concepts, especially Stability and Change, as a lens to ask questions that help better understand the particular problem of sea level rise.

Building toward: 1.A.3 Ask questions that arise from examining models to clarify and seek additional information about changes and rates of change in sea levels and the resulting impact on human migration. (SEP: 1.2; CCC: 7.2; DCI: ESS3.B.1)

Gather around the DQB. Display **slide W**. Direct students to bring their questions on sticky notes.✱

Say, *We have a lot of really helpful questions that will direct our work. It is important that we hear everybody's questions, and we might find that we have questions similar to some of our classmates' questions. We are going to create a Driving Question Board. We want to group and organize our questions so that they can help guide our investigations and keep track of what we want to figure out.*

✱ ATTENDING TO EQUITY

Students' questions are vital to drive their thinking forward. The Driving Question Board underscores the importance of questions and the crucial role they have in the work of the class. Students will return to the DQB throughout the unit to add questions and identify questions that they have already answered through investigations and sensemaking. Ensure that the Driving Question Board is accessible for future use, and promote it as a product that represents students' thinking, rather than as a mere "hook" for the unit.

✱ ATTENDING TO EQUITY

The first priority during the formation of the DQB is reinforcing a classroom community wherein all ideas are valued. As such, everyone should have a question on the board. Use your judgment as to how to prompt students to form "how" and "why" questions. If students struggle with sharing, encourage them to go public with question(s) as they are, rather than focusing specifically on forming a "how" or "why" question.

Instruct students to share their questions, one by one, with the whole group. Explain to students how you will create the DQB:

- The first student reads their question aloud to the class, then posts it on the DQB.
- Other students raise their hands if they have a question that relates to the question that was just read aloud.
- The first student selects the next student whose hand is raised.
- The second student reads their question, says why or how it relates, and posts it near the question it most relates to on the DQB.
- That student selects the next student.
- Continue until everyone has at least one question on the DQB.
- If a question does not fit with any questions that are already on the board, students should create a new cluster.

Some of the students' questions might include:

- Are sea levels rising due to ice melt or other causes?
    - How could scientists know if ice melt is causing sea levels to rise?
- Can we slow down ice melting/sea level rise?
    - Is there a way to stop ice melting/sea level rise?
    - How can we slow down ice melting/sea level rise?
- How will this impact people globally?
    - How could rising sea levels affect people in the US?
    - Can the ocean "overfill"?
    - Could cities (states, countries) disappear?
    - How can melting at the poles affect the whole world?
- What is causing the ice to melt?
    - Is it only increasing air temperatures (climate) causing the ice to melt?
    - Are oceans getting warmer?
    - Is this because of increasing carbon dioxide levels?
- Why are responses so different in different places?
    - Why do some communities have to move while others are building expensive seawalls?
- Did the sea level rise only start in the last century or so?
    - Have people ever encountered something similar before?

Label the questions. After all students have shared their questions you will have several different clusters of questions on the DQB. As a class, decide on "umbrella" questions or topics for the clusters and label them. Here is an opportunity to turn the facilitation of this task over to students.

Title the DQB with a version of the unit question. Propose that these questions are all related to an overarching question, such as, "How can we slow the flow of energy on Earth to protect vulnerable coastal communities?" Title the DQB with this question or a similar one as phrased by your students.

12 · GENERATE IDEAS FOR INVESTIGATIONS

8 min

MATERIALS: science notebook, Driving Question Board, chart paper

Turn and talk about our questions. Display **slide X**. Ask students to briefly turn and talk, then discuss their ideas as a class. Lead students toward the idea that it will be easier for us to figure out the cause of sea level rise and its connection to climate change, but harder for us to fully explain why some people become climate refugees while others have expensive seawalls and other protections built for them.

Generate ideas for investigations. Display **slide Y**. Say, *We have so many ideas to explore! How could we start to investigate the answers to some of these questions? Title the next page in your science notebook "Ideas for Investigations." Choose one question or category of questions from our Driving Question Board✱ and talk with a partner or partners near you to consider how we might find the answer—what investigation could we design, what data should we gather, and how could we figure this out in our classroom? Keep track of your ideas in your notebook. After you have discussed one question, move on to another. We will work for about 5 minutes.*

✱ ATTENDING TO EQUITY

Universal Design for Learning: It will be helpful to students if they can clearly see the question(s) or category of questions they are focused on when generating ideas for investigation. So, you may have students temporarily disassemble the DQB and take sticky-note questions or groups of questions

Compile a whole-class list of ideas for investigations to reference throughout the unit. Display **slide Z**. Begin by asking students to share investigation ideas in pairs or trios. Then have several students share one of their investigation ideas with the whole class. Continue soliciting ideas from each pair or trio. Record these ideas on the chart paper for the whole class to keep as a reference. The goal is to hear a variety of ideas that we may be able to investigate over the course of the whole unit.

Celebrate the status of the plan students have developed so far. Say, *We have so many great ideas to investigate! We have great ideas for finding the data we need a little bit at a time. That will help make our work manageable and successful. And remember, when we make progress on one question, that progress usually helps us answer others. I'm excited to get started on this work in our next class, but let's first identify where we want to start.*

You already said that we are in a better position to focus on the science part of the how and why. At this point we are not entirely sure about the cause of sea level rise and if people have ever encountered something similar before, so that might be a good place to start.

ADDITIONAL GUIDANCE	This list of ideas for investigations can be revisited throughout the unit, just like the Driving Question Board. When a future lesson involves an investigation like one the class has suggested, take the time to point that out. If your students suggest ideas that are not planned in the unit but that you feel would be productive to pursue, use your discretion and your knowledge of the storyline to decide where these additional investigations would best fit so that the unit's takeaways continue to build on one another. The *OpenSciEd Teacher Handbook: High School Science* provides guidance on managing the Driving Question Board and similar classroom artifacts.

to their partners for reference while they generate ideas. Or, if possible, you might take photos of sections of the DQB and share those digitally with students to refer to while they brainstorm. Students may also benefit from the movement of getting up to examine the DQB.

13 · REFLECT ON OUR USE OF COMMUNITY AGREEMENTS

6 min

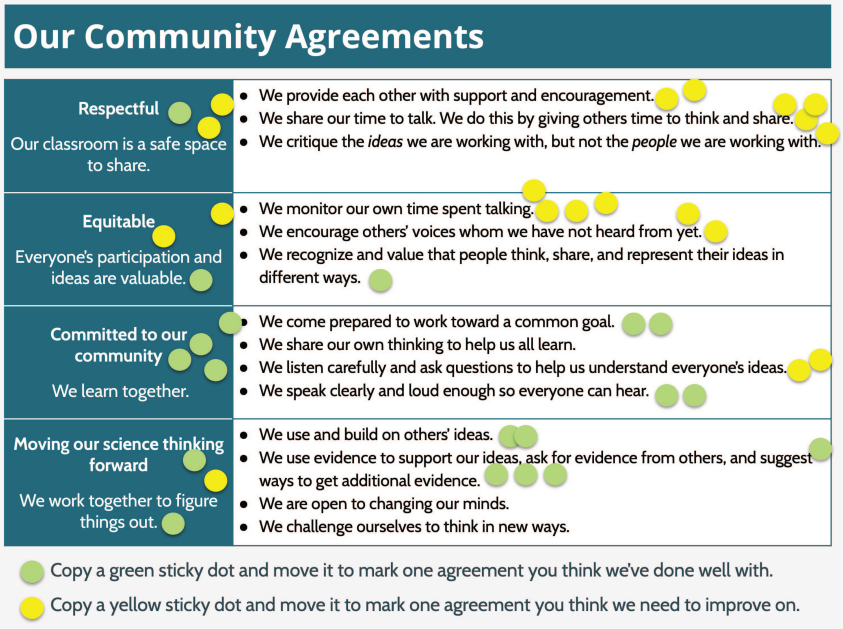
MATERIALS: 1 green and 1 yellow sticky note or dot sticker, Community Agreements

Reflect on how the class has been doing on the community agreements. Display **slide AA.** Say, *Think back to the discussions we had throughout this lesson. Which of our community agreements did we do well with, and which do we need to work on?*

Refer to the community agreements. Direct students to use a green sticky note or dot to mark one agreement they think we have done well with, and to mark an agreement they think we need to develop more with a yellow sticky note or dot.

ALTERNATE ACTIVITY	If you have a digital representation of the community agreements that all students can access at once (see Materials Preparation section), have them mark their ideas virtually instead with green and yellow squares/stickies or circles/dots.

An example of the completed activity is shown.



Analyze the patterns in the green and yellow sticky notes.

Suggested prompt	Sample student response
What patterns do you see in the sticky notes?	Accept all responses.
Which agreements are we doing well with?	Accept all responses.
Which agreements could we develop more?	Accept all responses.
What are some ways we might continue to develop _____ (specific agreement)?	Accept all responses.

Reflect on the Anchoring Phenomenon routine as a whole. Display **slide BB.** Say, *The way we began this unit--exploring a new phenomenon, attempting to make sense of it, collecting ideas about related phenomena, and gathering our questions—is how we will begin each of our units this year. We will get used to these routines and get more comfortable with them. But it was new this time, and when we try new things, it is helpful to pause and check in about how it went. So, turn and talk with a neighbor about how you felt in our classroom as we began this new unit over the past few days.*

After a moment of partner talk, summarize by saying, *We can expect a mix of emotions when we try something new or different from what we are used to, right? We will continue reflecting on our science work this year, refining our community agreements, and getting comfortable doing this work together.*

14 · SET UP SCIENCE NOTEBOOKS

5 min

MATERIALS: science notebook, dividers

Motivate the need for organizing our current and future work. Say, *When pursuing different lines of inquiry around different questions, scientists and engineers often find it useful to keep scientific or engineering notebooks and to organize them in such a way that they can cross-reference evidence and ideas across multiple weeks of investigations.*

Set up science notebooks. Show **slide CC.** Instruct students to follow the directions on the slide to set up their notebooks.

You may also give students a moment to add any words to their personal glossaries that might have been new to them or used in an unfamiliar way, such as *consensus*, *climate migrant*, or *glacier*.✱

SCIENCE NOTEBOOK

Each student should have a binder that will serve as their "science notebook" for the course. A binder was selected for ease of adding supplemental materials. Students can use large dividers to indicate the start of a new unit. Students can use additional smaller dividers or sticky notes to create three sections within the unit for the Progress Tracker, unit materials, and Personal Glossary.

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

It is fine if students' personal glossary entries are not perfectly in alignment with dictionary definitions. They should reflect students' thinking at the time and are always subject to change. Encourage students to always add to existing entries in their personal glossaries as they figure out new ideas, using practices, with crosscutting concepts as a lens.

Additional Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.4: Determine the meaning of ~~symbols, key terms,~~ and other domain-specific words and phrases as they are used in a specific ~~scientific or~~ technical context relevant to grades 9–10 texts and topics.

Students co-create a term to apply to people who have to move due to climate change, using the United Nations definition of a climate migrant as a starting point.

LESSON 2: What can the past help us figure out about what is causing sea level rise in the present?

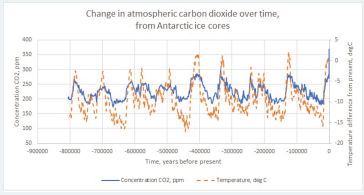
PREVIOUS LESSON

We explored three coastal communities that are affected by rising sea levels and their responses to this global problem. We recognized that sea levels have been rising for over a hundred years and modeled ideas about the matter and energy changes that are causing sea levels to rise. We built a Driving Questions Board and gathered ideas for investigations.

THIS LESSON

ANCHORING PHENOMENON, INVESTIGATION

3 days



We look at historical data to see if sea level rise is new and whether people have experienced sea level rise like this before. We see that the sea level has been this high in the last million years, but maybe not recently. We also see that temperature and ice volume change somewhat with sea level. We read about how this and similar data were collected, then analyze data about potential causes using a Chalk Talk protocol, discuss the likely cause of current ice melt and sea level rise, and model how these different potential causes could affect climate.

NEXT LESSON

We will investigate how increased CO2 in the atmosphere causes warmer temperatures using water bottles, digital thermometers, and CO2 from fizzing tablets. We will collaboratively outline important variables of the investigation, create hypotheses, and design data tables to organize and collect evidence for the investigation.

BUILDING TOWARD NGSS

HS-PS3-1, HS-PS3-4, HS-ESS2-2, HS-ESS2-4, HS-ESS3-1, HS-ESS3-5, HS-ESS3-6, HS-ESS2-7

WHAT STUDENTS WILL DO

2.A Evaluate the impact of new data showing indirect evidence of energy flows of changes in Earth's orbit, the Sun's energy output, volcanic activity, vegetation, and carbon dioxide on a working model of sea level rise. (SEP: 4.5; DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 3.2, 5.2)

2.B Construct an oral argument of how changes in Earth's orbit, the Sun's energy output, volcanic activity, vegetation, and carbon dioxide affect changes in climate over different timescales. (SEP: 7.4; DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 7.2)

WHAT STUDENTS WILL FIGURE OUT

- Over the last million years, global temperatures seem to increase around the same time that ice volumes decrease and sea levels increase.
- Scientists have to use indirect sources of evidence to figure out what Earth's climate was like in the past.
- Changes in sunlight due to Earth's orbit and tilt can affect climate.
- Changes in sunlight due to solar activity can affect climate.
- Volcanic activity can affect climate.
- Changes in carbon dioxide due to plant growth or human activity can affect climate and can help explain current temperature increases.
- Climate is impacted when something changes energy flows into or out of Earth systems, but it is unclear how carbon dioxide does that.

Lesson 2 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	6 min		**NAVIGATE** Establish the importance of the Navigation Routine and help students navigate to the new lesson.	A	Community Agreements
2	18 min	☑	**ANALYZE HISTORICAL DATA** Support students as they consider the relationship between sea level rise, polar ice melt, and global temperatures.	B-C	*Sea Level*, Earth squeeze balls, https://youtu.be/oM4iNRlR7bM, https://youtu.be/ev9QMpp757M
3	5 min		**CONSIDER HOW SCIENTISTS COLLECT DATA** Raise the question of how data from many years ago was collected.	D	
4	13 min	☑	**CONSIDER DATA COLLECTION METHODS** Give students time to jigsaw and discuss different data collection methods.	E-F	*Geological Data*, *Ice Cores*, *Clues from Humanity*
5	3 min		**NAVIGATE** Gather ideas for data that could help answer the class's questions about Earth's sea levels and temperatures.	G	
					End of day 1
6	3 min		**NAVIGATE** Help students remember why they wanted the new data.	H	
7	28 min		**ANALYZE AND INTERPRET DATA** Support students as they work through the Chalk Talk task.	I-J	*Earth's Orbit*, *Earth's Atmosphere*, *Year Without Summer*, chart paper, chart paper markers
8	9 min		**GALLERY WALK** Students examine the different posters from the Chalk Talk activity.	K	Chalk Talk posters
9	5 min	☑	**NAVIGATE** Give students time to complete an exit ticket.	L	*Exit Ticket*
					End of day 2
10	4 min		**NAVIGATE** Reflect on the exit tickets from day 2.	M	*Exit Ticket*
11	11 min		**CONSTRUCT AN ARGUMENT ABOUT THE CAUSE OF ICE MELT** Support students in organizing an argument about the cause of current ice melt.	N-O	*Data Analysis*, *Earth's Orbit*, *Earth's Atmosphere*, *Year Without Summer*
12	10 min	☑	**BUILDING UNDERSTANDINGS DISCUSSION** Lead a Building Understandings Discussion to help students share oral arguments around the most likely cause of current sea level rise.	P	*Data Analysis*, *Earth's Orbit*, *Earth's Atmosphere*, *Year Without Summer*

Part	Duration		Summary	Slide	Materials
13	14 min		**MODEL ENERGY FLOWS** Develop an energy transfer model for the phenomena examined in the lesson.	Q-S	*Data Analysis*, "Rules for Energy Transfer Models" anchor chart
14	6 min		**NAVIGATE** Close class by starting progress trackers and reflecting on our focal agreement and what we still need to figure out.	T-U	

End of day 3

Lesson 2 • Materials List

	per student	per group	per class
Lesson materials	• *Sea Level* • science notebook • *Exit Ticket* • *Data Analysis*	• Earth squeeze balls • *Geological Data* • *Ice Cores* • *Clues from Humanity* • *Earth's Orbit* • *Earth's Atmosphere* • *Year Without Summer* • chart paper • chart paper markers	• Community Agreements • https://youtu.be/oM4iNRlR7bM • https://youtu.be/ev9QMpp757M • Chalk Talk posters • *Earth's Orbit* • *Earth's Atmosphere* • *Year Without Summer* • "Rules for Energy Transfer Models" anchor chart

Materials preparation (35 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Test the videos to ensure they play correctly:
- https://youtu.be/oM4iNRlR7bM
- https://youtu.be/ev9QMpp757M

For the jigsaw activity:
Ensure that there is a copy of each of the following for every 3 students in the class:
- *Geological Data*
- *Ice Cores*
- *Clues from Humanity*

Ensure that students have access to physical or digital color versions of the following, as well as all other materials in either color or black and white:
- *Sea Level* (all students)

For the Chalk Talk:
- *Earth's Orbit* (enough for 1/3 of the class, left at a large poster for students to write on)
- *Earth's Atmosphere* (enough for 1/3 of the class, left at another large poster for students to write on)
- *Year Without Summer* (enough for 1/3 of the class, left at another large poster for students to write on)

Setup tip: For a class of 35 students, plan for 6 large blank posters with 5-6 copies of the assigned reading at each one.

Earth's Orbit, *Earth's Atmosphere*, and *Year Without Summer* will be used in a collaborative Chalk Talk activity (with talking allowed). Students will work in a group and rotate to write responses on three posters, each with one of these references. At each poster, students should find enough copies of the reference that every one or two students can view it. The group will work together to answer the prompts on **slide J**, then rotate to the next poster. Set up enough pieces of chart paper with materials so that there are no more than 6 students per group.

Prepare a piece of chart paper titled "Rules for Energy Transfer Models" with the following text. Make sure to use no more than half the space, if possible. See *Energy Anchor Chart* to see how this anchor chart will be built throughout the unit.

1. Boxes represent objects.
2. Arrows represent energy flows/transfers.
3. A dotted line shows which objects are in the system

4. We can use text to say what happens to the particles in an object when energy transfers to or away from it.
5. We can use prompts about where energy comes from and goes (and how it moves) to help us think through energy flows.
6. We can draw separate energy transfer models to show situations where energy transfer is different.

Lesson 2 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students establish that sea levels are likely rising due to temperature increases melting polar ice and that there are a number of factors that can impact temperatures on Earth, but only increases in atmospheric carbon dioxide can explain the recent rate of change in global temperatures. As they do so, they further answer the Learning in Places Ethical Deliberation and Decision-Making question, "How did the need to make the decision come to be?" For more information, see http://learninginplaces.org/frameworks/ethical-deliberation-and-decision-making-in-socio-ecological-systems-framework/. If a significant percentage of students hold an alternate model of increased precipitation driving sea level rise, you may supplement the provided data in this lesson with additional data on historical, global precipitation patterns.

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **ESS1.B.2: 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.
- **ESS2.A.3: Earth Materials and System.** The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles.
- **ESS2.D.2: Weather and Climate.** Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.

Students examine various factors in part because these factors are important demonstrations of how energy flows into, between, and out of Earth's systems (CCC: 5.2), but also because they represent common objections to the scientific consensus that climate change is caused by anthropogenic carbon dioxide emissions. Students engage with the crosscutting concept of scale (CCC: 3.2), previously developed in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)* and *OpenSciEd Unit B.5: What will happen to Arctic bear populations as their environment changes?(Speciation Unit)*, to figure out how scientists have developed a strong understanding of how Earth systems have operated throughout history, and the crosscutting concept of stability and change (CCC: 7.2) to identify that alternative factors do not explain current global temperature increases.

Students interpret curated data (SEP: 4.5) for purposes of revising their existing model and constructing an argument (SEP: 7.2) about which of the various factors could be causing current temperature increases. Analyzing and interpreting data was previously developed in *OpenSciEd Unit B.4: How does urbanization affect nonhuman populations, and how can we minimize harmful effects? (Urbanization Unit)* and engaging in argument from evidence in *Speciation Unit*.

Where We Are NOT Going

Students will not establish a mechanism for how carbon dioxide and other greenhouse gases contribute to climate change in this lesson. In Lesson 3 students will gather experimental evidence that it is occurring and tie this evidence to energy being trapped. In Lesson 7 they will extend this model by building an initial understanding that carbon dioxide is transparent to visible light but absorbs infrared light. This idea was placed later in the unit so that students naturally arrive at it as they investigate how microspheres work. In *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)* students will explain absorption partially with bond behavior and extend their thinking to other greenhouse gases, as these ideas fit more coherently with the investigation of energy in chemical reactions. Students will figure out how carbon cycles through all of Earth's systems in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)* and they will develop a complete model that can explain climate change due to greenhouse gases in *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*.

This lesson also does not spend time dwelling on the other mechanisms that can cause changes in climate. Students already have familiarity with the role of photosynthesis in carbon cycling from *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*. In *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)* they will deepen their middle school explanation of geological phenomena like volcanoes, and in *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)* they will develop a model that can explain the basics of orbital mechanics.

Students will only evaluate the impact of new data on a working model of a proposed system in this lesson. They will have the opportunity to evaluate the impact of new data on an explanation or a proposed process later in the Chemistry course. Similarly, they will use arguments and consider counter-arguments later in the course.

In this lesson, students only focus on systems that are too slow to observe directly. They focus on energy flows, returning to matter flows in the context of CCC: 5.2 in Lesson 12. They also do not quantify rates of change and do not think about how some changes are irreversible.

LEARNING PLAN for LESSON 2

1 · NAVIGATE

6 min

MATERIALS: Community Agreements

Help students navigate to the new lesson. Show **slide A** and say, *We will often begin or end a lesson, or even a day, with the Navigation Routine. We use navigation to help us remember what we figured out the last time we met and decide what we should do next to answer the questions that we still have.*

ADDITIONAL GUIDANCE

The Navigation Routine is used throughout OpenSciEd units. It takes a slightly different form every time it is used. Sometimes it resembles a traditional "bellringer" or "exit ticket" task or discussion question. However, it reaches beyond these traditional classroom activities by not only asking students to recall what they learned (or as OpenSciEd units typically say, figured out), but also by pushing students to consider what new questions they have and how to figure out answers to those questions.

Give students a couple of minutes to turn and talk about the prompts on the slide, then discuss them as a class.

Suggested prompt	Sample student response
What types of things did we say we wanted to figure out last class?	We wanted to know if melting ice is really causing sea levels to rise and how that would work. We wondered if people have been affected by sea level rise before.
Why might scientists study what happened in Earth's past to answer questions like these?	The same things that are happening now may have happened in the past. Maybe things have changed from the past, and that should show up in historical data too.
What types of historical data might help us answer these questions?	We could look at data to see if sea levels have been higher in the past and what could have caused that. Maybe temperature data or other climate information would help. We could learn more about polar ice melt to see if that could really be affecting sea level rise.

Say, *I have data that might be able to help us. First though, we want to make sure we are sticking with our community agreements throughout the unit. Today, we will focus on the agreements we made around being "Respectful."* Show students the community agreements and elicit reminders about how the class decided to act to show respect.✱

✱ ATTENDING TO EQUITY

Building classroom culture: In the first few lessons, the class will focus on practicing one area of the community agreements. These areas were chosen to match the types of discussions students have in each lesson. Later in the unit, students will have an opportunity to individually choose a focal agreement to work on.

2 · ANALYZE HISTORICAL DATA

18 min

MATERIALS: *Sea Level*, science notebook, Earth squeeze balls, https://youtu.be/oM4iNRlR7bM, https://youtu.be/ev9QMpp757M

Set up data analysis.✱ Display **slide B.** Distribute *Sea Level*. Pair students and tell them they will have 8 minutes to analyze data. They will answer the prompts on the slide in their notebooks as they do so.

Discuss observations as a class. Lead a brief discussion about conclusions from students' data analysis.

ADDITIONAL GUIDANCE

In *Sea Level*, "meters of sea level rise if melted" are the units of volume being used in the graph. The temperature data refers to atmospheric surface air temperature. The graph includes two vertical axes. The axis on the left is meteors of sea level rise and the axis on the right is temperature. The graph was adapted from data in: Bintanja, R., van de Wal, R.S.W., & Oerlemans, J. (2005). Modelled atmospheric temperatures and global sea levels over the past million years. *Nature (437)*, 125-128. https://doi.org/10.1038/nature03975

Suggested prompt	Sample student response
What patterns do you notice in the data?	The temperature, sea level, and ice all went up and down over time in fairly regular cycles. Temperature and sea level were high at the same time, and opposite when ice volume was higher.
What do the data say about whether people have dealt with sea level rise before?	People might have dealt with sea level rise before, since it was higher at different points in the past.
What problems could result if sea levels and temperatures are high?	Living things would lose habitat. It might be too hot for some organisms to survive. People and non-human animals might have to move.
Based on the data, what relationships might exist between temperature, sea level, and ice volume?	Ice might melt when temperatures increase. Sea levels rise when ice is melted.
Do you think that is what is happening now to cause sea level rise?	Yes, because the graphs move very closely together throughout history. No, because we need to see data closer to what is happening today.

Distribute the Earth squeeze balls. Ask students to indicate where the melting ice might be. They should point to the poles. Say, *Let's take a look at additional data and see if the ice has been melting recently.*

✱ SUPPORTING STUDENTS IN ENGAGING IN ANALYZING AND INTERPRETING DATA

This activity assumes that students have experience with analyzing graphical data from OpenSciEd High School Biology and middle school coursework. If they need more support, consider incorporating a tool like the Identify and Interpret (I^2) strategy https://media.bscs.org/icans/Icans_I2_SE.pdf.

ASSESSMENT OPPORTUNITY	**What to look/listen for in the moment:** Students evaluate how new data showing slow system changes impact their sea level rise model. (SEP: 4.5; CCC: 3.2) **What to do:** Students who had initial ideas about causes of sea level rise other than polar ice melt might be reluctant to let go of those ideas. It is fine if the class is not fully in consensus at this point. Students will engage with more data that shows evidence of polar ice melt later in the activity. If additional data does not sway students, that is also fine. Throughout Lesson Set 1, students will have an opportunity to build a more complete mechanism of atmospheric carbon dioxide causing increased temperatures, ice melt, and sea level rise. **Building toward: 2.A.1** Evaluate the impact of new data showing indirect evidence of energy flows of changes in Earth's orbit, the Sun's energy output, volcanic activity, vegetation, and carbon dioxide on a working model of sea level rise. (SEP: 4.5; DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 3.2, 5.2)

Examine recent ice melt and sea level data. Display **slide C.** Say, *This graph from Lesson 1 showed us how sea level has been changing over the last century or so.* Ask the question on the slide before playing the videos. Student responses may include:

- The ice would be melting.
- There would be less ice.
- A similar graph would slope downward.

Tell students to think about whether their predictions match the videos they are about to see. Before playing either video, help students find the Arctic Ocean, Greenland, and Antarctica on their Earth squeeze balls. You may wish to collect these before starting the first video.

Play both videos and discuss. When each video begins, briefly help students orient to what is shown--typically a graph of the amount of ice, along with a map showing where ice is present and lost in each area.

After playing the videos, ask, *Did the videos show what we expected?* Listen for the following student ideas:

- Yes, because there was visibly less ice.
- Yes, because the graph went down.

Follow up by asking, *Why is the ice melting, besides increases in temperature?* Listen for the following ideas:

- Global warming/climate change
- Something related to carbon dioxide
- A hole in the ozone layer
- Maybe the sun is hotter

ADDITIONAL GUIDANCE	Even when students are aware of a relationship between climate change and atmospheric carbon dioxide, they often hold the simultaneous, contradictory conception that a hole in the ozone layer is also responsible. The investigation in Lesson 3 is designed to help students think about how carbon dioxide can cause temperature increases without the "ozone hole" playing a role.

3 · CONSIDER HOW SCIENTISTS COLLECT DATA

5 min

MATERIALS: None

Point out a discrepancy. Show **slide D.** Say, *We would probably need more information to figure out why temperatures have been increasing and polar ice has been melting recently. The videos we watched both show information from satellite data, but we also just saw data from long before there were satellites. How do you think the data we looked at from the last million years was collected, if we did not have access to satellite data?*

If students struggle to generate ideas, follow up with, *How do scientists, or people generally, usually figure out information about the past?*

Listen for these ideas:

- Fossils (maybe cold-weather animals where they are no longer found)
- Layers of decomposed organisms (like peat under the ice)
- Hieroglyphics, oral histories, written accounts, primary documents, human artifacts
- DNA
- Rocks

Lead into examining different methods. Say, *Those all sound promising, and there might be some other methods we do not know about. Let's take a deeper look at how scientists figure these things out.*

4 · CONSIDER DATA COLLECTION METHODS

13 min

MATERIALS: science notebook, *Geological Data*, *Ice Cores*, *Clues from Humanity*

Give students time to read about data collection methods. Display **slide E.** Structure the reading jigsaw-style. Divide students into groups of three and give each student one of the three readings--*Geological Data*, *Ice Cores*, and *Clues from Humanity*. Give students a few minutes to independently read. They may either answer the prompts in their notebooks or highlight the answers in the text directly, then come together as a group and share their responses with each other.✱

Discuss data collection methods as a class. Show **slide F.** Use the prompts on the slide to lead a brief discussion about data collection methods.

Suggested prompt	Sample student response
What did you figure out from the readings?	We can learn about the past from rocks, ice cores, or stories/records/ items left by people, as well as from fossils and DNA. Earth has changed in other ways besides what we have discussed. Earth is wobbling on its axis and used to have a different atmosphere. There also have been major events like volcanic eruptions.

✱ ATTENDING TO EQUITY

Universal Design for Learning: You may wish to allow students to self-select readings based on interest, before dividing them into groups. Or, for this activity, students can choose which text to read based on difficulty. *Ice Cores* is most accessible, while *Clues from Humanity* is at the highest reading level. You can read more about the text adaptations and text-specific suggestions in *UDL for Jigsaw Readings*.

Suggested prompt	Sample student response
How could the data in the readings help us to answer our questions?	We could figure out if there are other changes that have affected Earth's climate. We could figure out why temperatures changed in the past, and if that is why sea levels are rising now.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
Students should identify that long-ago changes in Earth's orbit, volcanic activity, and atmosphere left indirect evidence, which can be studied today to build a picture of the past. (DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 3.2)

What to do: Encourage students to dwell on the idea that evidence available to us today can help us figure out what happened long ago. Also push to have students identify the readings' specific examples of what indirect evidence sources tell scientists about the past, as these evidence sources are intended to help seed different ideas about what could be affecting global temperatures and, therefore, sea levels.

Building toward: 2.A.2 Evaluate the impact of new data showing indirect evidence of energy flows of changes in Earth's orbit, the Sun's energy output, volcanic activity, vegetation, and carbon dioxide on a working model of sea level rise. (SEP: 4.5; DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 3.2, 5.2)

5 · NAVIGATE

3 min

MATERIALS: None

Close out by thinking about data. Display **slide G.** Ask students, *What particular pieces of data might be interesting or helpful to see to answer our questions?* Students might say:

- We need more information about recent temperatures.
- It would be good to learn more about changes in Earth's atmosphere or tilt.
- We want to hear more specific stories about whether there have been drastic changes in climate before.

Thank students and say you will work on tracking down that data.✱

✱ SUPPORTING STUDENTS IN ENGAGING IN ANALYZING AND INTERPRETING DATA

It is important that students are analyzing data that they have a need for and that will help answer questions that they have. This aligns with the Lesson-Level Performance Expectation in that students are evaluating how the data impacts their model, not what data means out of context.

End of day 1

6 · NAVIGATE

3 min

MATERIALS: None

Tie new data to where students wanted to go. Display **slide H.** Say, *Last time we decided we were interested in getting more information about things that could be affecting temperature, polar ice, and sea level changes in the past. I brought three pieces of data, which you can read about here.* Give students a moment to read the blurbs about the references on the slide.

Ask, *How do you think these different things could affect temperature, sea level, and polar ice?* Student responses may include:

- More sunlight probably makes Earth hotter and melts more ice.
- If there was a volcanic eruption that "prevented" summer, maybe it was making the Earth colder, or WAY hotter.
- We have heard that carbon dioxide or maybe ozone can cause temperature increases.

Say, *Let's dig into the data and figure out what is going on.*

7 · ANALYZE AND INTERPRET DATA

28 min

MATERIALS: *Earth's Orbit*, *Earth's Atmosphere*, *Year Without Summer*, chart paper, chart paper markers

Explain the analysis activity to students. Display **slide I.** The three data sets used for this activity are *Earth's Orbit*, *Earth's Atmosphere*, and *Year Without Summer*. Set up the activity and explain the steps on the slide. Assign students to groups of 6 or fewer and have them divide out among the posters. Ask each group to write the three prompts on their poster before answering them. Make sure students leave enough space for their group and two other groups to respond. Explain that students may have completed similar Chalk Talk tasks individually and in silence in the past, but in this activity they are encouraged to talk and collaborate with their group.✱

Give students time to complete the activity. Display **slide J.** Allow for 8 minutes at each poster, then call for students to rotate on their side of the room. Make sure all groups have had time to analyze each piece of data and encourage students to take turns writing.

ALTERNATE ACTIVITY

Chalk Talk can also be done virtually using a platform such as Jamboard. A physical method is preferred because (1) grouping students tightly around a poster encourages them to engage in conversation around the data, and (2) using physical materials pushes students to focus deeply on one of the items at a time. However, a digital Chalk Talk can have a lower barrier to participation for some students because it allows them to share their thoughts without turn-taking.

✱ ATTENDING TO EQUITY

Building classroom culture: You may wish to explicitly tie this activity to the focal agreement of "Respectful." Ask students, *How can we show respect in this activity?* Listen for ideas like the following:

- We write down everyone's ideas.
- We do not make one person do all the work.
- We listen to each other's ideas.

One way to encourage more widespread student participation is to give each group member a different-colored marker to use during the Chalk Talk protocol. This will encourage each student to add their own thoughts instead of relying on one of their group mates to record everyone's thinking.

8 · GALLERY WALK

9 min

MATERIALS: science notebook, Chalk Talk posters

Conduct a gallery walk. Display **slide K.** Ask students to retrieve their science notebooks. Then give students the remainder of the activity to examine the posters that they have not seen or worked on earlier and record notes on each poster using one of the sentence starters on the slide.

9 · NAVIGATE

5 min

MATERIALS: *Exit Ticket*

Collect exit tickets. Have students return to their seats and display **slide L.** Distribute *Exit Ticket* and ask students to complete the prompts and turn in the exit ticket before leaving. Tell them it is okay if they do not finish completely, but the questions will form the basis of our discussion at the start of class tomorrow.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
Students' exit tickets include an initial idea that changes in carbon dioxide are more likely than other factors to be causing current sea level rise because carbon dioxide and sea levels changes have mirrored each other historically. (DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 7.2)

What to do: Students will have another opportunity to dive into the data on day 3 to explicitly consider whether or not the changes currently occurring in Earth's orbit, volcanic activity, and atmosphere are likely causes of ice melt and sea level rise. This is a useful opportunity to see where each student is in their thinking--have they already concluded that carbon dioxide is the most likely cause, or do they need this planned time with the data? Are they resistant to the idea of anthropogenic climate change? This knowledge can help inform how much time to give students to construct and share their oral arguments and counterarguments on day 3.

Building toward: 2.B.1 Construct an oral argument of how changes in Earth's orbit, the Sun's energy output, volcanic activity, vegetation, and carbon dioxide affect changes in climate over different timescales. (SEP: 7.4; DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 7.2)

ALTERNATE ACTIVITY

Extension opportunity: If students are particularly curious about historical data, give them 15-20 minutes to analyze geological and historical data from your own region. Then discuss these prompts:

- How has our area changed over time?
- What effects would that have on the living and nonliving world?
- How would our community be different if we were living under the different conditions we saw in the past?

End of day 2

10 · NAVIGATE

4 min

MATERIALS: *Exit Ticket*

Discuss the exit ticket. Show **slide M**. Point out to students that the exit ticket they completed yesterday can help us navigate between different activities and figure out what we as a group are thinking. Distribute the exit tickets to students and discuss the prompts as a class.

Suggested prompt	Sample student response
What are two pieces of evidence from class that were most powerful for deciding what is causing sea level rise?	Accept all responses.

Suggested prompt	Sample student response
What does our evidence so far tell us about energy, matter, and climate?	Some changes in matter, like Earth tilting the right way, cause more energy to reach Earth. Some changes in matter, like volcanic dust, cause less energy to reach Earth. More energy reaching Earth seems usually to result in temperature increases.
How are we doing as a class in meeting our Community Agreement of being "Respectful?"	Accept all thoughtful responses.

Say, *On the exit ticket, you shared some initial ideas about how different factors might be affecting current ice melt. Let's take a look back at the data and focus specifically on the question of which of these potential causes is the most likely cause of the ice melt and sea level rise we see today.*

11 · CONSTRUCT AN ARGUMENT ABOUT THE CAUSE OF ICE MELT

11 min

MATERIALS: *Data Analysis*, *Earth's Orbit*, *Earth's Atmosphere*, *Year Without Summer*

Figure out how we can determine the cause of ice melt. Display **slide N**. Pose the question on the slide and give students a minute to turn and talk before discussing their responses as a class. Listen for these student ideas:

- We could look at the data to see if the possible cause is changing right now or if it changed before temperatures started rising.
- We have to see if the possible cause is changing in the right direction to cause increased temperatures.

Thank students for their thoughts and distribute *Data Analysis*, noting that it will help them think about the data in a different way.✱

Orient students to the handout. Tell them to focus only on the table on the first page for now. Point out that there is a row for each potential cause the students analyzed. In each row there is space to explain how that potential cause actually affects temperature, to discuss whether the timing of the potential cause is right to affect recent temperature changes, and to discuss whether the potential cause is changing in the right direction or quickly enough to increase temperatures. Then point to the prompts below the table. Encourage students to complete these prompts with their groups, incorporating everyone's ideas.

Break into groups. Display **slide O.** Tell students they will be working in their previous (day 2) groups. Make sure each group has access to at least one or two copies of all three references from the poster activity. Give students 8 minutes to work. You may use *Data Analysis Key* to gauge likely student thinking.

COLLABORATION

Alternatively, give students a few minutes to begin *Data Analysis* individually or with a partner, then use the peer feedback protocols described in the *OpenSciEd High School Teacher Handbook* to give each other feedback. Then, students can return to individual or pair work and refine their ideas.

✱ SUPPORTING STUDENTS IN ENGAGING IN ARGUMENT FROM EVIDENCE

The handout is intended to help students break down the processed data, using the crosscutting concept of stability and change, in order to make an argument about which factor might be behind climate change.

12 · BUILDING UNDERSTANDINGS DISCUSSION

10 min

MATERIALS: *Data Analysis*, *Earth's Orbit*, *Earth's Atmosphere*, *Year Without Summer*

Lead a Building Understanding Discussion. Gather students, with their handouts, in a Scientists Circle and display **slide P.** Have digital versions of *Earth's Orbit*, *Earth's Atmosphere*, and *Year Without Summer* ready to show students if there are disagreements about the data.✱ See *Data Analysis Key* for likely student responses in the discussion.

KEY IDEAS

Purpose of the discussion: This Building Understandings Discussion is intended to help students come to the tentative conclusion that recent increases in atmospheric carbon dioxide are the most likely cause of global temperature increases and therefore ice melt and sea level rise. The discussion is structured to help students place evidence from the data in the table before sharing their arguments.

Listen for these ideas:

- Of the listed causes, CO_2 is the most likely because global temperatures have tracked with CO_2 for a long time, as well as recently.
- CO_2 started changing *before* the recent temperature increase, and started increasing, which is known to cause temperature changes.
- CO_2 has been changing recently at a high rate, whereas none of the other possible causes has.

Conclude the discussion by saying, *It sounds like we are pretty confident that carbon dioxide is the most likely cause of temperature increases and therefore ice melt and sea level rise. But to be sure our arguments make sense, we have to be able to explain how carbon dioxide could cause temperatures to increase. This means we have to think about how the different potential causes affect energy flows.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' arguments are based on evidence from the data focusing on the timing of changes and rates of change in sea level and their possible causes. (SEP: 7.4; CCC: 7.2)
- Students' arguments should reflect understanding of how changes in Earth's orbit, the Sun's energy output, volcanic activity, vegetation, and carbon dioxide affect climate. (SEP: 7.4; DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2)

What to do: Ask probing questions to ensure students' understanding of the mechanisms and timings of different possible causes. Consider the following prompts:

- *How could [potential cause] cause Earth's temperature to increase?*
- *How would [potential cause] have to change to cause Earth's temperature to increase?*
- *Is [potential cause] changing like that right now? Is it changing quickly enough to explain the temperature increase?*

You should collect *Data Analysis* to better understand the thinking of students who do not share in the oral argumentation. This is an important moment to gather evidence of students' argument-based evidence, using pieces of disciplinary core ideas from their readings, with Stability and Change as a lens.

Building toward: 2.B.2 Construct an oral argument of how changes in Earth's orbit, the Sun's energy output, volcanic activity, vegetation, and carbon dioxide affect changes in climate over different timescales. (SEP: 7.4; DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 7.2)

✱ STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

This is the second time in the unit, and likely the course, that students have engaged in a Building Understandings Discussion. Remind students that your role is to press for evidence from the data, regardless of whether students' ideas are right or wrong.

13 · MODEL ENERGY FLOWS

14 min

MATERIALS: *Data Analysis*, science notebook, "Rules for Energy Transfer Models" anchor chart

Discuss energy flows.✱ Display **slide Q.** Begin by discussing "normal" energy flow without global temperature increases. Point out that here, our system might be different than in Lesson 1, since we are focusing on the whole Earth as the system.

Suggested prompt	Sample student response
Where does Earth's energy come from?	It comes from the Sun.
How does the energy get to Earth?	It comes to Earth through light.
Does the energy transfer directly into ice, or go through something else first?	It goes into the atmosphere or ocean before reaching the ice. It goes directly into the ice.
What happens to the ice once the energy reaches it?	Particles speed up and it melts. Some might reflect.
What does the energy do next? Does it all do the same thing?	We are not sure. Some might transfer to other objects, like the air and water.

Say, *That was a lot to process. Scientists often find it useful to model how energy is moving. In Lesson 1, I drew some boxes and arrows in the initial consensus model to show your ideas about how energy is moving. This is called an energy transfer model, and it is a tool that we will use throughout the unit. Energy transfer models follow a few simple rules.* Display the "Rules for Energy Transfer Models" anchor chart and explain the rules to students.

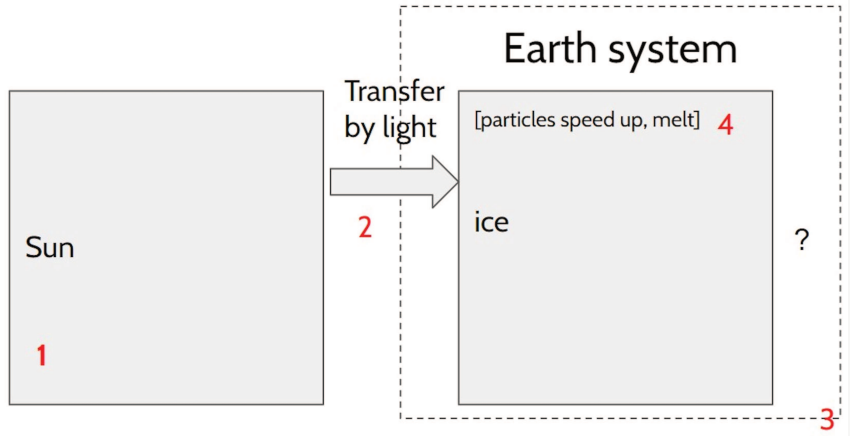
Model "normal" energy flow as a class. Ask students to take out their science notebooks and draw what you draw. Use the rules on the anchor chart to draw an energy transfer model based on what students shared in the discussion. An example annotated with the rule numbers is below. You should draw this model on a chalkboard or whiteboard, so you can easily modify it in the next step.✱

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

The energy transfer diagrams or models introduced here are heavily scaffolded with gradual release throughout the unit. This is because the focus is to be on students' thinking about energy flows, not on the practice of modeling. Modeling as a practice will be further developed in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*.

✱ ATTENDING TO EQUITY

Universal Design for Learning: Here and throughout the course you may wish to draw small images in energy transfer models, like a sun or iceberg, to help quickly distinguish between objects. This is particularly helpful to students when several diagrams are utilized together.



Consider changes in energy flows with a partner. Show **slide R.** Give students 5 minutes to work with a partner to discuss how the "normal" energy transfer model would change with different possible causes of climate change. Encourage students to use *Data Analysis* to help them remember the different mechanisms.

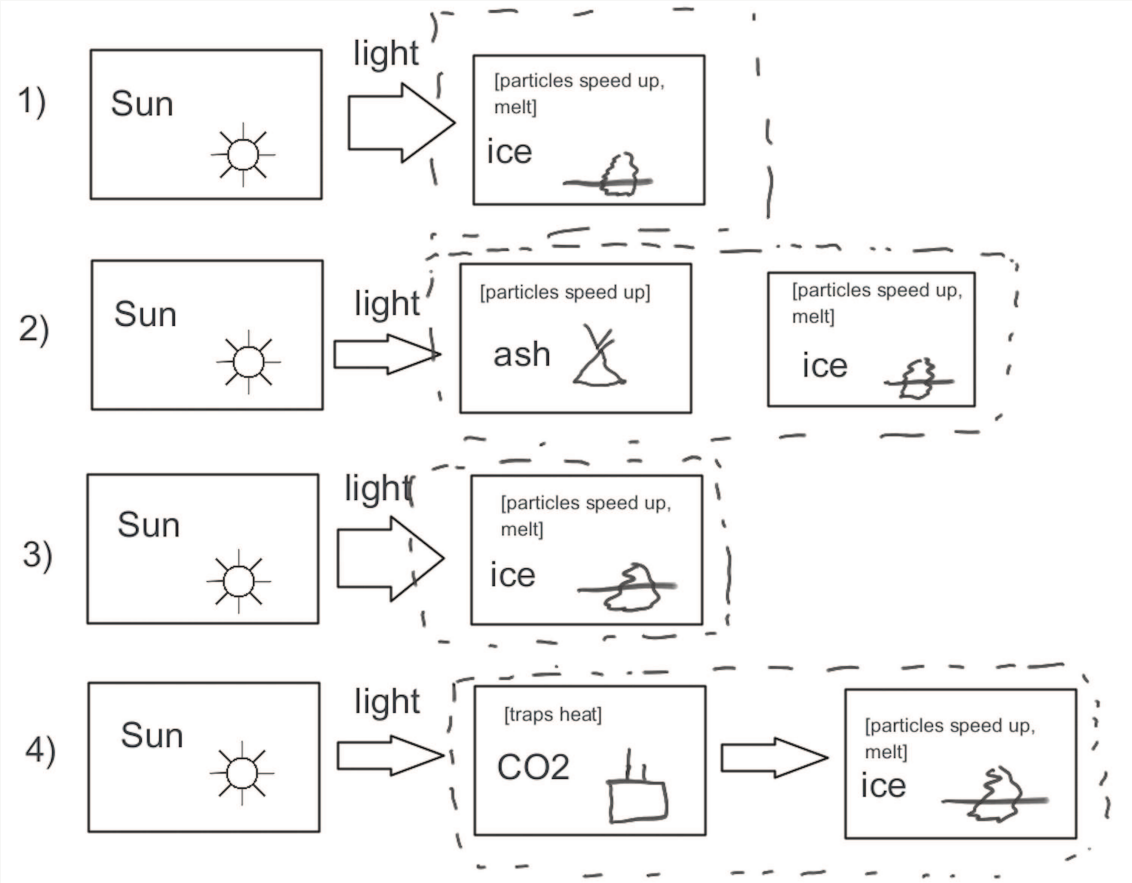
ADDITIONAL GUIDANCE

The carbon dioxide model is likely to be particularly difficult for students. This is to be expected, as student materials do not explain *how* greenhouse gases cause temperature increases. Encourage students to put their best ideas on paper at this point, and later in the lesson you will use this ambiguity to navigate into Lesson 3.

Discuss model changes as a class. Display **slide S.** Use the prompts on the slide to lead a discussion about how we could change the energy transfer model. As students propose changes, modify the model on the board and encourage students to record the changed models in their notebooks.

Suggested prompts	Sample student responses	Follow-up questions
How would our energy transfer model change if Earth's tilt was greater than it is now?	More light would reach a part of Earth during its summer. More ice would melt during summer.	*How can we show "more light" in our models?* *What data supports that change?*
How would our energy transfer model change if there was a major volcanic eruption?	The ash would block light from getting to the ice. The ice would not melt as much.	*How would the ash be affected when it blocks the light?* *What data supports that change?*
How would our energy transfer model change if the Sun had greater activity than it does now?	More light would reach Earth. More ice would melt.	*How is this different from situation 1 (greater tilt)?* *What data supports that change?*

Suggested prompts	Sample student responses	Follow-up questions
How would our energy transfer model change if there was more atmospheric carbon dioxide than there is now?	CO_2 would trap the energy, so Earth would get hotter. CO_2 would cause a hole in the ozone layer, letting more light through.	*Why would CO_2 have that effect?* *How would this model change if there were fewer plants on Earth?* *What data supports that change?*



Conclude the discussion. After different models have been shared, ask students, *Which of these changes were we more unsure of?* Listen for these ideas:

- Orbital cycles, because the effects are complicated.
- Carbon dioxide, because we do not understand why it would affect energy.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' models should represent energy flows within, into, and out of Earth systems based on the data students engaged with throughout the lesson. (SEP: 4.5; CCC: 5.2)
- Students should accurately represent energy flows using a basic understanding of changes in Earth's orbit, the Sun's energy output, volcanic activity, vegetation, and carbon dioxide. (DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 5.2)

What to do: Ensure that the definition of the system is the same across all changed models as what students decided in Lesson 1. Encourage students to return to *Data Analysis* or other materials from the lesson to identify different pieces of data that support changes to the model. Finally, it may be challenging to students to see visibly similar models lined up in their notebooks. Use small symbols, like a Sun or volcano, to help differentiate the boxes. Collect notebooks to examine models more closely if needed, and provide students feedback around their use of all three dimensions together as well as specifically around the energy transfer models. This will support student use of energy transfer models in subsequent lessons.

Building toward: 2.A.3 Evaluate the impact of new data showing indirect evidence of energy flows of changes in Earth's orbit, the Sun's energy output, volcanic activity, vegetation, and carbon dioxide on a working model of sea level rise. (SEP: 4.5; DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 3.2, 5.2)

14 · NAVIGATE

6 min

MATERIALS: None

Start Progress Trackers.✱ Display **slide T**. Say, *We are now going to navigate out of the lesson, with the Navigation Routine. One thing we will sometimes do when moving between different ideas is update our Progress Trackers.*

Explain that the Progress Tracker section of their science notebooks is intended:

1. As a thinking tool to help you keep track of important discoveries that you or the class makes.
2. To provide you a place to individually organize your thoughts and reflect on what you are figuring out without having to worry about if your ideas are correct.

Have students label a blank page in their notebook with "Progress Tracker" at the top and make a table as shown on the slide. Once students have set up their Progress Tracker page, continue as follows.

Question	What I figured out in words/pictures
What can the past help us figure out about what is causing sea level rise in the present?	• *Earth has been this warm in the past and the sea level has been this high before, but the rate of change has never been this high.* • *Carbon dioxide in the atmosphere is the only thing we have seen that could explain temperature increases at their current rates.*

✱ ATTENDING TO EQUITY

Universal Design for Learning: Moments that follow major discussions are excellent opportunities for students to summarize their thinking and reflect on their progress, a purpose Progress Trackers serve. Another tool that may supplement the Progress Tracker is the self-assessment tool in the *OpenSciEd Teacher Handbook: High School Science.* Consider using this tool at least once every week or two.

ADDITIONAL GUIDANCE	The sample Progress Tracker included in these materials serves as teacher guidance for what students **may** say at various points throughout the unit. Some students may say more, others may say less. It is important that what the students write in the Progress Tracker reflects their own thinking at that particular moment. In this way, the Progress Tracker can be used to formatively assess individual student progress throughout the unit. When the class develops ideas together and comes to agreement, students will record this in their Progress Tracker and indicate the sources of evidence, but make it clear that this is a classroom consensus model.

Close class. Display **slide U**. Acknowledge that we think carbon dioxide is our most likely cause of temperature increases and therefore ice melt and sea level rise, but we do not understand how carbon dioxide could actually cause temperature increases. Ask students the questions on the slide.

Suggested prompt	Sample student response
How did we do in attending to our agreement of being "Respectful?"	Accept all responses.
What do we still need to explain?	How carbon dioxide can affect energy transfer to cause ice melt.
What could we do to figure it out?	Maybe we could look at more data. An experiment could help us see how energy transfer is different with more carbon dioxide than with less.

Follow up by asking, *How could this Navigation Routine help move our thinking forward in the future?* Accept all responses.

Additional Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.ELA-LITERACY.RST.9-10.9: Compare and contrast findings presented in a text to those from other sources ~~(including their own experiments)~~, noting when the findings support or contradict previous explanations or accounts. CCSS.ELA-LITERACY.WHST.9-10.9: Draw evidence from informational texts to support analysis, ~~reflection, and research.~~ Students evaluate how written and graphical text impact their model of how and why the sea level is rising, comparing across data and their prior understanding.

LESSON 3: How does carbon dioxide contribute to climate change?

PREVIOUS LESSON *We looked at historical data on sea level rise, temperature, ice volume, and potential causes of climate change. We analyzed this data to determine that carbon dioxide is the most likely cause of current ice melt and modeled how all the potential causes would affect climate.*

THIS LESSON

INVESTIGATION

3 days

We investigate how increased CO2 in the atmosphere causes warmer temperatures using water bottles, digital thermometers, and CO2 from fizzing tablets. We outline variables we change, measure, and keep the same throughout the investigation. We collaboratively write directional hypotheses detailing what we think happens and design data tables to organize our collected evidence. Using our data, we model how energy stays in the atmosphere with more CO2 in the system, causing warmer temperatures and sea level rise. We learn that CO2 concentrations in Earth's atmosphere are increasing rapidly. Because CO2 stays in the atmosphere for centuries, we want to find solutions to address impending sea level rise.

NEXT LESSON *We will develop and evaluate a mathematical model of the impact on sea level if Greenland and Antarctica's ice melted. We will plan and carry out an investigation to test the idea that sea ice may not affect sea levels. We will calculate the impacts of sea level rise.*

BUILDING TOWARD NGSS

HS-PS3-1, HS-PS3-4, HS-ESS2-2, HS-ESS2-4, HS-ESS3-1, HS-ESS3-5, HS-ESS3-6, HS-ESS2-7

WHAT STUDENTS WILL DO

3.A Collaboratively outline the variables and test an investigation to identify the directional relationship between the amount of carbon dioxide and temperature change in a defined model atmospheric system. (SEP: 3.1, 3.5; DCI: ESS2.D.3; CCC: 4.2)

3.B Develop a model based on evidence to predict how energy flows between the Sun, the atmosphere, and the cryosphere and how its absorption impacts climate. (SEP: 2.3; DCI: ESS2.D.1, PS3.B.2; CCC: 4.3)

3.C Ask questions about the unexpected result that conservation of energy and matter lead to models that predict that global temperatures will continue to rise on average even if carbon dioxide emissions stop. (SEP: 1.1; DCI: ESS2.D.4; CCC: 5.1)

WHAT STUDENTS WILL FIGURE OUT

- The presence of carbon dioxide somehow enhances the rate of warming in a closed water bottle system, which we can use to model Earth's atmosphere.
- Energy that enters a system with more carbon dioxide is less likely to exit that system compared to a system with less carbon dioxide.
- Earth's atmosphere is a mixture of many different types of gases, including carbon dioxide.
- The concentration of carbon dioxide in Earth's atmosphere has increased rapidly over time. Because it can last in the atmosphere for a very long time, we need to find another way to address sea level rise besides reducing CO_2 emissions.

Lesson 3 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	2 min		**NAVIGATE** Recall our predictions of the most likely cause of Earth's temperature increase.	A	
2	5 min		**BRAINSTORM IDEAS ABOUT CO2 AND TEMPERATURE** Brainstorm mechanisms of how CO_2 can cause Earth's temperature to increase.	B	
3	5 min	✓	**GENERATE IDEAS FOR INVESTIGATION** Consider ways to investigate the relationship between amount of carbon dioxide and temperature.	C	chart paper, chart paper markers
4	10 min		**PLAN AN INVESTIGATION** Identify variables in a scientific investigation that will test how CO_2 in a system affects the temperature of that system.	D	*CO2 Investigation Procedure*, Investigation Anchor Chart
5	10 min	✓	**MAKE A PREDICTION** Generate hypotheses and explanations for what will happen in the investigation.	E-G	*Carbon Dioxide Investigation*, *CO2 Investigation Procedure*
6	13 min		**PLAN DATA COLLECTION** Co-construct data tables to collect the necessary information from the investigation.	H-J	*Carbon Dioxide Investigation*, *CO2 Investigation Procedure*, Investigation Anchor Chart
					End of day 1
7	24 min		**CONDUCT THE INVESTIGATION** Gather data on temperature changes over time with varied amounts of CO_2.	K-L	Community Agreements, Carbon Dioxide Investigation
8	10 min		**SUMMARIZE INVESTIGATION FINDINGS** Draw conclusions from the Carbon Dioxide Investigation.	M	*Carbon Dioxide Investigation*
9	11 min	✓	**BUILD CONSENSUS MODEL** Create a consensus model of energy flows between the Sun, atmosphere, and cryosphere.	N-O	*Carbon Dioxide Investigation*, "Rules for Energy Transfer" anchor chart, chart paper, chart paper markers
					End of day 2
10	6 min	✓	**IDENTIFY IMPACTS OF CO2 ON EARTH SYSTEMS** Discuss ideas about the long-term impacts of carbon dioxide and brainstorm questions about these impacts.	P	
11	16 min		**OBTAIN INFORMATION ABOUT ATMOSPHERIC GASES** Read about changes in atmospheric gases and how these changes affect temperature.	Q-R	*Atmospheric Carbon Dioxide*

Part	Duration		Summary	Slide	Materials
12	13 min		**INTERPRET INFORMATION ABOUT ATMOSPHERIC GASES** Ask questions about the impacts of atmospheric carbon dioxide based on findings from the reading.	S-U	*Atmospheric Carbon Dioxide*
13	10 min		**NAVIGATE** Return to the Driving Question Board to identify what the next steps should be.	V-W	Driving Question Board, sticky notes, chart paper markers

End of day 3

Lesson 3 • Materials List

	per student	per group	per class
Carbon Dioxide Investigation materials	• *Carbon Dioxide Investigation* • *CO2 Investigation Procedure* • indirectly vented chemical splash goggles • nitrile gloves and non-latex apron	• 1 heat lamp • 1 16.9 oz. plastic water bottle • 1 100-mL graduated cylinder • 1 digital thermometer with metal probe • 1 timer • fizzing tablets and water • 1 stick of modeling clay • 1 sheet of plastic wrap • rubber bands or clear tape	
Lesson materials	• science notebook • *CO2 Investigation Procedure* • *Carbon Dioxide Investigation* • *Atmospheric Carbon Dioxide*		• chart paper • chart paper markers • Investigation Anchor Chart • Community Agreements • "Rules for Energy Transfer" anchor chart • Driving Question Board • sticky notes

Materials preparation (40 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Make copies of *Carbon Dioxide Investigation* for each of your students to add to their science notebook.

Make at least one copy per student per class of each of the following materials:
CO2 Investigation Procedure, *Atmospheric Carbon Dioxide*

Make 1-2 pieces of chart paper and chart paper markers available when creating the anchor chart on day 1.

Make sure the Driving Question Board is accessible to students for day 3 when they revisit it.

Support for scientific language/vocabulary:
Be sure students are ready to record the following terms in their personal glossaries: *independent variable, dependent variable, controlled variables, concentration, mixture, solution, greenhouse effect, greenhouse gases.* We recommend that you do not post any terms or ask students to record any words until after your class has developed a shared understanding of their meanings.

Day 2: Carbon Dioxide Investigation

- **Group size:** Divide the class among the 3 heat lamp stations. Each station should have at least 5 students and ideally not more than 10 students.
- **Setup:** Within one classroom there should be 3 different stations, each with 1 heat lamp. Each heat lamp consists of a bulb, metal lampshade, electrical cord, and clamp. Set up each heat lamp near an electrical outlet in a position where the lamp is clamped onto something and pointing outward, as shown in the image. Gather all other materials for the lab and distribute them among the stations. Each station should have 1 heat lamp, 1 timer, 1 plastic water bottle, 1 stick of modeling clay, 1 digital thermometer with metal probe, 1 sheet of plastic wrap, rubber bands or clear tape, 0/2/4 fizzing tablets depending on the assigned CO_2 level, 1 100-mL graduated cylinder, and water. Another option is to place 3 plastic water

bottles representing each of the conditions students will investigate. This will provide more data points but may be more difficult due to the necessity of quickly sealing bottles.

- **Notes for during the investigation:** Each heat lamp will be plugged into an electrical outlet and will get hot during the course of the investigation. Ensure that each student assigned the role of heat lamp manager understands the important safety precautions described below.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*. Students will be working with a heat lamp plugged into an electrical outlet. Make sure that any students working with the outlet are NOT touching water. Students who are working with water should NOT be near the electrical outlet. All students must be careful not to touch any metal parts of the heat lamp or bulb once it is plugged in, and up to 30 minutes after it has been unplugged, as it could potentially burn skin. Students should also place the plastic water bottle at least 6 inches away from the bulb of the heat lamp, as placing it any closer to the bulb will cause the plastic to melt. In addition:
    - Wear indirectly vented chemical splash goggles, nitrile gloves and non-latex apron during the setup, hands-on, and takedown segments of the activity.
    - Secure loose clothing, wear closed-toe shoes, and tie back long hair.
    - An eyewash station is required in case of a splash with hazardous chemicals or contact with physical hazards.
    - Hard printed or electronic copies of Safety Data Sheets for all hazardous chemicals used are required.
    - Hand sanitizer wipes must be provided for participant use at the completion of the activities.
    - Spill control containers for overflow of products produced.
    - Immediately wipe up any spilled liquids - slip/fall hazard.
    - Follow procedures set up by your instructor for disposal of materials.
    - Use only GFI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
    - Any electrical cords must be off the floor to prevent trip/fall hazards.
    - Use caution when working with glassware or plasticware - can break and cut/puncture skin.
    - Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
    - Direct supervision will be required during all aspects of this activity.

- **Disposal:** All liquid waste can be disposed of down the drain. Any solid materials that cannot be reused should be disposed of in the garbage bin. However, many items can be reused multiple times, such as water bottles and modeling clay.
- **Storage:** Keep the heat lamp in a cabinet not easily accessible by students when not in use.

Lesson 3 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students begin to figure out how carbon dioxide can cause temperature increases on Earth by absorbing energy. On day 3, they consider the implications of carbon dioxide's presence in the atmosphere and realize that even today's carbon dioxide level is sufficient to cause increased warming, and therefore increased polar ice melt and sea level rise.

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **ESS2.D.3: Weather and Climate.** Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.
- **ESS2.D.1: 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~~.
- **PS3.B.2: Conservation of Energy and Energy Transfer.** Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- **ESS2.D.4: Weather and Climate.** Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year ~~and by the ways in which these gases are absorbed by the ocean and biosphere.~~

Students plan an investigation collaboratively to produce data to serve as the basis of evidence for revising models (SEP: 3.1) and make directional hypotheses (SEP: 3.5). They then revise models from prior lessons (SEP: 2.3) and have an opportunity to ask questions in a different way than in Lesson 1 (SEP: 1.1). Students consider system boundaries (CCC: 4.2) and how models can track energy flows (CCC: 4.3). They establish that energy is conserved in closed systems.

This lesson is students' first experience in this unit planning and carrying out investigations. Although they have previously developed this practice at the high school level in *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*, they can now develop this practice in a chemistry laboratory environment and with increasingly complex investigations. *Investigation Anchor Chart* tracks how students build this practice throughout the course.

Students are building on prior understandings about energy not being created or destroyed (that is, being conserved) from *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*. This experience was in the context of ecosystems, so this unit helps systematize the thinking more, beginning in this lesson as energy conservation is brought into physical systems.

In this lesson, students will co-construct a definition for the following words, which they should add to their personal glossaries: *independent variable, dependent variable, controlled variables,* and *greenhouse effect*. Students may also add other important terms like *concentration, mixture, solution,* and *greenhouse gases*. **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

For ESS2.D.1, students will build a full model of light that includes reflection and re-radiation in Lesson 7. Students will be able to partially explain why greenhouse gases, in particular, absorb radiation in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*. Students will not consider the wave nature of light or the relationship between electricity and magnetism until *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*.

Students will complete their exploration of ESS2.D.4 in Lesson 13.

Students will not plan or test the investigation individually here, first doing so in Lesson 10. Instead, the practice is heavily scaffolded here. Designs are not explicitly tested in this unit, nor are investigations for supporting explanations (as opposed to revising models). Students also do not consider confounding variables explicitly, as they will do so in Lesson 6. Students only revise a model in this lesson, illustrating the relationships between components. They do not use their model explicitly to make predictions, doing so in the context of mathematical modeling in Lesson 4. They will utilize CCC: 4.3 several times in the unit, expanding beyond the physical model here to mathematical and computer models.

LEARNING PLAN for LESSON 3

1 · NAVIGATE

2 min

MATERIALS: None

Recall predictions from Lesson 2. Present **slide A** and have students turn and talk with a partner about the prompt. After a minute, ask students to share their discussion. Look for students to say that the increasing amount of carbon dioxide in the atmosphere was the most likely cause of Earth's temperature increase.

2 · BRAINSTORM IDEAS ABOUT CO2 AND TEMPERATURE

5 min

MATERIALS: science notebook

Independently brainstorm potential explanations. Show **slide B** and read the prompt aloud, stressing that students should consider possible mechanisms that occur between carbon dioxide and energy on Earth. Emphasize that students should stop and jot down all ideas in their notebook, even if they seem silly, because this is an opportunity to generate as many ideas as possible and not to evaluate which ideas are the best. Give students three minutes of independent time to record their ideas.

Share explanations with a partner. While students talk about their ideas for two minutes, walk around the room to listen to the ideas they generated about how CO_2 contributes to Earth's temperature increase. If there is debate within partner pairings, ask students to share their ideas with the class and acknowledge that all ideas are OK right now.✱

Suggested prompt	Sample student response
How do you think adding more carbon dioxide to the atmosphere might cause Earth's average temperature to increase?	CO_2 absorbs energy and continues to release it over time. CO_2 creates the ozone hole over the Arctic circle, which lets in more sunlight and heats up the Earth. CO_2 somehow "traps" heat that is generated from human activity and traps the energy from sunlight to make things hotter and hotter. It acts like a blanket.

Transition to the need for investigation. Say, *When we are trying to figure out how something happens, it is often helpful to set up our own investigation that could help us identify what happens when we change one factor in the world. Investigation will be another routine we will have throughout the course. When we investigate we will think about what we want to figure out, and how, before we actually do the experiment.*

✱ ATTENDING TO EQUITY

Building classroom culture: Especially this early in the year/unit, frame your community agreements as a work in progress. The priority during the brainstorming process is reinforcing a classroom community wherein all ideas are valued. However, students may be afraid to share things that are "wrong" or "incorrect". Acknowledge that fear, but use this opportunity to reiterate the goal of the classroom culture and agreements: to be supportive to all students and all ideas.

3 · GENERATE IDEAS FOR INVESTIGATION

5 min

MATERIALS: chart paper, chart paper markers

Generate ideas for an investigation question. Display **slide C.** Give students one minute to turn and talk about what question they would like to answer in a classroom investigation, based on their ideas from the previous brainstorming activity.

Come to consensus on an investigation question. Ask students to share their ideas with the class to generate a consensus investigation question. It should be something similar to, *How does more carbon dioxide in a system lead to warmer temperatures in that system?*

ASSESSMENT OPPORTUNITY

What to look and listen for in the moment:
Students develop an investigation question that is able to test the relationship between the amount of carbon dioxide present and increased temperature (SEP: 3.1; DCI: ESS2.D.3).

What to do: If students are unsure how to rephrase their ideas in the form of a question, provide a sentence stem such as, "How does _____ lead to ____?"

Building toward: 3.A.1 Collaboratively outline the variables and test an investigation to identify the directional relationship between the amount of carbon dioxide and temperature change in a defined model atmospheric system. (SEP: 3.1, 3.5; DCI: ESS2.D.3; CCC: 4.2)

Define "investigation question." Introduce the concept of a scientific investigation question. Say, *To test any science idea, we begin by identifying the relationship that we need to know more about. We do this by writing an investigation question like the one we just generated together.*

Start an Investigation Anchor Chart.✱ Say, *We will be designing a lot of investigations this year, so let's create an anchor chart to refer to in the future that will help us organize our investigations so that they actually answer our questions.* Set up the anchor chart so that the investigation question is the title. Add a short definition for the investigation question that says, "The question that identifies the purpose of our investigation, usually seeking to define a relationship between two variables."

✱ SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

Investigation is emphasized throughout this unit. *Investigation Anchor Chart* explains how the Investigation Anchor Chart is continually used as a tool to support students in developing this practice.

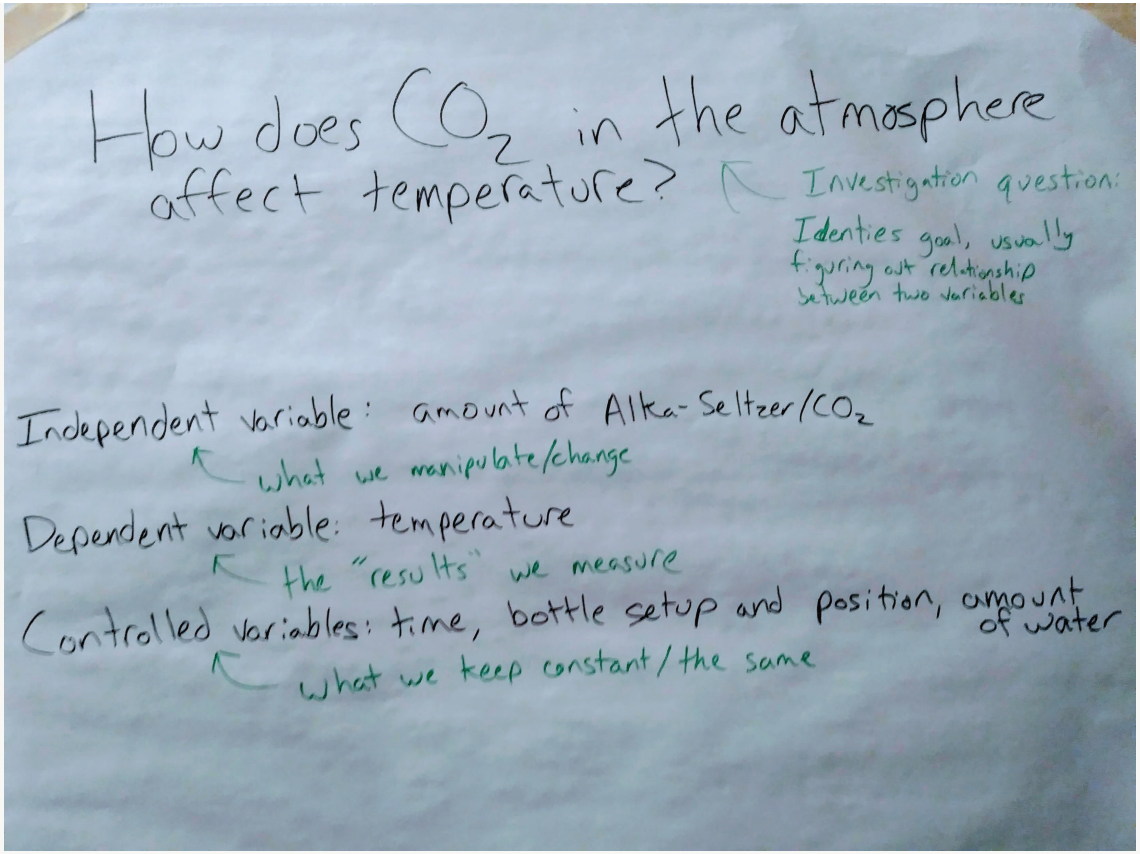
4 · PLAN AN INVESTIGATION

10 min

MATERIALS: *CO2 Investigation Procedure*, science notebook, Investigation Anchor Chart

Read the investigation procedure and identify variables. Display **slide D** and distribute *CO2 Investigation Procedure* to students. Instruct them to read through the procedure two times. The first time, they should read and visualize what will happen during the investigation. The second time, students should use their notebooks to record what will change, what will be measured, and what will be kept the same in the investigation. Allow students to read independently for five minutes.

Define variables as a class. Ask students to share what will change, what will be measured, and what will be kept the same in the investigation. As students share each of these parts of the investigation, pause to define the three variables and write the definitions on the anchor chart. Ask students to include these definitions in their personal glossaries as well.



Suggested prompt	Sample student response	Follow-up in anchor chart and personal glossaries
What will change between the three bottles?	The amount of fizzing tablets we put in. The amount of carbon dioxide generated in the bottle.	*In all investigations, there is a variable we change each time we test a new condition. This is called the independent variable.* ***We can define this as what we manipulate in the investigation.***
What will we measure in all three bottles?	The change in temperature over time.	*In all investigations, there is a variable we observe to see if it is caused by a change in the independent variable. This is called the dependent variable.* ***We can define this as the results variable.***

Suggested prompt	Sample student response	Follow-up in anchor chart and personal glossaries
What will we keep the same in all three bottles?	The amount of water in each bottle. The distance and angle between the heat lamp and the bottle. The way the bottles are set up with the modeling clay, digital thermometers with metal probes, and plastic wrap. The length of time each bottle is exposed to the heat lamp.	***The variables we keep constant across each condition that we test** are called controlled variables.*

5 · MAKE A PREDICTION

10 min

MATERIALS: *Carbon Dioxide Investigation*, *CO2 Investigation Procedure*

Record consensus investigation question. Display **slide E** and provide students with *Carbon Dioxide Investigation*. Ask students to record the consensus investigation question on their handout and to wait before moving on.✱ Refer to the key for *CO2 Investigation Key* for guidance on what students might say throughout the investigation and follow-up.

Discuss the importance of predicting investigation outcomes. Display **slide F** and explain what a hypothesis is. Ask the class to consider why generating a hypothesis might be useful.

Suggested prompt	Sample student response
Why is it useful to generate a hypothesis before conducting an investigation?	It will help us to know what to look for in our investigation.

Generate a directional hypothesis. Say, *Use the sentence stem provided in the investigation handout to come up with a hypothesis for this investigation. What do you think will happen to the temperature of the system if the amount of carbon dioxide **increases**?* Give students one minute to write their own hypothesis about what will happen in the investigation.

ASSESSMENT OPPORTUNITY

What to look and listen for in the moment:
Students write a hypothesis that outlines a directional relationship between the amount of carbon dioxide and temperature change. (SEP: 3.5; DCI: ESS2.D.3)

What to do: If students are unsure how to complete the sentence stem, provide additional scaffolding by asking them to consider whether they think the temperature will increase or decrease with an increase in carbon dioxide.

Building toward: 3.A.2 Collaboratively outline the variables and test an investigation to identify the directional relationship between the amount of carbon dioxide and temperature change in a defined model atmospheric system. (SEP: 3.1, 3.5; DCI: ESS2.D.3; CCC: 4.2)

✱ SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

Emphasize to students that we as scientists need to keep track of our investigations--not just our data, but our question and the specific procedure that we followed. We might need to come back to this information in the future to support arguments, run a similar experiment, or just remember what we did.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

Carbon Dioxide Investigation is structured to support students in thinking about the system inputs and outputs. This is vital in this investigation as it allows students to determine that carbon dioxide is, in fact, causing the observed temperature increase.

Independently model or explain hypotheses. Present **slide G.** Give students three minutes to explain their hypothesis under "Reasoning 1" and "Reasoning 2" in the handout, in the context of the water bottle system they will use in the investigation. If students get stuck defining energy and matter in the system, help them identify the energy as the heat coming from the heat lamp and the matter as the CO_2 that is contained in the water bottle.✱

Share explanations of hypotheses to the class. Ask students to share their ideas about the flows of energy and matter in the water bottle system. Emphasize that it is fine for students to have different ideas right now, especially because we have not conducted the investigation or obtained any evidence to support our explanations yet.

Suggested prompt	Sample student response
How does matter (CO_2) flow into and out of the water bottle system, if at all?	The carbon dioxide produced by the fizzing tablets will mostly stay in the bottles.
Where does the energy come from?	The energy comes from the heat lamp.
How does the energy get to the water bottle?	When the lamp shines on the bottle, the energy radiates through the space into the water bottle.
What does the energy do in the bottle if there is CO_2? If there is no CO_2?	The energy might get stuck in the bottle. That might make the bottle warmer. The increased CO_2 might cause more energy to get stuck in the bottle and cause it to warm up.
Where does the energy go after getting into the water bottle? Is the answer different if CO_2 is present or absent?	The energy that does not stay in the water bottle leaves the bottle and goes into the air surrounding it. The energy that does not stay in the water bottle could leave the water bottle as more light shining out of the bottle, or as heat that warms up the surrounding air.

If students have not explicitly stated it yet, ask, *What are the boundaries of the water bottle system? How does that compare when thinking about carbon dioxide in the real world?* Students should say that the water bottle itself is the boundary here, and the edge of the atmosphere marking the boundary in the real world.

If a student's explanation incorporates a hole in the ozone layer, be sure to ask these additional follow-up questions.

Suggested prompts	Sample student responses	Follow-up questions
What in the water bottle system represents the "ozone layer"? Is there an "ozone layer hole" represented in the water bottle system?	The modeling clay or plastic wrap covering the top of the water bottle.	*If our theory is that the ozone hole lets more heat in, what could our hypothesis be for this particular experiment?*

Suggested prompts	Sample student responses	Follow-up questions
If our theory is that the ozone hole lets more heat in, what could our hypothesis be for this particular experiment?	Since there isn't anything in this setup that we could call an "ozone hole," our hypothesis could be that the bottles will not heat up. We could make a hole at the top of one of the bottles and our hypothesis could be that this bottle gets hotter.	

ASSESSMENT OPPORTUNITY

What to look and listen for in the moment:
Students define the boundaries of the water bottle system as a model for the atmospheric system and identify changes in inputs and outputs of energy and matter. (CCC: 4.2)

What to do: Use this as an opportunity to gauge how varied students' ideas may be. If students are not showing a direct connection between their hypothesis and reasoning, ask them to draw lines on their handout to connect the parts of their reasoning to the hypothesis.

Building toward: 3.A.3 Collaboratively outline the variables and test an investigation to identify the directional relationship between the amount of carbon dioxide and temperature change in a defined model atmospheric system. (SEP: 3.1, 3.5; DCI: ESS2.D.3; CCC: 4.2)

6 · PLAN DATA COLLECTION

13 min

MATERIALS: *Carbon Dioxide Investigation*, *CO2 Investigation Procedure*, Investigation Anchor Chart

Introduce the data table as an organizational tool. Say, *If we want to know how the temperature changes in each bottle, we are going to need to keep track of the temperature in an organized manner. We can do that by making a data table.*

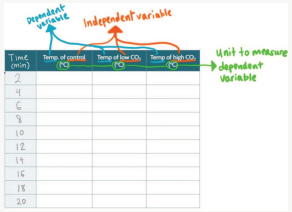
Structure the columns of the data table to highlight independent and dependent variables. Display **slide H.** Have students turn and talk for one minute to discuss the questions on the slide and the data table printed on *Carbon Dioxide Investigation*. While students do this, draw a version of the data table from the handout on the anchor chart.

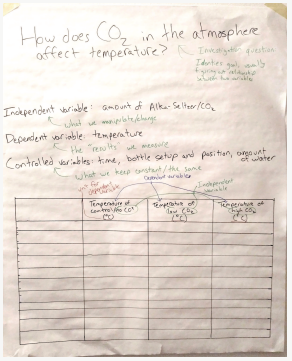
Ask students to share what is being changed and measured in the investigation with the class. Use this information to label the three rightmost column headers with the temperature of each bottle. Emphasize that our measurements of temperature should be in Celsius and add that label to the column headers as well.

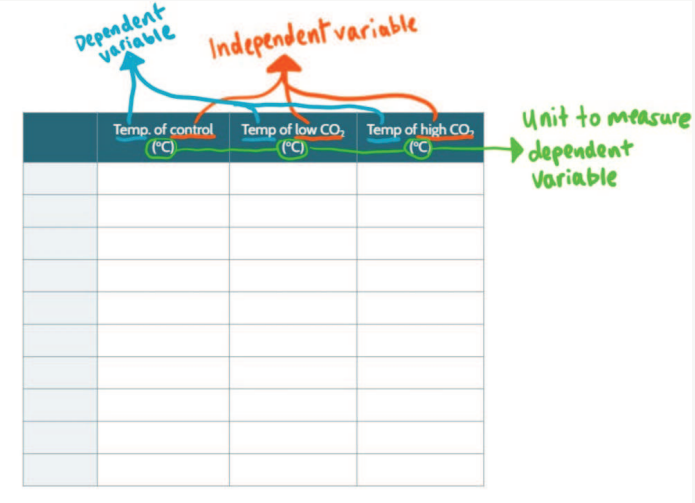
As students write these headers in the three columns of the data table, annotate the data table on the anchor chart like the table in *Carbon Dioxide Investigation*.

Show **slide I.** Provide students with another opportunity to discuss whether they should take measurements over time and if they think they will need more data tables. Then ask students to share with the class. Discuss that taking measurements over time will be useful in this particular investigation because it will provide more information about how energy flows through each system. Also explain that it is not necessary to create multiple data tables for this investigation because each bottle already has its own column. Add "Time (min)" to the left column header and update the anchor chart.

Structure the rows of the data table to identify when measurements should be taken. Display **slide J.** Have students turn and talk for one minute to discuss the questions on the slide. Ask students to consider their answers based on the investigation procedure. Listen for the idea that measurements should be taken every two minutes over a period of 20 minutes. Add these time intervals to the left column of the data table and update the anchor chart.







Decide on a title for the data table. To help them generate a title, ask students to identify the relationships they are keeping track of in this data table. If students are unsure how to title the data table, refer them to the investigation question as a place to start. A good example of a title might be, "Temperature of bottles under a heat lamp with varied amounts of CO_2 over time."

End of day 1

7 · CONDUCT THE INVESTIGATION

24 min

MATERIALS: Carbon Dioxide Investigation, Community Agreements

Emphasize safety. Have students take out *Carbon Dioxide Investigation* and elicit reminders about the investigation plan. Display **slide K** and review safety guidelines for this activity and for lab work in general.

Prepare the investigation. Show **slide L**. Ask students to assign themselves to one of the following roles within their groups:

- Timer (at least 1): Keeps track of the time and tells the recorder to record data every two minutes.
- Recorder (at least 1): Writes down the temperature of the bottle every two minutes and shares the data with other students in the group.
- Material managers (at least 3):
    - Heat lamp manager: Makes sure that the heat lamp is not plugged in until all other parts of the lab are set up, monitors the heat lamp, and makes sure all students in the group are not at risk of burning.
    - Water bottle manager: Covers the water bottle with modeling clay, puts the digital thermometer with metal probe into the bottle, and covers the bottle and digital thermometer with metal probe with plastic wrap.
    - Fizzing tablets and water manager: Collects 100 mL of water, breaks up the tablets, and places them into the bottle.

Establish "Equitable" as a focal agreement. Display the Community Agreements and elicit suggestions on how we can conduct this investigation in an equitable manner and how the roles can help in doing that.

ALTERNATE ACTIVITY

You may also have students use 3 16.9 oz. plastic water bottles at their station each representing one of the conditions they are testing. This will require students to coordinate who will seal each of the bottles to ensure accurate results.

Conduct the investigation. Set a timer for 20 minutes with a student who is designated to call the time every two minutes. Make sure the Recorder and Timer in each group are keeping track to get a precise temperature measurement at each 2-minute mark. Students can then share their data from the bottle they observed with other groups and record data from other groups while they wait for the next 2-minute mark.

SAFETY PRECAUTIONS

Students will be working with a heat lamp plugged into an electrical outlet. Make sure that any students working with the outlet are NOT touching water. Students who are working with water should NOT be near the electrical outlet. All students must be careful not to touch any metal parts of the heat lamp or bulb once it is plugged in, and up to 30 minutes after it has been unplugged, as it could potentially burn skin. Students should also place the plastic water bottle at least 6 inches away from the bulb of the heat lamp, as placing it any closer to the bulb will cause the plastic to melt.

In addition, use only GFI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.

8 · SUMMARIZE INVESTIGATION FINDINGS

10 min

MATERIALS: *Carbon Dioxide Investigation*

Use evidence to evaluate hypotheses. Display **slide M**. Say, *Let's revisit our hypotheses now that we have gathered evidence from the investigation. How would you summarize our findings? Use the prompt and sentence stems provided in the handout to structure your thoughts.* Have students work independently on their summaries for six minutes.

Give students two minutes to turn and talk about how the increased carbon dioxide affected the temperature changes in the bottles based on their written summaries. As a class, come to the conclusion that the bottle with the most carbon dioxide in it saw the greatest increase in temperature, but all bottles had some increase in temperature.

Say, *You also had some time to think about how energy flowed in the investigation. Let's try to turn that into a model.*

9 · BUILD CONSENSUS MODEL

11 min

MATERIALS: *Carbon Dioxide Investigation*, "Rules for Energy Transfer" anchor chart, chart paper, chart paper markers

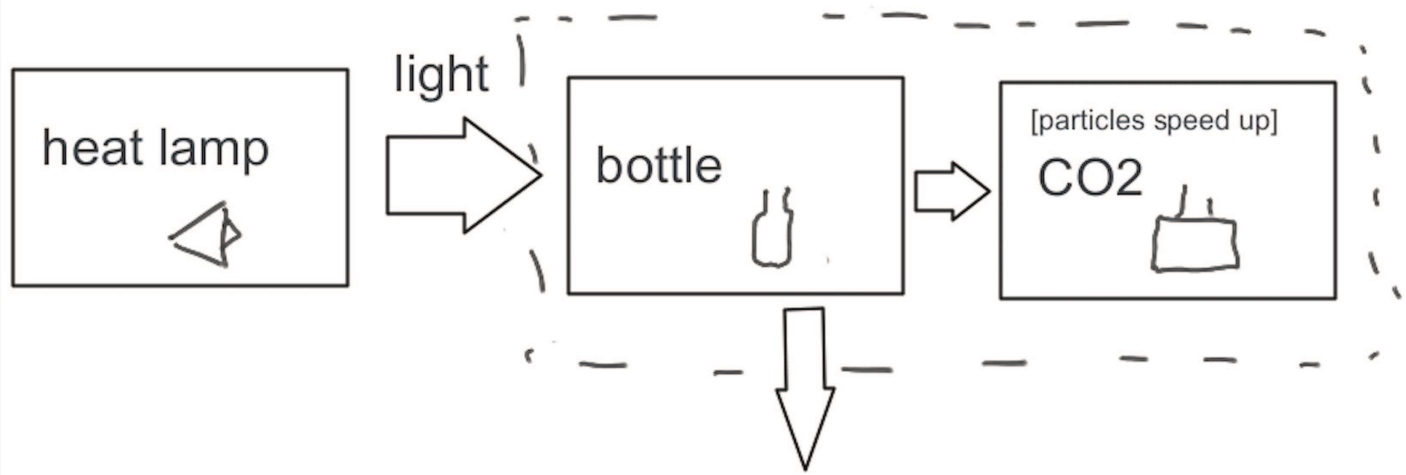
Develop a class model of how energy flows in a high-CO_2 atmosphere. Display **slide N** and the "Rules for Energy Transfer" anchor chart, as well as a sheet of chart paper. Ask students, *According to what you wrote in the Carbon Dioxide Investigation handout, how did energy flow in the investigation?* Listen for these ideas:

- Energy transferred from the heat lamp through light, to the air in the bottle.
- Air particles in the bottle sped up, especially when there was CO_2 in the bottle.
- Some energy passed through the bottle.

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Modeling is intentionally used here because the emphasis is on students' use of evidence from their investigation to revise their model.

As students share their ideas, ask how we would represent them in an energy transfer model using our "Rules." Add this model to the chart paper, leaving space for a second model below.✱



Consider how changes in CO_2 affect the model. Follow up with the prompts below.

Suggested prompt	Sample student response
Did the energy ever disappear?	The bottles kept getting hotter as more energy was added to them, so probably not. It might leave the bottle, but we do not have evidence that it ever disappeared. It disappeared because it got colder.✱
How was the energy flow different when there was more CO_2 in the system?	More energy would be kept in the system instead of passing through.
What evidence do we have for that?	We saw the temperature increase more when there was more CO_2 in the system.
How could we show this in our model?	We could vary the sizes/thicknesses of the arrows' lines.

Say, *We have an interesting idea on the table that the energy does not disappear. Is there a way we could modify our model to show that the energy that went in is the same as the amount of energy at the end?* Listen for these ideas:

- We could make the first arrow's line as thick as the other arrows combined.
- We could put numbers next to the arrows.

However, students are not expected to independently draw energy transfer models yet.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

If students bring up this alternate idea, ask if they saw energy disappearing in biology class, in *Fires Unit* or a similar unit, as they thought about energy transfer in cellular respiration and photosynthesis. Help students recall that energy flowed from the Sun and throughout the forest ecosystem in this unit, rather than appearing and disappearing out of nowhere.

Add another point on the "Rules" anchor chart, as follows:

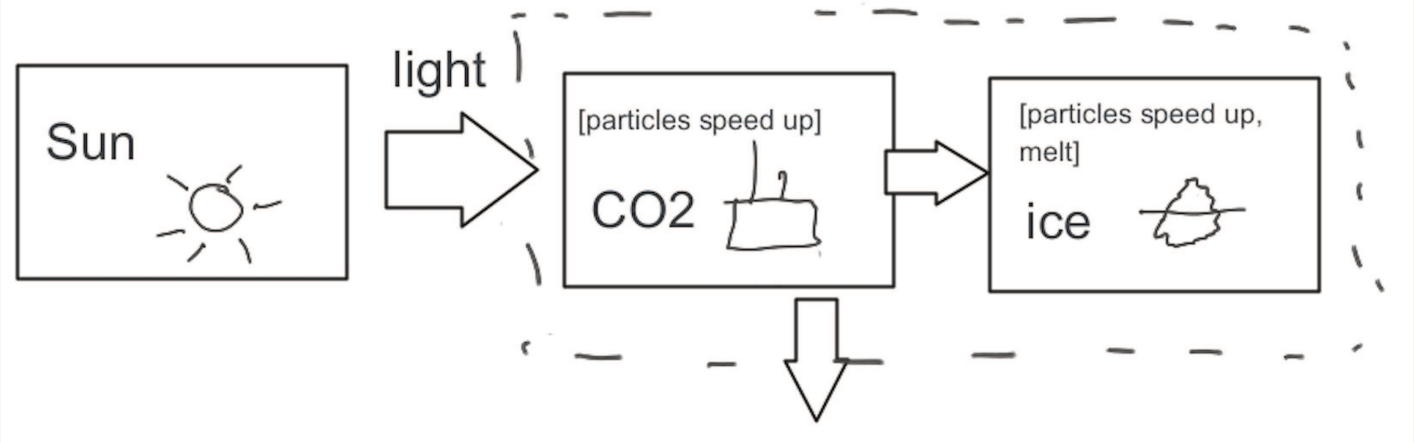
- We can change arrow line widths to show that the energy that came into the system does not disappear (energy is conserved).

Apply the model to the Earth system. Display **side O.** Say, *We originally conducted this investigation to figure out how carbon dioxide causes temperature increases on Earth. How would the energy transfer model be different if we wanted to show how atmospheric CO_2 affects ice melt on Earth?* Listen for these responses:

- Energy comes from the Sun, not a heat lamp.
- There is nothing holding Earth's atmosphere "in" like a bottle.
- The higher-temperature atmosphere would cause polar ice to melt.

Point out that the water bottle system and Earth system are representing distinct scales, to help us think about how changes at the particle level could add up to significant changes around the world.

Represent these changes in a second energy transfer model.



Continue with additional follow-up questions.

Suggested prompt	Sample student response
How would the model change if there were more CO_2 in the atmosphere?	The CO_2 particles would speed up more. More energy would transfer to polar ice, causing it to melt and raise sea levels.
Do we have to allow the higher-CO_2 scenario to happen?	No, we could take steps to decrease emissions. No, we could try to figure out ways to take carbon dioxide out of the atmosphere. It is already kind of happening, but we could take steps to make sure we do not release as much carbon dioxide in the future.

Suggested prompt	Sample student response
What parts of our findings can we not explain with our models?	Why carbon dioxide affects temperature more than other gases like oxygen do. How or if carbon dioxide can get out of the atmosphere.

Next to the model, jot down the ideas that students expressed could *not* be explained by our models. Wrap up the discussion by pointing out these ideas that need additional explanation and letting students know that we will explore those ideas the following day.

ASSESSMENT OPPORTUNITY

What to look and listen for in the moment:

- Students describe energy flowing from the Sun to the atmosphere and the atmosphere to the cryosphere in the outlined boxes. (DCI: ESS2.D.1; CCC: 4.3)
- Students mention evidence from the investigation that the energy stayed in the atmosphere when more CO_2 was present. (SEP: 2.3; DCI: PS3.B.2)

What to do: Encourage students to draw comparisons between the investigation and the real-world Earth system. Use the "Rules" to help establish how the energy source (Sun) varies between the models, but energy likely behaves in a similar way once in the system.

Building toward: 3.B Develop a model based on evidence to predict how energy flows between the Sun, the atmosphere, and the cryosphere and how its absorption impacts climate. (SEP: 2.3; DCI: ESS2.D.1, PS3.B.2; CCC: 4.3)

End of day 2

10 · IDENTIFY IMPACTS OF CO2 ON EARTH SYSTEMS

6 min

MATERIALS: None

Apply findings from the investigation model to Earth systems. Display **slide P**. Give students about two minutes to turn and talk with a partner about the prompts on the slide. Then ask students to share their ideas with the class.

Suggested prompt	Sample student response
What do you think would happen if we extended our consensus model showing the effect of CO_2 after 20 minutes to show what happened after 1 year?	So much CO_2 would get stuck in the atmosphere it would warm the Earth until all the ice melted. Maybe some of the CO_2 would escape the atmosphere and go into space or into other Earth systems.

Suggested prompt	Sample student response
What specifically about the impacts of carbon dioxide on Earth systems do we want to know more about?	How much CO_2 has gotten into the atmosphere over the past century? How long can CO_2 stay in the atmosphere and continue to trap energy in the atmosphere? How will the CO_2 already in the atmosphere affect sea level rise in the future?

ASSESSMENT OPPORTUNITY

What to look and listen for in the moment:

- Students' questions focus on the impact of energy and matter flows taking place within Earth's systems. (SEP: 1.1; CCC: 5.1)

What to do: At this point, students may have many different ideas and questions about the long-term impacts of carbon dioxide on the atmosphere and other Earth systems. Use this as an opportunity to gauge how varied students' ideas may be.

Building toward: 3.C.1 Ask questions about the unexpected result that conservation of energy and matter lead to models that predict that global temperatures will continue to rise on average even if carbon dioxide emissions stop. (SEP: 1.1; DCI: ESS2.D.4; CCC: 5.1).

11 · OBTAIN INFORMATION ABOUT ATMOSPHERIC GASES

16 min

MATERIALS: *Atmospheric Carbon Dioxide*, science notebook

Distribute *Atmospheric Carbon Dioxide*. Show **slide Q.** Use students' questions from the previous activity to introduce the reading. Say, *Let's see if this reading can answer any of the questions you brought up.* Instruct students to use their science notebooks to record the summary statements and questions they come up with at each break in the reading. After students read for 8 minutes, remind them to record both a summary statement and a question after completing the reading. Give them two additional minutes to read and record their summaries and questions.✱

ALTERNATE ACTIVITY

For students who benefit from additional reading comprehension support, the Coherent Reading Protocol is well-suited for *Atmospheric Carbon Dioxide*. The Coherent Reading Protocol guides students to monitor their understanding after each chunk of text, identify the main idea, and connect the information in the reading to the lesson question. The Coherent Reading Protocol can be found in the *OpenSciEd Teacher Handbook: High School Science*.

Summarize the ideas and questions that arose from the reading. Display **slide R**. Give students three minutes to turn and talk about their summaries and questions from the reading.

✱ SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

Although this reading introduces a number of terms typically emphasized early in a chemistry class, its primary purpose is to help consolidate student thinking about the role of carbon dioxide in the atmosphere and problematize the fact that carbon dioxide will continue to affect global temperatures, and therefore sea levels, for many centuries. This will bring new questions to the fore for students and help re-center the anchoring phenomenon in students' minds.

12 · INTERPRET INFORMATION ABOUT ATMOSPHERIC GASES

13 min

MATERIALS: *Atmospheric Carbon Dioxide*, science notebook

Discuss key ideas as a class. Display **slide S** and ask students to use their summary statements to respond to the prompts on the slide. Use this slide as an opportunity to discuss the need for a unit such as "ppm" when measuring amounts of carbon dioxide in the atmosphere, and the concept of looking at concentrations rather than an entire amount to simplify measurements and numbers.

Suggested prompt	Sample student response
How much CO_2 is in the atmosphere?	A lot more than there used to be. 410 parts per million, and this is projected to increase in the future.
Where did that CO_2 come from?	People. It is released into the atmosphere as humans burn fossil fuels. Rich countries that use lots of fossil fuels.
What other gases are present in the atmosphere?	Nitrogen, oxygen, water vapor, argon, and other gases.
What unit do scientists use to measure the amount of CO_2 in the atmosphere? Why?	Parts per million, because there are very small amounts.
How long does CO_2 stay in the atmosphere?	CO_2 can stay in the atmosphere for a long time, since it cannot leave the atmosphere and go back into space.

Add relevant terms from the reading to personal glossaries. Show **slide T**. Give students three minutes to use their summaries from the reading to define the terms *concentration, mixture, solution, greenhouse effect,* and *greenhouse gases* in their personal glossaries..

Ask questions about the impacts of atmospheric gases. Show **slide U** and ask students to share the questions that came up for them during the reading, specifically at the end when prompted about the effects of CO_2 staying in Earth's atmosphere.

Suggested prompt	Sample student response
What questions do you have about the effects of CO_2 staying in Earth's atmosphere?	If we could take CO_2 out of Earth's atmosphere, would the atmospheric temperature decrease? Where does the CO_2 go if it does not go back into space or into plants via photosynthesis? How much will the sea level rise at each of the different scenarios predicted by scientists? How can we prevent the sea level rise from getting worse if the atmospheric temperature continues to rise despite our reducing emissions?

Once students have shared their ideas, emphasize the importance of not only reducing carbon dioxide emissions in the future but also addressing the damage caused by sea level rise that will occur regardless of reducing emissions.

ASSESSMENT OPPORTUNITY

What to look and listen for in the moment:

- Students indicate that conservation of energy and matter within Earth's systems causes global temperatures to continue to rise on average even if carbon dioxide emissions stop. (DCI: ESS2.D.4; CCC: 5.1)

What to do: Many of the questions that students propose will be insightful and highlight their personal interests and assets. Affirm all questions and ideas and elevate those that consider the cascading consequences of carbon dioxide already in Earth's atmosphere.

Building toward: 3.C.2 Ask questions about the unexpected result that conservation of energy and matter lead to models that predict that global temperatures will continue to rise on average even if carbon dioxide emissions stop. (SEP: 1.1; DCI: ESS2.D.4; CCC: 5.1).

13 · NAVIGATE

10 min

MATERIALS: Driving Question Board, sticky notes, chart paper markers

Return to the Driving Question Board. Display **slide V** and direct students to take out a pen or pencil. Say, *We have made a lot of progress but also have a lot more that we want to figure out. Let's use our Driving Question Board to see what we should investigate next based on what we have just figured out.* Instruct students to draw a checkmark on sticky notes that have questions that were answered in the last three lessons, and to draw a star on sticky notes that have questions they think should be investigated next. If students want to add questions from the previous discussion to the board on a new sticky note, encourage them to do so.

Reflect on the Investigation Routine and the importance of being "Equitable." Display **slide W** and discuss the prompts on the slide.

Suggested prompt	Sample student response
How did the Investigation Routine help us make progress in answering our questions?	We had a clear idea of what we were investigating. We knew what to do in the investigation. We knew how to make sense of our results.
Why was it important to work together in an equitable way in this investigation?	We had limited equipment. We all had ideas that were important to share.

Point out to students that sometimes our investigation involves analyzing data or other non-experimental work, but in any case we are working together to answer particular questions that we have.

ALTERNATE ACTIVITY

Extension opportunity: Because of common ideas about ozone influencing climate change, students may now wonder what ozone *does* do in the atmosphere and if it is a problem. You may wish to have students research these questions, as the 1987 Montreal Protocol, phasing out of chlorofluorocarbons (CFCs), and subsequent healing of the ozone layer represent an excellent example of people successfully working together to address an environmental issue originally caused by humans.

Additional Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

Students summarize the text in *Atmospheric Carbon Dioxide* and consider how it applies to the process of energy transfer.

CCSS.ELA-LITERACY.RST.9-10.3 Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text.

Students follow an experimental procedure for the first time in the course and attend to the details of the experimental setup.

LESSON 4: What would happen if the Earth's ice melted?

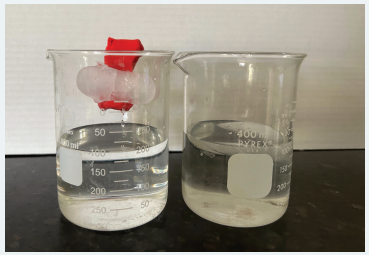
PREVIOUS LESSON

We investigated how increased CO2 in the atmosphere causes warmer temperatures. We used our data to model how energy stays in the atmosphere with more CO2 in the system. We learned that CO2 concentrations in Earth's atmosphere are increasing rapidly, and because CO2 stays in the atmosphere for centuries, we wanted to find solutions to address impending sea level rise.

THIS LESSON

INVESTIGATION, PUTTING PIECES TOGETHER

3 days



We examine where ice is found on Earth's surface and make predictions and model what would happen if Earth's cryosphere melted. We develop a mathematical model to figure out the impact on sea level if Greenland and Antarctica's ice melted. We evaluate our answer using a simulation of sea levels and notice that the ice in the Arctic Ocean is not represented. We wonder if this ice affects sea levels, so we plan and carry out an investigation to see if ice in water affects the water level when it melts. We determine it does not, update our model, and calculate the human impacts of sea level rise.

NEXT LESSON

We will analyze changes occurring over time at Ilulissat Glacier, a site of fast ice melt. We will read about two design solutions for slowing or preventing further melt. We will model the energy transfers and ask questions about the energy flows and overall suitability of the designs.

BUILDING TOWARD NGSS

HS-PS3-1, HS-PS3-4, HS-ESS2-2, HS-ESS2-4, HS-ESS3-1, HS-ESS3-5, HS-ESS3-6, HS-ESS2-7

WHAT STUDENTS WILL DO

4.A Apply ratios and unit conversions at different scales to make predictions about the impact of human-caused ice melt on sea levels and human populations. (SEP: 5.5; DCI: ESS3.B.1, ESS3.D.1; CCC: 3.1)

4.B Plan and carry out an investigation to revise a model to reflect that sea ice is in the ocean system (hydrosphere) and therefore does not change sea level, though losing it might have other negative effects. (SEP: 3.1; DCI: ESS3.D.2; CCC: 4.2)

WHAT STUDENTS WILL FIGURE OUT

- We estimate that if all of Greenland's land ice melted, Earth's sea levels would rise by almost 7 meters. If all of Antarctica's land ice melted, Earth's sea levels would rise by about 55 meters.
- A sea level rise of 7 or 55 meters, or even 0.5 meter, would cause many major cities and other places to be covered by water for at least part of the year.
- Earth's sea levels would not rise if Earth's sea ice melted, because this ice is already in the ocean.
- We have initial ideas about ways that ice sheets could be prevented from melting.

Lesson 4 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Discuss what we have figured out so far and decide to investigate how high sea levels could actually rise if all the ice in Greenland melted.	A-C	
2	10 min		**CREATE INITIAL MODEL ABOUT MELTING ICE** Support partner thinking about specific implications of the Earth's cryosphere melting and build an initial consensus model to show what might happen.	D-F	chart paper, clay, Community Agreements
3	2 min		**INTRODUCE KEY INFORMATION** Introduce the information students will need for their calculations.	G	
4	10 min		**BEGIN TO DEVELOP A MATHEMATICAL MODEL** Help students think about the mathematical tools they could use to build a mathematical model.	H-I	*Sea Level Calculations*, clay
5	5 min		**USE MATHEMATICAL MODEL TO CALCULATE VOLUME OF GREENLAND ICE** Support students in using mathematical thinking to estimate the volume of ice on Greenland.	J	*Sea Level Calculations*, clay (optional)
6	13 min		**USE MATHEMATICAL MODEL TO CALCULATE VOLUME OF ANTARCTIC ICE** Support students as they work in pairs to find the volume of ice on Antarctica.	K	*Sea Level Calculations*, scientific calculator, clay (optional)
					End of day 1
7	7 min		**REFLECT ON OUR MATHEMATICAL MODEL** Identify problem-solving strategies that we used on day 1 and can carry forward, and add them to a class anchor chart, along with a review of unit conversions.	L-N	*Sea Level Calculations*, scientific calculator, chart paper
8	6 min		**CALCULATE SEA LEVEL RISE FROM GREENLAND ICE MELT** The class collaboratively calculates the sea level rise that would occur if all the ice on Greenland melted.	O	*Sea Level Calculations*, scientific calculator
9	16 min		**CALCULATE SEA LEVEL RISE FROM ANTARCTICA ICE MELT** Support students as they work in pairs to calculate the sea level rise that would occur if Antarctica's ice melted, and check answers as a class.	P-S	*Sea Level Calculations*, scientific calculator, https://sealevel.nasa.gov/vesl/web/sea-level/slr-eustatic/
10	16 min		**PLAN AN INVESTIGATION FOR HOW MELTING ICE AFFECTS SEA LEVEL** Develop and document an investigation plan and set up the investigation to run overnight.	T-Y	chart paper, "Planning an Investigation" anchor chart from Lesson 3, Land Ice vs. Sea Ice Investigation
					End of day 2
11	2 min		**TAKE FINAL MEASUREMENTS** Collect water-level measurements from both systems.	Z	Land Ice vs. Sea Ice Investigation

Part	Duration		Summary	Slide	Materials
12	8 min		**SHARE AND MAKE SENSE OF THE RESULTS** Share results and develop a model to account for movement of matter between the related systems in the hydrosphere.	AA-BB	
13	8 min		**REVISE OUR MODEL** Work as a class to revise the initial consensus model developed on day 1 and acknowledge that these changes would have significant impacts on real places and people.	CC-DD	initial consensus model from day 1, https://sealevel.nasa.gov/vesl/web/sea-level/slr-eustatic/
14	10 min		**CONSIDER THE HUMAN IMPACTS OF SEA LEVEL RISE** Give students time and space to use the mathematical tools developed in this lesson to determine the human impacts of even modest sea level rise.	EE-FF	
15	9 min		**BRAINSTORM SOLUTIONS AND NAVIGATE** Students brainstorm some ways to keep sea levels from rising.	GG-II	
16	8 min		**ELECTRONIC EXIT TICKET** Give students time to complete an Electronic Exit Ticket.	JJ	computer, copy of https://docs.google.com/forms/d/1jvpWOSDPElhPiwg1jzX96kVWPgkedGGmRnBGQErvozo/copy, scratch paper
17	0 min		**HOME LEARNING (OPTIONAL)** Assign home learning for Lesson 4.	KK	*Conversions Home Learning* (optional)

End of day 3

Lesson 4 • Materials List

	per student	per group	per class
Land Ice vs. Sea Ice Investigation materials		• 2 8-oz cups or 2 250-mL beakers • 1 ¼-lb stick modeling clay • 2 ice cubes in bags • 24-oz plastic cup with about 20 oz dyed water • 1 clear metric ruler • clear tape • 1 ultra-fine-tip permanent marker • Investigation setups from prior day	• ice cubes
Lesson materials	• *Sea Level Calculations* • scientific calculator • science notebook • computer • copy of https://docs.google.com/forms/d/1jvpWOSDPElhPiwg1jzX96kVWPgkedGGmRnBGQErvozo/copy • scratch paper • *Conversions Home Learning* (optional)	• clay • clay (optional)	• chart paper • clay • Community Agreements • https://sealevel.nasa.gov/vesl/web/sea-level/slr-eustatic/ • "Planning an Investigation" anchor chart from Lesson 3 • initial consensus model from day 1

Materials preparation (60 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

If you do not have access to a large number of ice trays or an icemaker, start the ice-making process at least two days ahead of time. In order to make enough ice for all your classes, you will need to make multiple batches of ice cubes, taking them out about every 4 hours and then refilling the trays For example, for 6 classes, you would need to make 2 cubes per group x 7 groups per class x 6 classes = 84 cubes. If each tray makes 8 cubes and you have 2 trays, you will need to make 6 batches of ice cubes. Store the ice cubes individually in plastic snack bags to keep them from sticking to each other. If you do not have a freezer in your class, use an insulated cooler to transport the ice cubes and keep them cold between classes.

For the Electronic Exit Ticket, make a copy of https://docs.google.com/forms/d/1jvpWOSDPElhPiwg1jzX96kVWPgkedGGmRnBGQErvozo/copy and make the link to your local copy of the form accessible to students. Instructions on this task may be found in *Electronic Exit Ticket*.

Day 2 (40 minutes)
Land Ice vs. Sea Ice Investigation

- **Group size**: 5 students
- **Setup**:
  - Gather a set of the following materials for each group, with one group's set serving as demonstration materials:
    - 2 8-oz cups or 2 250-mL beakers

        - 1 ¼-lb stick modeling clay
        - 2 ice cubes, each in a plastic bag
        - 24-oz plastic cup with about 20 oz water dyed with 4 drops blue food coloring
    - Set aside the following materials to distribute and later collect from groups for reuse:
        - 1 clear metric ruler
        - clear tape
        - 1 ultra-fine-tip permanent marker
- **Notes for during the lab:** If leaving the cups overnight, cover them with plastic wrap to reduce evaporation. https://youtu.be/3ILxhlnrn7g shows an example of an alternate setup in which the land ice is propped up within the container, instead of being suspended above the water.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*. Immediately wipe up any spilled water on the floor–it is a slip and fall hazard. In addition:
    - Wear indirectly vented chemical splash goggles, nitrile gloves and non/latex apron during the setup, hands-on, and takedown segments of the activity.
    - Secure loose clothing, wear closed-toe shoes, and tie back long hair.
    - Immediately wipe up any spilled liquids - slip/fall hazard.
    - Follow procedures set up by your instructor for disposal of materials.
    - Use caution when working with heated liquids–they can burn skin.
    - Use only GFI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
    - Use caution when working with glassware or plasticware - can break and cut/puncture skin.
    - Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
    - Direct supervision will be required during all aspects of this activity.
- **Disposal:** None
- **Storage:** Non-consumable materials can be stored and reused from year to year. Be sure to store clay in a resealable plastic bag with the air squeezed out.

Lesson 4 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **ESS3.B.1: 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.D.1: 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.2: Global Climate Change.** Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, ~~and the biosphere~~ interact and are modified in response to human activities.

In this lesson, students apply ratios and unit conversions in the context of figuring out how much the sea level could rise due to polar ice melt (SEP: 5.5). In doing so they leverage thinking about scale, proportion, and quantity (CCC: 3.1). Because of the importance of mathematical thinking in this lesson and the unit, students develop an anchor chart for mathematical thinking, tracked on *Mathematical Anchor Chart*.

They also plan an investigation to rule out the role of sea ice, leveraging understandings built in Lesson 3 (SEP: 3.1), taking into consideration system boundaries, inputs, and outputs (CCC: 4.2).

Mathematical thinking in this lesson builds on ideas from late elementary (simple conversions in CCSS.MATH.CONTENT.5.MD.A.1 and area in CCSS.MATH.CONTENT.4.MD.A.3).

In this lesson, students encounter words like *cryosphere*, *unit conversion,* and *assumptions*. These may be added to personal glossaries if the class has agreed on definitions or students wish to independently record them.

Where We Are NOT Going

There is a limited amount of unit conversion practice in this lesson, as practice is most effective when it is done in the context of sensemaking. There are opportunities for students to practice dimensional analysis in the home learning for day 3 of this lesson *Conversions Home Learning*.

As ice melts, there is an approximately 8% loss of volume due to the spatial arrangement of molecules in ice from the hydrogen bonds that form. This spatial arrangement makes ice less dense than liquid water, which is the reason that ice floats. This concept will be investigated in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*, after students have had a chance to build an atomic model and explore the concept of polarity in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*.
If questions related to these concepts arise, celebrate those inquiries and place them on the Driving Question Board. Tell students that these are great questions that we should continue to investigate, even if we do not get to all of them in this unit. Consider carrying over questions from this unit into subsequent units, which will support between-unit coherence from the students' perspective.

If students strongly suggest that the change in volume from ice to liquid water is an important factor to include in a mathematical model, then instead of trying to convince them that it is negligible, follow their lead to help them develop a general rule of thumb to include in their models (liquid water takes up about 90 to 95% of the volume of the same mass of ice). This guideline can be established by measuring from the bottom of the container in the timelapse video: https://youtu.be/tbBn9DOtxd0.

Keep in mind that the empirical mathematical model that students develop from lab results will be based on measurement of water-level rise in the containers, and so will likely only be as accurate as the divisions on the ruler. This will lead most students to claim that the sea level rise in the land ice bin is ~0.4 cm (or 4 mm). The smallest markings on the ruler are 0.1 cm in scale. Although one can estimate the measurement to the nearest half mm (+/- 0.05 cm), this idea is not the focus of this lesson. Students will be introduced to measurement precision and significant figures later in Lesson 9.

Students will address the rest of ESS3.B.1 in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)* and more explicitly consider the role of the biosphere in Lesson 13.

Students do not consider rates and percentages in this lesson, doing so later in the course. They will consider the impact of confounding variables on investigation design in Lesson 6. They will go on to plan and test an investigation individually in Lesson 10 and plan an investigation around testing a design solution or supporting explanations elsewhere in the Chemistry course.

LEARNING PLAN for LESSON 4

1 · NAVIGATE

5 min

MATERIALS: None

Navigate into today's work by revisiting the model students built last class. Display **slide A.** Say, *We have spent the first few lessons thinking about why sea levels are rising. What have we figured out that we think is causing sea level rise?* Listen for these ideas:

- CO_2 emissions are increasing Earth's average temperature.
- Increased temperature causes ice melt.
- Ice melt causes sea level rise.

Follow up by asking, *Where is the ice on Earth?* Accept all student responses.

Examine where ice is found on Earth. Display **slide B** and give students a few moments to read the slide. Then say, *These maps show different views of the world than we are used to.* Point out the southern tips of South America and Africa to students before identifying Antarctica. On the map on the right, point to your location (if visible) and show students where Greenland and the ice in the Arctic Ocean are.

Ask, *How do these views compare to the maps we are used to seeing?* Listen for these ideas:✱

- The world looks a lot different from the poles.
- There is a lot more ice at the South Pole than the North Pole, which is not how it looks on many world maps.
- There is a lot more ice than I thought.

Say, *There is actually a lot of ice on Earth. About 10% of Earth's surface is covered by ice. With so much ice, scientists actually consider it to be an important Earth system, much like the atmosphere or hydrosphere.*

Define the cryosphere. Show **slide C** and share the definitions with students. Then ask, *What would happen if Earth's cryosphere disappeared, melting into the hydrosphere?* After each idea, ask the student or a classmate to rephrase it using the terms cryosphere and hydrosphere. Listen for the following ideas:

- Sea levels would rise and the ice would disappear.
- There would be more matter in the hydrosphere than the cryosphere.
- Whichever parts of the cryosphere disappeared would leave exposed land or water where it used to be.

Thank students for sharing and say, *Let's try to get a little bit more specific about the consequences if a large portion of the cryosphere were lost.*

✱ ATTENDING TO EQUITY

Maps are not politically neutral. Most maps are designed to render a relationship to a place in a "settled" or unproblematic way, when many names and borders on maps are disputed. Another example is the orientation of the map. While no map can show everything, students are accustomed to seeing themselves at the center of the map oriented with North at the top, which can lead to distortion in the Northern and Southern poles. This has consequences for the way students understand the world (e.g., as segmented rather than connected) and many people advocate for a more thoughtful approach to geography. See the following resources for more information:

Crampton, J. W. (2001). Maps as social constructions: Power, communication and visualization. *Progress in Human Geography*, *25*(2), 235–252. https://doi.org/10.1191/030913201678580494

Fotiadis, P. (2008). *The Strange Power of Maps: How maps work politically and influence our understanding of the world* (dissertation). Retrieved July 1, 2022, from https://www.bristol.ac.uk/media-library/sites/spais/migrated/documents/fotiadis0609.pdf.

Pflughoeft, A. (2021, July 3). *The world probably doesn't look like you think it does - and that matters, a lot*. Retrieved July 1, 2022, from https://www.deseret.com/u-s-world/2021/7/2/22537588/map-bias-the-world-probably-doesnt-look-like-you-think.

2 · CREATE INITIAL MODEL ABOUT MELTING ICE

10 min

MATERIALS: chart paper, clay, Community Agreements

Work with a partner to think about melting ice. Display **slide D**. Give students four minutes to answer the prompt on the slide in their notebook.

Say, *In this lesson, we are going to do some important work as we think about these changes. We need to rely on each other to move our thinking forward, because there will be lots of little ideas to consider.* Indicate the Community Agreements and elicit students' ideas for how we can work on the focal agreement of "Moving Our Thinking Forward."

Build an initial consensus model. Display **slide E** and ask students to share their ideas with the class. As students share ideas, represent them on the chart paper. Emphasize to students that we do not have a lot of evidence to back up our ideas, so you will record all their thoughts as best as you can.

Suggested prompts	Sample student responses	Follow-up questions
What changes would happen to the oceans if Earth's cryosphere melted?	The water in the oceans will rise a lot.	*How much would the sea level rise?* *How many people and other organisms would be impacted by the sea level rise?*
(Show students a piece of clay.) If this clay were Greenland's ice sheet, how would it change if it melted?	It would go into the water. It would flatten out.	*How can I show that using the clay?* *When I flatten the clay to show melting, what on the clay would indicate the amount of sea level rise?*
What changes would happen to the area where the ice was if Earth's cryosphere melted?	If the ice was floating on water, there would be open ocean where the ice was. If the ice was on land, the dark land would be exposed.	*What would we find underneath the ice?* *What would happen to organisms and even people that rely on the presence of large amounts of ice?*
What changes would happen to the ice if Earth's cryosphere melted?	Ice is breaking off and going into the water.	*How is ice different from water?*

Make a prediction about sea level rise. Say, *Let's get even more specific about the sea level rise we think would happen if the whole cryosphere melted.* Display **slide F.** Ask students to describe what the pie chart shows. Listen for these ideas:

- Most of Earth's water is in the ocean.
- Some of it is in the cryosphere.
- A small amount is in rivers, lakes, and groundwater.

Then ask, *Given this information, how much do you predict the melting of ice in the cryosphere would raise sea levels?*

Accept all responses, then follow up by asking, *What additional information would we need to figure out how much sea levels would rise?* Listen for these ideas:

- We would need to know specifically how much ice there is in the cryosphere.

- We would need information about how much water the melted ice would create and how deep that would be when added to the ocean.

3 · INTRODUCE KEY INFORMATION

2 min

MATERIALS: None

Introduce the key information students need. Display **slide G.** Say, *We will spend some time figuring out how much the sea level would rise if the ice in Greenland and Antarctica melted. We will put aside the ice in the Arctic Ocean for now.* Lead students in a brief discussion about the information on the slide.✱

Suggested prompt	Sample student response
What observations do you have about the information on the slide?	It gives the area of the ocean, but the number looks kind of weird. I think it is called scientific notation. The ice sheets on Greenland and Antarctica are very thick. The units are in kilometers, but we are given a conversion into meters. It gives us dimensions of Greenland and Antarctica and compares them to simpler shapes.
How could this information help us?	We could figure out how much ice there is, then figure out how much water it would make if it melted. The water it would make would be what covers Earth's surface.
Which parts make sense?	Converting between kilometers and meters Figuring out the areas
Which parts are confusing?	How to read the scientific notation How to do other conversions

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY

Students may need some help understanding what the measurements on **slide G** mean. Use familiar examples to help make this scale more intuitive to students. Some strategies to consider:

- Convert the distance to miles and the areas to square miles and map onto your state.
- Select familiar landmarks that are similar in distance or height to the Greenland and Antarctica ice sheets. (In the United States, Grand Teton, Wyoming, rises approximately 2,000 m above the surrounding land, and Mount Moriah, Nevada, rises approximately 1,500 m above its surroundings. The tallest building in the United States, One World Trade Center, is 546.2 m tall.)

ADDITIONAL GUIDANCE

Some students will have more experience with conversions and area calculations than others. While both these tools are a part of grade school mathematics standards, we recommend reviewing these ideas in context if additional support is needed.

To support simple conversions, have students begin by measuring the dimensions of Greenland on *Sea Level Calculations* using different units (e.g., centimeters and millimeters). Ask students to compare these numbers and think about how we could convert between them. They should then test their conversion. Is it the same every time?

To support area calculations, have students focus only on the rectangle in the Greenland model. Ask, *If we had added a second rectangle next to it, how would the area change? How would the area change if this second rectangle were above it?* Focus students on how length and width measurements change in these scenarios, and how either one will give the same result if length is multiplied by width.

4 · BEGIN TO DEVELOP A MATHEMATICAL MODEL

10 min

MATERIALS: *Sea Level Calculations*, clay

Support students to think through and practice representing large numbers using scientific notation.✱ Show **slide H.** Say, *Some of you mentioned scientific notation as being challenging. Let's talk through that so you have it as a possible strategy to lean on when making your calculations. Here is one of the key pieces of information we needed--the area of Earth's oceans.*

Talk through the example on the slide. Then model entering this number into a calculator, both in long form and in scientific notation. Highlight that the numbers work out to be equivalent and that this is a representational difference.

Develop the mathematical model. Display **slide I.** Say, *We have a lot of information that could help us, but we need a path between this information and finding an amount of sea level rise. This simple model represents what we know already and what we need to figure out to get there. I also have a paper version for you, along with the specific information we know.* Distribute *Sea Level Calculations*.

Continue by saying, *Take a few minutes with your partner and brainstorm how we go from information about the size of Greenland or Antarctica to the amount of sea level rise that would occur if their ice melted. Since we tried modeling this ice melt with clay before, I have clay for you to use to help your brainstorming.*

ADDITIONAL GUIDANCE

Encourage students to use the clay to think about solving the problem step by step. The ice starts as a chunk with certain dimensions, but as it melts it flattens and spreads out. However, its volume does not change, so if we know the area it covers, we can figure out how high it rises.

Discuss the problem-solving strategy as a class.✱ Use the prompts to complete the table on **slide I**. Encourage students to record this strategy on *Sea Level Calculations* as well. It is fine if students do not come to agreement on the whole process, as long as they agree that they need to start by finding the volumes of the two ice sheets.

Suggested prompt	Sample student response
What can we figure out about the ice sheets if we know their dimensions?	We can figure out how much ice there is in each ice sheet. We can determine the volume of ice in each ice sheet.

✱ SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

If this is difficult for your students, slow down and help them understand that the higher the positive exponent, the more place values, or zeroes, to add to the right. Some students might understand this by moving the decimal point. This will be an important and helpful skill later on, so it is worthwhile to spend time helping students gain conceptual familiarity here.

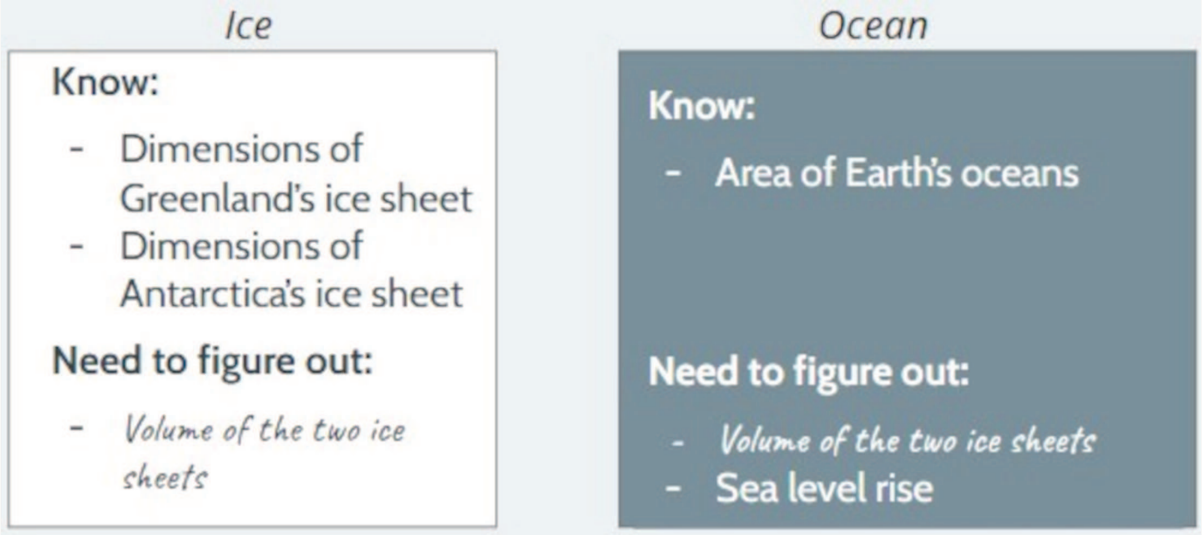
✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

This activity introduces students to the idea that our models of systems are not perfect or entirely accurate, but are reasonable approximations. This idea will be more fully developed in lessons 9 and 13.

Suggested prompt	Sample student response
Once we know the volume of ice, what else can we easily figure out?	How much water it melts into The volume of water
How can we get from the volume of water to the sea level rise?	We could divide by the area of the oceans.

Highlight assumptions. Say, *Our mathematical model will not be perfect. We might have to make some assumptions about what is going to happen. For example, we can only do our calculations if we assume that all the melted ice goes into the ocean, instead of getting caught on land. What other assumptions might we want to make?* Accept all reasonable responses, but listen for these ideas in particular:

- Melted ice takes up the same space as frozen ice.
- The area of the ocean does not measurably increase as water is added.
- The ice on Greenland and Antarctica all on land (students will investigate this assumption on day 2 of the lesson).



If students are confident in their plan to find the sea level rise, you may collect the clay. If not, you may wish to let students hang on to it through the end of class.

ADDITIONAL GUIDANCE

The next few activities are sequenced so that after developing a possible mathematical model, students have an opportunity to apply part of it as a class before a "gradual release" into partner work. Students will focus only on the first part on day 1, finding the ice volume, and then will find the sea level rise on day 2.

5 · USE MATHEMATICAL MODEL TO CALCULATE VOLUME OF GREENLAND ICE

5 min

MATERIALS: *Sea Level Calculations*, clay (optional)

Help students think through finding the volume of Greenland's ice. Display **slide J.** Say, *We decided that the best place to start is by finding the volume of the ice sheet on Greenland. The slide and handout show us that Greenland is shaped like a rectangle attached to a triangle, with the ice sheet on top. How do we find the volume of the ice sheet?* Listen for these ideas:

- The volume will be the area of the base times the height.
- We need to find the total area of the rectangle and triangle combined, then multiply by the thickness of the ice sheet.
- We need to work in the same units, so we should convert the thickness to km first.

Say, *Before we do these calculations, do we expect our answer to be small, large, or somewhere in the middle?* Listen for these responses:

- All the numbers are large, so we should get a large answer.
- The number should be at least as large as the area, since we are multiplying it by another number greater than 1.

Complete the calculations. Use students' ideas to walk through the calculations as a class, as shown in *Sea Level Calculations*.

After you have finished, model checking your answer by saying, *We have an answer here. Does it feel like it makes sense based on what we expected?* Accept all student responses.

6 · USE MATHEMATICAL MODEL TO CALCULATE VOLUME OF ANTARCTIC ICE

13 min

MATERIALS: *Sea Level Calculations*, scientific calculator, clay (optional)

Work with a partner to find the volume of Antarctic ice. Display **slide K** and say, *Let's try this with the ice sheet in Antarctica.* Ask students, *What is different between this situation and Greenland?* Listen for these ideas:

- Antarctica's shape is pretty circular, instead of a triangle and rectangle.
- There is land/ice outside the circle and some water inside it, but it is basically circular.
- We need to use the area of a circle instead of a triangle and rectangle combined.
- The ice is a lot thicker in Antarctica, so we should get a larger answer.

Give students time to work with a partner for about seven minutes.
Listen for these calculations:

- The formula for calculating the area of a circle is r^2.
- The radius is 2,100 km.
- The radius squared is 4,410,000 or 4.41×10^6. (This is not the area yet; if students say this is the area, remind them to include *pi*.)
- Antarctica's approximate area is 13,850,000 or 1.385×10^7 km^2.
- The ice sheet thickness is about 2 km. (This should be multiplied by the approximate area of Antarctica.)
- The total volume of Antarctic ice can be estimated at 27,700,000 km^3.✱

COLLABORATION

This can be an opportunity for students to provide peer feedback to other pairs using the protocols shared in the *OpenSciEd High School Teacher Handbook*. Because of the prevalence of math anxiety, peer feedback here can encourage students about portions of their work that are on the right track even if they are not at the correct solution yet.

Discuss solutions as a class. Call the class back together and give a couple of pairs a chance to present their solutions.

✱ ATTENDING TO EQUITY

Universal Design for Learning: The clay makes this modeling more accessible to all students because it reminds them that the ice melts and then takes up the same space as before, just spread out. If a student needs additional support, you may wish to have them talk about how they would figure out the sea level "rise" a piece of clay would cause if melted (flattened).

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should use appropriate unit conversions with consideration of which label should be written in the denominator of the fraction to cancel out unwanted units. (SEP: 5.5)
- Students' calculations show that Antarctica has approximately 2.77×10^7 km^3 of ice. (SEP: 5.5)

What to do: If students struggle with identifying and using unit conversions, encourage them to think about which orientation of the conversion factor (which label in denominator) will allow them to cancel out unwanted units. If students struggle with identifying next steps in the calculation, use the plan developed on **slide I** and recorded on *Sea Level Calculations* to help students think about how they can iteratively move toward a solution.

Building toward: 4.A.1 Apply ratios and unit conversions at different scales to make predictions about the impacts of human-caused ice melt on sea levels and human populations. (SEP: 5.5; DCI: ESS3.B.1, ESS3.D.1; CCC: 3.1)

End of day 1

7 · REFLECT ON OUR MATHEMATICAL MODEL

7 min

MATERIALS: *Sea Level Calculations*, scientific calculator, chart paper

Elicit reflections on the class mathematical model.✱ Display **slide L**. Say, *Yesterday we used some different strategies and tools to help us start to figure out how much the sea level would rise if all the ice in Greenland and Antarctica melted. Let's reflect on those tools a bit before we finish the problem.*

Suggested prompt	Sample student response
What strategies and tools did we use or discuss to help us start to figure out the amount of potential sea level rise?	We brainstormed a plan to solve the problem. We used a physical model to help us imagine the problem. Estimating area Formulas for area Scientific notation Converting units Predicting how big our answers would be and checking if they made sense We used slightly different approaches to get the same answer. We made assumptions that will get us a pretty good answer.

✱ SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

The anchor chart in this activity will return throughout the unit to continually support students, as described in *Mathematical Anchor Chart*.

Suggested prompt	Sample student response
How did we use those strategies and tools?	We recorded our plan and did the first couple steps. The clay helped us figure out how we could use different knowledge we are already familiar with to solve the problem. We used estimations and area formulas to help us calculate areas, then find volumes. We used scientific notation to make it easier to write big numbers. We converted between units because we had information with different units or labels. We checked our answers to help give evidence that we had done the calculations correctly.

Build an anchor chart for Developing Mathematical and Computational Models. Say, *A lot of these strategies and tools sound like they could be useful in different situations. We should record them so that we can use them later if we have to solve similar problems.* Create an anchor chart titled "Strategies and Tools for Developing Mathematical and Computational Models." Add the ideas that students shared, along with a brief explanation of how these different strategies and tools are used. Use students' words as much as possible, but several examples are below. The anchor chart should focus on usability for students rather than comprehension, so feel free to add what they need the most help recalling rather than listing all ideas below.

- Physical models help us plan.
- We can estimate area using simple shapes and areas formulas.
- Scientific notation allows us to represent big numbers.
- We can convert between different units using conversion factors.
- We can predict how big our answers will be and check if they make sense.
- Different approaches can get to the same answer.
- Assumptions help simplify the problem to get a pretty good answer.

Focus on unit conversions. Say, *One tool that we used, without thinking about it too much, was unit conversions. Unit conversions can be very helpful to us, but they are especially useful when we are careful about how we use them.* Point out to students that there was likely some disagreement the day before about whether they should divide or multiply by 1,000 to convert kilometers to meters. Show **slide M** and say, *In a unit conversion, we have information about our starting amount and a conversion factor.* Explain how the process works. Say, *We begin with writing the initial amount as a fraction over 1, because anything divided by 1 is 1. Then we multiply by a conversion factor. A conversion factor has different ways of saying the same thing--like 12 inches and 1 foot—in the numerator and denominator.* Explain how this is like multiplying the initial amount by 1.

Give an example unit conversion. Display **slide N** and walk students through how the conversion between meters and kilometers that they did on day 1 could be done more systematically with unit conversions.

Say, *Today we will have an opportunity to use this and other tools to finish figuring out how much the sea levels would rise if all the ice in Greenland and Antarctica melted.*

8 · CALCULATE SEA LEVEL RISE FROM GREENLAND ICE MELT

6 min

MATERIALS: *Sea Level Calculations*, scientific calculator

Transition into calculating sea level rise from Greenland melt. Display **slide O**. Say, *Like last class, we will think through Greenland's sea level rise together, then work with a partner to finalize the calculation for Antarctica.*

Give students time to discuss the problem setup with a partner. Then discuss their ideas as a class. Students should recall that the volume of ice we figured out on day 1 is the same as the volume of water produced, so we just need to figure out how high that water would cover the area of Earth's oceans.

Walk students through the recommended calculation steps, as shown in *Sea Level Calculations*.

9 · CALCULATE SEA LEVEL RISE FROM ANTARCTICA ICE MELT

16 min

MATERIALS: *Sea Level Calculations*, scientific calculator, https://sealevel.nasa.gov/vesl/web/sea-level/slr-eustatic/

Complete the calculation in pairs. Display **slide P**. Give students eight minutes to complete the calculation for Antarctica with a partner.

Discuss as a class. Bring students back together and have a couple of different pairs share their method. Be sure to come to consensus, as on *Sea Level Calculations*, before moving on.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should use appropriate unit conversions with consideration of which label should be written in the denominator of the fraction to cancel out unwanted units. (SEP: 5.5)
- Students' calculations show that if all Antarctica's ice melted, sea levels would rise by approximately 76.5 m. (SEP: 5.5)

What to do: If students struggle with identifying and using unit conversions, encourage them to think about which orientation of the conversion factor (which label in the denominator) will allow them to cancel out unwanted units. If students struggle with identifying next steps in the calculation, use the plan developed on **slide L** and recorded on *Sea Level Calculations* to help students think about how they can iteratively move toward a solution.

Building toward: 4.A.2 Apply ratios and unit conversions at different scales to make predictions about the impacts of human-caused ice melt on sea levels and human populations. (SEP: 5.5; DCI: ESS3.B.1, ESS3.D.1; CCC: 3.1)

Complete the final calculation and check answers as a class. Display **slide Q.** Give students a moment to determine the total sea level rise, then check answers using the simulation https://sealevel.nasa.gov/vesl/web/sea-level/slr-eustatic/. Show Greenland and Antarctica separately, then together. Cycle through different regional views so that students can see how this sea level rise would affect different coastlines in the United States. Use references in the school environment to help students visualize the different amounts of sea level rise.

The simulation's prediction for sea level rise if Antarctic ice melted is lower than our prediction. Ask, *What could account for this difference?* Listen for the idea that we must have made different assumptions than the simulation. Emphasize that whether the sea level would rise 55 m (62 m total with the contribution from Greenland) or more, either outcome would be bad for coastal communities.

Identify something that is missing in the simulation. Display **slide R.** Say, *There is not a slider in the simulation for the ice in the Arctic Ocean, even though it looks like there is a lot of it on the map. Why do you think the simulation left out this sea ice?* Listen for these ideas:

- Maybe they just forgot it.
- Maybe there is not very much of it.
- Maybe it does not cause the sea level to rise when it melts.

If students struggle to identify reasons, ask, *What is different between the Arctic sea ice and the glaciers on Greenland and Antarctica?* Listen for these ideas:

- Greenland is land, while the sea ice is just floating on the ocean.
- The sea ice freezes and melts seasonally.

If students do not propose why Arctic sea ice might not contribute to sea level rise, ask, *Why would sea ice melting not affect the sea level? Do we have anything in our lives that is like floating sea ice melting?* Listen for these responses:

- It is in the water, so it is already affecting the sea level.
- Ice melting does not make your drink overflow.

Poll students on the effects of sea ice compared to land ice. Show **slide S.** Say, *We know there is both sea ice melt and land ice melt occurring over time in and around Greenland, and we know global sea levels are rising. Let's think about these two types of ice melt and make some predictions about how they may impact sea level rise.*

Conduct the poll and ask several students for their rationale. Then use the results of the poll to motivate the need to build evidence for our predictions. Say, *Some of us think that sea ice has less of an effect than land ice because it is already in the ocean, while others are not sure. In Lesson 3, we did a good job of developing an investigation to produce evidence that we could use to support ideas like this.*

ALTERNATE ACTIVITY

Alternatively, share the simulation https://sealevel.nasa.gov/vesl/web/sea-level/slr-eustatic/ with students so they can explore the simulation individually before discussing it as a class.

Or invite students to do their own search for a simulation or scientific papers that could help them both check their calculations against other scientists' work and get a better understanding of what the potential impacts will be if Greenland's ice sheet melts. Ask students to share the resources they found, offering https://sealevel.nasa.gov/vesl/web/sea-level/slr-eustatic/ as an option if students do not.

10 · PLAN AN INVESTIGATION FOR HOW MELTING ICE AFFECTS SEA LEVEL

16 min

MATERIALS: Land Ice vs. Sea Ice Investigation, science notebook, chart paper, "Planning an Investigation" anchor chart from Lesson 3

Develop the question we are planning an investigation for. Say, *Let's get ready to plan an investigation to get the data we need to support or refute our predictions. At the start of our plan for an investigation, we should always be thinking about what question we are trying to figure out. And we should record this in our notebooks for every investigation plan we develop.*

Show **slide T**. Discuss and decide on the question that we are trying to investigate as a class. This will be something like:

- How much do melting sea ice and land ice affect sea levels?
- Which contributes to sea level rise more, melting sea ice or melting land ice?
- How much do sea levels rise when sea ice melts compared to when land ice melts?

Record the question the class decides on at the top of our chart paper and have students record this question on a new page in their notebooks. Students should decide on something like, "How much does melting sea ice and land ice affect sea levels?"

Introduce the materials available for the investigation. Show **slide U**. Say something like, *So if we want to compare melting land ice and melting sea ice, some of our tests need to have ice in water to mimic sea ice and other tests will need to have ice on a surface outside of the water to mimic land ice. Let's take a look at some of the materials we have available for this and start brainstorming how we could use them.* Hold up each of the items below and discuss what we can use them for. Anticipated student responses are given after each item.

- **Cups/beakers** - *We can use these to hold water to represent the "ocean.". If we draw a line on the side of the container, we can easily compare the water level before and after ice melt.*
- **Ice cubes** - *We can use these in the water as sea ice and on top of a surface as land ice.*
- **Colored water** - *We can fill the containers with this to use as our "ocean."*
- **Clay** - *We can use this to create "land structures" in our ocean system. We can hang it over the side of the container.*
- **Rulers** - *We can use this to measure things like the dimensions of the container, the dimensions of the ice cubes, the water height before and after ice melt, etc.*
- **Clear tape and markers** - *We can use these to mark the initial water level on the containers before the ice melts so that we can observe if the water level changes.*

When you introduce the clay, you may want to suggest that one challenge in making "land" to hold the ice is to figure out how to keep it on the land until it melts, while still ensuring that the ice melt drains into the "ocean" (just as it does in Antarctica) instead of forming an "inland lake."

After showing the rulers, ask that students make their marks on the tape when recording the water level rather than directly on the containers, as that makes it easier to reuse them for other experiments.

ADDITIONAL GUIDANCE

Students may wonder if all melted land ice really does flow into the ocean. Is it possible that some of the ice melt stays in lakes on land? The answer is yes, although the majority of melted land ice does run into the ocean. You may wish to ask students to think about what the consequences of this pooling melt water might be, and add this question to the DQB. Later in the unit, as students explain how an underwater berm can help prevent ice melt, they will also be able to figure out that pooling water can have a warming effect on the ice it sits on or flows past, causing it to melt. For more information, see https://www.nature.com/articles/s41467-022-29385-3.

Build a data table. Display **slide V** and the "Planning an Investigation" anchor chart from Lesson 3. Give students a few minutes to work with their group to build a data table for the investigation in their notebook.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students identify land ice vs. sea ice as an independent variable and water level rise as a dependent variable. (SEP: 3.1)
- Students' data tables that allow for systematic collection of data. (SEP: 3.1)

What to do: Use the "Planning an Investigation" anchor chart from Lesson 3 to help students remember how independent and dependent variables can be incorporated into a data table. Remind students of how building space into a table for planned data ensures that we will collect the data we need to revise our model in the way we would like.

Building toward: 4.B.1 Plan and carry out an investigation to revise a model to reflect that sea ice is in the ocean system (hydrosphere) and therefore does not change sea level, though losing it might have other negative effects. (SEP: 3.1; DCI: ESS3.D.2; CCC: 4.2)

Set up the equipment. Show **slide W.** Assign students to their groups and distribute materials (except for the colored water) for them to set up their two systems with their group.

Record procedures and system diagrams. Show slide X. Explain that recording our procedures makes it possible for others to replicate our tests if needed, and that sketching diagrams of lab setups is a good way to do this as it often provides a better understanding of the experimental procedure than using words alone. Add a note to the anchor chart about the importance of recording procedures and diagrams.

Instruct students to now measure and sketch diagrams of each system in their notebooks with dimensions and labels for all the parts/components. Explain that this will require drawing the systems from more than one perspective (top view, side view, etc.) to provide a detailed layout of the materials and their dimensions.

Sample Investigation Procedure describes an example procedure.

Add colored water to containers and mark initial "sea" levels. Show **slide Y.** Once everything is set up, review the instructions on the slide. Distribute one 24-ounce plastic cup to each group, each containing about 20 ounces of water already dyed with blue food coloring, for students to use in their sea ice and land ice systems. Monitor students' setup work throughout.

After groups have placed their setups in a location to allow the ice to melt until the following day, collect these supplies to reuse next class:

- rulers
- tape
- markers
- 24-ounce cups with any remaining colored water in them

Leave the setups out overnight.

ALTERNATE ACTIVITY

The ice does not take all night to melt. If you do not reach this point at the end of class, consider the following alternate activities:

- Use heat lamps to speed the melting process.
- Ask students to provide feedback on each other's calculations. Remind students that even if they were "right", it is easy to multiply or divide the wrong way if your work is not organized, and that this is an opportunity to help each other see how organization can help.
- Support ratio thinking by asking students how their results would change if only half (or some other fraction) of the ice in Greenland or Antarctica melted.
- Tell students that there are glaciers in high mountain ranges as well, not just at the poles. Have them research the properties of the glaciers of the Himalayas, Alps, or another region and calculate the sea level impact if any of those glaciers were to melt into the ocean.

End of day 2

11 · TAKE FINAL MEASUREMENTS

2 min

MATERIALS: Land Ice vs. Sea Ice Investigation, science notebook

Cue the data collection that remains to be done. Show **slide Z**. Have students record the measurements in their notebook.

ADDITIONAL GUIDANCE

If you are prevented from collecting results on day 3 or a student misses that day of instruction, this time-lapse video https://youtu.be/3ILxhlnrn7g can provide an alternate source for qualitative results (though not quantitative ones).

12 · SHARE AND MAKE SENSE OF THE RESULTS

8 min

MATERIALS: science notebook

Share and record class results. Show **slide AA.** Bring students back together to have each lab group share their results with the whole class. Record a running list on the board of how much the water level rose for each condition. This should yield the following patterns, as well as give the class an opportunity to identify any outliers in the data:

- On average, the water level did not change in the sea ice melt conditions.
- On average, the water level rose about X cm in the land ice melt conditions.

Ask students to summarize what our investigation results tell us about how melting sea ice vs. melting land ice can affect sea levels on Earth. Students may say something like:

- Since the water level did not change in our sea ice testing system, melting sea ice does NOT change the sea level of Earth's oceans.
- Since the water level went up in our land ice testing system, melting land ice can increase the sea level of Earth's oceans.

Discuss why there would be no rise in sea level from sea ice melt. Show **slide BB.** Discuss the questions on the slide. Accept all answers.

Suggested prompt	Sample student response
*Why would melting sea ice **not** cause a rise in sea level?*	The sea ice is already in the water, so it's already taking up space in it. The ice in the ocean is displacing water before it melts. The weight of the ice floating on the water pushes the water levels up. The space that the ice takes up in the water is equal to the space that all the melted ice takes up when melted.
If melting sea ice does not affect sea level, then does it matter if sea ice melts?	No, as there are polar bears and other organisms up there. No, as that ice might help keep Earth cool. No, as there might be other negative impacts we do not know about yet.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students identify that sea ice does not affect sea level rise because its matter is already in the ocean system (hydrosphere). (DCI: ESS3.D.2; CCC: 4.2)
- Students acknowledge that there may be negative effects we are still learning about if sea ice melts. (DCI: ESS3.D.2)

What to do: If students struggle to explain why sea ice does not affect sea level rise, show students another example setup of sea ice in a cup, this time measuring the water level both before and after the ice is placed in the container. Students will notice that the water level rose when the ice was added. Encourage them to consider what this means for the ocean–that sea ice is already affecting sea levels, so melting of the ice does not.

Building toward: 4.B.2 Plan and carry out an investigation to revise a model to reflect that sea ice is in the ocean system (hydrosphere) and therefore does not change sea level, though losing it might have other negative effects. (SEP: 3.1; DCI: ESS3.D.2; CCC: 4.2)

13 · REVISE OUR MODEL

8 min

MATERIALS: initial consensus model from day 1, https://sealevel.nasa.gov/vesl/web/sea-level/slr-eustatic/

Introduce the Putting the Pieces Together Routine. Display **slide CC**. Say, *We have figured out a lot in the last few lessons. The rest of today, we will be pulling pieces together from our investigations and other lessons to make sense of the problem of polar ice melt and sea level rise.*✱

Revise the initial consensus model from day 1. Display the model developed at the beginning of the lesson. Ask, *What revisions should we make to this model given what we have figured out in the lesson?* Listen for and represent the following ideas:

- Only land ice (Greenland and Antarctica) contributes to sea level rise when it melts.
- Land and sea are exposed when existing ice melts.
- We can quantify how much the sea level would rise in this situation.

Display https://sealevel.nasa.gov/vesl/web/sea-level/slr-eustatic/ and say, *Our model is an important tool because it can help us think about how sea level rise is actually occurring. However, this simulation does a really good job of reminding us that this is a problem that affects real places and real people.*

Show students the effects on different coastlines again. Say, *scientists predict much lower sea level rise than the 62 meters total shown here. However, even much lower amounts could impact a lot of people.*

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

The Putting the Pieces Together Routine looks a little bit different every time. Sometimes, like in Lesson 12, it utilizes a structure called a Gotta-Have-It Checklist. Here, students simply return to the model the class developed before Lesson 4's mathematical modeling and investigations, update it, and reflect on the implications of significant amounts of sea level rise.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students propose a change to the model to reflect that only land ice affects sea level rise, while sea ice does not. (SEP: 3.1)
- Students model how matter from land ice moves into the ocean, while matter from sea ice is already in the ocean but changes state. (SEP: 3.1; CCC: 4.2)

What to do: If students do not immediately propose this change, ask, *How does what we figured out in our investigation affect our model?* Use this modeling opportunity as a chance to prompt students to think about matter flows.

Building toward: 4.B.3 Plan and carry out an investigation to revise a model to reflect that sea ice is in the ocean system (hydrosphere) and therefore does not change sea level, though losing it might have other negative effects. (SEP: 3.1; DCI: ESS3.D.2; CCC: 4.2)

Reflect on feelings associated with the Sea Level Change simulation. Say, *There is a lot to process in this simulation. Let's take some time to reflect.* Display **slide DD.** Have students turn and talk with a partner about the questions on the slide. Then have students share ideas with the class. Accept all responses.

Acknowledge the range of thoughts and emotions students may have after exploring the NASA Sea Level Change simulation. Say, *Each of us is thinking, feeling, and wondering about different things, based on our own experiences. Some of us might be feeling pretty pessimistic, but the good news is that scientists and engineers have the tools to make more specific predictions and develop solutions. And know what? We have these tools too!*

14 · CONSIDER THE HUMAN IMPACTS OF SEA LEVEL RISE

10 min

MATERIALS: science notebook

Share statistics around the impacts of sea level rise. Display **slide EE.** Say, *Let's start by looking more specifically at how many people in the United States are likely to be affected by sea level rise.* Walk students through the statistics on the slide.✱

Complete the calculation and share solutions. Give students seven minutes to work with a partner to solve the problem in their notebooks. Then, discuss students' work as a class. Allow students to share different solutions, but come to agreement on an answer as demonstrated below.

461 people live in a square mile.

$1\ mi^2 \times (1.61\ km / 1\ mi) \times (1.61\ km / 1\ mi) = 2.59\ km^2$

$(461\ people / 2.59\ km^2) \times 24{,}000\ km^2 \approx 4{,}270{,}000\ people$

Discuss the meaning of students' solutions. Show **slide FF** and lead a brief discussion using the prompts on the slide.

Suggested prompt	Sample student response
How would completely flooded-out people in the United States be impacted by a 0.5-m sea level rise?	They would have to move or invest lots of money to keep water out.

✱ ATTENDING TO EQUITY

This activity pushes students to think about the human impact of sea level rise in more detail, leading into additional thinking later in the lesson around impacts on other living things. This helps answer the Learning in Places Ethical Deliberation and Decision-Making question, "Who will be impacted by the decision and how (both human and more-than-human)?"

Suggested prompt	Sample student response
How would people who now live closer to the ocean be affected?	Other, nearby people would be more affected by storms. (Follow up by pointing out that estimates show that an additional 9 million people might have to move not because they are flooded out, but because the ocean comes too close for safety during storms.)
How do you feel about these likely impacts, and about even greater potential impacts?	We feel bad for people who are affected. We are concerned this will affect us. We are worried about how impacts could be even bigger than what we predicted here. We want to do something!
Why is it important that we can make predictions about likely impacts?	It can help us figure out better solutions for what can be done. It shows us the scale or size of the problem.
Would this ability have been helpful for the people who had to migrate long ago due to changes in sea level?	Probably, yes.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should use appropriate unit conversions with consideration of which label should be written in the denominator of the fraction to cancel out unwanted units. (SEP: 5.5)
- Students' calculations show that if sea levels rose by 0.5 m, approximately 4 million people in the United States would be flooded out and have to move. (SEP: 5.5; CCC: 3.1)
- Students should recognize that the scale of sea level rise matters for human migrations. (DCI: ESS3.B.1; CCC: 3.1)
- Students should recognize that our ability to make predictions about human impacts on climate allows people to prepare for effects. (DCI: ESS3.D.1)

What to do: This calculation represents students' first opportunity to use a more complex unit conversion, but they may not immediately recognize it as such because the information was presented in words. Leverage students' intuition about the easy-to-grasp concept of people in an area (population density) to show them that this can be rewritten as 461 people = 1 mi^2. Then help students think about how they can cancel both "miles" with the conversion factor 1 mi = 1.61 km. Also, encourage students to think about how even this relatively modest sea level rise could have major impacts on people, but being able to predict the impacts can help us figure out how to prepare.

This discussion provides an opportunity to gain initial evidence for students' three-dimensional thinking. They use a mathematical tool like unit conversions, along with Scale, Proportion, and Quantity thinking, to track increasingly nuanced understandings of how humans are impacted by natural hazards. Push to ensure that all three elements are present and used together, as students must use multiple dimensions together, particularly unit conversions, in the individual exit ticket at the end of the lesson.

Building toward: 4.A.3 Apply ratios and unit conversions at different scales to make predictions about the impacts of human-caused ice melt on sea levels and human populations. (SEP: 5.5; DCI: ESS3.B.1, ESS3.D.1; CCC: 3.1)

15 · BRAINSTORM SOLUTIONS AND NAVIGATE

9 min

MATERIALS: science notebook

Share research on addressing climate change anxiety. ✱ Say, *There has been research on climate-change anxiety in young people. If you are feeling anxious, you are not alone. Even though this problem might feel overwhelming, let's think about what we can do. Let's brainstorm some ways that we might be able to slow or decrease sea level rise.*

Show **slide GG**. Say, *People have found ways to brainstorm that give rise to the most promising ideas. Here are some guidelines for having these brainstorming conversations.*

1. *Share as many ideas as possible.*
2. *Don't judge ideas, just list them. Creative spaces are judgment-free zones. They let ideas flow so that people can be inspired by each other's great ideas.*
3. *Build on the ideas of others. The ideas that seem wacky can inspire other ideas! Often there is not a whole lot of difference between outrageous and brilliant.*

ADDITIONAL GUIDANCE

The guidelines for brainstorming are adapted from IDEO's Rules of Brainstorming https://www.ideou.com/blogs/inspiration/7-simple-rules-of-brainstorming. Use this link for more background information or guidance around this activity.

✱ ATTENDING TO EQUITY

Some students may be more susceptible to climate-change anxiety. Some research on climate-change anxiety in young people shows that it can have lasting mental health consequences (https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(20)30223-0/fulltext). Symptoms associated with climate anxiety include panic attacks, insomnia, and obsessive thinking. It is important to be sensitive in the way you discuss climate change with young people because evidence shows that worrying about climate change can have serious negative overall mental health effects, potentially leading to increases in stress-related

Invite students to brainstorm initial ideas about solutions that could stop or slow polar ice melt. Say, *Humans use scientific tools not only to model and predict what might happen in a system, but to design solutions that can help solve challenges facing people and other life on the planet. Let's take a little time now to think about possible solutions with a partner.*

Allow partners to generate ideas in their science notebooks for four minutes.

Elicit student ideas about how to stop or slow polar ice melt. Ask, *What ideas do we have?* Listens for these responses:

- Move people from those at-risk cities.
- Stop climate change.
- Put a giant container around the iceberg.
- Pump rising seawater to dry areas.
- Collect carbon dioxide and send it into outer space.

Thank students for their ideas and encourage them to keep thinking. Pose the question, *I wonder if scientists and engineers have had any similar ideas?*

Update personal glossaries and Progress Trackers. Show **slide HH** and give students a couple of minutes to record any terms from the lesson in their personal glossaries. Encourage them to capture not just content terms like *cryosphere*, but other words that help us figure things out, like *unit conversion*. Additionally, students should update their Progress Trackers.

Question	What I figured out in words/pictures
What would happen if the Earth's ice melted?	• *Sea levels would rise by dozens of meters.* • *Only land ice would affect the sea level rise.* • *If sea levels rose only 0.5 m, 4,000,000 people around the world would have to move.*

Reflect on the Putting Pieces Together Routine and focal agreement. Display **slide II** and briefly discuss the prompts on the slide.

problems such as substance-use disorders, anxiety disorders, and depression. If you suspect that any of your students are experiencing anxiety, refer them to appropriate mental health student services.

16 · ELECTRONIC EXIT TICKET

8 min

MATERIALS: computer, copy of https://docs.google.com/forms/d/1jvpWOSDPElhPiwg1jzX96kVWPgkedGGmRnBGQErvozo/copy, scratch paper

Shift to the Electronic Exit Ticket. Display **slide JJ**. Say, *You have some really interesting ideas about how to stop polar ice melt! Scientists and engineers have actually explored some of these same options, which we can look into more tomorrow. In the meantime, we have figured out a lot in this lesson. This Electronic Exit Ticket will give you a chance to show where you are on these ideas that we have developed.* Give students time to complete a copy of https://docs.google.com/forms/d/1jvpWOSDPElhPiwg1jzX96kVWPgkedGGmRnBGQErvozo/copy. There is also a key for this Electronic Exit Ticket: *Exit Ticket Key*. Make sure students have access to scratch paper to help them track their work.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
- See *Exit Ticket Key* for guidance.

What to do: See *Exit Ticket Key* for guidance.

Building toward: 4.A.4 Apply ratios and unit conversions at different scales to make predictions about the impacts of human-caused ice melt on sea levels and human populations. (SEP: 5.5; DCI: ESS3.B.1, ESS3.D.1; CCC: 3.1)

17 · HOME LEARNING (OPTIONAL)

0 min

MATERIALS: *Conversions Home Learning* (optional)

Assign home learning activity (optional). Students can investigate the consequentiality of a 6.84-meter sea level rise at home using unit conversions.

Show **slide KK**. Distribute copies of *Conversions Home Learning*. Students will figure out that the 6.84 meters of sea level rise is equivalent to about 22 feet if all of Greenland's ice melted, and about 5.6 feet if one-quarter of its ice melted.

Assess students' mathematical reasoning on the home learning assignment. Look for appropriate use of unit conversion and labels in order to properly convert and cancel unwanted units, as well as to explain sea level rise when answering the "what do these numbers mean" questions. See *Home Learning: Conversions Key* for solutions.

Additional Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HSN.Q.A.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; ~~choose and interpret the scale and the origin in graphs and data displays.~~

CCSS.MATH.CONTENT.HSN.Q.A.2: Define appropriate quantities for the purpose of descriptive modeling.

CCSS.MATH.CONTENT.HS.G-GMD.3: Use volume formulas for cylinders, ~~pyramids, cones, and spheres~~ to solve problems.

Students identify the quantities that need to be used in mathematical modeling and use the quantities in unit conversions to determine the sea level rise if Earth's cryosphere melted.

LESSON 5: How can we best slow or stop the land ice melt?

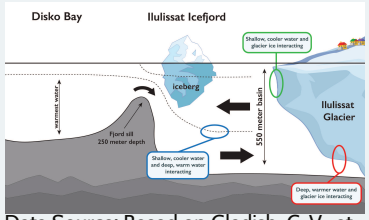
PREVIOUS LESSON

We developed a mathematical model to figure out the impact on sea level if Greenland and Antarctica's ice melted. We evaluated our answer using a simulation. We wondered if sea ice affects sea levels, so we planned and carried out an investigation to test this idea. We calculated the human impacts of sea level rise.

THIS LESSON

PROBLEMATIZING

2 days



Data Source: Based on Gladish, C. V., et al. (2015)

We analyze the changes occurring over time at a site of fast ice melt in Greenland (Ilulissat Glacier) using satellite images on video recordings of the glacier front. We read about two design solutions for slowing or preventing further melt. We hear concerns from local rights holders and attempt to model the energy transfers that occur to make these solutions work. We ask questions about these energy flows and overall suitability of the designs.

NEXT LESSON

We will plan and carry out an investigation to test our ideas about how microbeads prevent ice melt. We will see that darker colors heat up more, and we will use a reading to help explain how carbon dioxide causes temperature increases and how microbeads work.

BUILDING TOWARD NGSS

HS-PS3-1, HS-PS3-4, HS-ESS2-2, HS-ESS2-4, HS-ESS3-1, HS-ESS3-5, HS-ESS3-6, HS-ESS2-7

WHAT STUDENTS WILL DO

5.A Ask questions to refine a model of the energy transfer into, out of, and within the system if proposed solutions prevent glacier ice melt in Disko Bay. (SEP: 1.4; DCI: PS3.B.2; CCC: 4.1)

5.B Use energy transfer consensus models to ask questions that challenge the suitability of the design solutions based on their current and future impacts. (SEP: 1.7; DCI: ESS3.D.1; CCC: 4.3)

WHAT STUDENTS WILL FIGURE OUT

- The Ilulissat Glacier is the single largest flow of melt in Greenland. The front edge of the glacier has been receding over many decades.
- There are two proposed solutions. One is to build a huge underwater barrier between Disko Bay and Ilulissat Icefjord to prevent warm salty ocean water from coming into contact with the Ilulissat Glacier. The other is to spread thin layers of microbeads on Arctic ice in the summer months.
- Rights holders have concerns about the suitability of these designs and their potential impacts.

Lesson 5 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Identify locations in Greenland where a design solution to ice melt could have a lot of potential impact.	A-C	*Greenland Land Ice Data*
2	10 min		**INTRODUCE THE ILULISSAT GLACIER CASE SITE AND ANALYZE CHANGES OCCURRING THERE** Orient to one area where a lot of ice melt is happening (the Ilulissat Glacier) and analyze satellite images to make sense of the changes happening there.	D-H	*Ilulissat Ice Changes*, https://youtu.be/zoLGW2NcSeo
3	20 min		**LEARN ABOUT TWO PROPOSED SOLUTIONS** Read about two proposed design solutions and hear comments from local rights holders and other interested parties.	I-L	*Ilulissat Design Solution Proposals*, *Peoples' Concerns*, *Being Healthy* (optional), https://youtu.be/rdOst2woWww
4	10 min		**MODEL THE PROPOSED SOLUTIONS** Develop an initial energy transfer model to explain how one of the proposed solutions might work at the particle level.	M-N	*Ilulissat Design Solution Proposals*
					End of day 1
5	2 min		**SHARE IDEAS IN SMALL GROUPS** Share initial models with partners.	O	*Ilulissat Design Solution Proposals*
6	2 min		**INTRODUCE THE DISCUSSION MAPPING TOOL** Introduce the discussion mapping tool as a way to visualize the conversation patterns happening within the class.	P	*Discussion Mapping Tool*, clipboard (optional)
7	8 min		**GO PUBLIC WITH IDEAS ABOUT PROPOSED SOLUTIONS** Build consensus as a class around what we can and cannot explain about both proposed solutions.	Q	*Ilulissat Design Solution Proposals*, chart paper, *Discussion Mapping Tool*, clipboard (optional)
8	8 min		**REFINE THE MODEL TO INCLUDE ENERGY** Ask questions to refine the consensus model to include ideas about energy transfer.	R	*Ilulissat Design Solution Proposals*, initial consensus model, "Rules for Energy Transfer Models" anchor chart, chart paper
9	7 min		**REFLECT ON OUR DISCUSSION MAPPING PROCESS** Facilitate a discussion around patterns in the discussion map.	S	completed discussion map
10	12 min		**ADD TO THE DRIVING QUESTION BOARD** Generate new questions for the DQB using unexplained ideas from the model.	T	sticky notes, class consensus model, Driving Question Board
11	6 min		**NAVIGATE** Discuss which questions to focus on first and consider how the community agreements can support upcoming investigations.	U-W	Driving Question Board
					End of day 2

Lesson 5 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Ilulissat Design Solution Proposals* • *Peoples' Concerns* • *Being Healthy* (optional) • sticky notes	• *Greenland Land Ice Data* • *Ilulissat Ice Changes*	• https://youtu.be/zoLGW2NcSeo • https://youtu.be/rdOst2woWww • *Discussion Mapping Tool* • clipboard (optional) • chart paper • initial consensus model • "Rules for Energy Transfer Models" anchor chart • completed discussion map • class consensus model • Driving Question Board

Materials preparation (25 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Ensure that there is a copy of *Ilulissat Design Solution Proposals* for every student in each class.

Ensure that there is a copy of *Peoples' Concerns* for every student in your largest class. This is a non-consumable item that you collect and reuse in all classes.

Make color copies of *Greenland Land Ice Data* and *Ilulissat Ice Changes* to have enough for every pair of students in your largest class. Put each page in its own clear, full-sheet protector. These are non-consumables that you collect and reuse in all classes.

Print one copy of *Discussion Mapping Tool*. This is a teacher document that will be used to track the discussion on day 2 of the lesson.

After completing the discussion mapping activity, add an image of the completed discussion map from day 2 to **slide S**. If you are unable to add an image, project or pass around the completed discussion map so students can analyze the data.

The video about Inuit rights holders, https://youtu.be/rdOst2woWww, is long and should be stopped at 4:29. The optional *Being Healthy* summarizes this portion of the video if you wish to include a place for students to take notes. The remainder of the video includes important ideas about Inuit health, including powerful examples of young people working to improve mental health in Inuit communities. However, this portion of the video includes discussions of potentially traumatic issues, including high suicide rates in many Inuit communities. If you are considering the latter section of the video, make sure to preview it. Provide forewarning in accordance with school policy and appropriate supports, including counselor access, for students as needed if you choose to show it in class.

Lesson 5 • Where We Are Going and NOT Going

Where We Are Going

This lesson introduces students to two proposed solutions that are designed to prevent glacier ice melt in Disko Bay. The targeted disciplinary core ideas that we are beginning to develop are:

- **PS3.B.2: Conservation of Energy and Energy Transfer.** Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- **ESS3.D.1: 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.

Students analyze changes to the ice at the Ilulissat Glacier case site and collaboratively develop models to simulate the system and the interactions that occur within the system (CCC:4.3) when the proposed solutions are in place.

Students practice asking questions as they seek to refine their class consensus particle models to include ideas about energy transfer (SEP: 1.4), and as they challenge the suitability of each design (SEP: 1.7) to change the system to prevent ice melt (CCC: 4.1). The new questions that students ask throughout this lesson are added to the Driving Question Board and are used to drive the work students do in the next several lessons.

Students are able to build on their prior work asking questions in Lessons 1 and 3, as they now return to the Driving Question Board for a third time in the unit.

Students may wish to add the terms *berm* or *microbeads* to their personal glossaries at the end of this lesson. See the "What are recommended adult-level learning resources for the science concepts in this unit?" section of the unit front matter for more information about these potential solutions to polar ice melt. You may also see the final model for microbeads, in Lesson 6 *Revising Prior Models Key*, and the berm, in Lesson 12 *Berm Model Key*, for more information.

This lesson also introduces some thinking that engineers use, including considering values that guide decisions and examining the values of interested parties. These ideas correspond to the Learning in Places Ethical Deliberation and Decision-Making questions, *What values will guide your decision?* and *Who will be impacted by the decision and how (both human and more-than-human?* The interested parties focused on in this lesson are Inuit rights holders. Language of "interested parties" and "rights holders" was intentionally selected as the term "stakeholders" implies that all interested parties have an equal stake or investment in the decision.

Where We Are NOT Going

A large part of this lesson is developing consensus around what we think we know and do not know about how these design solutions work. Throughout this lesson, students should have a lot of questions about how these proposed solutions would prevent ice melt and will not have the evidence to fully support their ideas in their models. In Lesson Set 2 students will determine how the microbeads prevent ice melt at the ice surface, and in Lesson Set 3 they will develop an explanation for how the berm prevents ice melt underwater.

Many proposed solutions to protect glaciers are controversial in the communities where they have been proposed. They may be developed by outside scientists without consulting the knowledge of Inuit scientists and other local experts. Furthermore, these solutions help *mitigate* the effects of climate change, rather than addressing the root cause. In subsequent lessons, students continue to explore the proposed solutions in this lesson, but it is important to help keep front and center that although we want to understand how they work, their functioning does not mean that they *should* be implemented. Human-caused greenhouse gas emissions, which students have identified to be at the root of climate change, are addressed in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)* and *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*.

In Lesson 13 students will have an opportunity to model the effects of additional solution ideas, such as reducing carbon dioxide emissions.

Students do not ask questions to refine an explanation in this lesson, or that evaluate the premise of an argument or interpretation of a data set. These opportunities will occur elsewhere in the Chemistry course.

Similarly, they will only use drawn models in this lesson, having used physical models of sorts in Lesson 3 and returning to mathematical models in Lesson 10 and computational models in Lesson 13. Information flows are not addressed in this unit.

Although there are engineering ideas in this lesson, students do not explicitly define an engineering problem or design a solution. Students will more explicitly consider engineering thinking later in the course, in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)* and *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*.

LEARNING PLAN for LESSON 5

1 · NAVIGATE

5 min

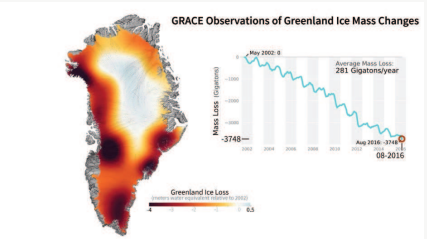
MATERIALS: *Greenland Land Ice Data*

Navigate by recalling ideas from Lesson 4. Display **slide A**. Direct students to turn and talk with a neighbor about the question on the slide. Listen in on partner discussions of ideas for helping to stop or slow polar ice melt.

Display **slide B**. Direct students to continue talking with their partner about the questions on the slide. Ask a few students to share their ideas.

Suggested prompt	Sample student response
What might it look like to carry out our ideas at the poles?	Can we build our design everywhere there is ice? If not, we would need to narrow it down to a specific location. We would need to figure out how our design would impact the environment and living things in that area. We would need to send all of the equipment and building materials, and a crew of workers there. We would probably need a lot of money to pay for everything.
Are there certain areas where our designs might be most effective?	Maybe we could find out where the ice is melting the most. Are there certain spots where the ice is more vulnerable than others?

Introduce the Problematizing Routine. Say, *We have a lot of different ideas for preventing ice melt. We are going to do something now that we will do many more times this year, but at first it might feel strange or frustrating. We are going to consider a new problem or phenomenon that we might disagree with or have competing ideas about for how it works. We will go public with our ideas and argue for these competing ideas to figure out next steps to resolve our new questions. The purpose of this routine is to push our thinking deeper and revise the science ideas we have built together so far.*



NASA/JPL-Caltech

It may not be realistic to come up with a solution for all of the land ice in the world. We can narrow it down to Greenland, to make things simpler. But even so, how would we decide what part(s) of Greenland to focus on where a design solution might have the biggest impact?

Students will suggest we focus on the areas with the largest amount of melt.

Display **slide C**. Distribute a copy of *Greenland Land Ice Data* to each pair of students. Give students a minute to orient to the color-coded key on the reference. Then, discuss the question on the slide as a class.

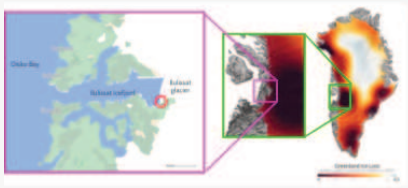
Suggested prompt	Sample student response
What are some of the locations in Greenland where a design solution could have a lot of impact?	We need to focus on the areas with the largest amount of melt. The dark red spots show areas with a high amount of melt. There are five of them – two on the west coast, two on the east coast, and one on the southern tip. The biggest one is on the middle of the west coast of Greenland.

2 · INTRODUCE THE ILULISSAT GLACIER CASE SITE AND ANALYZE CHANGES OCCURRING THERE

10 min

MATERIALS: *Ilulissat Ice Changes*, https://youtu.be/zoLGW2NcSeo

Introduce a case site. Display **slide D**. Read the text on the slide. Orient students to the location of the Ilulissat Glacier using the progressive zoom in the maps on the slide.✱ Point out that this site is located in the largest dark red section of the map, indicating there is a high amount of melt there.



Zoom in on the glacier. Display **slide E**. Orient students to the features on a satellite image of the glacier. Point out the following:

- Disko Bay, which is connected to the ocean to the west.
- The Ilulissat Icefjord, which is covered in sea ice. This ice floating on the surface of the water is sometimes referred to as an ice melange (a mixture of smaller pieces of ice of different sizes, snow, and an occasional iceberg).
- The edge of the Ilulissat Glacier, which makes contact with the waters in the Icefjord. This edge is labeled as a *calving front*.

ADDITIONAL GUIDANCE

The term *calving front* is introduced to help students identify features of the glacier. On **slide G**, students will watch a video clip showing this calving front where ice is breaking off and falling into the water. Introducing this term here will allow students to use common language when talking about the region of the glacier where land ice turns into sea ice. It is not meant to be memorized or assessed. You may also wish to note that calving is a natural process, although it may also occur more frequently as global temperatures rise.

Tell students to pay attention to what they notice about that front in the next slide, video, and handout you share with them.

Compare two satellite images of the glacier. Display **slide F.** Point out that this is a satellite image of the same area from a different date. Then toggle back and forth between **slide E** and **slide F** (with a ~10-second delay between each toggle). This will allow the differences between the two images to become more apparent.

Observe changes occurring along the front of the glacier. Display **slide G.** Show students where the video clips they are about to watch were shot from. The yellow box indicates the approximate location of the camera that recorded the video, and the yellow triangle indicates the approximate field of view in the recording. Play the video https://youtu.be/zoLGW2NcSeo.

✱ ATTENDING TO EQUITY

Some articles, maps, and design solutions may refer to this glacier as the Jakobshavn Glacier, which is a Danish name. Where possible, this unit will refer to it as the Ilulissat Glacier to preserve its indigenous name, with parenthetical reference to the Danish name. "Ilulissat" is from the Eskimo-Aleut language, which is spoken mostly by the indigenous Greenlandic Inuit people. It is closely related to the Inuit languages in Canada, such as Inuktitut. The glacier is also locally known as Sermeq Kujalleq (Greenlandic for "southern glacier"), but we will use Ilulissat instead to maintain similar naming for the glacier and icefjord.

This is similar to how the name Denali has been recently preferred over "Mount McKinley" in Alaska. During colonialism, many indigenous lands were renamed. This practice has worked to erase indigenous peoples from their land. Consciously using indigenous place names is part of the process of undoing the injustices of the past.

Discuss some initial explanations for these changes. Give students two minutes to turn and talk to discuss their initial ideas related to the questions on the slide:

- What evidence did you see of land ice becoming sea ice?
- What do you think is causing these changes?

Analyze satellite image data of the glacier over time. Display **slide H**. Distribute a copy of *Ilulissat Ice Changes* to each pair of students. Give students the remaining time to discuss the questions on the slide in pairs.

3 · LEARN ABOUT TWO PROPOSED SOLUTIONS

20 min

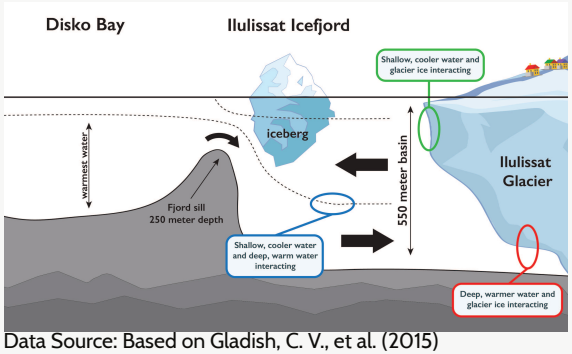
MATERIALS: science notebook, *Ilulissat Design Solution Proposals*, *Peoples' Concerns*, *Being Healthy* (optional), https://youtu.be/rdOst2woWww

Identify today's focal community agreement. Display **slide I.** Say, *We are going to learn about two possible solutions that engineers have proposed to reduce the amount of ice melt in this area. Before we do that, let's take a moment to consider how we can focus on being committed to our community while we learn about these proposed solutions. Turn and talk with a partner about how we can support this agreement today.* Call on a few students to share their ideas with the whole class.

Consider priorities for a design solution. Display **slide J.** Say, *When we read about these solutions, we will want to be critical evaluators of what the engineers have proposed. In your science notebook, take a few minutes to reflect on the different aspects we expect to see in a solution proposal and how much value you associate with them. Think about what you will prioritize when considering which solution is "better" than the other.* ✱

Introduce the two proposed design solutions. Say, *One way we can consider these design solutions is by attempting to understand how they would (or would not) work.* Display **slide K**. Distribute *Ilulissat Design Solution Proposals* to each student. Give students five minutes to do the following:

- Review the two proposed design solutions.
- Annotate the handout to indicate:
  - What makes sense about how the proposed solution would work?
  - What does not make sense?



Data Source: Based on Gladish, C. V., et al. (2015)

ADDITIONAL GUIDANCE

The diagram of the original design solution (published in Gladish, C. V., Holland, D. M., Rosing-Asvid, A., Behrens, J. W., & Boje, J. (2015). Oceanic boundary conditions for Jakobshavn Glacier. Part 1: Variability and renewal of Ilulissat Icefjord waters, 2001-14. *Journal of Physical Oceanography*, 45(1), 3-32. https://doi.org/10.1175/JPO-D-14-0044.1) was modified for increased accessibility for students. These modifications were:

- the use of "Ilulissat Glacier" rather than "Jakobshavn Glacier";
- the removal of extraneous labels/symbols (i.e., sill spillway and subglacial discharge);
- the removal of theta symbols and values and one intermediate water layer;
- the addition of captions indicating various water interfaces;
- the addition of an Inuit village on the glacier.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

Over the course of the unit, students will consider two proposed design solutions. When they are introduced to these solutions during this lesson, students will need to consider how they are designed to do the specific task of preventing ice melt. In this instance, articulating the important parts of the Ilulissat Icefjord/Ilulissat Glacier system and how they interact, without the design solution in place, is useful when students think about how the design would change the system to accomplish the task.

✱ ATTENDING TO EQUITY

Support for Universal Design for Learning: To foster a safe, supportive reading culture in your classroom, consider structures for reading out loud. Some options include: allowing students time to practice reading the quotes ahead of time; asking for volunteers instead of cold-calling; encouraging students to choral read in groups of two or more. You can also distribute the quotes based on reading level. Group A readings (1, 4, 7, 8, 12) are the highest level; Group B (2, 6, 10, 13, 15) are the middle level; and Group C (3, 9, 11) are most accessible.

Consider whether solutions should be pursued. Say, *We might have initial ideas about whether or not these solutions would work, but let's take some time to consider these decisions. Just because a solution might work, does that mean we should do it? Who or what might be affected?* Listen for responses including:

- We should weigh the pros and cons before deciding whether or not to build a solution.
- Building a solution might impact the people and organisms who live there.
- Building a solution might impact the food chain.
- Building a solution might harm animals that rely on the glacier for shelter and food.

Hear from rights holders. Display **slide L**. Say, *Another important way to evaluate whether proposed solutions are worth pursuing is understanding the potential impacts on local people and the environment. We have a few resources that will help us hear from the local rights holders in this community.* Play the video https://youtu.be/rdOst2woWww through 4:28. Then, distribute *Peoples' Concerns* to each student. Assign 13 students a number 1–13. Ask these students to read their assigned quote aloud so that the class can hear the concerns of the people.✱

After listening to the quotes, give students a few minutes to reflect in their notebook about the following:

- Who will be impacted by the decision and how?
- What potential impacts resonate with you?
- What do you wonder?

ADDITIONAL GUIDANCE	The video is intentionally stopped after the key ideas for this lesson are introduced. The remainder of the video delves into many other health issues that affect Inuit and includes powerful examples of the work that young people are doing to support mental health in Inuit communities. However, use it only with great care due to references to potentially traumatic issues like high suicide rates in some Inuit communities.

ALTERNATE ACTIVITY	You may wish to forego the video and have students read the optional video summary *Being Healthy*, as well as *Peoples' Concerns*, then research the values of the Inuit and Indigenous peoples in your area to gain perspective on the quotes. The Inuit Circumpolar Council is a good starting point for such resources.

4 · MODEL THE PROPOSED SOLUTIONS

10 min

MATERIALS: science notebook, *Ilulissat Design Solution Proposals*

Model how the proposed solutions might work.✱ Display **slide M**. Say, *The local rights holders have raised many concerns about these proposed solutions. We may echo some of their concerns or have other concerns of our own. We should acknowledge that we cannot geoengineer our way out of this big problem, and we may be curious about whether these proposed solutions would even work. Independently, we are going to spend some more time with one of the proposed solutions to try to figure out how it might work.*

Assign each student either of the proposed design solutions so that half of the class is modeling how they think the berm would work (Proposed Design Solution 1), while the other half models how they think the microbeads would work (Proposed Design Solution 2).

Direct students to independently develop an initial model in their notebook to explain what they think is happening at the particle level to make their assigned solution work. Say, *Remember that in chemistry, we focus on what is happening with things too small to see. Since these proposed solutions are designed to prevent ice melt, it can be useful to think about what the particles are doing.*

ADDITIONAL GUIDANCE	If students are struggling to get started, prompt them to look back at the class consensus model that was developed in Lesson 1 to see how we drew particle motion there. Frame the models as "first drafts."

✱ ATTENDING TO EQUITY

The home learning at the end of this section is used to broaden students' thinking about the values systems of different communities and who has had a seat at the table when important decisions about these lands have been made in the past.

Students' initial models might show ideas like:

- Maybe the warm particles cannot hit the ice, so the energy does not get transferred at all.
- Maybe the warm particles bump into the berm instead of the ice, which makes the berm warmer.
- Maybe the light-colored beads reflect the sunlight away from the ice, so the energy does not get transferred to the ice.

Ask students to keep these initial models in their notebooks. In the next class students will go public with their ideas.

Introduce the home learning. Display **slide N.** Say, *Tonight for home learning, take a few minutes to write a reflection in your notebook about the questions on the slide.*

End of day 1

5 · SHARE IDEAS IN SMALL GROUPS

2 min

MATERIALS: science notebook, *Ilulissat Design Solution Proposals*

Go public with our ideas in small groups. Display **slide O**. Say, *Last class we created initial models to try to explain how these proposed solutions might work. Today we are going to go public with our ideas to build consensus on what we agree on and what we cannot explain yet.*

Divide the class into small groups that include partners from both proposed solutions (e.g., two students who modeled the berm solution and two students who modeled the microbeads solution). Direct students to take turns sharing their initial energy transfer models with the group members that modeled the other design solution. After all group members have shared, they should discuss the question on the slide.

6 · INTRODUCE THE DISCUSSION MAPPING TOOL

2 min

MATERIALS: *Discussion Mapping Tool*, clipboard (optional)

Introduce the discussion mapping tool. Have students meet in a Scientists Circle and explain that we will be participating in a Consensus Discussion about what we think we know about the proposed solutions. ✱ Say, *In a Consensus Discussion, we will press toward a common explanation or model. We will try to resolve disagreements and different perspectives to take stock of where we are in our "figuring out." At the end of our discussion, we might have new questions to investigate next.* Ask students which two focal community agreements they think will be important to balance for this discussion. Students will likely say *respect* and *moving our thinking forward*. If the class suggests other community agreements and is in agreement on why they are important, adopt those as the focus for this discussion instead. ✱

Display **slide P**. Say, *We are going to use a new tool today to map our discussion. This will help us think about how we can all work together when we are discussing new ideas to move our thinking forward.* After framing the questions, take a seat in the circle as a co-participant rather than as a facilitator.

ADDITIONAL GUIDANCE

Discussion Mapping Tool gives students a visual representation of the conversation patterns happening within the class. Use lines to track how the discussion moves between speakers, including yourself. After you track the first several moves, pause the discussion to show students what the map looks like. If possible, it may be helpful to ask another adult, such as a co-teacher or instructional coach, to do this for you as the discussion unfolds. In future discussions, you can also ask for a student volunteer to map the discussion after you set up the tool. This can be a way to involve a student who is less comfortable speaking publicly at that point. Each time you use the discussion tool, rotate the student responsible for recording the map. While *Discussion Mapping Tool* includes codes to mark different types of contributions, you may want to track only discussion patterns the first few times you use the tool, adding contribution codes once comfortable.

✱ STRATEGIES FOR THIS CONSENSUS DISCUSSION

A Consensus Discussion is different from other kinds of discussions because its purpose is to converge on one or more ideas that the whole class agrees upon. In this discussion, your classroom community is pressing toward a common (class-level) model. During this work, the class resolves disagreements where possible. Your role is to help students see where they agree and where they still disagree. Helpful prompts include:

- What ideas are we in agreement about?
- Did anyone represent this idea in a different way?
- Who feels like their idea is not quite represented here?

- Are there still places where we disagree? Can we clarify these?

✱ ATTENDING TO EQUITY

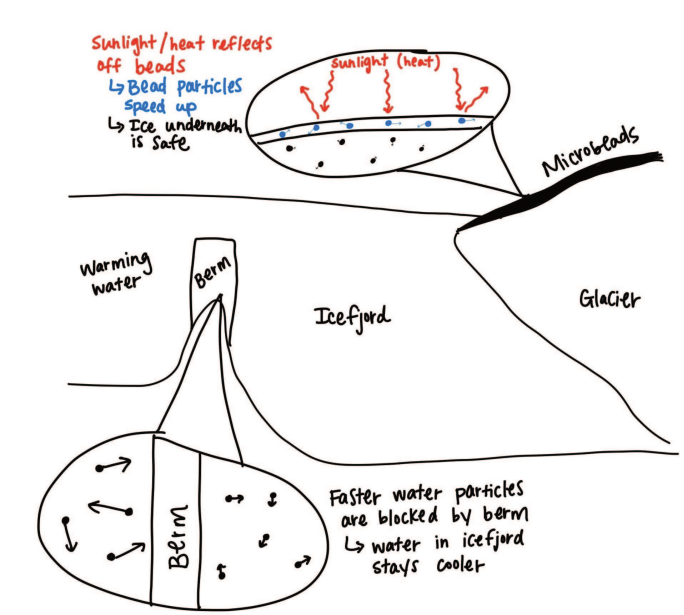
Building classroom culture: Having students choose focal agreements for their work today will help reinforce that the class agreements are important, and it will also create an opportunity for students to actively participate in group work following these agreements and to self-regulate their participation in group activity. Over time, these agreement-reinforcing strategies can help build a positive group-work culture by encouraging students to identify resources and systems that can strengthen their group and ensure that all students are actively participating in sense-making.

7 · GO PUBLIC WITH IDEAS ABOUT PROPOSED SOLUTIONS

8 min

MATERIALS: science notebook, *Ilulissat Design Solution Proposals*, chart paper, *Discussion Mapping Tool*, clipboard (optional)

Go public with our ideas to build consensus. Display **slide Q**. Ask students who were assigned to each proposed solution to share their initial models with the class. As ideas are shared, build an initial class consensus model of both proposed solutions on chart paper with ideas that are shared by multiple students. ✱ See the example initial class consensus model shown here, keeping in mind that the one you and your class develop may look different.



✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Through a collaborative process--starting with individual reflection, then a group discussion, and finally a whole-class conversation--students develop and revise shared models that represent a class consensus. Emphasize productive and respectful discourse during group and class discussions to support collaboration by asking questions, such as:

- Does anyone disagree with the idea presented?
- Is there anything about the phenomenon that we have not explained yet? Are there any gaps that need filling?

KEY IDEAS

Purpose of the discussion: to come to consensus on key features of the two proposed solutions and to see what we can agree upon regarding how these solutions might work.

Listen for students to highlight key design features, such as:

- building up the natural sill into an underwater berm;
- dredging gravel and sand from the ocean bottom to add to the natural sill, then covering it with concrete;
- spreading a thin layer of light-colored microbeads on top of ice during summer months;
- using microbeads that are hollow and made of silica.

Listen for student ideas about how these design features will prevent ice melt, such as:

- The berm will block warm water particles from bumping into the ice particles.
- The beads will cause sunlight to reflect off the ice.

As students share, use *Discussion Mapping Tool* to record which students are offering ideas. Take a moment to show the tool to students before continuing the discussion.

Ask students to share what makes sense about these proposed solutions and what does not. Keep track of the questions students have and the things they say we cannot explain yet on the initial consensus model.

Suggested prompt	Sample student response
How do we think the berm solution would work? What about the microbeads solution?	By building an underwater dam, many miles long. By dredging sand to raise up the height of the land underwater along the sill and covering it in concrete. By spreading a thin layer of microbeads on top of the ice. By manufacturing light-colored microbeads and covering Arctic ice during the summer months.
What makes sense about how the proposed solution would work?	Blocking warm water from entering the bay does seem like it could slow or stop melt from the glacier. Maybe covering the ice protects it from melting somehow. Reflecting sunlight away from the ice with shiny or light-colored beads seems like it would slow down the melt rate.

Suggested prompt	Sample student response
What does not make sense about the proposed solution?	If the wall isn't blocking all of the water from the ocean, it seems like warm water could still get over it. The solution proposes to block warm water that is on the ocean floor, but I thought warmer things rise and colder things sink. All the melt in Disko Bay looks like it's happening 550 meters or so below sea level. Why is it happening there instead of closer to the surface? Shouldn't the warmer ocean water be near the surface? How do the beads reflect light? And why would that help prevent melting? The solution proposes covering Arctic land ice during the summer months. Why only during the summer months?

8 · REFINE THE MODEL TO INCLUDE ENERGY

8 min

MATERIALS: science notebook, *Ilulissat Design Solution Proposals*, initial consensus model, "Rules for Energy Transfer Models" anchor chart, chart paper

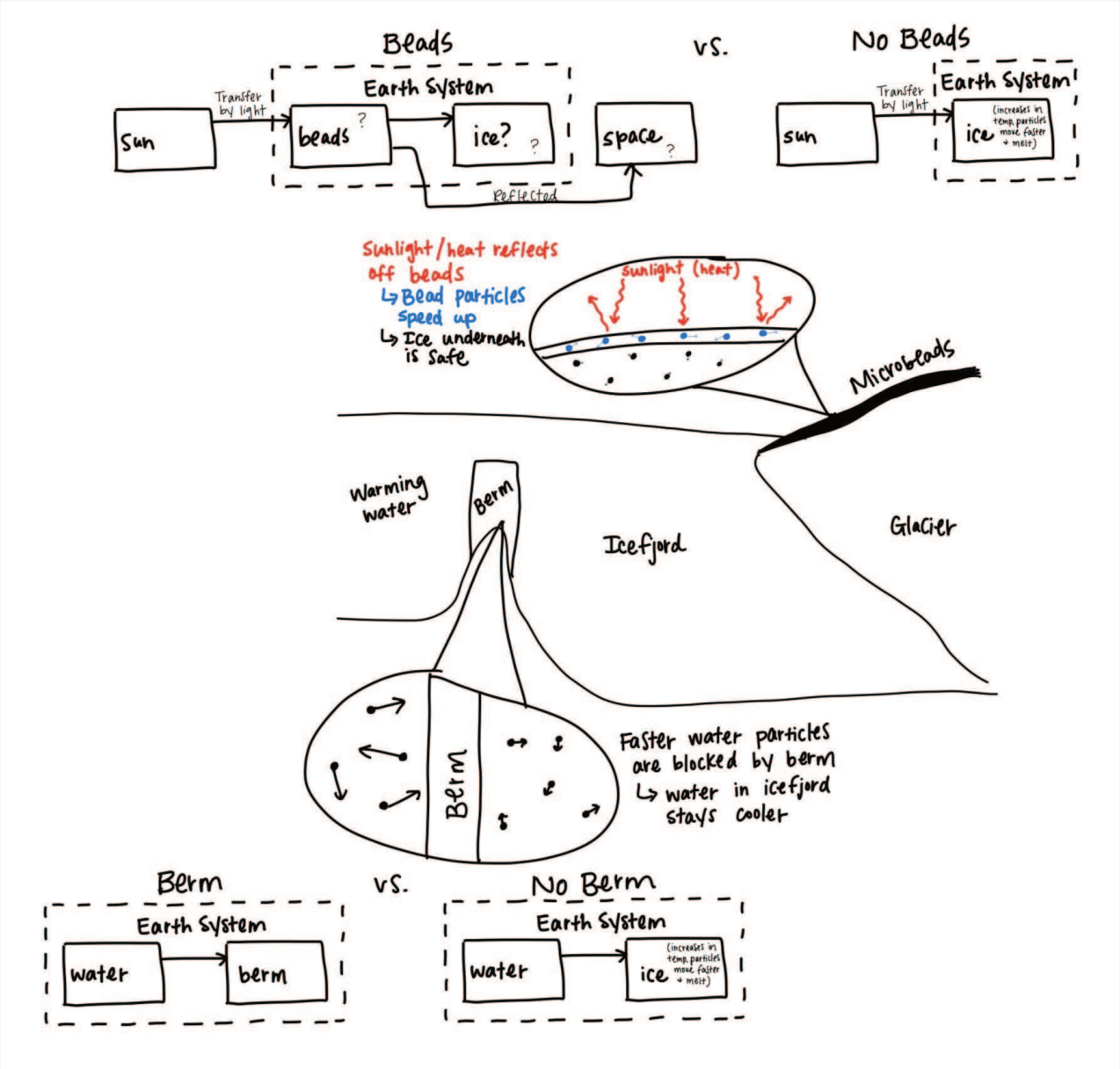
Refine the model to include energy. Display **slide R.** Say, *We have some ideas about what the particles might be doing in different parts of this system to explain decreased ice melt. What questions do we need to ask in order to also model the energy transferring into, out of, and within the system?*

Continue to use *Discussion Mapping Tool* to record which students are offering ideas. Display the "Rules for Energy Transfer Models" anchor chart to support students during this portion of the discussion.

Suggested prompt	Sample student response
What questions do we need to ask to also model the energy transferring into, out of, and within the system?	Where does the energy in the system come from? Without any design solution, how does the energy normally transfer to the ice to melt it? How does the berm or beads prevent the energy from transferring to the ice? Where would the energy from the warm water move if the berm was built? Where would the energy from the sun move if the beads were spread over the ice?

As students ask questions, record them on a piece of chart paper. Ask, *What questions do you think we can answer? What don't we know a lot about? How can we put these ideas on our model?*

Add students' ideas to the class consensus model. See the example shown here of how this might look.



ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' questions seek to:
  - clarify or refine a portion of their model. (SEP: 1.4)
  - refine how energy moves into the system. (SEP: 1.4; DCI: PS3.B.2)
  - refine where energy is moving from one place to another. (SEP: 1.4; DCI: PS3.B2)
- Students wonder:
  - how energy would move within the system without any proposed solution. (DCI: PS3.B2; CCC: 4.1)
  - how energy would move within the system if the proposed solution prevents ice melt. (DCI: PS3.B2; CCC: 4.1)
  - about specific design features of the proposed solutions. (CCC: 4.1)

What to do: If students are struggling to ask questions to refine the class consensus model, you can show them how to ask these types of questions by pointing to a spot on the model where they represented some amount of energy and asking, "How can you show where this energy came from?" Additionally, you can prompt students to ask their partner questions about things that might be missing from their model to figure out how to revise it.

Building toward: 5.A Ask questions to refine a model of the energy transfer into, out of, and within the system if proposed solutions prevent glacier ice melt in Disko Bay. (SEP: 1.4; DCI: PS3.B.2; CCC: 4.1)

9 · REFLECT ON OUR DISCUSSION MAPPING PROCESS

7 min

MATERIALS: science notebook, completed discussion map

Reflect on the discussion map. Show **slide S.** Display the discussion map by inserting an image into **slide S** or by projecting it another way. Have students observe the map and write any patterns they notice in their science notebook. Give students a few minutes to complete this task individually. Say, *After looking at this map, what are some things we should consider during our discussions to make sure that everybody plays a role in moving our thinking forward?* ✱ Listen for responses such as:

- We should ask questions and respond to each other instead of directing our responses to the teacher.
- We should invite people into the discussion who have not had chances to add to the discussion.
- We should monitor our airtime and give other people time to talk.

✱ ATTENDING TO EQUITY

Building classroom culture: The goal of this reflection is to notice whole-class patterns and decide how all students can move discussions forward as a community. Avoid addressing the contributions or behaviors of specific students. If they are brought up, prompt students to return to the class-level patterns they observed, saying, *Let's look at the whole map. What suggestions can we make that would support our whole-class community?* This is also an opportunity to remind students that *Discussion Mapping Tool* captures only spoken contributions and to explicitly state that non-verbal participation and listening closely are also valued contributions.

10 · ADD TO THE DRIVING QUESTION BOARD

12 min

MATERIALS: sticky notes, class consensus model, Driving Question Board

Generate new questions for the Driving Question Board. Display **slide T**. Say, *We have a lot of new questions to add to our Driving Question Board.* ✱

Direct students to return to their seats. Distribute two sticky notes to each student and ask them to write down at least two new questions that they have now that we have explored the proposed design solutions. Remind students to write only one question per sticky note in marker, and to add their initials on the back in pencil.

Give students a minute or two to generate their questions and record them on sticky notes. Distribute more sticky notes as needed.

Add new questions to the Driving Question Board. After students are finished writing their questions, gather around the DQB. Instruct students to share their questions, one by one, with the class. Remind students how you will add to the DQB.

- The first student reads their question aloud to the class, then posts it on the DQB.
- Other students raise their hands if they have a question that relates to the question that was just read aloud.
- The first student selects the next student whose hand is raised.
- The second student reads their question, says why or how it relates, and posts it near the question it most relates to on the DQB.
- That student selects the next student.
- Continue until everyone has at least one question on the DQB.
- If a question does not fit with any questions that are already on the board, students should create a new cluster.

Students' new questions might include:

- How does the berm stop the ice from melting?
- Why is the proposed berm underwater?
- Would a short berm work better than a full sea wall?
- How do the beads stop the ice from melting?
- Why do the beads only go on ice during the summer?
- Does it matter that the beads are light-colored?
- Should we build these proposed solutions?
- What are the harmful effects?
- If we decide to build a solution, which one should we choose?

✱ ATTENDING TO EQUITY

A Driving Question Board (DQB) provides a public representation of the class's joint mission. Students can share their questions and wondering with one another, and the visual representation offers another modality for students to access science in the classroom. Continuing to add questions to this DQB throughout the unit reinforces the idea that as scientists figure things out, they often have additional questions that need to be answered.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' questions:
  - challenge the suitability of the proposed design. (SEP: 1.7)
  - grapple with predicting and managing current and future impacts of the design solution. (SEP: 1.7; DCI: ESS3.D.1)
  - are inspired by the class consensus model that simulates energy flows within and between systems. (SEP: 1.7; CCC: 4.3)
- Students wonder about the magnitude of human impacts in consideration of these design solutions. (DCI: ESS3.D.1)

What to do: If students struggle to identify questions, encourage them to revisit the class consensus model for both proposed solutions. You may also cue them specifically to a region of the consensus model that the class labeled as confusing to help elicit a question. Students could also return to *Ilulissat Design Solution Proposals* to review their annotations and *Peoples' Concerns* to reread the concerns of local rights holders.

In addition, the questions students ask in this question should be three-dimensional: focused on the suitability of the proposed designs, concerned with managing impacts, and with a Systems lens that emphasizes interactions between potentially disparate components. If students' questions are not three-dimensional, you encourage them to re-write them as such or develop new questions that are. This feedback will be beneficial as students are responsible for asking three-dimensional questions in the assessment task in Lesson 7.

Building toward: 5.B Use energy transfer consensus models to ask questions that challenge the suitability of the design solutions based on their current and future impacts. (SEP: 1.7; DCI: ESS3.D.1; CCC: 4.3)

11 · NAVIGATE

6 min

MATERIALS: Driving Question Board

Turn and talk about our questions. Display **slide U**. Acknowledge that there are upsides and downsides to these proposed solutions and that we have many new questions about how they might work. Ask students to briefly turn and talk about the new questions we added to our DQB and to consider the questions on the slide.

Ask students to share their ideas with the class. Lead students toward the idea of figuring out first how the microbeads work to prevent ice from melting and then returning to the berm later on.

Reflect on the Problematizing Routine as a whole. Display **slide V**. Say, *The work that we did during this lesson--considering a new phenomenon that we had competing ideas about, going public with and arguing for our competing ideas, and asking new questions to figure out our next steps--is something we will do again throughout this unit and other units we work on this year. We will get used to these routines and get more comfortable with them. Since this was a new experience for us, we want to pause and check in about how it went. So, turn and talk with a neighbor about how you felt in our classroom over the past few days.*

Revisit community agreements to support upcoming investigations. Display **slide W.** Say, *We have these shared community agreements that we created as a class. How can these agreements support us as we work together in upcoming investigations?* ✱

Direct students to turn and talk about which agreements they think we can rely on to support our class community through future investigations. Listen in on partner discussions. Then, invite students to share their ideas with the class.

✱ ATTENDING TO EQUITY

Building classroom culture: This is an important opportunity to emphasize that each individual has contributions to make to their community of learners. It is through differences in thinking that the class will grow their knowledge together. Throughout the rest of this unit, students will be planning investigations to figure out how the design solutions work. Being open to sharing knowledge products that depict their current thinking and listening to classmates who share their knowledge too will help move the community's understanding forward.

ALTERNATE ACTIVITY	**Extension opportunity:** As home learning, assign students to do value mapping (https://rpp.wtgrantfoundation.org/wp-content/uploads/2019/09/Value-Mapping_Nov2015.pdf) and reflect on what they would value in a solution to slow or prevent polar ice melt and sea level rise. This will provide ideas of what they are looking for in the microbeads solution in Lessons 6-7 and the berm solution in Lesson 9-12.

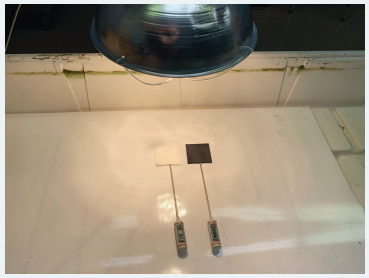
LESSON 6: Why would some engineers want to sprinkle glass microbeads on the Arctic?

PREVIOUS LESSON *We analyzed changes occurring over time at Ilulissat Glacier, a site of fast ice melt. We read about two design solutions for slowing or preventing further melt. We modeled the energy transfers and asked questions about the energy flows and overall suitability of the designs.*

THIS LESSON

INVESTIGATION

2 days



We plan an investigation to test our ideas about how microbeads prevent ice melt. Our teacher proposes a setup with a heat lamp shining on different colors of construction paper, and we discuss how to control variables and conduct the investigation safely. We see that darker colors heat up more. We read about light energy and discuss how what we read can explain both how carbon dioxide causes temperature increases and how the beads can help prevent melt. We use our model to make predictions, update our personal glossaries and progress trackers, and reflect on who should get to decide to use microbeads.

NEXT LESSON *We will discuss who should decide whether microbeads should be used to slow polar ice melt. We will read about feedback loops' impacts on the development of Earth systems. We will engage with a short mid-unit assessment and check in on our Driving Question Board.*

BUILDING TOWARD NGSS

HS-PS3-1, HS-PS3-4, HS-ESS2-2, HS-ESS2-4, HS-ESS3-1, HS-ESS3-5, HS-ESS3-6, HS-ESS2-7

WHAT STUDENTS WILL DO

6.A Plan and conduct a safe investigation with controlled variables and well-defined system boundaries to figure out how the reflection, absorption, storage, and reradiation of energy from the Sun affect climate. (SEP: 3.1, 3.3; DCI: ESS2.D.1, PS3.D.1; CCC: 4.2)

6.B Use mathematical representations to support a claim about whether the changes in energy flows and disrupted feedback loops caused by microbeads make them a viable solution to help prevent polar ice melt. (SEP: 5.2; DCI: ESS2.A.1; CCC: 5.3)

WHAT STUDENTS WILL FIGURE OUT

- Light energy (radiation) causes dark materials to increase in temperature more than light materials.
- Different materials absorb and reflect light energy differently. More reflective materials, like fresh ice or snow, have a high albedo.
- There are different kinds of light, including infrared light.
- When dark materials absorb visible light, their particles speed up and re-emit infrared light over time.
- Carbon dioxide and other greenhouse gases transmit visible light, but absorb infrared light, trapping it in the Earth system.
- A feedback loop could occur as additional carbon dioxide causes increased temperatures, which would melt ice, which would decrease the albedo of Earth's surface, which would cause more energy to be absorbed.

Lesson 6 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	8 min		**NAVIGATE** Help students figure out how they want to proceed given their questions from Lesson 5.	A-B	Driving Question Board, class consensus model from Lesson 5
2	7 min	☑	**PLAN AN INVESTIGATION** Support planning of an investigation to figure out how microbeads prevent ice melt.	C-E	*Light Investigation*, investigation anchor chart from Lesson 3, Light Investigation
3	15 min	☑	**CARRY OUT AN INVESTIGATION** Lead students in investigating how different-colored materials change temperature under a heat lamp.	F	*Light Investigation*, Light Investigation
4	7 min	☑	**DISCUSS RESULTS FROM THE INVESTIGATION** Give students time to turn and talk and lead a discussion about the results of the investigation.	G	*Light Investigation*
5	8 min		**READ ABOUT LIGHT AND MATERIALS** Give students time to read about how light interacts with different materials.	H	*Light and Materials*
					End of day 1
6	6 min		**DISCUSS THE LIGHT AND MATERIALS READING** Lead a discussion about the reading and its implications.	I	*Light and Materials*
7	7 min		**MODEL THE EFFECTS OF CO2 AND MICROBEADS** Support students in modeling how CO_2 and microbeads affect energy flows.	J	*Revising Prior Models*, class consensus models from Lesson 3 and Lesson 5, "Rules for Energy Transfer" anchor chart from Lesson 2
8	9 min		**MODEL HOW MICROBEADS WORK** Lead a Consensus Discussion to record student ideas about how CO_2 and microbeads affect ice melt.	K-L	*Revising Prior Models*, chart paper, class consensus models from Lesson 3 and Lesson 5, "Rules for Energy Transfer" anchor chart from Lesson 2
9	6 min	☑	**USE OUR MODEL TO MAKE A PREDICTION** Help students build the idea of feedback loops by carefully examining the class consensus model.	M	class consensus model
10	5 min		**UPDATE PERSONAL GLOSSARIES AND PROGRESS TRACKERS** Co-construct the words and ideas that students have figured out in this lesson.	N-O	
11	8 min		**MAKE A CLAIM ABOUT MICROBEADS** Help students calculate costs and further consider the impact of microbeads on preventing ice melt and sea level rise.	P	*Microbeads Claim*

Part	Duration		Summary	Slide	Materials
12	4 min		**REFLECT ON THE DECISION TO USE MICROBEADS** Present students with individual reflection prompts that will be discussed in Lesson 7.	Q	

End of day 2

Lesson 6 • Materials List

	per student	per group	per class
Light Investigation materials	• safety glasses with side shields or safety goggles	• thermometers • scissors • timer • white construction paper • black construction paper • heat lamp • clear plastic ruler • stapler • thick string or cord	
Lesson materials	• *Light Investigation* • *Light and Materials* • science notebook • *Revising Prior Models* • *Microbeads Claim*		• Driving Question Board • class consensus model from Lesson 5 • investigation anchor chart from Lesson 3 • class consensus models from Lesson 3 and Lesson 5 • "Rules for Energy Transfer" anchor chart from Lesson 2 • chart paper • class consensus model

Materials preparation (40 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

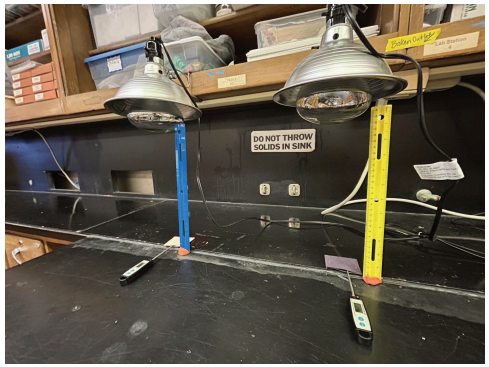
Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Day 1: Light Investigation

- **Group size:** Divide the class among the 3 heat lamp stations or as you have available. Each station should have at least 5 students and ideally not more than 10 students.
- **Setup:**
    - Each heat lamp consists of a bulb, metal lampshade, electrical cord, and clamp. Remove the clamp from the heat lamp. If a good clamping surface is not available, find a separate cord or string to hang the heat lamp vertically so it is pointing directly downward toward the table. Make sure that the lamp is hung from a stable object, like a built-in beam or cabinets so that it is 30 cm (12 inches) above where students would place the testing materials. If you have more lamps available, use a separate one for each sample. If not, center the lamp so that it is shining equally on the samples.
    - Gather materials for the lab and divide them among the heat lamp stations. Each station should have 1 heat lamp, 1 timer, 2 thermometers, white construction paper, black construction paper, 1 clear plastic ruler, 1 scissors, and 1 stapler.
- **Notes for during the lab:** Each heat lamp will be plugged into an electrical outlet and will get hot during the course of the investigation. Ensure that all students understand the important safety precautions of working with the heat lamp after discussing the first prompt on **slide E.** These safety precautions are also outlined below.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*. Students will be working with a heat lamp plugged into an electrical outlet. All students must be careful not to touch any metal parts of the heat lamp or bulb once it is plugged in, and up to 30 minutes after it has been unplugged, as it could potentially burn skin. Ensure that all heat lamps are hung in a secure fashion, in positions where no one can bump into them or easily cause them to become loose. In addition:
    - Wear safety glasses with side shields or safety goggles during the setup, hands-on, and takedown segments of the activity.
    - Use only GFI protected circuits when using electrical equipment and keep away from water sources to prevent shock.
    - Use caution when using sharp objects (scissors, etc.), which can cut or puncture skin.

- **Disposal:** Any solid materials that cannot be reused should be disposed of in the garbage bin. However, any items that are not damaged can be reused multiple times, such as the construction paper pockets.
- **Storage:** Keep the heat lamp in a cabinet not easily accessible by students when not in use.



Lesson 6 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students finish their explanation of how microbeads work (begun in Lesson 5) and also expand their explanation of how carbon dioxide and other greenhouse gases contribute to global warming. These seemingly disparate ideas are united as students figure out that both situations rely on interaction of radiation with substances on Earth. The energy transfer models that students have built throughout the unit are then leveraged to show that as energy flows into, out of, and between Earth systems, it can contribute to feedback loops.

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **ESS2.D.1: 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 reradiation into space.
- **PS3.D.1: Energy in Chemical Processes.** Although energy cannot be destroyed, it can be converted to less useful forms—for example, to ~~thermal~~ energy in the surrounding environment.
- **ESS2.A.1: Earth's Systems.** Earth's systems, being dynamic and interacting, cause feedback effects that can increase ~~or decrease~~ the original changes.

Students leverage new (to the course) investigative practice elements (SEP: 3.1) and (SEP: 3.3) as they plan an investigation using familiar equipment from Lesson 3. They take system boundaries into consideration as they examine their results (CCC: 4.2). They use mathematical representations of the microbeads to make a claim about cost-effectiveness (SEP: 5.2), leading to problematization of the complexity of the system. Although the element is new in the unit, the tools (unit conversions) are familiar from Lesson 4. They also track energy movement between objects and systems given new understanding of the role of radiation in this transfer (CCC: 5.3).

In this lesson, students consider the Learning in Places ethical decision-making question, *How does the natural world impact this decision? How is the natural world impacted by this decision?* To support this, students use both energy transfer models and unit conversions.

In this lesson, students will co-construct a definition for the following words, which they should add to their personal glossaries: *albedo, feedback loop*. They may also wish to add a definition for *infrared light*, *radiation,* or *confounding variable*. **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

For ESS2.D.1, students will be able to partially explain why greenhouse gases, in particular, absorb radiation in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*. Students will not consider the wave nature of light or the relationship between electricity and magnetism until *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*, which is why the word "electromagnetic" is not used when discussing radiation.

Students will not differentiate between positive and negative feedback loops in this lesson, but will build out that idea in Lesson 7. Students will return to the idea of feedback loops in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)* to explain how water's polarity allows it to cause erosion and freezing feedback loops that produce distinctive geological features.

They will consider ethics in investigations, as well as environmental and social impacts, later in the course. Although students evaluate a presented investigation design in this lesson, the remainder of SEP: 3.1 is addressed in Lessons 3, 4, and 13. Students will not support a claim about phenomena until Lesson 13, when they do so using a computational representation. Algorithmic representations and support of explanations are not addressed in this unit.

Although this lesson includes unit conversions to help support a claim related to ethical decision-making, engineering thinking is not systematically addressed.

Finally, students will consider how energy transfers to fields in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)* and *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*, as well as *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*.

LEARNING PLAN for LESSON 6

1 · NAVIGATE

8 min

MATERIALS: Driving Question Board, class consensus model from Lesson 5

Help students recall where Lesson 5 left off. Display **slide A** and the Driving Question Board. Have students turn and talk around the prompts on the slide for a couple of minutes before discussing them as a class.

Suggested prompt	Sample student response
Last lesson, what questions did we have about the sprinkling of light-colored glass microbeads on the glacier to protect it?	How do the microbeads work? How do the microbeads keep ice from melting? How do the microbeads prevent energy from flowing to the ice?
What is our current best guess for the answer for how microbeads protect a glacier?	The beads somehow reflect light so the stuff underneath doesn't get as warm. The beads are a light color so they do not absorb as much light and heat up.

If students are not making a connection between the microbeads' light color and reflectivity, say, *I noticed the beads are light-colored. In the summer, people tend to wear a lot of light-colored clothing. Why is that?* Listen for responses related to lighter colors not heating up as much. Suggest that something similar might be happening with the microbeads.

Brainstorm investigation ideas. Display **slide B.** Direct students to examine our class consensus model from Lesson 5. After students have had a moment to examine the model, ask, *How can we test our specific ideas about how microbeads work?* Listen for the following student responses:

- We could try to see how hot different colors get under light.
- We could see how ice melts under different color objects.

Say, *Those are interesting ideas! Let's think more specifically about what this investigation could look like.*

2 · PLAN AN INVESTIGATION

7 min

MATERIALS: Light Investigation, *Light Investigation*, investigation anchor chart from Lesson 3

Introduce the proposed investigation design. Display **slide C** and say, *One way to test the ideas you mentioned is to see how substances with different properties heat up differently when placed under a heat lamp. How could we test this idea with the materials we have available?*

Independently evaluate the proposed investigation design. Display **slide D** and the investigation anchor chart from Lesson 3. Direct students to use the anchor chart and *Light Investigation* to outline the important variables that need to be considered, changed, and controlled in the version of the investigation the class plans to carry out. Give students four minutes of independent work time.

Share ideas about the investigation design. Display **Slide E.** Ask students to share ideas for how to prioritize their personal safety during the investigation. Make sure that all students are aware of the safety risks when using a heat lamp before moving on to other aspects of the investigation plan. Then ask the following prompts on **slide E.**

Suggested prompt	Sample student response
How can we prioritize safety during this investigation?	We should make sure we are not touching the heat lamp since it could burn us. We should be careful around the electrical outlets. We should keep our hands to ourselves. (Add a note about safety to the Investigation Anchor Chart, either general or specific to the class.)
How will energy flow?	Energy will flow from the heat lamp into the construction paper. Some energy will get absorbed by the construction paper. Some energy will heat the air surrounding the construction paper.
What is the independent variable?	The color of the construction paper.
What is the dependent variable?	The temperature change of the construction paper when placed under the heat lamp.
What are the controlled variables? How do we make sure these variables are controlled?	Both types of construction paper should be the same distance and angle from the heat lamp. We can do this by measuring how far each one is from the bulb of the heat lamp before we turn it on. Both types of construction paper should be the same thickness and size; the only difference should be their colors. We will need to measure our paper to ensure this is true.

Follow up by asking, *Do we always remember to control all the variables we should?* Students will likely say no. Point out that if a variable should be controlled but is not, and the data are affected, we call that a confounding variable. It "confounds" because it messes up both the independent and dependent variables in a way that is unpredictable.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students identify distance and angle between the samples and heat lamp as confounding variables due to possible differential energy flow between systems and propose a solution to control the experiment. (SEP: 3.1; CCC: 4.2)
- Students identify type of paper and placement around thermometers as confounding variables and propose a solution to control the experiment. (SEP: 3.1)
- Students recall appropriate heat lamp-specific safety measures from Lesson 3 and make suggestions on modifications in light of the new experimental setup. (SEP: 3.3)

What to do: Encourage students to consider their experiences at home with lamps and hot objects when considering personal safety. If students are unsure of how energy flows through the system, remind them of earlier lessons in the unit where we identified energy transfers through light. Direct students to use the provided investigation design as a place to look for key ideas about controlled variables.

Building toward: 6.A.1 Plan and conduct a safe investigation with controlled variables and well-defined system boundaries to figure out how the reflection, absorption, storage, and reradiation of energy from the Sun affect climate. (SEP: 3.1, 3.3; DCI: ESS2.D.1, PS3.D.1; CCC: 4.2)

3 · CARRY OUT AN INVESTIGATION

15 min

MATERIALS: Light Investigation, *Light Investigation*

Set up data tables. Display **slide F.** Before beginning the investigation, give students one minute to set up their data table with the appropriate column titles based on the independent and dependent variables discussed in the previous activity. They may turn and talk to check their data tables with one another.

Carry out the investigation. Ask students to assign themselves to one of the following roles within their groups:✱

- Timer (at least 1): Keeps track of the time and tells the recorder to record data every minute.
- Recorder (at least 2): Writes down the temperature of the white or black pocket every minute and shares the values with other students in the group.
- Material managers (at least 2):
  - Heat lamp manager: Makes sure that the heat lamp is not plugged in until all other parts of the lab are set up, monitors the heat lamp and makes sure all students in the group are not at risk of burning themselves.
  - Construction paper manager(s): Assembles the construction paper pockets, places the thermometer in each pocket, and ensures that each pocket is equidistant from the heat lamp.

Conduct the investigation. Set a timer for 10 minutes with a student who is designated to call the time every minute. Make sure the recorders and timer are keeping track to get a precise measurement right at the minute mark. They can then share their data with other students in the group while they wait for the next minute mark.

✱ ATTENDING TO EQUITY

As in Lesson 3, students are assigned roles to promote equitable engagement in the large groups required for the activity. If you are able to obtain more heat lamps, do so and reduce the group size and adjust roles accordingly.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students follow planned measures to control variables and carry out the investigation safely. (SEP: 3.1, 3.3)

What to do: If an individual student is not following agreed-upon safety guidelines, provide a gentle reminder for the first time you notice it. If issues are prevalent across the class, you may wish to pause the activity to have all students review the safety guidelines the class agreed on.

Building toward: 6.A.2 Plan and conduct a safe investigation with controlled variables and well-defined system boundaries to figure out how the reflection, absorption, storage, and reradiation of energy from the Sun affect climate. (SEP: 3.1, 3.3; DCI: ESS2.D.1, PS3.D.1; CCC: 4.2)

4 · DISCUSS RESULTS FROM THE INVESTIGATION

7 min

MATERIALS: *Light Investigation*

Turn and talk about the investigation results. Show **slide G.** Give students two minutes to turn and talk about the prompts on the slide before discussing them as a class.

Suggested prompt	Sample student response
What did we see in the investigation?	Darker colors heat up more than white or lighter colors. Both colors heated up somewhat.
How is energy flowing differently for the white pocket and the black pocket?	More energy flows into the black pocket than the white pocket, which is why it heats up more.
How is the energy flow different in each system? ✱	Energy must stay in the system with darker colors. Lighter colors must reflect more light so the energy does not stay in the system.
What do you think causes different energy flows between different materials? Is it just about colors?	The colors that reflect more light do not heat up as much. Maybe they don't absorb the light as much? It is unclear.

Say, *It seems like we still have some questions about why the different materials behaved differently. It seems to be related to color, but that does not fully explain the differences in energy that we see.*

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

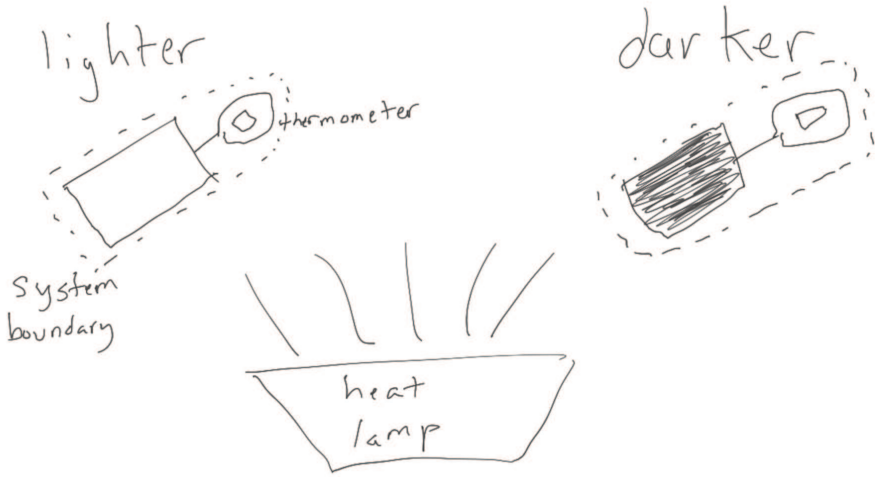
It is important here to make sure that students are on the same page about what is in the system. In particular, probe the students to get consensus on whether the thermometer is "in" or "out," while establishing that all other surroundings are out of the system.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students establish energy flows into and out of the boundaries of the systems that vary based on different colored materials' interactions with radiation. (DCI: ESS2.D.1; CCC: 4.2)
- Students propose that darker colors absorb more light energy, causing melt, and/or that lighter colors reflect more light energy. (DCI: ESS2.D.1)

What to do: If students struggle to think about how energy moves into and out of the systems, draw an experimental setup and ask students what the system is -- that is, what the thermometer is actually measuring the temperature of. Label this one "lighter." Then draw another setup, define the system similarly, and label it "darker." Ask students which will get hotter, and what that must mean about how much energy is in the system. Since the two systems have the same energy input, it must mean that less energy is leaving the system with the darker construction paper.



Building toward: 6.A.3 Plan and conduct a safe investigation with controlled variables and well-defined system boundaries to figure out how the reflection, absorption, storage, and reradiation of energy from the Sun affect climate. (SEP: 3.1, 3.3; CCC: 4.2; DCI: ESS2.D.1, PS3.D.1)

5 · READ ABOUT LIGHT AND MATERIALS

8 min

MATERIALS: *Light and Materials*, science notebook

Introduce the reading. Display **slide H.** Say, *We are still not sure why the darker colored construction paper seemed to absorb so much more energy than the lighter colored paper. I have a reading that can help answer some of the questions that we still have.*

Introduce the "Know, Want to know, Learned" structure on slide H and have students make a chart in their notebooks while you distribute *Light and Materials*. Then give students the remainder of class to read and record their thoughts in the KWL chart.✱

✱ ATTENDING TO EQUITY

Support for Universal Design for Learning: The "Know, Want to know, Learned" (KWL) chart structures the reading to provide support for emerging multilingual students and students with learning disabilities. However, this particular scaffold benefits all students by priming them to consider their relevant experiences before reading as well as helping them to identify a purpose for the reading. As students read, they are seeking the answers to their questions. This improves both their comprehension and the lesson's overall flow and coherence, since in the next activity students will learn what makes white paper reflective.

End of day 1

6 · DISCUSS THE LIGHT AND MATERIALS READING

6 min

MATERIALS: *Light and Materials*, science notebook

Discuss the reading. Display **slide I.** Ask students to take out their science notebooks and look back at their KWL charts. Give students a couple of minutes to turn and talk about the prompts on the slide, then lead a whole-class discussion.

Suggested prompt	Sample student response
What did the reading tell us about how the different materials interact with light?	Lighter-colored materials tend to reflect more light (have a higher albedo).✱ There are different kinds of light which interact with materials differently.
How do the microbeads compare to different materials in the natural world?	The microbeads have a fairly high albedo, but not as high as fresh snow or clouds.✱

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: The word "albedo" is likely unfamiliar to many students. You may choose to draw comparisons to similar words in English (like the condition of albinism, or albacore/white tuna) to help students remember that a high albedo means an object is lighter or whiter colored. These words have cognates in many languages, but a more universal example might be the character of Albus Dumbledore, who has a white beard and is named similarly in most translations of the *Harry Potter* books.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING STRUCTURE AND FUNCTION

Suggested prompt	Sample student response
What did the reading tell us about how carbon dioxide affects energy flow across the boundaries of Earth's system?	Carbon dioxide and other greenhouse gases let visible light through, but absorb infrared light. Carbon dioxide absorbs energy in the form of infrared light that is radiated from Earth's surface.
Follow up: What will carbon dioxide molecules do once they absorb this energy?	They will speed up.
Normally, energy transferred by sunlight is useful to us. What are some different ways we use this energy?	It keeps us warm. It drives photosynthesis. It can be used for solar power.
Can we use the energy for anything once it is absorbed by the carbon dioxide in the atmosphere?	Yes, because it still keeps us warm. No, because it is not doing anything else besides speeding up carbon dioxide molecules and maybe melting stuff.
How could these new pieces of information help us improve our models?	We can explain how adding microbeads would help prevent melt – it would reflect more light, so less light/energy would be absorbed. We can explain why CO_2 absorbs energy – it allows visible light through, but not infrared light.

Say, *We have some different pieces of information that can help us revise our models for how microbeads work, but also for how CO_2 impacts climate. Let's go all the way back to our models from Lesson 3 and Lesson 5 and revise them to reflect our latest thinking.*

You may take a moment to highlight how materials and structures that already exist in the world often serve as inspiration for designed solutions. Students have already seen another influence of albedo on Earth's temperature (volcano ash) and will be introduced to other solutions involving albedo in Lesson 13.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students verify that different colored materials have different albedos, causing differences in how they absorb and reflect radiation. (DCI: ESS2.D.1)
- Students should state that carbon dioxide and other greenhouse gases prevent energy flow across the boundaries of the Earth system by preventing reradiation into space, causing temperature increases. (DCI: ESS2.D.1; CCC: 4.2)
- Students identify that once energy is transferred to carbon dioxide molecules, it cannot be used for any particular purpose besides promoting melting. (DCI: PS3.D.1)

What to do: If students struggle to articulate the general principles in the reading, support them by using modeling as in the previous assessment opportunity. Draw a model like the one in 6.A.3, then ask students to describe what the reading said about how light will interact differently with the two systems. Then ask how things would change if a layer of carbon dioxide surrounded each system, and prompt students to explain how the carbon dioxide would absorb infrared light that is reradiated from the darker paper, but not visible light that is reflected off the lighter paper.

Building toward: 6.A.4 Plan and conduct a safe investigation with controlled variables and well-defined system boundaries to figure out how the reflection, absorption, storage, and reradiation of energy from the Sun affect climate. (SEP: 3.1, 3.3; DCI: ESS2.D.1, PS3.D.1; CCC: 4.2)

7 · MODEL THE EFFECTS OF CO2 AND MICROBEADS

7 min

MATERIALS: *Revising Prior Models*, class consensus models from Lesson 3 and Lesson 5, "Rules for Energy Transfer" anchor chart from Lesson 2

Revise the class consensus models of the effects of CO_2. Display the Lesson 3 and Lesson 5 class consensus models, the "Rules for Energy Transfer" anchor chart, and **slide J.** Distribute *Revising Prior Models* and remind students that even though they have not drawn these models on their own, they have a number of resources to help them do so, including the previous class models, the anchor chart, and the completed Scenario 1 model in the handout.

The key *Revising Prior Models Key* shows anticipated student ideas.

8 · MODEL HOW MICROBEADS WORK

9 min

MATERIALS: *Revising Prior Models*, chart paper, class consensus models from Lesson 3 and Lesson 5, "Rules for Energy Transfer" anchor chart from Lesson 2

KEY IDEAS

Purpose of this discussion: This Consensus Discussion uses the new ideas about radiation that students figured out in this lesson to better explain phenomena from earlier in the unit (temperature increases due to atmospheric CO_2 and how microbeads could protect polar ice). The class consensus model should be similar to that shown in *Revising Prior Models Key*.

Listen for these ideas:

- CO_2 absorbs infrared light but not visible light.
- Microbeads on ice reflect more visible light and absorb/reradiate less than the ground they cover.
- Energy that is not absorbed by CO_2 in the atmosphere because it is transmitted into space as visible light does not contribute to temperature increase on Earth because it leaves Earth's system.

Build a "Gotta-Have-It" checklist. Gather students in a Scientists Circle. Display **slide K** and a piece of chart paper**.** Write "Gotta-Have-It Checklist" at the top and say, *One way we can build a model as a class is to start with all the ideas we need to include, then draw the model to incorporate those ideas.*

Ask students, *What ideas do we have to include in our model to answer the questions in Scenarios 2 and 3?* Listen for these ideas:

- More CO_2 absorbs more infrared light.
- Microbeads reflect visible light.
- Visible light reflected by microbeads is not absorbed by CO_2 and goes into space.

Build the class consensus model. Display **slide L.** Below the checklist, draw an energy transfer model that incorporates students' ideas about how microbeads work. Start by drawing the objects in Scenarios 2 and 3 and defining the system, then draw and label the energy transfers. The prompts can help students clarify differences between all three scenarios' models.

Suggested prompts	Sample student responses	Follow-up questions
How are the objects or components different in Scenarios 2 and 3 compared to Scenario 1?	In Scenario 2, the CO_2 level in the atmosphere is high instead of low. In Scenario 3, the CO_2 level is high and there are also microbeads instead of dirty ice and snow.	*Does the system we care about change between scenarios? Why or why not?*
How are energy transfers different in Scenario 2 compared to Scenario 1?	In Scenario 2, less or no energy leaves the system into space because it is all absorbed by CO_2.	*What evidence do we have for the differences?*
How are energy transfers different in Scenario 3 compared to Scenario 2?	In Scenario 3, much of the energy is reflected back into space and transmitted through CO_2 in the atmosphere as visible light. Less energy is absorbed and reradiated by the ground.	*What evidence do we have for the differences?* *What does that tell us about microbeads as a solution?* *Could other materials be used instead of microbeads?* *Could some materials have the opposite effect?*

Add the following idea to the "Rules for Energy Transfer": We can label transfer by light with the particular type of radiation involved.

ALTERNATE ACTIVITY

You may wish to use https://phet.colorado.edu/sims/html/greenhouse-effect/latest/greenhouse-effect_en.html or a similar simulation with students to help them more easily visualize how the absorption and reflection of light contributes to the enhanced greenhouse effect.

9 · USE OUR MODEL TO MAKE A PREDICTION

6 min

MATERIALS: class consensus model

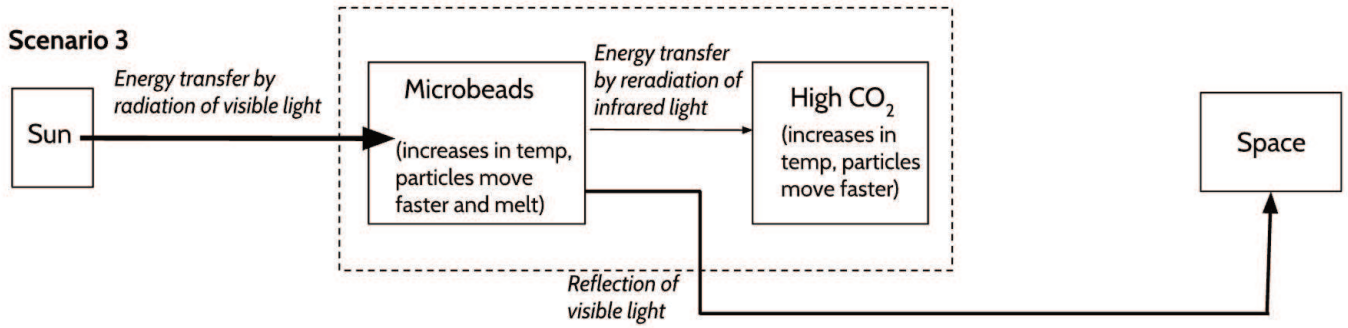
Use our model to make a prediction.✱ Display **slide M.** Say, *Now that we have modeled what we know, we can use that model to make predictions about what might happen to polar ice in the future.* Give students a couple of minutes to turn and talk about the prompt on the slide, then discuss as a class. Follow up using the prompts below.

Suggested prompt	Sample student response
What would happen to polar ice if humans continued to release more CO_2 in the atmosphere AND no solutions like microbeads were implemented, as in Scenario 2?	Ice would melt more. There would be more CO_2 in the atmosphere. Earth's average temperatures would get warmer.
What energy flows would occur in this scenario? *(Use your finger to trace the energy flows through the model to help students visualize where the energy goes.)*	Less light would be reflected than if there were microbeads. More energy would be absorbed and re-emitted as infrared light. There would be more infrared light to be absorbed by CO_2 in the atmosphere.
What would happen if there were more CO_2 absorbing more energy from infrared light?	Temperatures would increase even more. Melting would occur even more.
Why doesn't the energy just disappear?	It is trapped in Earth's system by CO_2. Energy is conserved – it cannot just be destroyed or disappear. It has to go somewhere.
How could we represent the flow of energy from CO_2 in the atmosphere back to ice in our model?	We could show an arrow going back to the melting ice/snow.

Add the arrow to Scenario 2 as shown below.

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Students use models throughout this unit in order to make predictions. Although most instances use mathematical models to make predictions (as in Lesson 4), it is worth pointing out to students that we are doing the same thing here, even though our model is captured in an image rather than numbers.



Ask, *What would happen as this process continues?* Listen for these ideas:

- It would just keep getting warmer.
- Ice would keep melting.
- As ice melts, less light would reflect/more would be absorbed because the melting ice and ground/sea underneath have lower albedos.
- It would keep reinforcing itself.

Introduce feedback loops. Say, *You all just identified that this process could get worse and worse over time if nothing is done. Scientists call it a feedback loop when one change in a system causes other changes in the system that affect the original change.*

Ask, *How would using microbeads or reducing carbon dioxide emissions lessen the damage caused by that feedback loop?* Listen for these ideas:

- Using microbeads would prevent ice melt by reflecting visible light into space so it is not absorbed by CO_2.
- Reducing carbon dioxide emissions would make it so less reradiated energy is trapped in Earth's atmosphere.
- This means that the feedback loop would be somewhat broken up.

Note that these are big ideas to have figured out, so we are in a good place to record some of our thinking.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' predictions are based on the idea that energy cannot be created or destroyed, and if trapped continues to flow between Earth systems. (CCC: 5.3)
- Students propose a chain of events consistent with a feedback loop between ice melt, decreasing albedo, increased energy absorption/temperatures, and ice melt. (DCI: ESS2.A.1)

What to do: Use prompts like the following to encourage students to think about what happens in the process:

- *Then what happens?*
- *How does that affect [other part of the system]?*
- *What are the effects of that energy transfer on temperatures?*

Building toward: 6.B.1 Use mathematical representations to support a claim about whether the changes in energy flows and disrupted feedback loops caused by microbeads make them a viable solution to help prevent polar ice melt. (SEP: 5.2; DCI: ESS2.A.1; CCC: 5.3)

10 · UPDATE PERSONAL GLOSSARIES AND PROGRESS TRACKERS

5 min

MATERIALS: science notebook

Update personal glossaries. Display **slide N.** Say, *We have co-constructed some different ideas in this lesson and have read about new concepts that we have incorporated in our models. Take a couple of minutes to record any terms that you would find useful to refer to in the future.*

Update Progress Trackers. Show **slide O.** Say, *We also have figured out some important ideas about how microbeads could work as a solution to polar ice melt.* Give students three minutes to record thoughts in their Progress Tracker.

Question	What we figured out in words/pictures
Why would some engineers want to sprinkle glass microbeads on the Arctic?	*The beads have a high albedo (reflect light), so some energy is not absorbed by the ice underneath.* *Melting ice and other materials that do not reflect light will tend to absorb more and reradiate it as infrared light.* *CO_2 and other greenhouse gases transmit visible light but absorb infrared light.* *Infrared light being absorbed causes temperature increases that can melt more ice, lowering albedo and causing more light to be absorbed/reradiated. This is a feedback loop.*

Elicit a couple ideas that we figured out in this lesson. Then say, *Based on what we have figured out, it sounds like microbeads might be able to help slow polar ice melt. But there could be other issues to consider. What still concerns you about microbeads?* Listen for these ideas:

- They could be expensive.
- They could be hazardous to living things.
- They might affect Indigenous communities in unpredictable ways.
- There could be feedback loops that cause problems for people, other living things, or the environment.

Say, *Those are all valid concerns. Let's start by thinking specifically about cost, and then we will think more about feedback loops.*

11 · MAKE A CLAIM ABOUT MICROBEADS

8 min

MATERIALS: *Microbeads Claim*

Apply mathematical thinking to the microbeads solution.✱ Display **slide P** and distribute *Microbeads Claim*. Give students five minutes to approach this problem with a partner. Encourage students to refer back to ideas from Lesson 4 as they consider their solution strategy.

110,000 km^2 x (300,000,000 kg / 25,000 km^2) x ($1 / 1 kg) = $1,320,000,000 (1.32 billion dollars).

Discuss as a class. Have two or three pairs present their solutions. Then ask, *What do you think of that result?* Listen for these ideas:

- It sounds expensive.
- $1.3 billion seems like a lot for just one area of glacier.
- Other solutions could be far more expensive.
- We do not know if there are other feedback loops that could influence this result.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
Students' claims are based on calculations and note that unknown feedback loops could result in other unintended effects to either action or inaction. (SEP: 5.2; DCI: ESS2.A.1)

What to do: Encourage students to go back to their calculations from Lesson 4 to help them work through the math. If students need more support and you have not yet utilized *Conversions Home Learning*, you may wish to do so. The extension opportunity at the end of this lesson also makes suggestions for additional, contextualized practice

If students struggle to think about their result of over $1 billion, help them contextualize this cost with some facts:

- The professional football stadium in Minneapolis, Minnesota, and the professional baseball stadium in Arlington, Texas, each cost about $1 billion to build.
- In 2021, the United States government spent $6.82 trillion (or 6,820 billions of dollars).

If students struggle to think about concerns beyond cost, ask them about how specific ideas they figured out in recent lessons (concerns of Indigenous peoples, feedback loops, etc.) affect their thinking.

Building toward: 6.B.2 Use mathematical representations to support a claim about whether the changes in energy flows and disrupted feedback loops caused by microbeads make them a viable solution to help prevent polar ice melt. (SEP: 5.2; CCC: 5.3; DCI: ESS2.A.1)

✱ SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Consider posting and reviewing the Mathematical Anchor Chart to support students in this work. This problem has been added to help students think about the decision to use microbeads while reviewing and reinforcing ideas from Lesson 4 in context.

12 · REFLECT ON THE DECISION TO USE MICROBEADS

4 min

MATERIALS: science notebook

Reflect on the decision to use microbeads. Display **slide Q.** Say, *You had some interesting thoughts on whether or not microbeads make sense as a solution. It is a big decision to make, so we should take some time to reflect on it.* Give students the rest of class to write responses to the prompts on the slide in their notebook. Consider having students take the prompts home so they have additional time as a home learning assignment.

ALTERNATE ACTIVITY

Extension opportunity: Because of the many dark surfaces used in cities, many solutions have been proposed to change cities to increase their albedo (and the "urban heat island" effect that comes with a low albedo). Consider having students research these solutions, including "green roofs" and painting more urban surfaces white.

This can also be an opportunity for contextualized practice of unit conversions. Specify an amount of paint required to cover a square foot and give information about the average square footage of roofs in your community. Have students set up their own conversion factors and calculate the amount of paint required to cover the roofs in a block or small area, your community, or the country.

Additional Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.5: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).

CCSS.ELA-LITERACY.RST.9-10.10: By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Students independently read a technical grade level text that introduces important new information and develop a model based on the relationships they identified between carbon dioxide, ice and snow, microbeads, and the Sun.

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HSN.Q.A.1: Use units as a way to understand problems and to guide the solution of multi-step problems; ~~choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.~~

Students use units to solve a problem involving the cost of a proposed solution.

LESSON 7: How do feedback loops affect Earth's systems?

PREVIOUS LESSON

We investigated our ideas about how microbeads prevent ice melt. We saw that darker colors heat up more. We discussed how what we read about light energy can explain how carbon dioxide causes temperature increases and how microbeads can help prevent melt. We used our model to make predictions and reflected on who should get to decide to use microbeads.

THIS LESSON

PUTTING PIECES TOGETHER

1 day

USGS, B. Jones

We discuss who should decide whether microbeads should be used to slow polar ice melt. We have questions and concerns, many of them related to unpredictable feedback loops. We read about feedback loops and recognize that some have had profound impacts on the development of Earth systems and living things. We engage with a short mid-unit assessment and check in on our Driving Question Board.

NEXT LESSON

We will pose questions about where glacial ice meets ocean water, then learn from Inuit and NASA experts to formulate hypotheses about how proposed solutions would affect energy flows in the area. We will be puzzled to learn that the warmest water is at the bottom of the bay.

BUILDING TOWARD NGSS

HS-PS3-1, HS-PS3-4, HS-ESS2-2, HS-ESS2-4, HS-ESS3-1, HS-ESS3-5, HS-ESS3-6, HS-ESS2-7

WHAT STUDENTS WILL DO

7.A Ask questions to clarify the role of positive and negative feedback loops involving the co-evolution of plants and other organisms with other Earth systems. (SEP: 1.4; DCI: ESS2.E.1, ESS2.D.2, ESS2.A.1; CCC: 7.3)

WHAT STUDENTS WILL FIGURE OUT

- Earth's atmosphere and surface have changed significantly over time due to changes in living things, and changes in these systems impact living things in a feedback loop.
- A positive feedback loop is one where effects end up reinforcing the original cause, driving more change. A negative feedback loop is one where effects end up counteracting the original cause and limiting its impact.
- A positive feedback loop is not necessarily good and a negative one is not necessarily bad.
- One feedback loop is thawing permafrost releasing carbon dioxide, which can cause additional warming and permafrost thaw.

Lesson 7 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	4 min		**NAVIGATE** Discuss students' reflections on who should decide if using microbeads is a good idea.	A-B	
2	16 min		**EXAMINE AN INFOGRAPHIC AND DISCUSS FEEDBACK LOOPS IN HISTORY** Give students time to examine an infographic about feedback loops in history, then discuss as a class.	C-D	*Earth's Feedback Loops*, https://youtu.be/_3DYC3b23Ow (optional)
3	17 min		**MID-UNIT ASSESSMENT** Give students time to complete a short assessment using the context of thawing permafrost.	E	*Thawing Permafrost Transfer Task*, https://youtu.be/a_d3uqoYxRO
4	8 min		**REVISIT THE DRIVING QUESTION BOARD** Lead students in checking in on the Driving Question Board.	F-G	*DQB Questions*, Driving Question Board, sticky notes

End of day 1

Lesson 7 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Earth's Feedback Loops* • *Thawing Permafrost Transfer Task* • *DQB Questions*		• https://youtu.be/_3DYC3b23Ow (optional) • https://youtu.be/a_d3uqoYxR0 • Driving Question Board • sticky notes

Materials preparation (30 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Preview https://youtu.be/_3DYC3b23Ow. This optional video may be used with *Earth's Feedback Loops* to help students more easily process what is happening in the feedback loops.

Preview https://youtu.be/a_d3uqoYxR0. This video will be used in conjunction with the mid-unit assessment, *Thawing Permafrost Transfer Task*.

Prepare *DQB Questions* for your class. Use a digital copy of *DQB Questions* as a template. List all the questions that students have developed on the Driving Question Board on the bottom of the handout. For ease of reference, you can number each of the questions on the DQB and make sure the handout has the corresponding number next to that question. Then print sufficient copies for each student.

Lesson 7 • Where We Are Going and NOT Going

Where We Are Going

In Lesson 6, students figured out that a feedback loop can increase the harmful effects of melting ice on Earth systems. In this lesson, students consider other complex interactions that have resulted in positive and negative feedback loops in Earth's history,both long ago and today.

These phenomena build on students' prior understandings from this course and other courses:

1. A feedback loop in which grasslands and large herbivores spur each other's evolution builds on ideas from *OpenSciEd Unit B.4: How does urbanization affect nonhuman populations, and how can we minimize harmful effects? (Urbanization Unit)* and *OpenSciEd Unit B.5: What will happen to Arctic bear populations as their environment changes?(Speciation Unit)*.
2. A feedback loop in which forest fires become more common with increased global temperatures builds on understandings from *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*.
3. A feedback loop in which the atmosphere and plant life co-evolve builds on thinking from Lessons 2 and 3 in this unit.
4. A feedback loop in which clouds promote stability in Earth's climate builds on ideas from the middle school OpenSciEd unit *OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*.

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **ESS2.E.1: 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.D.2: Weather and Climate.** Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen.
- **ESS2.A.1: Earth Materials and Systems.** Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.

In the assessment and subsequent Driving Question Board check-in, students ask questions to clarify and refine models or engineering problems and solutions (SEP: 1.4). They also focus on how feedback, both negative and positive, can have different impacts on a system (CCC: 7.3).

Through the introduction of multiple feedback loops, this lesson is intended to help students think about how complex the interactions between Earth systems and human decisions really are. This supports thinking around the Learning in Places Ethical Deliberation and Decision-Making question, *how does the natural world impact this decision? How is the natural world impacted by this decision?*

Where We Are NOT Going

Students will examine only a limited subset of the feedback loops that occur within and between Earth's systems. They will not dive deeply into the origins of different photosynthetic organisms or the ways in which the relative impacts of photosynthesis and cellular respiration shift in the atmosphere on a seasonal basis. They will have opportunities to ask questions to clarify explanations elsewhere in the Chemistry course.

LEARNING PLAN for LESSON 7

1 · NAVIGATE

4 min

MATERIALS: science notebook

Navigate by returning to the reflection prompts from Lesson 6. Welcome students back to class and say, *At the end of yesterday's class, we took some time to reflect on who should get to decide whether or not we should use microbeads.* Display **slide A** and ask students to open their reflections from Lesson 6 in their science notebooks. Lead a discussion about these prompts.

Suggested prompt	Sample student response
Who will be impacted by the decision to use (or not use) microbeads? Consider rights holders and others.	Indigenous people will be affected by either melting polar ice or likely by the placement of microbeads. People all around the world will be affected by sea level rise if microbeads are not used and no other steps are taken to prevent sea level rise. People around the world might be impacted in unpredictable ways if microbeads end up in places where they are not supposed to be.
What other parts of the natural world will be impacted by the decision?	Microbeads could hurt wildlife or damage lands and waters. Microbeads could get into the hydrosphere or soil, so we should consider how those systems are affected. We know that some living things cannot survive if temperatures or sea levels get too high, so we need to think about how all living things could be affected by the decision to not use microbeads.
What can our models, and our study of the impacts on people and the natural world, tell us about the consequences of using (or not using) microbeads?	There could be really complex consequences and feedback loops if microbeads are used. There could be really complex consequences and feedback loops if microbeads are not used and nothing else is done to slow polar ice melt.

Identify what Earth systems could be involved in feedback loops. Display **slide B** and ask, *What other Earth systems or parts of the natural world could be involved in feedback loops?* Listen for these ideas:

- Hydrosphere
- Cryosphere
- Atmosphere
- Soil/rocks
- Living things

If you have not done so previously, you may name soil and rocks as the *geosphere* and living things as making up the *biosphere.*✱

✱ ATTENDING TO EQUITY

Support for emerging multilinguals: These terms have cognates in many other languages and use roots common across Indo-European languages. Highlight these similarities to students as you give them opportunities to practice these words.

2 · EXAMINE AN INFOGRAPHIC AND DISCUSS FEEDBACK LOOPS IN HISTORY

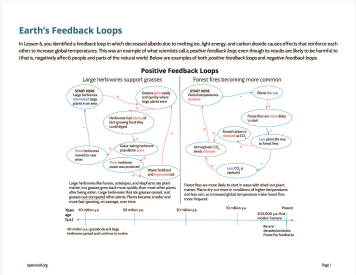
16 min

MATERIALS: *Earth's Feedback Loops*, science notebook, https://youtu.be/_3DYC3b23Ow (optional)

Navigate into the infographic. Say, *It sounds like we have questions about what other feedback loops may occur in Earth systems. I have an infographic that might help.*

Introduce the infographic. Display **slide C** and distribute *Earth's Feedback Loops*. Say, *This infographic presents several different feedback loops that have occurred throughout Earth's history or are occurring today.* Tell students they will have six minutes to examine the infographic with a partner and respond to the slide prompts in their notebook.

Discuss the infographic. Gather the class back together and display **slide D.** Lead students in a discussion about the infographic using the prompts on the slide.


Earth's Feedback Loops

In Lesson 6, you identified a feedback loop in which decreased albedo due to melting ice, light energy, and carbon dioxide causes effects that reinforce each other to increase global temperatures. This was an example of what scientists call a positive feedback loop, even though its results are likely to be harmful to (that is, negatively affect) people and parts of the natural world. Below are examples of both positive feedback loops and negative feedback loops.

Positive Feedback Loops

Large herbivores support grasses

Forest fires becoming more common

Suggested prompts	Sample student responses	Follow-up questions
What is different between the feedback loops?	They happen over different timescales. Some happened long ago, while some are happening now. Some are positive feedback loops and some are negative feedback loops.✱	*What is the difference between a positive feedback loop and a negative feedback loop?* *How are the arrows different in the models of positive and negative feedback loops? Why would that be?* *Which seem to promote changes more, positive or negative feedback loops?* *Which type of feedback loop helps keep things more the same?*
Which Earth systems (spheres) are involved in the feedback loops?	Hydrosphere. Atmosphere. Biosphere. Geosphere. Cryosphere.	*(Rephrase student responses in "sphere" language if not used.)*
How do the different feedback loops work?	(Accept all student responses that accurately describe the feedback loops.)	*Is that what others understood?* *Why is that feedback loop (positive/negative)?*

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING STABILITY AND CHANGE

The idea of feedback loops built in this lesson, particularly the distinction between positive and negative feedback loops, is complex. Take the time the class needs to build this idea together, and if necessary return to the mid-unit assessment the next day. If you need to fill time to allow for this arrangement, have an extended Driving Question Board check-in before the assessment, then briefly return to the DQB after the assessment so students can add the questions they developed during the assessment if they wish.

Suggested prompts	Sample student responses	Follow-up questions
How could these feedback loops affect sea level rise?	We are not sure how more grassland would affect sea level rise. More forest fires would definitely raise CO_2 and temperatures and increase sea level rise. More plants could help lower CO_2 and cause sea level rise to not be as bad. More evaporation could be okay because clouds would reflect some of the sunlight reaching Earth and keep temperatures from increasing more.	*Do any of these feedback loops change the predicted effects of microbeads? How?* *Which feedback loops make things change? Which make things stay the same?* *Are positive feedback loops always good? Are negative feedback loops always bad?*

Say, *It sounds like we have figured out a lot about how feedback loops can impact the world we live in. I have another example that we can look at to show more of what we have figured out.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should state that:
  - positive feedback loops tend to cause changes while negative feedback loops promote stability; neither type is inherently good or bad. (CCC: 7.3)
  - the evolution of plants and other photosynthetic organisms caused the development of our current atmosphere, which stabilized in a negative feedback loop. (DCI: ESS2.D.2; CCC: 7.3)
  - the evolution of grasslands and their rich soils was promoted by and helped promote the evolution of large herbivores in a positive feedback loop. (DCI: ESS2.E.1; CCC: 7.3)

What to do: Use the models to help students identify how in positive feedback loops, effects go on to reinforce the initial cause, while in negative feedback loops, effects go on to counteract the initial cause. This is seen in positive feedback loops with arrows that return back to an earlier cause, and in negative feedback loops with arrows that first pass through the *opposite* of the early cause.

Building toward: 7.A.1 Ask questions to clarify the role of positive and negative feedback loops involving the co-evolution of plants and other organisms with other Earth systems. (SEP: 1.4; DCI: ESS2.E.1, ESS2.D.2, ESS2.A.1; CCC: 7.3)

3 · MID-UNIT ASSESSMENT

17 min

MATERIALS: *Thawing Permafrost Transfer Task*, https://youtu.be/a_d3uqoYxRO

Set up the assessment. Explain to students that you have heard about an interesting phenomenon related to feedback loops and Earth's climate. Say, *In cold parts of the continental United States, soil freezes every winter and thaws in the summer. When you go toward the North Pole, there is soil called permafrost, which has been frozen since the last Ice Age thousands of years ago. It normally does not get warm enough, even in summer, to thaw this soil out. However, in recent years increased temperatures have caused permafrost to thaw. This is a problem, because then the ground gets soft and can even fall apart.*

Further explain how soil, because it is not solid, normally contains gases and even organisms like bacteria. These substances froze into permafrost thousands of years ago, but can be released as the permafrost thaws.

Highlight recent incidents in which permafrost thaw resulted in disease outbreaks. For example, in 2016, anthrax bacteria were believed to have been released by thawing permafrost near Salekhard, Russia. The outbreak resulted in dozens of people ill, at least one person dead, and more than 2,000 reindeer infected.

Give an assessment. Display **slide E** and distribute *Thawing Permafrost Transfer Task*. Read the introductory paragraph as a class and play https://youtu.be/a_d3uqoYxRO before beginning the assessment. You should play the video twice, directing students to pay attention to the time stamp on second viewing.

Debrief the assessment. Briefly discuss how permafrost fits with the anchoring phenomenon. Ask, *What does this new understanding of permafrost tell us about sea level rise specifically and climate change generally?* Listen for these ideas:

- There are a lot of different things that could impact sea level or climate!
- If there is water in the permafrost, rapid thawing could raise sea levels even faster than we anticipate.
- This system is really complex, so we need to understand better what we can do to prevent the worst effects.

ADDITIONAL GUIDANCE

Feedback loops and other phenomena associated with permafrost thaw are an integral part of understanding climate change and its impacts, including sea level rise. Like other feedback loops addressed in this unit, these feedback loops involve flows of energy and/or matter. The phenomena from this transfer task will return in Lessons 12-13 as students develop a Gotta-Have-It Checklist for a climate model that encompasses the whole unit and can be applied back to the anchoring phenomenon.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
See *Thawing Permafrost Key* for guidance.

What to do: See *Thawing Permafrost Key*.

Building toward: 7.A.2 Ask questions to clarify the role of positive and negative feedback loops involving the co-evolution of plants and other organisms with other Earth systems. (SEP: 1.4; DCI: ESS2.E.1, ESS2.D.2, ESS2.A.1; CCC: 7.3)

4 · REVISIT THE DRIVING QUESTION BOARD

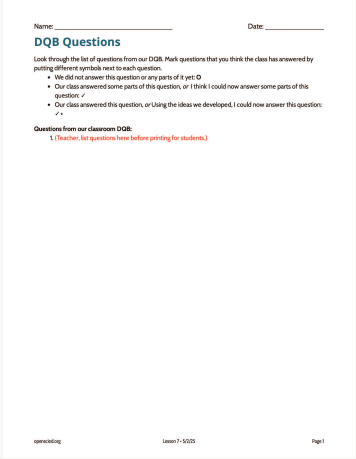
8 min

MATERIALS: *DQB Questions*, Driving Question Board, sticky notes

Revisit the Driving Question Board. Show **slide F**. Distribute *DQB Questions* with the list of questions developed on the Driving Question Board. Have students work individually to mark questions they think the class has answered using the key on the handout, replicated here:

- We did not answer this question or any parts of it yet: **O**
- Our class answered some parts of this question, *or* I think I could now answer some parts of this question: ✓
- Our class answered this question, *or* Using the ideas we developed, I could now answer this question: ✓+

Mark questions on the Driving Question Board. Gather students by the Driving Question Board and display **slide G**. Direct the students to the DQB, one by one, and mark questions that the class has answered in whole or in part through our investigations. Have as many students as possible participate until all questions that the class has answered have been marked. If time permits, ask students to share evidence that we have answered the questions as they check them off.


Name: _____ Date: _____

DQB Questions

Look through the list of questions from our DQB. Mark questions that you think the class has answered by putting different symbols next to each question.

- We did not answer this question or any parts of it yet: O
- Our class answered some parts of this question, *or* I think I could now answer some parts of this question: ✓
- Our class answered this question, *or* Using the ideas we developed, I could now answer this question: ✓+

Questions from our classroom DQB:

1. (Teacher, list questions here before printing for students.)

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Add questions to the Driving Question Board. Have sticky notes available for any students who suggest adding questions to the DQB. Ask, *Do we have any new questions to add?* Provide students with a few minutes to write down questions if they have them. Call on students to share their questions and add them to the DQB. Some new questions that may arise at this point include:

- What other feedback loops could impact the microbeads solution?
- What are other feedback loops involving permafrost?
- Is the microbeads solution better than the berm solution?
- What feedback loops and other factors affect the berm solution?
- Could there be feedback loops involving living things with the berm solution?✱

Thank students for their questions and say that we will follow up on them in future lessons, and that since we have not thought about the berm at all, that might be a productive direction to go.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
Students ask questions that seek to clarify how feedback loops would influence the berm solution. (SEP: 1.4; DCI: ESS2.A.1)

What to do: If students are not sharing any questions along this line, seed the idea by saying, *I notice lots of open questions about the berm solution. I wonder if anything we learned in the last couple of lessons might apply to the berms. How could we phrase that as a question?*

Building toward: 7.A.3 Ask questions to clarify the role of positive and negative feedback loops involving the co-evolution of plants and other organisms with other Earth systems. (SEP: 1.4; DCI: ESS2.E.1, ESS2.D.2, ESS2.A.1; CCC: 7.3)

✱ SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

If you have time, support students in honing their questions with one or both of the following strategies:
If students need to ask more specific questions: Generate ideas for investigations that could help answer these new questions. Ask, *How would these investigations help us answer the questions? Can rephrasing our questions to be more specific help us figure out what investigation is involved?*
If students need to ask more general questions: Show the consensus model from Lesson 5 and ask, *Where would we make changes on the model based on our answers to these questions? How could making them more general help us move them from a very specific situation or investigation to help us revise this model?*

Additional Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.ELA-LITERACY.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. Students describe in words what they see in the positive and negative feedback loops in *Earth's Feedback Loops* as well. They do so again in *Thawing Permafrost Transfer Task*.

LESSON 8: What is going on where the ice meets the water?

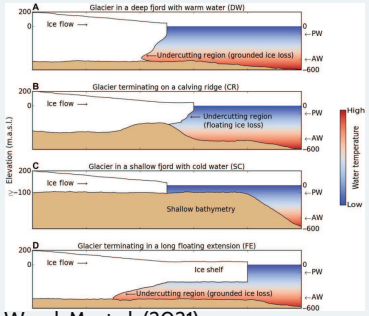
PREVIOUS LESSON

We discussed who should decide whether microbeads should be used to slow polar ice melt. Many of our questions related to feedback loops, so we read about the impacts of some feedback loops on the development of Earth systems. We engaged with a short mid-unit assessment and checked in on our Driving Question Board.

THIS LESSON

INVESTIGATION, PROBLEMATIZING

1 day



Wood, M. et al. (2021)

We already know a lot about surface glacial melt and decide to explore the melt happening underneath. We pose questions about what might be going on where glacial ice meets ocean water, then consider the information needed to answer our questions and how to gather it. We cannot go to Greenland ourselves but think we can learn from people there who already have systematically built this knowledge. We learn from Inuit and NASA experts, revisit our questions, and formulate hypotheses about how proposed solutions would affect energy flows. We are puzzled by data that suggest the warmest water is at the bottom of the bay.

NEXT LESSON

We will develop particle-level and energy models of water at different temperatures and salinities. We will collect data on the mass and volume of water under these different conditions and calculate its density. We will revise our models and explain how berms decrease energy transfer to the glacier.

BUILDING TOWARD NGSS

HS-PS3-1, HS-PS3-4, HS-ESS2-2, HS-ESS2-4, HS-ESS3-1, HS-ESS3-5, HS-ESS3-6, HS-ESS2-7

WHAT STUDENTS WILL DO

8.A Ask questions about the changing ice, waters, and lands of the circumpolar region that could be investigated in the field (using Indigenous Inuit and/or NASA methodologies) to frame a hypothesis about changes in energy and matter where glacial ice meets the ocean water at Ilulissat. (SEP: 1.6; DCI: ESS2.A.3; CCC: 5.2)

8.B Read and listen to scientific and technical information from two authoritative sources--Inuit Indigenous Knowledge and research from the NASA OMG Project--and consider the usefulness of describing and analyzing the boundaries, initial conditions, inputs, and outputs of the Arctic system from these different perspectives. (SEP: 8.3; DCI: ESS2.A.3; CCC: 4.2)

WHAT STUDENTS WILL FIGURE OUT

- In addition to surface melt and albedo effects, there are concerns about warming oceans driving glacial melt from below.
- Some questions are best answered through field-based investigations and experience.
- Indigenous Knowledge is a systematic way of thinking with its own purposes and methodologies, just as science is a systematic way of thinking with its own purposes and methodologies.
- Field-based investigations and experience can help people answer their questions, formulate hypotheses, and generate new questions.
- Both the berm solution and cutting carbon emissions could slow the transfer of energy at the interface between warm ocean water and glacial ice, through different mechanisms and on different timescales.
- Puzzlingly, the warmest ocean water is at the bottom of the bay.

Lesson 8 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	7 min		**NAVIGATE** Navigate from last class to prepare students to generate new questions about the interface between the glacial ice and ocean water at Ilulissat.	A-D	Driving Question Board
2	13 min		**ETHICALLY ENGAGE WITH INDIGENOUS KNOWLEDGE** Support students to engage with Indigenous Knowledge in a manner consistent with the guidelines for ethical engagement outlined by the Inuit Circumpolar Council (ICC).	E-H	*Inuit Belief Highlights* (optional), https://iccalaska.org/wp-icc/wp-content/uploads/2022/06/EEE-Protocols-LR-1.pdf%20-, https://youtu.be/ALJJaJ1LRAQ
3	12 min		**REVIEW DATA FROM THE NASA OMG PROJECT** Have students review data collected by NASA from the water near Ilulissat Glacier.	I-K	*NASA OMG Project*, https://youtu.be/N1T-1HAWxUU
4	13 min		**REVISIT QUESTIONS AND FRAME HYPOTHESES** Invite students to revisit their questions and frame hypotheses about how proposed solutions would affect matter and energy flows at the interface between glacial ice and ocean water.	L-M	*Revisiting Questions*, class consensus model from Lesson 5

End of day 1

Lesson 8 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • *Inuit Belief Highlights* (optional) • *Revisiting Questions*	• *NASA OMG Project*	• Driving Question Board • https://iccalaska.org/wp-icc/wp-content/uploads/2022/06/EEE-Protocols-LR-1.pdf%20- • https://youtu.be/ALJJaJ1LRAQ • https://youtu.be/N1T-1HAWxUU • class consensus model from Lesson 5

Materials preparation (30 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Ensure that students have access to p. 18-19 of https://iccalaska.org/wp-icc/wp-content/uploads/2022/06/EEE-Protocols-LR-1.pdf%20-, either digitally or on paper.

You may wish to print the optional *Inuit Belief Highlights* to supplement https://youtu.be/ALJJaJ1LRAQ.

Lesson 8 • Where We Are Going and NOT Going

Where We Are Going

This lesson follows from the DQB check-in at the end of Lesson 7, where students realize that although they have answered many questions about surface melt, many more questions remain about potential melt being driven from below the glacier. Whereas in earlier lessons students asked questions, arising from models and unexpected results, that were possible to investigate with available materials in a laboratory setting, in this lesson students ask questions that must be answered by gathering evidence from the field. This prompts them to turn to Inuit and NASA experts who have local knowledge about matter and energy flows in the Arctic system, but whose methodological approaches differ in how system boundaries, inputs, and outputs are defined and described.

This lesson is designed to coherently build ideas related to the following disciplinary core idea:

- **ESS2.A.3: Earth Materials and Systems.** The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output ~~or Earth's orbit, tectonic events~~, ocean ~~circulation, volcanic activity~~, glaciers, ~~vegetation~~, and human activities. These changes can occur on a variety of timescales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long term (tectonic cycles).

It also supports and assesses students as they ask questions that can be investigated in the field (SEP: 1.2) for the first time in the course. They have previously developed hypotheses in Lesson 3, but were not assessed on this practice element. They build on prior lessons with thinking about energy and matter flows (CCC: 5.2) and systems and system modeling (CCC: 4.2). In particular, students reading and evaluation of scientific and technical information from Inuit hunters and fishers and NASA scientists (SEP: 8.3) allows them to consider system inputs, outputs, and boundaries in a complex way. Students consider how these two groups both think in productive, complementary scientific ways.

Students have previously developed the practice of obtaining, evaluating, and communicating information at the high school level in *OpenSciEd Unit B.5: What will happen to Arctic bear populations as their environment changes?(Speciation Unit)*. They will continue to develop this important practice in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*.

Because of the possible dangers to Inuit peoples of co-constructing a definition of *Indigenous Knowledge*, students are provided on **slide E** with the definition that is used by the Inuit Circumpolar Council (ICC). Students will also encounter some words used in previous lessons and courses that they may wish to add to their personal glossaries during this lesson: *system, inputs, outputs*. Do not ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

This lesson supports thinking around two Learning in Places Ethical Deliberation and Decision-Making questions: *How does the natural world impact this decision? How is the natural world impacted by this decision?* and *Who will be impacted by the decision and how (both human and more-than-human)?*

Where We Are NOT Going

Though students may reference what they figured out in previous lessons about changes in the Sun's energy output, Earth's orbit, and volcanic activity when asking questions or framing hypotheses, this lesson focuses explicitly on changes related to ocean circulation, glaciers, plants, animals, and human activities as students continue to build ideas related to ESS2.A.3.

This lesson is **not** to be used to suggest that NASA methodologies are superior to Indigenous Knowledge, that Indigenous Knowledge merely supplements NASA findings, or that Indigenous peoples and individuals do not also practice formal science. Instead, the lesson offers an opportunity to appreciate the distinct purposes and methodological rigors of both knowledge traditions.

Students will have opportunities to ask questions that can be investigated in a school laboratory or research facilities elsewhere in the course. They will have opportunities to gather information from authoritative sources in *Electrostatics Unit* and *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*.

LEARNING PLAN for LESSON 8

1 · NAVIGATE

7 min

MATERIALS: science notebook, Driving Question Board

Navigate. Refer to the DQB and say, *Last time we checked in on our DQB, we realized we still have a lot of unanswered questions.*

Display **slide A.**✱ Refer to the image on the slide. Say, *We have been thinking about albedo and melt happening at the surface of the glacier due to warm air and solar radiation, and considered how cutting carbon emissions or using the reflective beads might disrupt the feedback loop at this location.*

Display **slide B.** Ask, *Are there any other potential locations of melt on the glacier that we should be paying attention to?*✱

As students share ideas and reference locations, consider pointing to them on the diagram.

Highlight a line of inquiry. After students have shared their ideas about other locations where melt might be occurring, say, *We identified some other areas of potential concern. Specifically, we are wondering what exactly might be going on at the base of the glacier that motivated the proposal for the berm, and if cutting emissions would also help with any melt happening at this location.*

Ask students to generate questions. Display **slide C.** Say, *What questions do you have about what is going on where the glacial ice meets the ocean water?* Offer students individual think time to develop their questions.

Suggested prompt	Sample student response
What questions do you have about what is going on at the water-ice interface?	Is the glacier melting more from below (where ice meets water) than it is from above (where ice meets air/solar radiation)? Is there another feedback loop speeding up melt below the glacier?

Display **slide D**. Invite students to reflect on their questions in their science notebooks and consider what information would help answer those questions, how they might go about gathering this information if they were in the field, and who might already have this knowledge.

Invite students to share their ideas with a partner. After students have had an opportunity for individual think time, ask students to turn and talk to share their ideas. As partners discuss, circulate to listen to their ideas.

Suggested prompt	Sample student response
What information might help answer your questions?	Signs that the ocean water is warming and that the type or amount of ice is changing where the ice meets the water compared to where the air or sunlight reaches the ice. Measurements or observations showing the difference between how fast the ice is melting on the top vs the bottom of the glacier.

✱ ATTENDING TO EQUITY

This image was selected to remind students that these solutions might be implemented in places where people live, including right near the town of Ilulissat shown here. In this lesson, students will dig into what Inuit in and around Ilulissat Glacier know about the changes in the glacier.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

This portion of the Navigation Routine is important because it helps ensure that students' thinking shifts from one part of the system (direct sunlight hitting the glacier) to others (such as the water-ice interface).

Suggested prompt	Sample student response
How might you figure this out if you were there?	I would put thermometers or other sensors above and below the glacier and measure differences in the changes in temperature and ice over time. I would look for physical signs that the ice is melting from below, or for changes in behavior of local plants and animals that suggest the water is getting warmer. I would listen to elders' stories to note differences between what the waters and ice were like when they were growing up compared to now.
Who might know about this already?	Indigenous peoples of the Arctic The Inuit researchers on site studying the ocean and glaciers

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
Students' questions require evidence from the field to answer and are focused on the interface between ocean water and glacial ice. (SEP: 1.6; DCI: ESS2.A.3)

What to do: Try not to interrupt student conversations or take over discussions. If you want to interject when circulating, ask students to "say more" about anything you may have heard that was puzzling or unclear to you. If students are struggling to get started generating questions, consider doing one of these:

- Ask students to describe what they already know and do not yet know about where the ice meets the ocean water in the Ilulissat glacier system.
- Prompt students to think about what they would want to know to be convinced of the argument for building a berm at this location.

Building toward: 8.A.1 Ask questions about the changing ice, waters, and lands of the circumpolar region that could be investigated in the field (using Indigenous Inuit and/or NASA methodologies) to frame a hypothesis about changes in energy and matter where glacial ice meets the ocean water at Ilulissat. (SEP: 1.6; DCI: ESS2.A.3; CCC: 5.2)

Transition to authoritative sources from the field. Acknowledge all of the ideas that were shared in the previous activity.

Say, *I got a chance to listen to your conversations, and it sounds like we specifically need more data about the water at points where it comes into contact with Ilulissat Glacier, and that there might be some ways that people on location could have gathered this data already. Does that sound right? Am I missing anything?*

2 · ETHICALLY ENGAGE WITH INDIGENOUS KNOWLEDGE

13 min

MATERIALS: science notebook, *Inuit Belief Highlights* (optional), https://iccalaska.org/wp-icc/wp-content/uploads/2022/06/EEE-Protocols-LR-1.pdf%20-, https://youtu.be/ALJJaJ1LRAQ

Introduce the first authoritative source. Display **slide E.** Say, *The Inuit Nunaat* (IN-you-it nu-nat)*--the lands, sea, and ice of the circumpolar region stretching from Greenland to Canada, Alaska, and the coastal regions of Chukotka, Russia* (choo-KOHT-kuh)*--are home to the Inuit people. Some of us thought that Indigenous peoples of the Arctic probably know a lot about what is going on where the glacial ice meets the ocean waters.*

Discuss the ethics of engaging with Indigenous Knowledge. Say, *The Inuit Circumpolar Council (ICC) released guidelines for equitable and ethical engagement of Indigenous Knowledge in the Arctic in 2022. Before we hear from Inuit experts, let's read the ICC guidelines and think about how to update our community agreements to include ethics for engaging with Indigenous Knowledge.*

Invite students to read the ICC's Protocols for Equitable and Ethical Engagement, particularly Protocol 2: Recognize Indigenous Knowledge in Its Own Right, on pages 18-19 in https://iccalaska.org/wp-icc/wp-content/uploads/2022/06/EEE-Protocols-LR-1.pdf%20-.

Lead a discussion to clarify the community agreements. Display **slide F** and any classroom record of community agreements, then use the prompts below to guide a discussion. Create a public record of updates and clarifications to the community agreements with respect to engaging Indigenous Knowledge.

Suggested prompt	Sample student response
How might we clarify our community agreements to be consistent with these ethics guidelines? *How might we show respect for Indigenous Knowledge?*	**Respectful** Indigenous Knowledge is its own systematic way of knowing about the world, with equal value to science.
How might we equitably engage with Indigenous Knowledge?	**Equitable** Inuit should lead and direct when and how to use Indigenous Knowledge.
How can we demonstrate commitment to our global community when engaging with Indigenous Knowledge?	**Committed to our community** Indigenous Knowledge should not be used against Inuit. Working with Inuit to make decisions is important to avoiding harm to Inuit communities.
What might it mean to move our science thinking forward in class today when non-Indigenous scientists have misused Indigenous Knowledge in the past?	**Moving our science thinking forward** Inuit have their own purposes for building knowledge that are separate from our scientific objectives in this class. Indigenous Knowledge is not a supplement to science, nor is it to be translated into science.

Introduce the Takuvit Project. Display **slide G**. Say, *Inuit fishers and hunters spend a lot of time at the interface between glacial ice and ocean water and have been there a lot longer than non-Inuit scientists. In this video from the Takuvit Project, Inuit fishers and hunters share their knowledge about changing conditions in the circumpolar region.* ✱

✱ ATTENDING TO EQUITY

Takuvit is pronounced like "tah-kuu-vee," with the last syllable sounding like the u in "rune." Qikiqtaaluk is pronounced somewhat like "kee-keek-taa-luuk."

Consider how Inuit build Indigenous Knowledge about changing conditions in the circumpolar region. Invite students to listen for information that helps answer the questions they generated at the beginning of the class, and/or that raises new questions or perspectives that differ from their own. Suggest that students jot notes in their notebook, then play https://youtu.be/ALJJaJ1LRAQ (from 8:26-14:44) showing Inuit fishers and hunters in the Qikiqtaaluk/Baffin Island region.

Discuss Inuit ways of knowing. Display **slide H.** Invite students to reflect on how Inuit fishers and hunters are 1) building Indigenous Knowledge, 2) defining the boundaries of the system, and 3) analyzing its inputs and outputs.

Suggested prompt	Sample student response
How do Inuit build Traditional Knowledge over time?	People pass on what they know to children over many years. Hunters and fishers learn from elders.
How do these hunters and fishers define system boundaries?	Hunters and fishers talk about "up here" and whether animals go farther up to where it is colder, and come "up here" from the south as "here" gets warmer. They talk about how animals are free to move where they want to, as people are.
How do they describe system inputs and outputs?	Hunters and fishers describe their interactions with the sea and the ice and the sky, and give examples of changes that have occurred since they or their elders were young–e.g. The air is warmer, it is not 50 below anymore, the quality of the sea ice is changing, it is taking longer to freeze and is not thickening up. They observe changes in ocean creatures' behavior and new species in the sky and waters–e.g., there are new fish, birds, and insects, and the people predict that they will see more of them in the future. Some elders say the warm weather is coming from the sky, but the "ones who have the real knowledge" say the ocean is warming everything.
Where do they think the glacier's melting is occurring?	In the ocean or bay.

Follow up by asking, *When have these changes been happening?* Students should highlight that they have occurred in recent decades or at a relatively high rate.

ADDITIONAL GUIDANCE

The hunters in the fishers describe system boundaries, inputs, and outputs in different language than students might be used to. You may wish to repeat each prompt with slightly different phrasing. For example, "What objects, beings, and places do the hunters and fishers talk about as being in their system?" or "What changes do the hunters and fishers talk about? Where are those changes coming from?"

ALTERNATE ACTIVITY

Extension opportunity: Have students critically examine research on Inuit lands and with Inuit people, using resources like those from the Inuit Circumpolar Council. The following article could provide a starting point: Sansoulet, J., Therrien, M., Delgove, J., Pouxviel, G., Desriac, J., Sardet, N., & Vanderlinden, J.-P. (2020). An update on Inuit perceptions of their changing environment, Qikiqtaaluk (Baffin Island, Nunavut). *Elementa: Science of the Anthropocene, 8*(025). https://doi.org/10.1525/elementa.025

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
Students should share specific examples of differences in how Inuit hunters and fishers and NASA researchers define system boundaries, inputs, and outputs; e.g., animal movement within and into Inuit Nunaat vs. water temperature readings in sampling grids. (DCI: ESS2.A.3; CCC: 4.2)

What to do: Support students to think broadly about what counts as energy, matter, and flows of energy. Ask students to notice and describe how hunters and fishers describe the boundaries of "here," and prompt students to give specific examples of birds, fish, and insects that are present on Qikiqtaaluk / Baffin Island that were not before (e.g., dragonflies, sardines, cranes), and that have moved to colder places within the Nunaat/Polar Region (e.g., migratory birds), as well as examples of energy flows (e.g., thawing permafrost). Revisit portions of the video clip as necessary.

Building toward: 8.B.1 Read and listen to scientific and technical information from two authoritative sources--Inuit Indigenous Knowledge and research from the NASA OMG Project--and consider the usefulness of describing and analyzing the boundaries, initial conditions, inputs, and outputs of the Arctic system from these different perspectives. (SEP: 8.3; DCI: ESS2.A.3; CCC: 4.2)

3 · REVIEW DATA FROM THE NASA OMG PROJECT

12 min

MATERIALS: science notebook, *NASA OMG Project*, https://youtu.be/N1T-1HAWxUU

Say, *It sounds like changes are happening on a very short timescale in this region. Some of us also thought there might be scientists on location whose research could help answer our questions. We know that melting is mainly happening in the bay, which is an idea scientists are studying too.*

Introduce the NASA Oceans Melting Greenland (OMG) project.✱ Display **slide I**. *There are international teams of researchers that are studying what happens where the glacial ice meets the ocean waters in the Arctic. This is a video from NASA in the US, who has a project called OMG , Oceans Melting Greenland, which sounds like it studies exactly what we want to investigate.*

Consider how NASA researchers gather data about the ocean-ice interface. Invite students to listen for information that helps answer the questions they generated at the beginning of the class and/or that raises new questions, and have students jot notes in their notebook. Play https://youtu.be/N1T-1HAWxUU (from timestamps 1:13-2:56) to show NASA OMG scientists dropping temperature probes into the water.

Introduce the reference When the video is over, explain, *The OMG researchers have presented their work for peer review and published lots of articles. One of these papers seemed really interesting, and I've summarized some key data and figures for us.*

Show **slide J**. Distribute copies of *NASA OMG Project*, which contains summarized OMG findings.

Say, *This paper examined the impact of warming Atlantic Ocean waters on 226 of what the researchers call "marine-terminating glaciers" on Greenland. Those are glaciers that flow into the Atlantic Ocean. There is a diagram showing the different types of glaciers and a map showing all the glaciers in Greenland, including Ilulissat. Ilulissat is called Jakobshavn, its Danish name, on the map.*

✱ SUPPORTING STUDENTS IN ENGAGING IN OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION

The resources in this section are very different from those in the previous section. This is intentional, as they all provide different kinds of evidence that support the same general conclusions. Prompts serve as a support to help students attend to particular ideas in the videos and other resources.

Briefly explain the labels on the map–N for North, CE for Central East, and so on. Give students a few minutes to process the reference with a partner.

Discuss NASA researchers' ways of knowing. Display **slide K** and discuss the prompts as a class.

Suggested prompt	Sample student response
How do NASA researchers build knowledge over time?	NASA scientists ask specific questions and then figure out what to measure to answer those questions . They write about and publish what they are learning and use numbers to show changes. They update their questions as they gain new information.
How do they define the boundaries of the system?	They are interested in where the ice meets the ocean in particular. They drew square sampling boundaries in different regions of Greenland (e.g., N, W, S, SW).
How do they describe the system's inputs and outputs?	They include only things that the instruments can pick up. They don't include the living things.
What are the consequences of drawing the boundaries this way compared to Inuit conceptualizations of the system?	Leaving out the animals is kind of sad and not realistic. We might overlook some things that matter for figuring out solutions if we don't include living things. Leaving out the living things helps us focus on one part of the system.
Where do they think the glacier's melting is occurring?	They see the most melting at the bottom of the glacier where the water is warmest.
Follow up: The water is warmest at the bottom...is that what we usually see, hot liquid or gas at the bottom and cooler liquid or gas on top?	No, we usually see hot substances near the top. No, because hot air rises.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should share specific examples of differences in how Inuit hunters and fishers and NASA researchers define system boundaries, inputs, and outputs; e.g., recent animal movement within and into Inuit Nunaat vs. water temperature readings in sampling grids. (DCI: ESS2.A.3; CCC: 4.2)
- Students should share specific examples of differences in how authorities of Indigenous Knowledge and the NASA OMG project approach building knowledge; e.g., passing knowledge through lessons and from generation to generation vs. publication. (SEP: 8.3)
- Students reflect on the consequentiality of defining systems boundaries, inputs, and outputs in different ways; e.g., considering the impact of including or not including humans and animals in the model on knowledge construction and conceptualization of potential courses of action. (CCC: 4.2)

What to do: Prompt students to identify assets of both NASA OMG researchers' and Inuit hunters and fishers' Ways of Knowing by asking them to reflect on what each knowledge tradition does well. For example, Indigenous Knowledge traditions do a good job of highlighting relationships between parts of a system, and holding on to complexity. Science does a good job of eliminating variables to answer narrow questions.

This three-dimensional assessment moment is important because of its emphasis on systems. You may wish to follow up with individual students to provide feedback on system definition, as this idea will play a key role in future lessons, including the transfer task. Also use this opportunity to identify evidence that students are using all three dimensions together in discussion.

Building toward: 8.B.2 Read and listen to scientific and technical information from two authoritative sources--Inuit Indigenous Knowledge and research from the NASA OMG Project--and consider the usefulness of describing and analyzing the boundaries, initial conditions, inputs, and outputs of the Arctic system from these different perspectives. (SEP: 8.3; DCI: ESS2.A.3; CCC: 4.2)

4 · REVISIT QUESTIONS AND FRAME HYPOTHESES

13 min

MATERIALS: science notebook, *Revisiting Questions*, class consensus model from Lesson 5

Reflect on questions and begin to frame hypotheses about the possible impacts of proposed solutions. Display **slide L**. and distribute *Revisiting Questions*. Invite students to complete this handout in pairs, revising a complex model of the system and generating hypotheses based on what they have figured out in this lesson.✱

Then discuss the prompts on the slide as a class.

Suggested prompt	Sample student response
What have we learned from Inuit fishers and hunters and NASA researchers?	Ilulissat is mainly melting because of warm, salty water at the bottom of the bay.
Think about our energy transfer models of how a berm might work to slow ice melt/sea level rise. *If the berm solution were implemented at Ilulissat, how might you expect flows of energy and matter to change?*	The berm might work at Ilulissat because it is a floating extension (FE) type and the ice comes into contact with warm water at the bottom of the bay. Since energy would go from the warm water into the berm instead of the ice, it might slow ice melt.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

The "Rules for Energy Transfer" anchor chart has been intentionally left out of this lesson so that students have an opportunity to apply those rules, with a partner, while they annotate a relatively complex energy transfer model. Here, the annotation, rather than an outside resource, serves as a scaffold. Use this as an opportunity to see how comfortable students are using the notation of energy transfer models.

Suggested prompt	Sample student response
Think about our energy transfer models of how cutting carbon emissions might work to slow ice melt/sea level rise. *If carbon emissions were reduced, how might you expect flows of energy and matter to change at Ilulissat?*	High levels of CO_2 result in energy being trapped instead of reradiating out into space. By reducing or slowing CO_2 emissions, we could prevent the situation from getting worse, potentially slowing the warming of the oceans and glacial melt.
Which would slow glacial melt quicker, a berm or reducing carbon emissions?	A berm, because carbon dioxide stays in the atmosphere for a long time.
Which would solve the problem of polar ice melt in more places?	Reducing carbon emissions, because you might not be able to put a berm everywhere.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
Students' hypotheses are consistent with models and rules of energy transfer from previous lessons and with evidence from the field. (SEP: 1.6; CCC: 5.2)

What to do: Refer back to models and rules of energy transfer from previous lessons and evidence from the field gathered in this lesson. Invite students to check each others' hypotheses against what they have already figured out about energy transfer and the conditions at the interface where ocean water meets glacial ice. *Revisiting Questions Key* shows specific model revisions and hypotheses.

Building toward: 8.A.2 Ask questions about the changing ice, waters, and lands of the circumpolar region that could be investigated in the field (using Indigenous Inuit and/or NASA methodologies) to frame a hypothesis about changes in energy and matter where glacial ice meets the ocean water at Ilulissat. (SEP: 1.6; DCI: ESS2.A.3; CCC: 5.2)

Return to the puzzling information about the location of the warmest water. Display **slide M** and revisit both the NASA OMG glacier types image and the quote from the video of Inuit fishers and hunters pointing to warming oceans as an example of changing climate.

Invite students to generate questions about the warm ocean waters to pursue in the next class period. Call attention to the puzzling information that suggests the warmest water is at the bottom of the bay.

Suggested prompt	Sample student response
What do we still want to know about the warm ocean water?	We are wondering why the warm salty water is on the bottom of the ocean, not the top. Is the warm salty water really going to stay below the cold freshwater? Isn't warm water supposed to float? There is already a raised area of ocean floor (the fjord sill) in front of the glacier, and warm water is spilling over it. Wouldn't this continue to happen with the berm?

Additional Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.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.

CCSS.ELA-LITERACY.RST.9-10.9: Compare and contrast findings presented in a text to those from other sources ~~(including their own experiments)~~, noting when the findings support or contradict previous explanations or accounts.

Students describe the important findings from the graphics in *NASA OMG Project* in words and compare and contrast the methodologies and findings of Inuit hunters and fishers with those of NASA researchers.

LESSON 9: Why does warm salty water sink to melt a glacier?

PREVIOUS LESSON *After learning about surface glacial melt we decided to explore the melt happening underneath. We posed questions about where glacial ice meets ocean water, then considered the information needed to answer them. We learned from Inuit and NASA experts and formulated hypotheses about how proposed solutions would affect energy flows. We were puzzled that the warmest water is at the bottom of the bay.*

THIS LESSON

INVESTIGATION

3 days

We wonder why cool water is on top of warm salty water. We develop initial particle-level and energy models of water at different conditions (warm fresh, cold fresh, warm salty, and cold salty) and collect data on its mass and volume . We graph our individual and class data, determine lines of best fit, and calculate the density of water under these different conditions. We revise our initial models, explain how berms decrease energy transfer to the glacier, and complete an exit ticket.

NEXT LESSON *We will plan and carry out an investigation to figure out if we can measure energy transfer between warm and cool water. From graphs, we will gain some additional evidence that energy is conserved. We will use a simulation to develop a mathematical model of energy transfer through conduction.*

BUILDING TOWARD NGSS

HS-PS3-1, HS-PS3-4, HS-ESS2-2, HS-ESS2-4, HS-ESS3-1, HS-ESS3-5, HS-ESS3-6, HS-ESS2-7

WHAT STUDENTS WILL DO

9.A Evaluate a question about the energy circulation in the ocean to see if it is testable and select appropriate tools to collect and record data in an investigation, considering predicted energy flows within the ocean system. (SEP: 1.5, 3.4; DCI: ESS2.D.1; CCC: 5.4)

9.B Apply function fits to data, consider limitations of data analysis, and consider model reliability to identify density as altering expected patterns of energy circulation in the ocean. (SEP: 4.2, 4.3; DCI: ESS2.D.1; CCC: 4.4)

WHAT STUDENTS WILL FIGURE OUT

- Though density is a property for a substance at room temperature, increased energy tends to increase the distance between particles and thus decrease the density of the particles that make up that substance.
- Density of a substance (or a sample) is its mass per unit volume.
- When denser fluids are added above less dense fluids, the denser fluids sink.
- When denser fluids are moved beneath less dense fluids, they tend to remain separated and flow independently of each other.
- Changes in energy and matter happen together, including in convection, when energy transfers as substances move.

Lesson 9 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Brainstorm ideas about why liquids float or sink.	A-B	
2	10 min	✓	**MODEL PARTICLES IN DIFFERENT LIQUIDS** Have students create an initial model about the particle level of water with different temperatures and salinities.	C-D	loose-leaf paper, chart paper, marker
3	15 min	✓	**PLAN AN INVESTIGATION** Discuss measurements and make a plan for testing them, including what data to collect and what safety guidelines to follow.	E-K	chart paper, graph chart paper, chart paper marker, Mathematical Anchor Chart
4	15 min		**INVESTIGATE MASS AND VOLUME** Work in small lab groups to measure the mass of different water samples for their assigned volume, add data to the class spreadsheet, and discuss trends in the data.	L-M	copy of https://docs.google.com/spreadsheets/d/1l2ArHNHyOTItwCW6BYqfx7wmBN52Uw4Wbky7FUxvqOA/copy, Mass and Volume Lab
					End of day 1
5	15 min	✓	**PRODUCE LINES OF BEST FIT AND INTERPRET OUR RESULTS** Create graphs from the class spreadsheet and interpret trends in the data.	N	loose-leaf paper, copy of https://docs.google.com/spreadsheets/d/1l2ArHNHyOTItwCW6BYqfx7wmBN52Uw4Wbky7FUxvqOA/copy
6	13 min	✓	**CALCULATE DENSITY** Discuss best-fit lines, consider limitations of the mathematical models, and calculate slope using Google Sheets.	O	calculators, sticky notes
7	17 min	✓	**INTRODUCE SIGNIFICANT FIGURES** Support students in figuring out the importance of significant figures.	P-R	calculator, *Significant Figures*, Mathematical Anchor Chart
					End of day 2
8	12 min		**CARRY OUT A SECOND INVESTIGATION** Conduct a demonstration to help students see that our results can explain warm water staying at the bottom of the bay.	S-T	Water-Density Layering Demonstration
9	12 min	✓	**UPDATE INITIAL PARTICLE MODELS FROM DAY 1** Revise initial models with density data from graphs and water-density layering demonstration.	U-W	initial particle models, tape, blank paper
10	4 min		**UPDATE PROGRESS TRACKERS** Give students a few minutes to update their Progress Trackers and debrief as a class.	X	
11	9 min		**MODEL ENERGY TRANSFER** Model the energy flow to the glacier that causes melting.	Y-Z	"Rules for Energy Transfer", *Revisiting Questions*

Part	Duration		Summary	Slide	Materials
12	8 min		**EXIT TICKET** Give students time to complete an exit ticket for the lesson.	AA	copy of https://docs.google.com/forms/d/1kAZBHTqV9mI57xxp-GgkoGeYvt-aYWD1TpzGgdsRDDU/copy

End of day 3

Lesson 9 • Materials List

	per student	per group	per class
Mass and Volume Lab materials	• science notebook • indirectly vented chemical splash goggles • nonlatex aprons • nitrile gloves	• 100-mL graduated cylinder • digital scale • 8-mL disposable plastic pipette	• fresh cold water • salty cold water • fresh warm water • and salty warm water
Water-Density Layering Demonstration materials			• 1000-mL beaker • 3 8-mL disposable plastic pipettes • 700 mL room-temperature tap water • 20 mL fresh cold water • 20 mL fresh warm water • 20 mL salty warm water • food coloring • sheet of white paper
Lesson materials	• science notebook • loose-leaf paper • copy of https://docs.google.com/spreadsheets/d/1l2ArHNHy0TItwCW6BYqfx7wmBN52Uw4Wbky7FUxvqOA/copy • calculator • *Significant Figures* • copy of https://docs.google.com/forms/d/1kAZBHTqV9mI57xxp-GgkoGeYvt-aYWD1TpzGgdsRDDU/copy	• calculators	• chart paper • marker • graph chart paper • chart paper marker • Mathematical Anchor Chart • sticky notes • initial particle models • tape • blank paper • "Rules for Energy Transfer" • *Revisiting Questions*

Materials preparation (45 (starting 1 day ahead of time) minutes)

Three-hole-punch all handouts so they can be added to students' notebooks.

Make a copy of the Google Sheets to use as a template to share with your students:

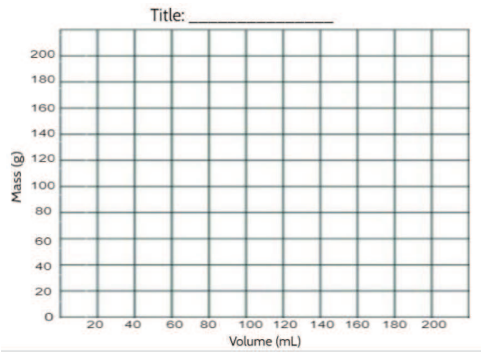
- https://docs.google.com/spreadsheets/d/1l2ArHNHy0TItwCW6BYqfx7wmBN52Uw4Wbky7FUxvqOA/copy

If you cannot access these and/or want to recreate the layout for this sheet from scratch, the image in *Spreadsheet References* provides a snapshot of what the layout should look like.

Set up a class data table, one copy in a Google Sheet for each class. Students will need to add data to the same Google Sheet, so share the document virtually with all the students or one student from each group. After students have added all of their data, each student will need their own copy. To make a copy for each student, follow these steps:

1. Click "Share" and change share settings to "Edit".
2. Paste the file link and change the end of the URL. Replace "edit?usp=sharing" with "copy".
3. Email students the new link (or share it on school software).
4. When the student taps the link, they are instructed to tap "Make a copy".

5. They can now edit their own version of the original document.



Review these two videos:

- https://youtu.be/W4CFkXCF3E8
- https://youtu.be/vgFarmoNrsQ

The first video will show you how to use Google Sheets to build a scatter plot and create a line of best fit. The second video will show you how to use Google Sheets to calculate the ratio of mass to volume for each measurement and the mean of the ratios. You will do both of these activities with the class on day 2 of the lesson.

Set up graph chart paper to use throughout the lesson. Label Volume (mL) on the *x*-axis and Mass (g) on the *y*-axis. Wait to add a title, but include a line where the title should go. See the example shown.

Prepare the saltwater and fresh water containers one day ahead of time. See *Preparing Water Containers* for guidance.

Make a copy of *Significant Figures* for each student.

Make a local copy of the electronic exit ticket at https://docs.google.com/forms/d/1kAZBHTqV9mI57xxp-GgkoGeYvt-aYWD1TpzGgdsRDDU/copy. Instructions on this task may be found in *Electronic Exit Ticket* in Lesson 4.

Day 1: Mass and Volume Lab

- **Group size:** Create groups of 3-4 students.
- **Setup before class:**
  - Prepare a container of room-temperature and cooled saltwater from the same 1-gallon mixture made for each class. The cooled saltwater should be placed in a refrigerator overnight. See *Preparing Water Containers* for guidance on concentration.
  - Prepare a half-gallon container each of room-temperature and cooled fresh water (distilled water) for each class.
  - Set aside a 100-mL graduated cylinder for each group.
  - Obtain the following materials: 100-mL graduated cylinders, digital scale, 8-mL disposable plastic pipette, ~50 mL of room-temperature fresh water, digital thermometer with metal probe
- **Notes for during the lab:** Students should rinse out and reuse the graduated cylinders.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*. These include:
  - Wear indirectly vented chemical splash goggles, nitrile gloves and non/latex apron during the setup, hands-on, and takedown segments of the activity.
  - Secure loose clothing, wear closed-toe shoes, and tie back long hair.
  - Immediately wipe up any spilled liquids - slip/fall hazard.
  - Follow procedures set up by your instructor for disposal of materials.
  - Use caution when working with heated liquids–they can burn skin.
  - Use only GFI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
  - Use caution when working with glassware or plasticware - can break and cut/puncture skin.
  - Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
  - Direct supervision will be required during all aspects of this activity.
- **Storage:** All the other materials can be stored and reused from year to year.

Day 2: Water-Density Layering Demonstration

- **Group size**: Whole-class
- **Setup before class:**
  - Repeat the preparation outlined in *Preparing Water Containers*, setting aside only a half-gallon of each temperature of salty water and a half-gallon of each temperature of fresh water for all 6 periods. Put another gallon of cold fresh water (distilled water) in the refrigerator.
  - Pour about 100 mL of each of the following into clear cups:
    - warm fresh water (red food coloring)
    - warm salty water (green food coloring)
    - cold (~5 deg C) fresh water (yellow food coloring)
  - Pour 700 mL of room temperature fresh water (no food coloring) into a 1000-mL beaker.

    - Place a sheet of white paper behind the class to make the color layering more visible.
    - Watch https://youtu.be/IcNPqzdlLvs.
    - Then practice the following:
        - Using a pipette, add 7 mL of warm fresh water (red) to the beaker of room temperature water. To do this, slowly slide the end of the pipette along the side of the beaker, stopping just above the surface of the water. Then slowly release the contents into the beaker.
        - To the same beaker, add 7 mL of warm salty water (green), using the method described in the previous step
    - Watch https://youtu.be/UXdq9a11GsY.
    - Then practice the following:
        - To the same beaker, add 7 mL of cold fresh water (yellow), using the method described above
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science* and above.
- **Storage:** All the other materials can be stored and reused from year to year.

Lesson 9 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build ideas related to the following disciplinary core idea:

- **ESS2.D.1: Earth's Systems.** 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.~~

Students carefully evaluate a question to determine if it is testable (SEP: 1.5) and select tools for data collection (SEP: 3.4), both for the first time in the course. These opportunities are scaffolded appropriately. The idea that energy is driving cycling of matter within and between systems (CCC: 5.4) is explicitly drawn out for the first time in the course and recorded in the M-E-F triangle. Students also first develop the idea in this course that models can be predictive, but are also limited (CCC: 4.4), building off thinking about assumptions that was built in Lesson 4.

Much of the lesson focuses on analyzing and interpreting data as students determine lines of best fit (SEP: 4.2) and consider limitations of their data analysis (SEP: 4.3) are heavily scaffolded, as students' prior experiences with this practice in *OpenSciEd Unit B.4: How does urbanization affect nonhuman populations, and how can we minimize harmful effects? (Urbanization Unit)* did not necessarily involve such complex quantification. The tools leveraged here was developed in middle school mathematics coursework:

- CCSS.MATH.CONTENT.8.SP.A.1 Construct and interpret scatter plots for bivariate measurement data to investigate patterns of association between two quantities. Describe patterns such as clustering, outliers, positive or negative association, linear association, and nonlinear association.
- CCSS.MATH.CONTENT.8.SP.A.2 Know that straight lines are widely used to model relationships between two quantitative variables. For scatter plots that suggest a linear association, informally fit a straight line, and informally assess the model fit by judging the closeness of the data points to the line.
- CCSS.MATH.CONTENT.8.SP.A.3 Use the equation of a linear model to solve problems in the context of bivariate measurement data, interpreting the slope and intercept. For example, in a linear model for a biology experiment, interpret a slope of 1.5 cm/hr as meaning that an additional hour of sunlight each day is associated with an additional 1.5 cm in mature plant height.

The particle-level models that students use in this lesson to represent why there might be density differences between warm water and saltwater can rely on middle-school ideas about how the speed of particles and therefore the space between them must be different in each condition. Students may also use the idea that a mixture of substances (salt and water) must have at least two different types of particles throughout, whereas a pure substance (water) has only one type of particle or molecule throughout. Students may also suggest that a saltwater mixture would have a density somewhere between those of pure salt and pure water.

Students may be familiar with the following uses of particle modeling from OpenSciEd Middle School Science:

- For explaining why some things are better thermal insulators (in a cup design) than others in *OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)*.
- For explaining why air parcels rise or sink in *OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*.
- For explaining why different substances have different properties and same substances have the same properties in *OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*.
- For explaining why different ratios of reactants produce different amounts of thermal energy in *OpenSciEd Unit 7.2: How can we use chemical reactions to design a solution to a problem? (Homemade Heater Unit)*.

One strategy for developing mathematical and computational models introduced in Lesson 4, *"We can predict how big our answers will be and check if they make sense"* is used again on day 1 of this lesson.

In this lesson, students will co-construct a definition for the following words, which they should add to their personal glossaries: *density* and *convection*. They may also choose to record *significant figures* and *meniscus* as words they encounter. **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

Although students saw what a water molecule looks like in Lesson 3, there is no need to use a detailed particle-level representation at this point. This unit focuses on using representations that are sufficient for explaining and predicting the phenomena at hand. For example, it is expected that students will represent saltwater as a simple mixture of two types of particles (water and salt). There is no need (nor line of evidence) at this point to support the representation of the ions that salt breaks into when it dissolves. Students will develop this idea in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*.

In Lessons 3 and 6, students already developed ideas about the many ways in which energy moves through Earth systems. Here, we seek only to clarify the ways in which energy is redistributed throughout the ocean (more specifically, Disko Bay) through convection.

Students will have opportunities to select tools to record, analyze, and evaluate data later in the course, once they have more experience with different tools. They will analyze data for use in engineering problems later in the Chemistry course (as well as considering sample selection) and will develop ideas about probability and correlation coefficients in the Physics course.

LEARNING PLAN for LESSON 9

1 · NAVIGATE

5 min

MATERIALS: science notebook

Navigate to today's work. Display **slide A**. Say, *Let's recall what we learned about the Ilulissat Glacier and the proposed design solution for that site.*

Suggested prompts	Sample student responses
Where is the design solution we critiqued last time located in the system shown? ✱	The solution proposed raising the berm higher up at the bottom of the ocean where the current sill is located.
What are we wondering about the water in this system?	We are wondering why the warm salty water is on the bottom of the ocean, not the top. Is the warm salty water really going to stay below the cold fresh water? Isn't warm water supposed to float? Will the berm actually work if it is not at the top, where we think the warm salty water should be?

Display **slide B.** Have students discuss the prompt on the slide, then discuss as a class.

Suggested prompts	Sample student responses
What makes one liquid float and another liquid sink anyway?	We think that one liquid might be heavier than another liquid. We think that one liquid might be more dense than another liquid. We're not sure.
What are the particles doing in a liquid?	They are constantly moving or rolling. They are faster than the particles in a solid.

Foreground the related question. Say, *If we want to figure out why the warm salty water stays near the bottom, we will need to do an investigation. We want to make sure when we investigate that we have an idea of what we think will happen, which means it is useful to think more about what is happening at the particle level first.*

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

Continue to reinforce with students what different components are included in the system here. You may wish to ask *What is included in this system?* or *What components do we care about?* whenever this or any new system is displayed.

2 · MODEL PARTICLES IN DIFFERENT LIQUIDS

10 min

MATERIALS: science notebook, loose-leaf paper, chart paper, marker

Create initial particle models with a partner. Display **slide C.** Say, *Let's consider this from a particle perspective. Thinking about a phenomenon at a particle scale often helps us figure out something about why a sample of matter behaves the way it does. In this case it may help us figure out why some liquids stay above or below others. What is different about the particles in different liquids? Let's consider differences in temperature—warm and cool—and composition—salty water and fresh water.*✱

Set up chart for particle models. Direct students to create a four-square chart on a sheet of loose-leaf paper in their science notebooks to record their initial ideas while you make a similar chart on the chart paper. Label the four boxes Fresh cold water, Fresh warm water, Salty cold water, and Salty warm water. Build the "Fresh cold water" model together as shown below, then give students three minutes to work with a partner to draw the other three models. Do not draw the energy transfer model yet.

Conduct an Initial Ideas Discussion about interactions between the water particles. Display **slide D.** Gather the class for a brief discussion.

KEY IDEAS

Purpose of this discussion: Provide students a supportive opportunity to voice partial understandings about the kinetic molecular theory of matter that are developed in middle school.

Listen for these ideas:

- More particles are in a given space at lower temperatures.
- Particles move slower at lower temperatures.
- Fewer particles are in a given space at higher temperatures.
- Particles move faster at higher temperatures.
- Salty water (warm or cold) has pieces of salt particles mixed among the water molecules.

Suggested prompt	Sample student response
What happens to particles when you add energy to a substance?	The particles move faster when the temperature increases. The particles speed up.
(Begin to draw the "Fresh warm water" model and pause.) What happens to the spacing of these particles as the temperature increases? *(Finish the "Fresh warm water" model after gathering student responses.)*	When the particles move more, they spread out more. This results in fewer particles in a space when the temperature increases.
Can we show this in an energy transfer model too? *(Add an energy transfer model above or below the particle models after gathering student responses.)*	Yes, we would just write "particles speed up and spread out" in the box.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SCALE, PROPORTION, AND QUANTITY

This brief reference to "*Thinking about a phenomenon at a particle scale often helps us figure out something about why a sample of matter behaves the way it does,*" can help prime students for later thinking in this course about why different substances have different bulk properties. See the "Where We Are Going" section for details on particular places students have used, and will use, this thinking.

Suggested prompt	Sample student response
Where would water in the ocean get energy?	From the Sun. From warm air.
Are we in agreement that if you add energy to a substance and it gets warmer, it will tend to float?	Yes, since that is what we figured out in middle school. Yes, because that is how hot air balloons work. No.
How would the particles compare in fresh and salty water?	Fresh water is just made of water particles.. Saltwater is a mixture/solution, so it would contain more than one type of particle. One of these types of particles would be water and the other(s) would be pieces of salt.
What happens when <u>two</u> variables are changed (warm and salty)? *(Finish the two saltwater models if desired.)*	The particles would be faster and spread out, but there would be both water and salt particles.
Let's summarize. What are the ways in which the four liquids are different?	Particle speed/temperature. How many particles there are and what kinds. Mass, maybe.

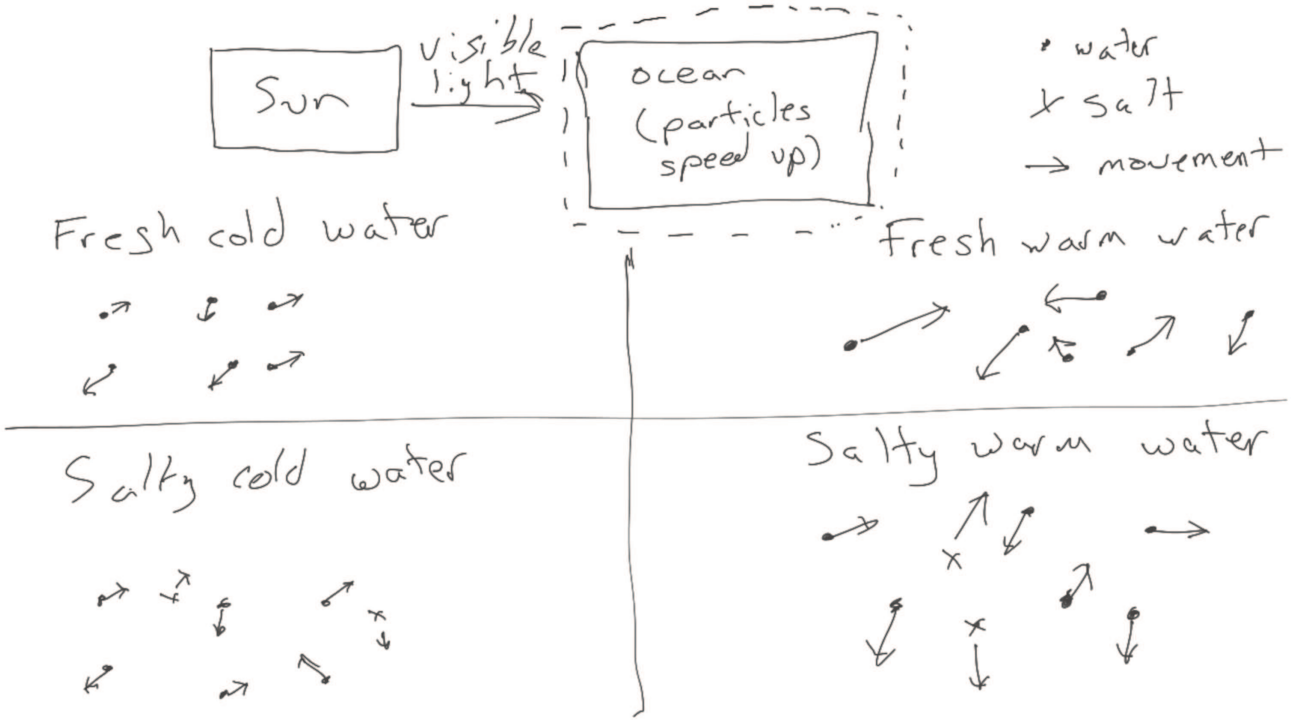
ADDITIONAL GUIDANCE

It is important that students are in agreement on the idea that warmer substances generally rise. If only some students think that warmer substances do not tend to rise, elicit evidence from those who do. If students are unsure of this middle school-level idea, suggest situations familiar to students in which they would have experienced or heard of this phenomenon (e.g., being told to crawl below the heat and smoke in a fire, or spending more time on lower floors of buildings if possible when it is warm outside.)

Say, *These particle-level models may give us some insight into our question about whether any of these different types of water would float on top of the others.* Ask students to share any new insights they have about this relationship now. Accept all responses and say that we can use these insights to strengthen our investigation question.

ALTERNATE ACTIVITY

Extension opportunity: Students may have mentioned earlier in the unit that the expansion of ocean water as it heats up due to changing global temperatures is an additional cause of sea level rise. This is correct, and the model students have developed here can be a point to return to this idea and establish an explicit temperature-volume relationship. You can accomplish this by placing a capped syringe in warm water and watching it expand, as done in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*.



ASSESSMENT OPPORTUNITY

What to look/ listen for in the moment:
Students should show that matter behaves differently based on the energy stored within it and energy originates from the Sun before reaching the ocean. (ESS2.D.1; CCC: 5.4)

What to do: Encourage students to return to their models from Lessons 5 and 6 as needed to help build out the particle and energy portions of the model. If students do not show differences in behavior of matter based on energy or temperature, encourage them to think about what would happen to a sample of salty or fresh water when heated.

Furthermore, ask students to show differences in composition if they do not represent water and salt particles separately.

Building toward: 9.A.1 Evaluate a question about the energy circulation in the ocean to see if it is testable and select appropriate tools to collect and record data in an investigation, considering predicted energy flows within the ocean system. (SEP: 1.5, 3.4; DCI: ESS2.D.1; CCC: 5.4)

3 · PLAN AN INVESTIGATION

15 min

MATERIALS: science notebook, chart paper, graph chart paper, chart paper marker, Mathematical Anchor Chart

Discuss the question we are trying to investigate. Display **slide E.** Give students a minute to turn and talk about the different prompts before discussing as a class. Listen for these ideas:

- Even though we care about (A), it is not really testable.
- (B) does not fully relate to or describe what we want to figure out.
- (C) is something we can test and it describes the specific question we want to clarify–why warm saltwater behaves differently than we expect based on its energy.

ASSESSMENT OPPORTUNITY

What to look/ listen for in the moment:
Students' responses should reflect the ideas that question C is both testable in the classroom and relevant to our investigation, and it is relevant because it addresses how it defies our expectations about the behavior that matter should have based on its energy. (SEP: 1.5; CCC: 5.4)

What to do: If students tend toward question A, ask them to consider what we would measure that would allow us to answer the question. If they push for question B, ask them how the phrasing could be clarified to more specifically address the phenomenon that we are examining.

Building toward: 9.A.2 Evaluate a question about the energy circulation in the ocean to see if it is testable and select appropriate tools to collect and record data in an investigation, considering predicted energy flows within the ocean system. (SEP: 1.5, 3.4; DCI: ESS2.D.1; CCC: 5.4)

Independently write down the data students would like to collect before discussing as a class. Display **slide F.** Give students a couple of minutes to write down any type of data they would want to collect to figure out if there is a measurable difference in these different types of water that could explain why one might float and one might sink.

Suggested prompt	Sample student response
What sorts of data could we collect to figure out an answer to our question?	Temperature. Mass or weight. Volume (or space water takes up).✱
How could we organize our data table?	We would need space for all of those variables. We would also need space to record if the water is salty or fresh.

Say, *Some of us suggested mass as one type of measurement, and maybe we will want to take other measurements too. So let's plan to record that on the board. I have some cold water set aside for use in our lab, as well as some warmer room-temperature water and salty water. Let's start with some of the warm fresh water and take a couple of measurements together to work through some of the details about the type of data we want to collect and how we can compare it across groups.*

Give students time to make a data table for the variables they discussed.

✱ ATTENDING TO EQUITY

Students may not remember what mass or volume are. You may wish to have students discuss these terms with a partner and have two or three groups share definitions or descriptions.

Furthermore, many students will use *mass* and *weight* interchangeably. The difference between these terms will become more important in *OpenSciEd Unit P.3: What can we do to make driving safer for everyone? (Vehicle Collisions Unit)*, so it is not necessary to correct students at this time; however, as the teacher you should use *mass* throughout the lesson.

Think about different measurement tools. Display **slide G**. Say, *If we want to measure temperature, that is pretty easy. But what tools here would work best to measure other variables?* Lead a brief discussion of the prompts on the slide.

Suggested prompt	Sample student response
Which of these tools would be most useful to measure mass?	The scale.
Which of these tools would be most useful to measure the space a small amount of liquid takes up (volume)?	Not a pipette, because it is hard to get the exact amount you want. Maybe a beaker. Not a flask because there are not very many markings. The tall skinny things (graduated cylinder) might be best because they have more marks.
Why would these tools be particularly useful?	They measure the variables we want to measure. They easily give us quantitative measurements.

Say, *We will definitely need to use the scale, and should think more about how to measure the space. Let's take a look at those tools.*

ALTERNATE ACTIVITY

Extension opportunity: Glassware and lab materials that are needed throughout the course are introduced "just-in-time." However, if you want students to be familiar with the materials they find in the lab space, this is an opportunity to briefly introduce different types of glassware that are not used in this unit.

ASSESSMENT OPPORTUNITY

What to look/ listen for in the moment:
Students should select the graduated cylinder and scale because they are appropriate to the investigation (i.e., they measure the desired variables). (SEP: 3.4)

What to do: If students select different tools, ask them to explain how they will get a measurement from them. For example, if a student thinks a beaker is the best tool to measure volume, ask them how they would read a volume if the measurement fell between the marks.

Building toward: 9.A.3 Evaluate a question about the energy circulation in the ocean to see if it is testable and select appropriate tools to collect and record data in an investigation, considering predicted energy flows within the ocean system. (SEP: 1.5, 3.4; DCI: ESS2.D.1; CCC: 5.4)

Gather students around a demonstration area. Display **slide H.** Students should bring their science notebooks with the prepared data table. Invite students to ask questions and record observations.

Review how to measure mass on a digital scale as a class. Follow the procedures and prompts below. The purpose of this demonstration is to remind students how to use an electronic scale with the tare function and discuss the importance of the meniscus.

- Place the electronic scale on a flat surface. Press the "ON" button and wait for the scale to show zeros on the digital screen.
- Measure the mass of the 100-mL graduated cylinder with 50 mL of fresh room-temperature water.

Suggested prompts	Sample student responses	Follow-up questions
The mass of the water is....	No it is not; you weighed the container and the water. We need the mass of just the water, not the container too.	*Is this just the mass of the **water**?* *Oh, who remembers how to do that?*

- Place an empty 100-mL graduated cylinder on the scale. Press the "Tare" or "Zero" button to automatically deduct the mass of the container. The digital display will show zero again.
- Carefully add ~50 mL of fresh room-temperature water to the graduated cylinder.
- Record the mass of the system now.

Measure the accurate mass of the water. Students do not have to record these specific measurements because they will collect their own data in their groups. Each group will be assigned a target volume, which they will try to keep relatively consistent across their four water conditions. However, make sure the mass of this sample you measured together as a class is now written on the board. You will add a volume measurement next to it in a moment.

Discuss other measurements we want to take.

Suggested prompt	Sample student response
What do we think would happen to the mass of the water if we increased the amount of water in the container?	It would increase.
What do we think would happen to the mass of the water if we decreased the amount of water in the container?	It would decrease.
(Pass around the graduated cylinder.) So, how can we measure the <u>volume</u> of liquid in this container?	We can read the height of the liquid and calculate its volume using its base area. We can use the marks on the side of the graduated cylinder.
What do those marks on the graduated cylinder measure?	We think that measurement is called volume. It measures how much space something takes up. They measure mL or milliliters.

Establish that the graduated cylinder marks are a shortcut for measuring volume, as opposed to measuring the height of the water with a ruler, calculating the area of the base of the cylinder, and multiplying those values to find the volume.

ADDITIONAL GUIDANCE	This is an opportunity for students to connect to a mathematical model that was developed in Lesson 4, when students calculated volume by finding the area and multiplying by the height.

Discuss the importance of the meniscus. Display **slide I.** Follow the same procedure used above to measure the mass of the fresh room-temperature water. When you add the water to the 100-mL graduated cylinder (model this using the plastic pipette for accuracy), say, *The water in the cylinder will form a curve called the meniscus. Hold the graduated cylinder at eye level and take your measurement from the bottom of*

the meniscus. Ask a student to measure the volume of water currently in the graduated cylinder. If students report a volume to the nearest mL, ask if the meniscus is exactly on a line or somewhere in-between. If somewhere in-between, ask students to estimate the volume to the nearest 0.1 mL.

Record the volume of water reported (in mL) on the board next to its mass (in g).

Plot the single data point that you measured (volume, mass) with a marker at the corresponding coordinate location on the graph chart paper. Say, *OK, we have one point of data for one of the four types of water that we are investigating.*

Emphasize that the qualitative reasoning we have done so far about the volume and mass of a substance makes sense–that when one goes up the other goes up, and when one goes down the other goes down.

On the graph, write "if V ↑, then m ↑".

Move toward more specific quantification. Suggest that now that we have exact values for the mass and volume of this sample, we might be able to make a more targeted prediction about their relationship. Remind students of this strategy for developing mathematical and computational models introduced in Lesson 4, which is displayed on the related anchor chart from that lesson:

- "Predict how big our answers would be and check if they are accurate."

Say, *This is not a math problem, but we could try doing that here. Is the amount of water we are working with today the same as in the bay?* When students say it is not, say, *Then we need to figure out the larger amount. Let's start with small steps and see what happens when we double the amount of water.* Display **slide J**.

ADDITIONAL GUIDANCE

Developing and testing mathematical models through the lens of scale, proportion, and quantity leverages prior middle-school level elements of this crosscutting concept from *OpenSciEd Unit 8.4: How are we connected to the patterns we see in the sky and space? (Space Unit)*, in particular the idea that:

- Algebraic thinking is used to make predictions about the relationship between mass and volume, which is linear.

This lens will be leveraged again in the work that students do in Lessons 10 and 11.

Suggested prompt	Sample student response
What do we think would happen to the mass of the water in the container if we had twice the volume that we have now?	The mass would be twice what it is now. (Whatever twice the value is for the mass that you wrote on the board).
What if there were four times as much water? Or eight times as much?	The mass would be four or eight times as much as it is now.

Say, *OK, we have one point of data for one of the four types of water samples we want to investigate. And we made predictions that increasing the volume would also increase the mass by the same multiplying factor. Let's add these predictions to the corresponding coordinates on the graph.*

Plot the predicted coordinate points on the graph chart paper. Ask students to describe what the graph would look like if we added a prediction for the water in the bay, with a volume maybe a million times as great. Students should say that the mass would also be a million times as great, and the point would lie on the same line as the others.

Motivate a digital graph. Say, *Plotting all of our data by hand introduces some error because we have to line up the coordinate values on the graph by eyeballing them. Even so, for one type of water sample on one graph, a hand-drawn graph can help us see two things: 1) whether the predicted relationship holds, and 2) whether there are any outliers. For example, maybe this one measurement we took as a class will end up being an outlier because of some unforeseen error in our system, like a faulty scale, or maybe we misread or misrecorded a measurement. One way to remove the risk of error from hand-drawing the graph is to use graphing software. The type of coordinate graph we are making can be easily produced using Google Sheets or other digital tools. During the lab, every group will take measurements by hand, record them in their notebook, and then record their measurements in this single class spreadsheet.*

Share with students the link to the class spreadsheet you prepared for this class period. Assign lab groups a corresponding letter for the space where they will record their data. Point out that different groups have been assigned a different target volume of liquid to measure.

Have students set up a corresponding data table in their notebooks to record their lab results for all four water conditions before transferring their data to the class spreadsheet.

Discuss safety guidelines. Show **slide K** and ask students to highlight the safety guidelines that will be most important in this investigation.

4 · INVESTIGATE MASS AND VOLUME

15 min

MATERIALS: Mass and Volume Lab, science notebook, copy of https://docs.google.com/spreadsheets/d/1l2ArHNHyOTItwCW6BYqfx7wmBN52Uw4Wbky7FUxvqOA/copy

Instruct students to gather supplies and measure the mass and volume of the water samples in their lab groups. Display **slide L.** Assign groups one row to complete (A-H) with the corresponding volume (20-90 mL).✱ Students will record data in their science notebooks and later add it to the class spreadsheet. Remind students to carefully record each measurement, zero the scale, and measure volume at the meniscus.

group	target volume (ml)	actual volume (ml)	mass (g)
A	20		
B	30		
C	40		
D	50		
E	60		
F	70		
G	80		
H	90		

Pool class data. Bring students back from the lab and share Google Sheets virtually.Have them enter the data for their group in the class spreadsheet for this period. Display **slide M.**

Suggested prompt	Sample student response
What patterns do you notice in the data?	The data appear to be directly proportional or linear.
What tends to happen to the mass when the volume increases?	The groups that used more volume had a higher mass.
How do our data compare to our predictions (what we expected to happen if we had twice, four times, or eight times the volume)?	It also looks like there is twice the mass in the data when there is twice the volume.

✱ ATTENDING TO EQUITY

Supporting emergent multilinguals: It may be helpful to mix students in groups to see who works well with each other. Then you can use those observations to inform intentional groupings.

It is helpful to intentionally group emerging multilingual students with thoughtfulness to their heritage languages. Sometimes this could be with peers who know the same languages, while other times it could be with peers whose English language development is slightly more advanced. Early in the year, it may be best to give students designated as "newcomers" a same-language partner. Then when they are more proficient and comfortable, give them other-language groupmates.

End of day 1

5 · PRODUCE LINES OF BEST FIT AND INTERPRET OUR RESULTS

15 min

MATERIALS: science notebook, loose-leaf paper, copy of https://docs.google.com/spreadsheets/d/1l2ArHNHyOTItwCW6BYqfx7wmBN52Uw4Wbky7FUxvqOA/copy

Demonstrate how to produce a scatter plot from the data in Google Sheets.✱ Say, *We need to scale our data up to the amounts of water we would see in different parts of the bay with the berm solution to make sure we would see similar trends.* Make four separate scatter plots for the four water conditions, titling each one after it is created. Point out that this is an important step when making multiple graphs.

data from fresh cold water

group	target volume (mL)	actual volume (mL)	mass (g)
A	20	19.5	19
B	30	28	27.9
C	40	39	38.9
D	50	48.5	47.3
E	60	58	58.9
F	70	70.5	72.6
G	80	79	77.7
H	90	89	89.2

data from salty cold water

group	target volume (mL)	actual volume (mL)	mass (g)
A	20	20.5	21
B	30	30	29.2
C	40	40.5	41
D	50	51	49.7
E	60	59.5	61.9
F	70	68.5	69.8
G	80	78.5	78.9
H	90	87	87.8

data from fresh warm water

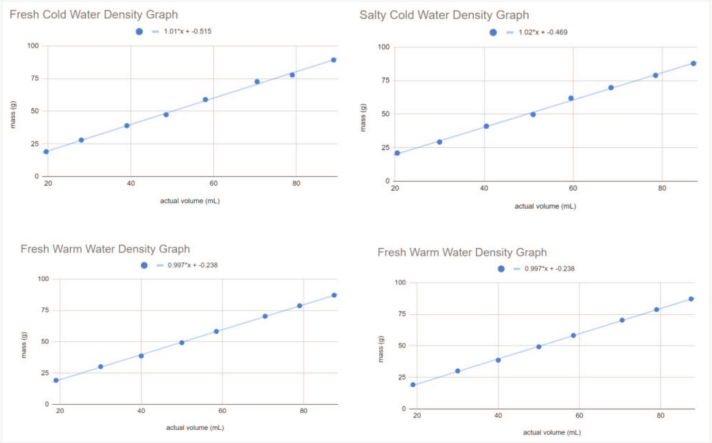
group	target volume (mL)	actual volume (mL)	mass (g)
A	20	19	19.2
B	30	30	30.1
C	40	40	38.6
D	50	50	49.2
E	60	58.5	58.2
F	70	70.5	70.3
G	80	79	78.7
H	90	87.5	87.1

data from salty warm water

group	target volume (mL)	actual volume (mL)	mass (g)
A	20	19	19.4
B	30	27.5	28
C	40	40.5	41.3
D	50	49	48.5
E	60	60.5	61.6
F	70	71	72.3
G	80	78.5	79.4
H	90	89	88.8

Review what a line of best fit is. Say, *The computer can also help us determine a line of best fit.* Ask students to recall what that is from their prior mathematics work. Discuss that a line of best fit is an average trend line through a scatter plot, and that it is drawn so that the distance between it and every point is minimized.A line of best fit represents the predicted average relationship across all the data, and it can be either linear or nonlinear. When using graphing software, we must often specify the type of relationship before the trend line can be created.

Remind students that we have already predicted a linear relationship for our data, and then show students how to use the software to produce a trend line. This image shows a sample answer key for the mass and volume for all four water conditions.



Demonstrate how to produce a line of best fit for all four scatter plots. Walk students through the process described in the callout.

ADDITIONAL GUIDANCE

To produce a line of best fit in Google Sheets:

1. Double-click the chart.
2. Click Customize.
3. Click Series.
4. Scroll down to click Trendline.
5. Under Label, select “Use Equation.”

✱ SUPPORTING STUDENTS IN ENGAGING IN ANALYZING AND INTERPRETING DATA

Students should be able to construct, analyze, and interpret graphed data and identify linear and nonlinear relationships. Ultimately, students should identify patterns in data to develop cause-and-effect relationships between mass and volume. Students should be able to explain the meaning of trends they notice in their data as well as what an individual data point represents.

Reflect on the meaning of slope. Show **slide N.** Point out to students where the slope is in the equation given. Give students three minutes to answer the questions on the slide in their notebook.

- What does the slope of the line mean in the context of what we were measuring in the lab?
- What do the different slopes tell us about these four different water conditions?
- Which line(s) have steeper slopes?

After students have had time to reflect, ask them to share their thinking with those around them.

ASSESSMENT OPPORTUNITY

What to look/ listen for in the moment:
Students should be able to fit the function to data with support and identify that the slope from any one of the graphs shows us the relationship between changes in mass to changes in volume for water (for that water condition). (SEP: 4.2)

What to do: Review the general meaning of slope (rise over run) with students who do not remember how to make sense of slope. Emphasize how in this case, the mass changes as the volume changes. It may be helpful to write a fraction like "change in mass/change in volume" on the board before the activity to help students spend more time in their groups thinking about the meaning, rather than the definition, of slope.

Building toward: 9.B.1 Apply function fits to data, consider limitations of data analysis, and consider model reliability to identify density as altering expected patterns of energy circulation in the ocean. (SEP: 4.2, 4.3; DCI: ESS2.D.1; CCC: 4.4)

6 · CALCULATE DENSITY

13 min

MATERIALS: science notebook, calculators, sticky notes

Lead a Building Understandings Discussion. Project the graphs produced in Google Sheets. Say, *Right now we have our data represented in these graphs and with these lines of best fit. Let's discuss what the slopes of these lines tell us.*

Suggested prompt	Sample student response
What does the slope of the line mean in the context of what we were measuring in the lab? ✱	The slope from any one of the graphs shows us the relationship between changes in mass to changes in volume for water (for that water condition).
What do the different slopes tell us about these four different water conditions?	The fact that there are different slopes tells us that the ratios of change in mass to change in volume for different water conditions may be different. Maybe this has something to do with density.
Which line(s) have steeper slopes?	The saltwater samples have steeper slopes than the fresh water ones.

✱ SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Students do not have to identify all the parts of the equation until the next round of discussion. If students do not readily identify the slope and y-intercept at that point, add a sample equation to the "Mathematical Anchor Chart" and have students help you label these different parts of the equation.

Suggested prompt	Sample student response
What does it mean, that both saltwater samples have steeper slopes than the fresh water ones?	It means they have more mass per unit volume. It means that salty water has heavier stuff in a space than fresh water does.
What does that tell us about the amount or mass of the particles in saltwater compared to fresh water if we compare equal volumes of both?	The saltwater has more massive particles in it,, and/or the particles are more closely packed together.

Consider limitations. Display **Slide O.** Introduce possible limitations in the mathematical models the computer produced. Say, *OK, let's keep in mind that these mathematical models we produced from data we collected might have sources of error in them.* Project the graphs again.

Suggested prompt	Sample student response
How close are the data points to the line of best fit?	The data points are all close to the line. Only a few data points are farther away.
Do any data points look farther away from the line and therefore may have contributed a greater source of error?	One of the data points. (Accept all answers.)
What does the slope of the equation tell us?	The salty water samples have steeper slopes than the fresh water samples.
What does the y-intercept tell us about the mass of 0 mL of water? Does the y-intercept make sense?	The y-intercept is close to 0, and 0 mL of water should have a mass of 0 g. This makes sense because "nothing" should have a mass of 0.

Emphasize that we have already identified some sources of mathematical uncertainty in the data, which should make us more skeptical of how accurate the slopes of these lines are. Suggest that we calculate the slope a different way, taking into account (0,0), because we are absolutely certain that this point should be part of our mathematical model.

Project the class spreadsheet. Add a new column to table 1 with the new heading shown. Show students how to have Google Sheets use a formula to determine the slope of the line between the coordinates for that row and (0,0). The formula for cell E3 is = D3/C3. Copy and paste that formula down the column.

		data from fresh cold water		slope = change in y / change in x
group	target volume	actual volume (ml)	mass (g)	slope btwn this point and (0,0)
A	20	20	20.1	1.005
B	30	30.45	30.1	0.9885057471
C	40			
D	50			
E	60			
F	70			
G	80			
H	90			
			average ratio of mass to volume	0.9967528736

Update the cell to the right of the average to label it "estimated density of this water."

Suggest that we check the computer's calculations against what we would expect to find using our own calculators.

average ratio of mass to volume	0.9967528736	estimated density of this water

Then show students how to produce the mean (or average) of these mass-to-volume ratios using Google Sheets. Also have several students use calculators to determine the mean ratio for each data set and record them on sticky notes. We will use these numbers later when discussing significant figures.

Ask students how the mean mass-to-volume ratio compares to the slope of the best-fit line that the computer made for each scatter plot. Students will say that the values are very close.

Consider the idea of density. Say, *Scientists call the amount of stuff in a space "density." We just found density mathematically— it is the ratio of the mass of a sample to its volume.* Ask students, *Have we seen anything else in this unit that tells us about the amount of stuff in a space?* Listen for these ideas:

- We looked at data for the concentration or ppm of carbon dioxide in the atmosphere.
- We used the number of people living in an area in calculations.

ASSESSMENT OPPORTUNITY

What to look/ listen for in the moment:
Students should reason that the *y*-intercept represents the mass when the volume is 0 and should therefore be 0. (SEP: 4.2)

What to do: If students do not quickly recognize the meaning of the *y*-intercept, suggest testing it during the lab and adding it as a data point. This will help students see that the actual *y*-intercept is very different from the expected one.

Building toward: 9.B.2 Apply function fits to data, consider limitations of data analysis, and consider model reliability to identify density as altering expected patterns of energy circulation in the ocean. (SEP: 4.2, 4.3; DCI: ESS2.D.1; CCC: 4.4)

7 · INTRODUCE SIGNIFICANT FIGURES

17 min

MATERIALS: science notebook, calculator, *Significant Figures*, Mathematical Anchor Chart

Contrast the numbers from density calculations. Display **slide P.** Have the students that used calculators share their data by placing the sticky notes on the board. Discuss the suggested prompts below. Accept all answers.✱

Suggested prompt	Sample student response
What is similar and different about the numbers on the class spreadsheet and the numbers we calculated?	The numbers in the beginning are similar, but there are more numbers in the Google Sheet. Our results do not match the exact digits in the results in the Google Sheet.
This seems like an important source of variation in our results, which may be another limitation to consider. Why do you think different people got slightly different answers?	Maybe someone misentered a number. Maybe they typed in different numbers of digits or rounded differently.

✱ SUPPORTING STUDENTS IN ENGAGING IN ANALYZING AND INTERPRETING DATA

This section introduces significant figures, which can be a challenging concept. It is more important at this juncture that students understand why significant figures are beneficial than that they apply them perfectly every time. Guidance on continuing to support their use is provided in Lesson 12 and throughout the course when precision is necessary.

Suggested prompt	Sample student response
Would it be helpful if all of us had done the same thing in our calculations? Why or why not?	No, because it sounds complicated. Yes, because it would be easier to compare our results.

Display **slide Q.** Say, *Scientists want to make sure they are doing calculations the same way so that they can compare results. They also need to account for their measuring tools and instruments being different. I have an article that will tell us a little bit more about how we could do this too.*

Invite students to independently read *Significant Figures*.

ALTERNATE ACTIVITY

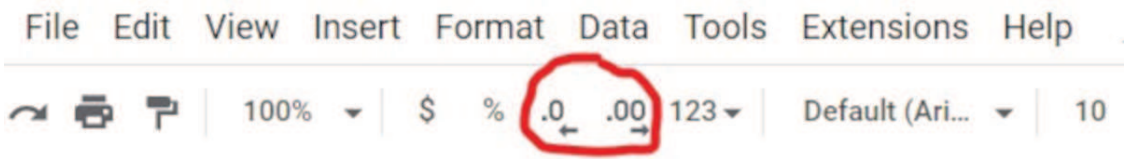
Significant Figures presents the concepts of significant figures, uncertainty, and error in measurement. The reading is at a high level, and the mathematical content may add to its difficulty. The think-aloud teaching strategy, in which you model your own thinking processes (e.g., pausing to monitor comprehension) during reading, is well-suited to this text. Find more information about this strategy in the *OpenSciEd Teacher Handbook: High School Science*.

Debrief the article in a whole-group discussion. Discuss the prompts on the slide. Then update the Google Sheet to display the data reported for mass, volume, and mass/volume using the number of significant figures the class agrees on. Use the custom format menu as described below. Then, follow up with additional discussion prompts.

ADDITIONAL GUIDANCE

This is how to set a number of significant figures shown in a Google Sheets column:

1. Select the column you want to alter.
2. Find the buttons shown below.



3. Click the buttons to adjust the number of decimal places shown.

Note that this procedure does not produce the correct number of significant figures in all cases. Rounding functions can be altered to accomplish this, even in cases where the number of significant figures does not readily correspond to the number of decimal places shown. However, this is not needed for this course.

Suggested prompt	Sample student response
What units do you think we should use for reporting density in the future?	We think we should use g/mL.
Some of the average densities appear to be really close. Is there a significant enough difference between them to explain or predict anything?	Not really. We know that the density of salty water is higher, but we still aren't sure about the density difference between cold and warm water because the numbers are very similar.
What were we trying to explain or predict with all these measurements in the first place?	We wanted to know why the engineers built the barrier on the bottom of the ocean. Specifically, why the warm, salty water was on the bottom of the ocean.
How would using too few significant figures affect our mathematical model?	Our results would not be as precise. Tiny differences would be magnified through rounding errors.
Would our mathematical model be perfect even if we used significant figures correctly?	No, because there still may have been errors in measurement or problems with the experiment.
What other errors or problems would there be?	The water we used might not be identical to that in Disko Bay in salt concentration or temperature. We may not have read the meniscus in exactly the same way.
Could these differences affect our ability to explain what is happening with the movement of water in the ocean?	Potentially, if it gave us different results.

Update the Mathematical Anchor Chart. Take this opportunity to add the following idea to the anchor chart:

- Significant figures help eliminate a source of error from our models.
- The greater the slope, the more the variable on the *y*-axis changes when the variable on the *x*-axis changes.

ASSESSMENT OPPORTUNITY

What to look/ listen for in the moment:

- Students should reason that our model is limited because our calculated answers would be more precise if we had used similar rounding procedures, and that other sources of error exist and are influencing our model. (SEP: 4.3; CCC: 4.4)
- Students should identify that error could affect our ability to explain the motion of water. (SEP: 4.3; ESS2.D.1)

What to do: Students may or may not be used to getting slightly different answers through rounding. If students do not immediately identify this as a source of error in their calculated results, ask them to compare their procedures. Discourage students from immediately jumping to the conclusion that they are right and others are wrong.

If students do not acknowledge that other sources of error exist, encourage them to think back to what they could have done better in the investigation.

Building toward: 9.B.3 Apply function fits to data, consider limitations of data analysis, and consider model reliability to identify density as altering expected patterns of energy circulation in the ocean. (SEP: 4.2, 4.3; DCI: ESS2.D.1; CCC: 4.4)

Emphasize the rules for significant figures. Display **slide R.** Give students a couple of minutes to work with partners to practice using significant figures to find the correct densities using two different sets of measurements. You may wish to ask students to do this on scratch paper and collect their work as an exit ticket.

Density of ice: 3.67 g / 3.9 mL = 0.94 g/mL
Density of microbeads: 9.1 g / 3.41 mL = 2.7 g/mL

Emphasize that because ice's volume and the microbeads mass each only have two significant figures, the answers have two significant figures. Use *Significant Figures* to clarify questions about the text on the slide as needed.

End of day 2

8 · CARRY OUT A SECOND INVESTIGATION

12 min

MATERIALS: Water-Density Layering Demonstration, science notebook

Brainstorm ideas to investigate the difference between warm and cold water. Display **slide S.** As a class, students brainstorm what we could do next to figure out if the density differences we calculated actually explain why the warm saltwater is on the bottom of the bay. Accept all answers. If it is not mentioned, suggest that we try mixing the different conditions of water in a lab so that we can visualize whether they form similar layers. Push students to think about how we can do this to make sure we get clear results.

Gather students around the demonstration area. Mix the waters together. Have ready a 1,000-mL beaker filled with 700 mL of room-temperature tap water, 3 8-mL disposable plastic pipettes, 20 mL of fresh cold water dyed yellow, 20 mL of fresh warm water dyed red, and 20 mL of salty warm water dyed green.

Tip: This investigation works best if the colors are distinct (that is, the dyes are concentrated) and you add each new water color slowly, with the tip of the pipette touching just above the surface of the water. Add about 7 mL of fresh warm water (red), then about 7 mL of salty warm water (green), and finally about 7 mL of fresh cold water (yellow).

Invite students to record their observations and ideas in their science notebook. Students will be updating the initial particle models from day 1 next.

ALTERNATE ACTIVITY

The following videos show this demonstration. They are intended for teacher use but may be used with students if supplies are not available, to refresh the class later in the unit, or to help a student catch up after missing class.

- https://youtu.be/JcNPqzdlLvs
- https://youtu.be/UXdq9a11GsY

Conduct a whole-group Consensus Discussion about the water-density layering demonstration. Display **slide T.**

Suggested prompt	Sample student response
Which is more dense, hot or cold liquid?	Cold water is more dense; the cold water forms layers under the warm water. Cold water is more dense because the particles are not moving as fast and are closer together.
What happened when we added the salty warm water and fresh cold water?	Cold water is more dense, so the cold water forms layers under the room-temperature water but above the salty warm water.
Why is the salty warm water on the bottom?	The salty warm water is on the bottom because it is more dense.
What makes the saltwater have more mass per unit volume compared to fresh water?	The salt particles.

KEY IDEAS

Purpose of this discussion: Work to a common understanding of the concept of density at the particle level. This is a Consensus Discussion because we are finalizing our thoughts about density.

Listen for these ideas:

- Though density is a property for a substance at room temperature, temperature increases tend to increase the distance between particles and thus decrease the density of the particles that make up that substance.
- When denser fluids are moved beneath less dense fluids, they tend to remain separated and flow independently of each other.

Summarize the class discussion. Say, *Let's try to explain these results beyond just saying that they are due to density differences. Let's get ready to show what we think is different at a particle level to explain why one liquid is denser than another.*

9 · UPDATE INITIAL PARTICLE MODELS FROM DAY 1

12 min

MATERIALS: science notebook, initial particle models, tape, blank paper

Revise initial water-particle models. Display **slide U** and the particle models from earlier in the lesson. Lead students in a brief discussion about how we should revise the models.

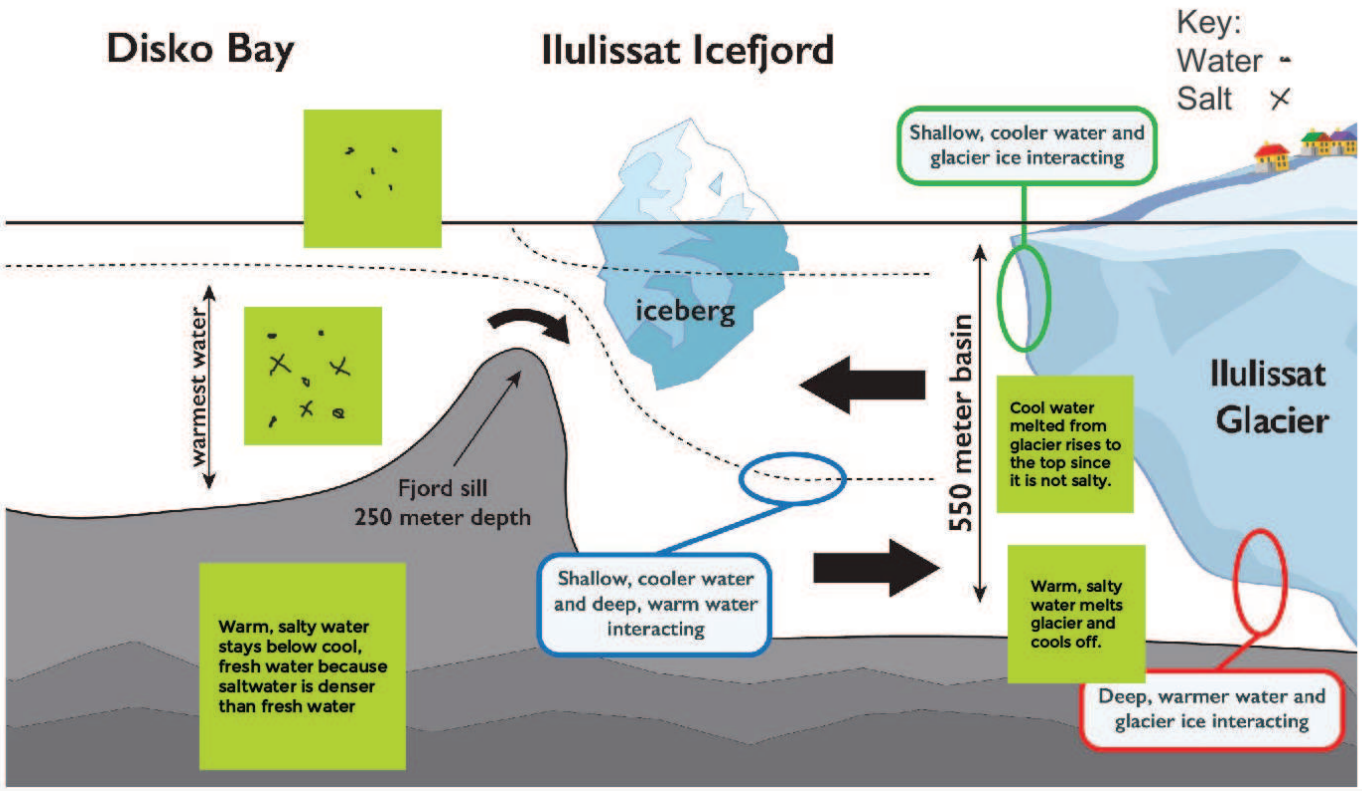
Suggested prompt	Sample student response
How should we revise these models based on what we figured out today?	We could indicate where the different conditions of water would layer. We could exaggerate how much the particles are spread out.
How do the temperature and saltiness of water affect its movement in the ocean?	Warmer water tends to rise to the surface. Salty water tends to sink.

Conduct a whole-group Consensus Discussion about density differences in the water at the glacier. Display **slide V.** An example is shown for how to annotate the slide during the discussion to reflect students' ideas. This can be done by writing or drawing on pieces of paper and taping them to the screen, with oversized sticky notes, or by annotating a screenshot of the slide.✱

Suggested prompt	Sample student response
So was it a reasonable assumption to show that salty warm water flows along the bottom of the bay and the icefjord?	Yes.
How is the water above it different?	It is colder and fresher, but still less dense than the saltwater below it.
According to the berm design solution, what happens to the salty warm water when it reaches the base of the glacier? (Point to the arrow next to the glacier.)	It melts the base of the glacier.
The glacier's ice is made of fresh water, so when the fresh water melts at the base, how does it interact with the salty warm water?	The fresh cool water rises to the top. The salty warm water stays at the bottom.
*But what might also happen to the temperature of the salty warm water **after** it melts the ice and fresh water is mixed into it?*	It might cool off.
How is energy transferred in this process?	It is transferred from the salty, warm water moving into the bay to the ice, which then melts, and then the cool water rises.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

This annotation is done instead of individual modeling so that students can focus on energy transfer and matter movement, rather than the practice of modeling.



Take a photo of the annotated screen for future use.
Say, *So far in this unit, we have mostly focused on energy transfer through radiation, or light. But this process seems different. Why is the energy being transferred in this system as the water moves around the bay?* Listen for these ideas:

- Salty warm water is denser than fresh cold water.
- The water conditions have different densities.

Point out that in *OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)* or a similar unit, students used convection to explain global ocean currents. Say, *We now know that the ocean is transferring energy. Where does that energy come from, and how might it affect the Earth's climate as it transfers throughout the ocean or to other systems?* Listen for ideas like these:

- The energy comes from the Sun (or from the Sun, through the atmosphere).
- The ocean might transfer energy to ice, melting it and causing albedo-related feedback loops.
- The ocean might transfer energy to land or air, heating it up. This could make temperatures for people even warmer.

Define convection. Say, *This phenomenon of less dense liquids or gases rising or floating above denser liquids or gases is pretty common. We know from the phrase "hot air rises" that this often involves a transfer of energy. Scientists have a name for energy transferred through this process--convection.*

ADDITIONAL GUIDANCE	If you wish, you may add "convection" alongside radiation as an energy transfer mechanism on the "Rules for Energy Transfer."

Update personal glossaries. Show **slide W.** Give students a moment to add *convection* to their personal glossaries as well as any others that came up in the lesson. Other potential words include *significant figures, meniscus,* and *density*.

ASSESSMENT OPPORTUNITY	**What to look/ listen for in the moment:** Students should show that matter behaves differently based on the energy stored within it and energy originates from the Sun before reaching the ocean. (ESS2.D.1; CCC: 5.4) **What to do:** Encourage students to use evidence from their investigations in their models. If students are not representing these ideas, ask them to consider what they know about what happens to particle speed and spacing as temperature increases. Ask students to consider how they would represent a greater density when there is more than one type of particle mixed together, compared to when there is only water. Encourage them to add bullet points referencing the data from their experiments where appropriate as evidence for their models. **Building toward: 9.A.4** Evaluate a question about the energy circulation in the ocean to see if it is testable and select appropriate tools to collect and record data in an investigation, considering predicted energy flows within the ocean system. (SEP: 1.5, 3.4; DCI: ESS2.D.1; CCC: 5.4)

10 · UPDATE PROGRESS TRACKERS

4 min

MATERIALS: None

Update Progress Trackers. Display **slide X** and give students a few minutes to add to their Progress Trackers. Then debrief as a class.

Question	What we figured out in words/pictures
Why does warm salty water sink to melt a glacier?	*Substances normally sink because they are more dense, and cooler substances are usually denser. But because it has salt in it (which increases the mass), warm saltwater sinks to the bottom of the bay, where it can melt the bottom of the glacier.*

Say, *We cared about the warm salty water because it is melting the glacier. Melting depends on energy, but we have not modeled the role energy has yet. Let's think about that.*

11 · MODEL ENERGY TRANSFER

9 min

MATERIALS: science notebook, "Rules for Energy Transfer", *Revisiting Questions*

Turn and Talk. Display **slide Y** and ask students to take out *Revisiting Questions* from last class. Invite students to add to their models as they turn and talk with a partner.✱

COLLABORATION

Students should be becoming more independent in energy transfer modeling at this point. If you wish to see where students are individually, this can be an opportunity for students to provide peer feedback using the protocols shared in the *OpenSciEd High School Teacher Handbook.* Have students begin this work individually, then share with a partner using the peer feedback protocol.

Suggested prompt	Sample student response
What do we know now that we could add to our model from Lesson 8?	We could add that warm water moves to the glacier through convection before transferring energy to it. We could add cool water off to the side.
Which parts of the Lesson 8 model have we not focused on or explained yet?	We have not explained what is going on with the other, unlabeled arrows as energy transfers to the ice.

Draw connections between energy and matter. Say, *We know how the energy gets to the glacier, but we have not figured out how it actually causes the glacier to melt. That might be a topic for next time, but there is an idea I want to highlight here.* Ask, *What types of things have we included in our different models in this lesson?* Listen for these ideas:

- Energy
- Matter
- Movement

Say, *We have used matter and energy together in this lesson to explain what is happening at the berm. We actually did this in our first lesson, too. Scientists can use matter and energy as different lenses to think about the same problem.*

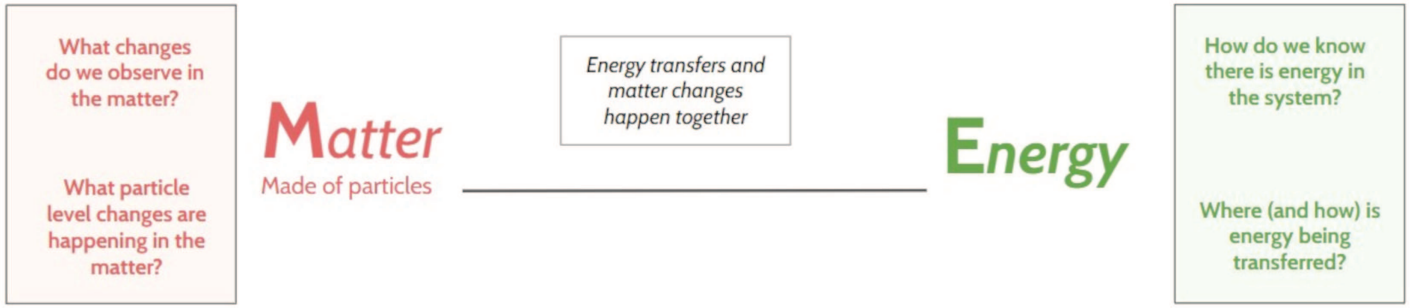
Add to the "Rules for Energy Transfer" anchor chart. Display **slide Z** and use the prompts to elicit ideas that we can add to our anchor chart. Start by drawing boxes labeled "Matter" and "Energy."

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

This diagram is the start of the "Matter-Energy-Forces triangles" (or M-E-F triangle for short) which will be more completely fleshed out in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)* and used throughout the course. This tool helps students identify the ways in which changes in matter, energy transfers, and force fields interact to cause changes in our physical world. Retain this diagram or be ready to reproduce it at the start of the next unit.

Suggested prompt	Sample student response
How do energy and matter work together to affect glacier melt?	Matter changes from solid to liquid when energy is transferred to it. Particles speed up when they have more energy. Warmer substances are usually less dense, unless they have heavier matter in them. Density differences allow energy to transfer through convection.
(Sum up by saying that energy transfers and matter changes seem to happen together. Draw a line between the boxes.) *What are some of the questions we have asked ourselves about energy?*	Where is energy in the system? Where or how is the energy being transferred?
(Add the energy questions next to the energy label.) *What are similar questions we could ask ourselves about matter?*	What is happening with the particles in matter? How are the particles moving or changing?

Capture this in a diagram at the bottom of the anchor chart, as shown. Use student language to Add a second sheet if needed.



ALTERNATE ACTIVITY

If students still have questions about matter and energy flows at the bottom of the glacier, consider providing https://www.jpl.nasa.gov/news/the-anatomy-of-glacial-ice-loss as a resource. This article provides visuals as well that may be beneficial to share with the whole class.

12 · EXIT TICKET

8 min

MATERIALS: copy of https://docs.google.com/forms/d/1kAZBHTqV9mI57xxp-GgkoGeYvt-aYWD1TpzGgdsRDDU/copy

Shift to the Exit Ticket. Display **slide AA**. Say, *We have figured out a lot today. This exit ticket will give you a chance to show where you are on these ideas that we have developed.* Give students time to complete the exit ticket found in the copy of https://docs.google.com/forms/d/1kAZBHTqV9mI57xxp-GgkoGeYvt-aYWD1TpzGgdsRDDU/copy.

ASSESSMENT OPPORTUNITY

What to look/ listen for in the moment: See *Lesson 9 Exit Ticket Key* for guidance.

What to do: See *Lesson 9 Exit Ticket Key*.

Building toward: 9.B.4 Apply function fits to data, consider limitations of data analysis, and consider model reliability to identify density as altering expected patterns of energy circulation in the ocean. (SEP: 4.2, 4.3; DCI: ESS2.D.1; CCC: 4.4)

Additional Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HSN.Q.A.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; ~~choose and~~ interpret the ~~scale and~~ origin in graphs and data displays.

CCSS.MATH.CONTENT.HSN.Q.A.2: Define appropriate quantities for the purpose of descriptive modeling.

CCSS.MATH.CONTENT.HSF.LE.A.2: Construct linear ~~and exponential~~ functions, ~~including arithmetic and geometric sequences,~~ given a graph ~~a description of a relationship,~~ or two input-output pairs (include reading these from a table).

CCSS.MATH.CONTENT.HS.S-ID.7: Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of the data.

CCSS.MATH.CONTENT.HSF.IF.B.6: Calculate and interpret the average rate of change of a function (presented symbolically or as a table) over a specified interval. ~~Estimate the rate of change from a graph.~~

CCSS.MATH.CONTENT.HS.S-ID.6b: Represent data on two quantitative variables on a scatter plot, and describe how the variables are related: Informally assess the fit of a function by plotting and analyzing residuals.

CCSS.MATH.CONTENT.HS.S-ID.6c: Represent data on two quantitative variables on a scatter plot, and describe how the variables are related: Fit a linear function for a scatter plot that suggests a linear association.

CCSS.MATH.CONTENT.HS.S-ID.7: Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of the data.

Students use units to make meaning of the mass-volume graph. They begin to identify the meanings of the slope and *y*-intercept of a best-fit line, in context, after constructing the function. They calculate the average rate of change as they seek to understand if the slope represents density.

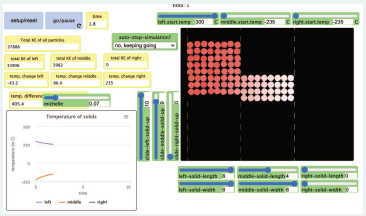
LESSON 10: How can we measure the energy transfer a berm prevents?

PREVIOUS LESSON *We developed particle-level and energy models of water at different temperatures and salinities. We collected data on the mass and volume of water under these different conditions and calculated its density. We revised our models, explained how berms decrease energy transfer to the glacier, and completed an exit ticket.*

THIS LESSON

INVESTIGATION

3 days



We plan and carry out an investigation to figure out if we can measure energy transfer between warm and cool water. We try to mathematically model our results using graphs and gain some additional evidence that energy is conserved. We need more information about what this looks like at a particle level, so we conduct an initial investigation with a simulation. We then use the simulation to develop a mathematical model of energy transfer through conduction. This model includes the new idea of specific heat.

NEXT LESSON *We will realize that we do not know all the factors that affect the amount of ice melt, so we will plan and conduct an investigation to measure how heat and mass are related. We will consider how our results might help us address glacier melt and sea level rise.*

BUILDING TOWARD NGSS

HS-PS3-1, HS-PS3-4, HS-ESS2-2, HS-ESS2-4, HS-ESS3-1, HS-ESS3-5, HS-ESS3-6, HS-ESS2-7

WHAT STUDENTS WILL DO

10.A Plan and conduct investigations of energy transfer between objects in order to quantify conserved energy. (SEP: 3.2; DCI: PS3.A.1; CCC: 5.3)

10.B Use simple limit cases to test a simulation of a closed system in which energy and matter are conserved that shows how an uncontrolled system with two different-temperature objects eventually reaches uniform energy distribution. (SEP: 5.4; DCI: PS3.B.5; CCC: 5.1)

10.C Apply techniques of algebra and functions to quantify, describe, and mathematically model the energy flows that result in measurable temperature changes in order to quantify conserved energy. (SEP: 5.3; DCI: PS3.B.3; CCC: 4.3)

WHAT STUDENTS WILL FIGURE OUT

- This is what happens when two objects/samples at different temperatures are in contact with one another:
  - Energy transfer between two objects/samples initially at different temperatures will cause both to eventually reach the same final temperature, which will be between the initial temperatures.
  - The mass and temperature of each sample affects where the final temperature stabilizes (ΔT depends on m).
  - Energy is conserved. It flows between the objects but is not created or destroyed.
  - Conduction is the transfer of energy through direct contact as particles collide.
  - The specific heat (c) of a substance or mixture tells us how much energy in calories is needed to change 1 gram of it by 1 °C.
  - Heat transfer Q into or out of a substance can be found by multiplying the specific heat, mass, and temperature change.

Lesson 10 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		**NAVIGATE** Support students in thinking about how they could figure out more about energy transfer.	A-C	"Rules for Energy Transfer" anchor chart
2	8 min	✓	**PLAN AN INVESTIGATION FOR LIQUID-LIQUID ENERGY TRANSFER INTERACTIONS** Introduce the materials available for the experiment.	D-F	Investigation Anchor Chart, Material Orientation
3	7 min		**SET UP THE EXPERIMENTAL CONDITIONS** Support students in recording procedures and constructing data tables.	G-H	Liquid-Liquid Investigation Setup
4	11 min		**COLLECT AND SHARE DATA** Collect data and share and record class results in a spreadsheet.	I-J	computer, copy of https://docs.google.com/spreadsheets/d/1jHmpxoaOSwF2EwqD4X6vThS5_9mzO83hJZBeNzUTPw8/copy
5	11 min		**HAVE A BUILDING UNDERSTANDINGS DISCUSSION** Lead a discussion in which students share their findings and propose initial explanations for their findings.	K-L	chart paper, markers, https://docs.google.com/spreadsheets/d/1jHmpxoaOSwF2EwqD4X6vThS5_9mzO83hJZBeNzUTPw8/copy
6	3 min		**NAVIGATE** Give students time to do a Stop and Jot activity to navigate into the next day.	M	
					End of day 1
7	10 min		**PREDICT TEMPERATURE CHANGES** Build a mathematical model that can be used to predict temperature changes.	N-O	*Summarizing Our Investigations*, 2 sheets of graph chart paper
8	10 min	✓	**MAKE SENSE OF THE AREAS** Build the idea of energy conservation using the areas of the graph.	P-Q	*Summarizing Our Investigations*, Key Ideas chart paper
9	4 min		**INTRODUCE A SIMULATION** Show students a screencast to familiarize them with the layout of the simulation.	R	computer, https://www.youtube.com/watch?v=f74iIJtGrtg&list=PLSLDxqPb5NQlFczx8-5QZIRw3xp0NGTRS&index=6
10	6 min	✓	**CARRY OUT AN INITIAL INVESTIGATION** Give students time to play with the simulation to get a sense of how it works and to notice and wonder about what it shows.	S-T	https://www.openscied.org/general/energytransfersolids/, computer
11	8 min	✓	**SHARE OBSERVATIONS FROM THE INITIAL INVESTIGATION** Have students use their initial observations to describe how different variables impact the rate and amount of energy transfer taking place, and to consider how the simulation could explain real-world phenomena.	U-V	*Summarizing Our Investigations*, Key ideas chart paper

Part	Duration		Summary	Slide	Materials
12	5 min		**NAVIGATE** Return to the anchor to realize that we need to generalize our simulation to different materials.	W	
13	2 min		**HOME LEARNING** Brief students on the home learning assignment to apply their investigation findings to a real-world scenario.	X	
					End of day 2
14	4 min		**NAVIGATE** Give time for a Turn and Talk and whole-class discussion of the home learning assignment.	Y	completed home learning assignment
15	4 min		**INTRODUCE UPDATED SIMULATION** Help students synthesize ways they can use the updated simulation to test their predictions from day 2.	Z	https://www.openscied.org/general/energytransfersubstances/, computer
16	8 min		**PLAN AN INVESTIGATION** Guide students to structure their investigations to incorporate two independent variables (mass and state of matter) and design a data table that allows them to record and quantify proportional changes in temperature.	AA	chart paper or whiteboard, copy of https://docs.google.com/spreadsheets/d/1UpxdUAbBWQsi1WxT0JKhUJA26XRssZ97xR-mcdIBlw0/copy, "Rules for Energy Transfer" anchor chart, Investigation Anchor Chart
17	9 min		**CARRY OUT AN INVESTIGATION WITH THE SIMULATION** Give students time to collect data using the simulation.	BB-CC	computer, https://www.openscied.org/general/energytransfersubstances/
18	15 min		**HAVE A BUILDING UNDERSTANDINGS DISCUSSION** As a class, have students share their findings and build a quantitative model to represent the relationship between mass, temperature change, and energy transfer in the system.	DD-FF	copy of https://docs.google.com/spreadsheets/d/1UpxdUAbBWQsi1WxT0JKhUJA26XRssZ97xR-mcdIBlw0/copy, Key ideas chart paper
19	5 min		**NAVIGATE** Have students complete and turn in the handout to help navigate into Lesson 11.	GG	*Summarizing Our Investigations*
					End of day 3

Lesson 10 • Materials List

	per student	per group	per class
Material Orientation materials	• science notebook		• 2 Styrofoam cups with lids • 1 digital thermometer with metal probe • 1 digital scale • 4 water baths of varying temperatures
Liquid-Liquid Investigation Setup materials	• science notebook • indirectly vented chemical splash goggles • nonlatex aprons • nitrile gloves	• 2 Styrofoam cups with lids • 1 digital thermometer • 1 digital scale	• 4 water baths of varying temperatures
Lesson materials	• science notebook • *Summarizing Our Investigations* • completed home learning assignment	• computer • copy of https://docs.google.com/spreadsheets/d/1jHmpxoaOSwF2EwqD4X6vThS5_9mzO83hJZBeNzUTPw8/copy • https://www.openscied.org/general/energytransfersolids/ • chart paper or whiteboard • https://www.openscied.org/general/energytransfersubstances/	• "Rules for Energy Transfer" anchor chart • Investigation Anchor Chart • chart paper • markers • https://docs.google.com/spreadsheets/d/1jHmpxoaOSwF2EwqD4X6vThS5_9mzO83hJZBeNzUTPw8/copy • 2 sheets of graph chart paper • Key Ideas chart paper • computer • https://www.youtube.com/watch?v=f74iIJtGrtg&list=PLSLDxqPb5NQlFczx8-5QZIRw3xp0NGTRS&index=6 • Key ideas chart paper • https://www.openscied.org/general/energytransfersubstances/ • copy of https://docs.google.com/spreadsheets/d/1UpxdUAbBWQsi1WxT0JKhUJA26XRssZ97xR-mcdIBlw0/copy

Materials preparation (60 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Make a copy of https://docs.google.com/spreadsheets/d/1jHmpxoaOSwF2EwqD4X6vThS5_9mzO83hJZBeNzUTPw8/copy to use for class data entry on day 1.

Make a copy of https://docs.google.com/spreadsheets/d/1UpxdUAbBWQsi1WxT0JKhUJA26XRssZ97xR-mcdIBlw0/copy to use for class data entry on day 2. https://docs.google.com/spreadsheets/d/1fMxhrOOT24K8O7KXhi2MiyUb-iItaKnD3dElUksZ_zg/copy gives an example of what this might look like after the investigation. If you are unable to access these documents, see *Spreadsheet References* for screenshots.

Test the video for orienting to the simulation:

- https://www.youtube.com/watch?v=f74iIJtGrtg&list=PLSLDxqPb5NQlFczx8-5QZIRw3xp0NGTRS&index=6

Check to see if the simulation links work on your students' devices, and familiarize yourself with the interface to provide troubleshooting help as students use the simulations:
- https://www.openscied.org/general/energytransfersolids/
- https://www.openscied.org/general/energytransfersubstances/

Have the "Rules for Energy Transfer" anchor chart ready for use during class.

Read through sample student responses so you can anticipate particular key ideas that you will highlight when guiding students through the model building on days 2 and 3.

Material Orientation
- **Group size:** whole class
- **Setup:**
    - Gather a set of the following materials to introduce to the class:
        - 2 Styrofoam cups with lids
        - 1 digital thermometer
        - 1 digital scale
- **Safety:** None
- **Disposal:** Let the cups dry out for us in other sections and in Lesson 11.
- **Storage:** All materials can be stored and reused from year to year.

Liquid-Liquid Investigation
- **Group size:** 5 students
- **Setup:**
    - Prepare 4 water baths. For the hot-water bath, use a hot plate or kettle to heat the water to almost boiling. For the warm-water bath, you can use room-temperature water or warm water from the faucet. For the cool-water bath, chill the water in a refrigerator. For the cold-water bath, chill the water in a refrigerator with a few ice cubes in the container. Ensure that at least 600 mL of each type is available. If you wish to simplify the lab, you may use cool or cold water and room-temperature water, providing 1.2 L of each for the class to share.
    - Gather a set of the following materials for each group. All materials can be collected and reused for other class periods.
        - 2 Styrofoam cups with lids
        - 1 digital thermometer
        - 1 digital scale
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*. Discuss with students how to transport the water for the hot-water bath to prevent burns. If you are heating water in a beaker on a hot plate, it is recommended that you transport and dispense the water for the hot-water bath to groups. In addition:
    - Wear indirectly vented chemical splash goggles, nitrile gloves and non/latex apron during the setup, hands-on, and takedown segments of the activity.
    - Secure loose clothing, wear closed-toe shoes, and tie back long hair.
    - Immediately wipe up any spilled liquids - slip/fall hazard.
    - Follow procedures set up by your instructor for disposal of materials.
    - Use caution when working with heated liquids–they can burn skin.
    - Use only GFI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
    - Use caution when working with glassware or plasticware - can break and cut/puncture skin.
    - Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
    - Direct supervision will be required during all aspects of this activity.
- **Disposal:** None
- **Storage:** All materials can be stored and reused from year to year.

Lesson 10 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **PS3.A.1: Definitions of Energy.** Energy is a quantitative property of a system that depends on the motion ~~and interactions of matter and radiation within that system~~. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another ~~and between its various possible forms~~.
- **PS3.B.5: Conservation of Energy and Energy Transfer.** Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., ~~water flows downhill~~, objects hotter than their surrounding environment cool down).
- **PS3.B.3: Conservation of Energy and Energy Transfer.** Mathematical expressions, which quantify how the stored energy in a system depends on ~~its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and~~ speed, allow the concept of conservation of energy to be used to predict and describe system behavior.

Students first identify that the area of the mass vs. temperature change graph in the Liquid-Liquid Investigation might represent energy. Then, they use a simulation to show that energy is conserved in a system even as it transfers between particles through conduction. Students then have the evidence to use $m \cdot \Delta T$ as a proxy for heat. Finally, they use more complex simulations to identify the slope of the Q vs. $m \cdot \Delta T$ graph as specific heat capacity and define the relationship as $Q = c \cdot m \cdot \Delta T$.

Students leverage experiences throughout the course, detailed in *Investigation Anchor Chart*, to plan an investigation individually for the first time, as well as a complex investigation collaboratively (SEP: 3.2). They spec out a simulation and use simple limit test cases to see if it "makes sense" (SEP: 5.4) and use their understanding of functions from Lesson 9 to represent heat transfer through conduction (SEP: 5.3). They are also able to quantitatively show energy conservation for the first time in the course (CCC: 5.1) and quantitatively track energy between objects (CCC: 5.3). In this lesson, students model energy flows mathematically and at a wide variety of scales, from the macroscopic to the particle level (CCC: 4.3).

In this lesson, students will co-construct a definition for the following words, which they should add to their personal glossaries: *equilibrium, conduction, heat, specific heat,* and *closed system*. **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Where We Are NOT Going

The heat transfer required to melt a substance, along with the equation $Q = m \cdot L$, will not be investigated in this lesson. Instead, students will figure out this step in Lesson 11, in addition to determining the specific heat of water.

Students do not consider or within the system here or consider energy transfer between forms. Radiation was already discussed in Lesson 6 and will return more explicitly in *OpenSciEd Unit P.5: How do we use radiation in our lives and is it safe for humans? (Microwave Unit)*. Energy transfer between forms (kinetic energy and energy in the field) will be considered in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*. *Electrostatics Unit* will also help students build the idea that energy depends on configuration, an idea that will be quantified in *OpenSciEd Unit P.4: Meteors, Orbits, and Gravity (Meteors Unit)*.

In this lesson, students will also consider how more uniform energy distribution is the norm at the microscopic level. They will not consider how objects move downhill in a similar fashion until *Meteors Unit*.

Students will have other opportunities in the course to consider risk in investigations and refine their investigation designs after feedback. They will also use simple limit cases in scenarios beyond simulations elsewhere in the course, and will apply techniques of algebra and functions to solve engineering problems in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*.

Students already modeled energy flows physically in Lesson 3 and will consider energy and matter flows together in Lesson 13, using a computational model. Here, the focus is on mathematically modeling energy flows. Information flows will not be modeled in this unit.

LEARNING PLAN for LESSON 10

1 · NAVIGATE

5 min

MATERIALS: "Rules for Energy Transfer" anchor chart

Think back to energy throughout the unit. Display **slide A.** Say, *Last lesson, we focused on the movement of warm water to the bottom of the bay.*

Display **slide B.** Point out to students that at the end of Lesson 9, we were wondering about how energy transfer actually happens once warmer water gets to the base of the glacier. Remind students of the "Rules for Energy Transfer" and lead a brief discussion.✱

Suggested prompt	Sample student response
Which of these rules do we know enough about to apply to this system (ice melt at the base of the glacier with no berm)?	We can say how the energy gets to the base of the glacier.
Which of them do we need more information about to apply?	Once the energy gets to the glacier, we do not know how to label its movement. It's not radiation or convection. We do not know how much energy is flowing or if the berm is really able to stop enough from reaching the glacier to be "worth it." We do not know how thick to draw lines on an energy transfer model for the berm.
To clarify, we do not know how much energy is flowing with the warmer and cooler water masses or how much energy actually gets to the base of the glacier?	That's right.

Navigate toward an investigation. Show **slide C.** Say that if we want to figure out how much energy is flowing with the warmer water to the glacier, we need to actually measure it, or at least measure variables that affect it. We can do this with ice, but it might be easier to do it with two masses of water first, as in the green area where the warmer and cooler water are in contact. Discuss the prompts on the slide.

Suggested prompt	Sample student response
How could we measure the energy transfer between different masses of water?	We could get an energy meter. We could measure something sort of like energy, like temperature.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

You may use the energy transfer model developed in Lesson 9 to support students' thinking here. Highlight that it seems like we know what arrows to put, but we do not always know how to label them or how thick they should be.

Suggested prompt	Sample student response
What factors or variables could influence the amount of energy transfer?	Temperature. Number of particles/mass. Area of matter in contact. Length of time they touch. Density.
What equipment would we need to investigate these factors?	Thermometers. Scales. Rulers.

2 · PLAN AN INVESTIGATION FOR LIQUID-LIQUID ENERGY TRANSFER INTERACTIONS

8 min

MATERIALS: Material Orientation, Investigation Anchor Chart

Develop the question we are planning an experiment for. Show **slide D**. Discuss and decide on the question that we are trying to investigate as a class. This will be something like:

- What affects how much energy transfers between warm and cool water when they are mixed together?
- What affects how much energy warm water is able to transfer?

Write the question on the board and have students record this question at the top of their new notebook page.

Introduce the materials available for the experiment. Show **slide E**. Say something like, *Let's take a look at some of the materials we have available for our experiment and start brainstorming how we could use them.* Hold up each of the items below and discuss possible uses. Anticipated student responses include:.

- **Hot, warm, cool, and cold water baths** -- *We can use these as our starting water samples.*
- **2 foam cups with lids** -- *We can use these to hold the water. They also provide insulation and an air barrier to keep the water temperature stable.*
- **Thermometer** -- *We can use this to measure the initial temperatures of the two water samples, and to measure the final temperature after combining them and equilibrium is reached.*
- **Digital scale** -- *We can use this to measure the mass of our water samples.*

When you introduce the foam cups with lids, ask why the lids are important. Students should realize that open containers will decrease the accuracy of results, as they allow heat to escape.

When you introduce the digital scale, you may need to remind students of the "tare" button which sets the scale back to zero. They will need to tare the scale after placing the empty cup and lid on it because students are measuring only the mass of the liquid water.

Argue for different investigation plans.✱ Show **slide F** and display the Investigation Anchor Chart**.** Identify that we want to investigate how exactly temperature and mass affect energy flow, and if there is any difference between different states of matter. Ask students to consider the two types of investigations proposed in the slides:

✱ SUPPORTING STUDENTS IN ENGAGING IN ARGUMENT FROM EVIDENCE

The practice of argumentation is one where students evaluate the evidence at hand and decide whether it supports or refutes one or more claims. In this particular context, students are arguing for a specific investigation structure, rather than a scientific claim. It is not important that students come to the "one correct answer," but rather that they support their ideas with different logistical concerns serving as evidence and reasoning.

A. Perform one trial for many conditions (e.g., testing many different masses of water one time each).
B. Perform many trials for fewer conditions (e.g., testing only a few masses of water several times each and averaging the results).

Say, *There are benefits and drawbacks to both types of investigations. What do you think these might be? Why might they give us different information?* Have students turn to their partner and discuss what they think, then give students a minute to summarize what they discussed.

Suggested prompt	Sample student response
What are the benefits of carrying out one trial for many conditions?	We will have diverse data points that tell us what happens across various scenarios. We can see a trend.
What are drawbacks to carrying out one trial for many conditions?	Fewer results to average out for precision. We wouldn't know if we messed up a trial because we don't have a comparison.
What are the benefits of carrying out many trials for fewer conditions?	More results to average out for precision. If we mess up one trial, it won't affect our results because we will know it's an outlier.
What are drawbacks to carrying out many trials for fewer conditions?	We won't have as much information on what might happen under different conditions. We won't be able to see a trend.
Do we really have to choose in this context?	No, because the materials are relatively inexpensive. Yes, because we have limited amounts of resources and time.

Move forward with students' conclusions. If they are in disagreement, you may wish to suggest some sort of compromise. The class data sheet https://docs.google.com/spreadsheets/d/1jHmpxoaOSwF2EwqD4X6vThS5_9mzO83hJZBeNzUTPw8/copy and materials list were developed for each group to investigate three conditions with seven trials of each. However, the data sheet can be readily modified to suit different class needs if materials are available.

You may wish to add a note to the Investigation Anchor Chart on the class conclusion about balancing the number of trials and number of different conditions.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should articulate investigation plans that consider what data to collect (mass and temperature) , how much data to collect (more trials or more conditions), and how keeping lids on improves the accuracy of data. (SEP: 3.2)
- Students should explicitly consider trade-offs between the number of trials and cost or time. (SEP: 3.2)

What to do: If students do not raise these issues, bring them up more explicitly using prompts like the following:

- What are the advantages of collecting more data points for the same set of conditions? Of investigating different conditions?
- What are the drawbacks of different experimental setups?
- Why is keeping the lid on the foam cup a reasonable step to take to promote reliable measurement? What steps might we decide not to take because they would require too much time?

Building toward: 10.A.1 Plan and conduct investigations of energy transfer between objects in order to quantify conserved energy. (SEP: 3.2; DCI: PS3.A.1; CCC: 5.3)

3 · SET UP THE EXPERIMENTAL CONDITIONS

7 min

MATERIALS: Liquid-Liquid Investigation Setup

Prepare for the investigation. Assign students to their groups and distribute materials for the groups to use to set up their testing conditions.

Record procedures in science notebooks. Show **slide G**. Remind students that recording their procedures makes it possible for others to replicate their tests if needed. Ask students to first outline their procedures for three different testing conditions in their notebooks, and then create the data tables to record the information they need to collect before and after combining the water samples for each condition. An example is included in *Liquid-Liquid Investigation Notebook Example*. Have students try this individually, then compare with their groups.

Show **slide H**. Remind students of the safety guidelines they should follow when completing investigations. Call special attention to the third-to-last bullet on this slide as it references heated liquids. Some groups may choose to use hot water in one or more of their testing conditions.

4 · COLLECT AND SHARE DATA

11 min

MATERIALS: science notebook, computer, copy of https://docs.google.com/spreadsheets/d/1jHmpxoaOSwF2EwqD4X6vThS5_9mzO83hJZBeNzUTPw8/copy

Monitor setup work. Display **slide I**. As groups begin measuring initial temperatures and mass, check to see that they are using the "tare" button correctly and that they are taking the temperatures of their water samples right before mixing them together to get the most accurate measurements. Additionally, as groups collect their final temperature data, check to see that they are waiting for the thermometer to reach a stable temperature before recording the results.

Share and record class results. Show **slide J**. Bring students back together to have each lab group share their results with the whole class. Ask students to calculate the change in temperature for both water samples in all their testing conditions before adding their results to the class copy of https://docs.google.com/spreadsheets/d/1jHmpxoaOSwF2EwqD4X6vThS5_9mzO83hJZBeNzUTPw8/copy.

Collect cups, lids, scales, and thermometers to reuse across classes.

5 · HAVE A BUILDING UNDERSTANDINGS DISCUSSION

11 min

MATERIALS: science notebook, chart paper, markers, https://docs.google.com/spreadsheets/d/1jHmpxoaOSwF2EwqD4X6vThS5_9mzO83hJZBeNzUTPw8/copy

KEY IDEAS

Purpose of this discussion: This is the first of several Building Understandings discussions in this lesson in which students come to important ideas about energy. Key ideas from these discussions will be recorded on chart paper and appended to the class's "Rules for Energy Transfer" anchor chart. This first discussion focuses on establishing a general pattern in the final temperatures that results from the energy transfer taking place in the experiment.

Listen for these ideas:

1. Energy transfer between two objects/samples initially at different temperatures will cause both to eventually reach the same final temperature, which will be between the initial temperatures.
2. The mass and temperature of each sample affect where the final temperature stabilizes (ΔT depends on m).✱

Make sense of investigation findings. Show **slide K.** Gather students in a Scientists Circle. Begin by having students share the patterns and trends they observed during their investigations. Label the chart paper "Key Ideas" and record students' observations, or ask a student to be the "scribe" for the day to keep track of what is said.

Suggested prompt	Sample student response
What patterns and trends did you observe within your group's investigation?	The farther apart the starting temperatures of the two different water samples, the more the temperature would change in each. Mixing the water helped it more quickly reach a stable temperature. If the samples were not the same mass, the final temperature ended up closer to the larger sample's initial temperature.
How did the final temperature compare to the initial temperatures? Was it ever greater than both of the initial temperatures? Was it ever less than both?	The final temperatures are very close or the same, regardless of the initial temperatures. The final temperatures end up somewhere in-between the initial temperatures.

Establish a mathematical relationship.✱ Say, *I hear that the temperatures follow a set pattern. When we see a pattern with numbers, we can model it with math since it is sometimes easier to represent the relationship using symbols.* On the chart paper, write the relationship shown in the image, which summarizes key idea #1: *Energy transfer between two objects/samples initially at different temperatures will cause both to eventually reach the same final temperature, which will be between the initial temperatures.*

✱ ATTENDING TO EQUITY

Universal Design for Learning: Because the Δ symbol is new, it is recommended to write the text "change in" alongside it so that all students can recall its meaning more easily.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

In the next step, students will begin to discuss how we can determine the exact final temperature and the amount of energy transfer. These are challenging ideas, and it is not vital at this point that students have determined an exact relationship between the masses of the objects, the final temperatures, and the energy transfer.

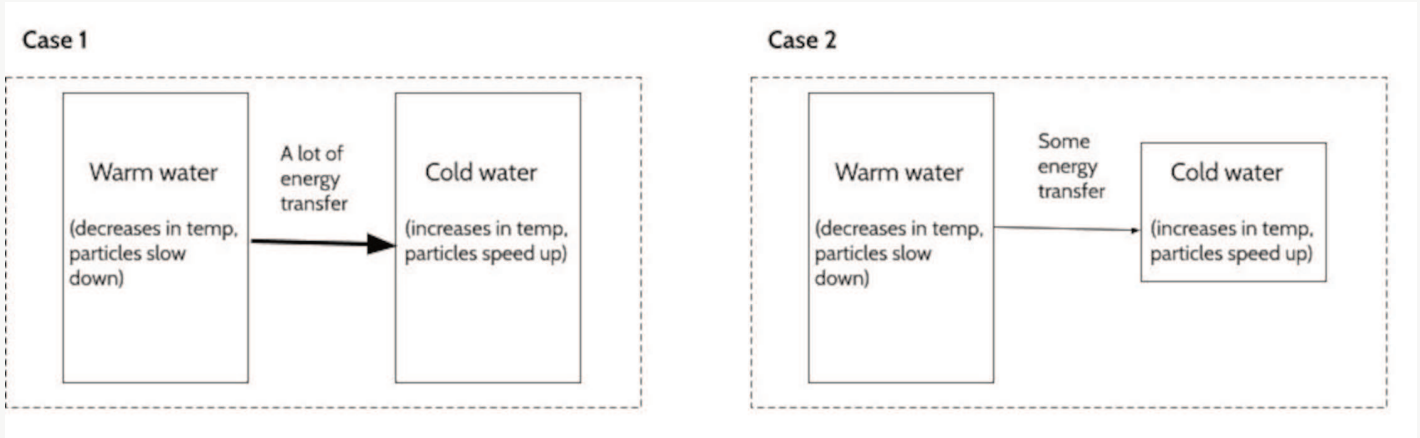
This is students' first use of subscripts in the course. Point out that subscripts are the way scientists keep track of separate pieces of information, in this case three different temperatures (cold-initial, final, and warm-initial).

Establish patterns in final temperatures. Display **slide L** and continue the discussion, starting with the prompt on the slide.

Suggested prompt	Sample student response
What would the final temperature of the system be in each of these cases?	In Case 1, it would be 15°C. In Case 2, it would be somewhere between 90°C and 10°C. In Case 2, it would be closer to 90°C.
Why is Case 1 easier to figure out than Case 2?	In Case 1, the samples are the same mass. We saw that if the masses are different, then the final temperature is somewhere in the middle. The final temperature is closer to the larger sample's temperature, but we are not sure how to figure that out.
Which sample will change in temperature more, the larger one or the smaller one?	The smaller one will change in temperature more.
Why would that be?	It is getting lots of energy from the larger sample.
Which case would have more energy transfer from the warm sample to the cool one?	Case 1, because the bigger cool sample can just keep taking on more energy. Case 2, because the temperature of the cool sample will change so much.
What if the warm sample were smaller? Would its temperature change more than the larger, cold sample?	It would change in temperature more than the larger, cold sample because it would give a lot of its energy away and the larger one would not be affected as much.
Do both masses affect how much each sample will change in temperature?	Yes.
How could we represent these ideas using energy transfer models?	We could use the size of a box to show its mass. We could use the size of the arrow to show how much energy is transferred.

Update the chart. Add energy transfer models showing students' ideas to the chart paper. It is more important that it shows different sizes of arrows than that it is completely accurate. Say, *We said that these energy transfers happen with temperature changes that depend on mass, too, and we can represent this with symbols.* Add "$\Delta T_a \uparrow$ if $m_a \downarrow$ or $m_b \uparrow$" to the chart paper along with key idea #2: *The mass and temperature of*

each sample affect where the final temperature stabilizes. Walk students through the terminology, pointing out that the delta symbol means "change in."



6 · NAVIGATE

3 min

MATERIALS: science notebook

Lead a Stop and Jot activity. Display **slide M**. Have students return to their seats and answer the prompts on the slide in their notebook. Students will be able to return to these prompts at the beginning of day 2.

End of day 1

7 · PREDICT TEMPERATURE CHANGES

10 min

MATERIALS: science notebook, *Summarizing Our Investigations*, 2 sheets of graph chart paper

Generalize the Stop and Jot activity from day 1. Display **slide N.** Welcome students and lead a discussion beginning with the prompt on the slide. You may wish to have students refer back to the Stop and Jot activity in their notebook before the class discussion.

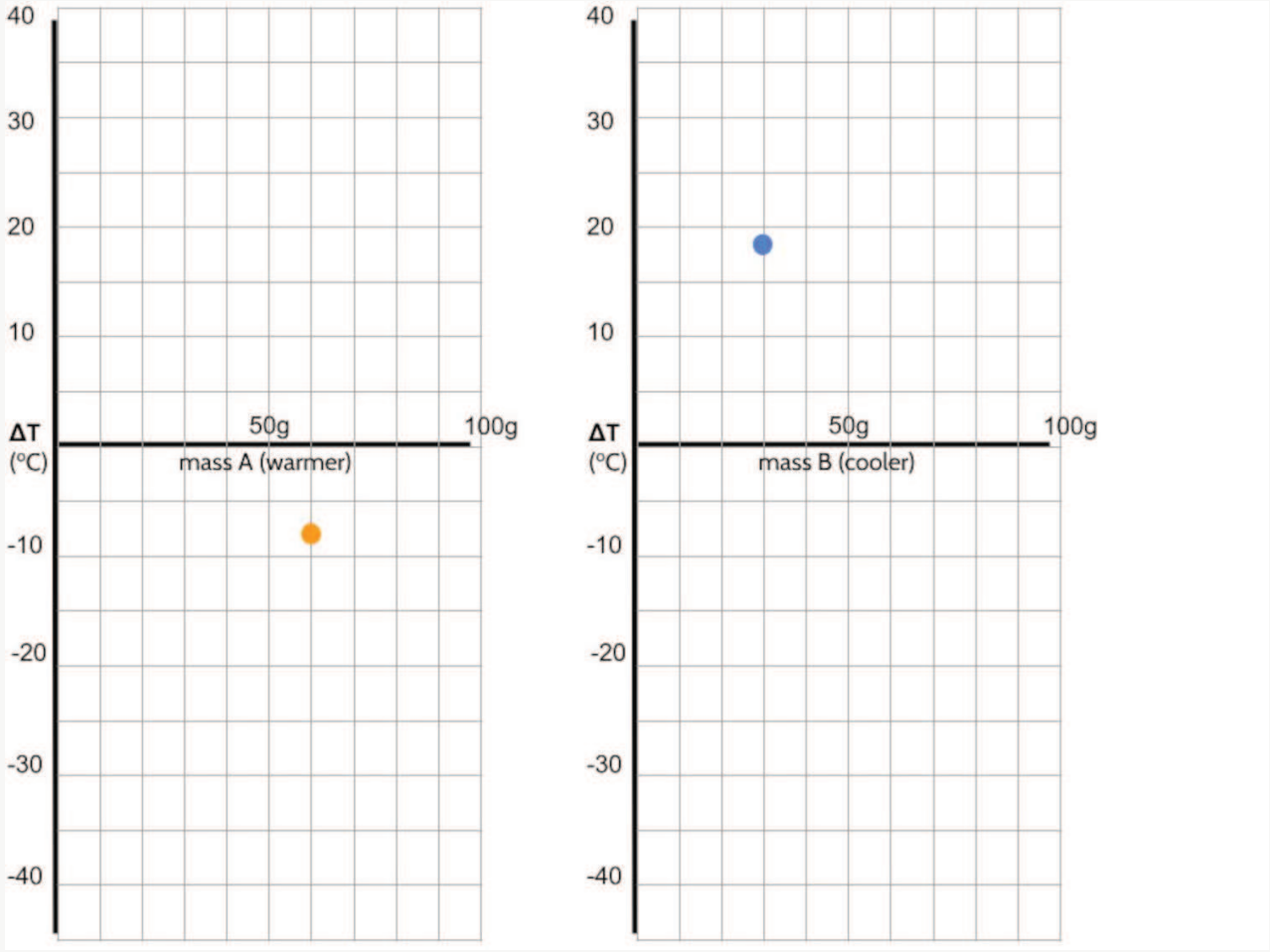
Suggested prompt	Sample student response
How can we predict how much each substance changes in temperature?	We are not quite sure. It has something to do with the masses and temperatures.
What patterns did we see?	Smaller masses changed in temperature more than larger ones.✱

✱ SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

You may wish to have students reconstruct the mathematical relationship shown with key idea #2 so that it is fresh in students' minds for the day's discussions. Many students benefit from the use of arrows to represent mathematical relationships, as done here. Additionally, you may wish to

Suggested prompt	Sample student response
How did we make predictions in the last lesson?	We graphed our data. We made a mathematical model using the graph.

Graph data from one trial. Suggest that we try graphing our data for one trial. Make two graphs on one sheet of graph chart paper, for the warmer sample and cooler sample, and plot one group's data. Start with the trial with the greatest mass difference and explain that if there are any relationships to see, they will be easier to identify with more extreme data. Suggest that we label mass on the *x*-axis since that is our independent variable, and temperature change on the *y*-axis for the dependent variable. An example is shown for a 60 g sample of 40°C water (which decreases in temperature by about 8.35°C) and a 30 g sample of 15°C water (which increases in temperature by about 16.65°C).



have the Mathematical Anchor Chart available for student support, even though nothing is added to it in this lesson.

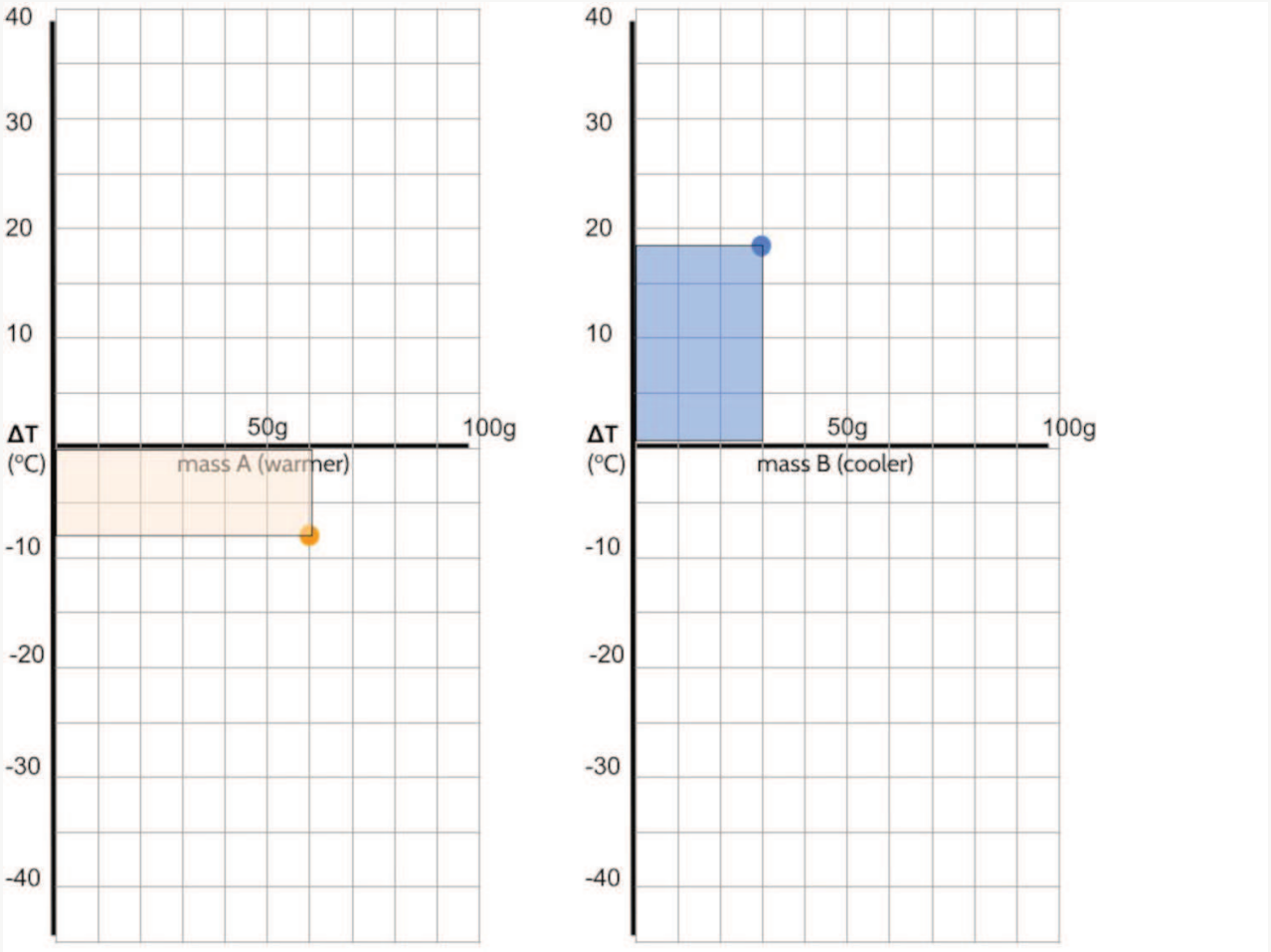
Ask students, *What do you notice?* Listen for these ideas:

- The larger mass of water changed in temperature more than the smaller mass of water.
- This does not help us predict anything about temperature.

Say, *We could plot more points and figure out the slopes, but that might be tricky when we have to track two graphs at once. Another way scientists look at graphs is by thinking about area. Just as a graph's slope can mean density, sometimes the area has a meaning too.*

Find areas. On each graph, extend lines from each axis to the point as shown, then shade the rectangle that is formed. Ask students again what they notice about the areas. Listen for these ideas:

- One rectangle is small and tall, while the other is short and wide.
- One rectangle is above the *x*-axis (horizontal axis), while the other is below the *x*-axis.



Ask students if they think the rectangles have the same area. If they are unsure, encourage students to calculate each area by multiplying the length along the *x*-axis (mass), by the height along the *y*-axis (change in temperature).

ADDITIONAL GUIDANCE

Students may be unsure what to do with the negative temperature changes or forget them entirely. If they are unsure, suggest that we use the negative values in our calculations and then think about the meaning of the result (which will also be negative). If students forget to account for negative temperature changes, ask, *How should we account for the negative temperature change in some cases?*

Discuss the results. Use the following prompts to decide whether this could be interesting, or a fluke.

Suggested prompt	Sample student response
What did we notice?	The areas are the same or pretty similar. The areas are the same, but one is negative.
Does it matter that the areas are the same, but opposite?	It is interesting. Maybe. We need more data.

Calculate areas for other trials. Suggest that we try this with more data. Display **slide O.** Distribute *Summarizing Our Investigations* and have students try the same process with data from one of their own trials, using prompts 1 and 2.

ADDITIONAL GUIDANCE

Students may not be familiar with the multiplication notation used on *Summarizing Our Investigations*, a dot (·). Highlight to students that when they have letters in equations, scientists often like to use symbols other than the multiplication "x" symbol. These may include a dot or, when working on a computer, an asterisk (*).

Circulate, checking students' work. After a few minutes, discuss as a class.

Suggested prompt	Sample student response
Did each group find that both areas were the same?	Yes. Not exactly, but they were close.
Did each group find that the areas were opposite each other?	Yes.
How could we use this information to make predictions about temperature changes?	We could start with the masses of each sample and trace to a point where the areas would be the same. Somehow probably, but it is weird why it is happening in the first place. We should focus on that.

Say that it sounds like we have established a trend, and that we should discuss its meaning.

8 · MAKE SENSE OF THE AREAS

10 min

MATERIALS: *Summarizing Our Investigations*, Key Ideas chart paper

KEY IDEAS

Purpose of this discussion: This second Building Understandings Discussion is intended to support students in figuring out that the areas represent energy, and that energy therefore is conserved as it is transferred.

Listen for these ideas:

3. Energy is conserved. It flows between objects but is not created or destroyed. $m_a \cdot \Delta T_a + m_b \cdot \Delta T_b = 0$

Make sense of the areas.✱ Display **slide P**. Continue the discussion to establish a meaning for the areas.

Suggested prompt	Sample student response
Why would the area (mass times temperature change) be the same in each case?	The smaller mass changes in temperature a lot, and the larger mass changes in temperature a little.
Why would the areas have opposite signs?	The warmer water cools, and the cooler water heats up.
(Remind students of key idea #2.)	Energy is going from the warm water to the cool water.
Why does it make sense that a little warm water cools down a bunch, while a lot of cool water heats up a little?	
(Remind students of the energy transfer model on the Key Ideas chart paper.)	They would be the same, because it is the same energy.
How would the amount of energy leaving the warm water compare to the amount going into the cool water?	
Wait...so you are saying that the area has something to do with energy?	Maybe.
Let's say the area was energy. What would it mean that the positive energy for the cool water is the same as the negative energy for the warm water?	The same amount of energy that flowed from the warm water went to the cool water.
This sounds like energy stays the same or is conserved. Is that right?	We have heard that before. If the area is the energy that is moving, it seems that way.
Would it make sense that energy in our investigation was conserved and did not escape anywhere else?	Yes, because our system was closed. Yes, because energy could not easily transfer outside the cup.

✱ STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

As in earlier Building Understandings discussions, make the roles of all participants explicit. Emphasize that you will be pushing for evidence or for connections between our graphs and conclusions, while students may get push-back to their responses to help deepen our understanding.

Say, *This sounds like a big idea! Let's record it, starting with the math we did. We said that the areas have opposite signs, right?* Use an example from the class and ask students, *If we added these two opposite areas or energies together, would we get zero?*

After students agree, write key idea #3 on the chart paper: $m_a \cdot \Delta T_a - m_b \cdot \Delta T_b = 0$. Draw a label pointing toward $m_a \cdot \Delta T_a$ that says "energy?" and write, *Energy is conserved. It flows between objects but is not created or destroyed.*

Give students a moment to record the equation and its meaning on *Summarizing Our Investigations* using prompts 3 and 4. Highlight to students that since we have a way we think we can measure energy, we are starting to think about it as a quantity that we can collect direct data on or use in calculations.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
Students should state that energy transfers between the warm and cool water, the areas of the graphs resemble quantities of energy, and energy is conserved within the closed system of the cup as energy transfers between warm and cool water. (DCI: PS3.A.1; CCC: 5.3)

What to do: Use the Key Ideas chart paper to remind students of the relationships they figured out on day 1. Students may not be sure that energy is conserved here because the areas are not identical, so encourage them to consider that the system may not be perfectly closed, but the similarities across groups indicate that most of the energy is transferred from the warmer water to the cooler water.

Building toward: 10.A.2 Plan and conduct investigations of energy transfer between objects in order to quantify conserved energy. (SEP: 3.2; DCI: PS3.A.1; CCC: 5.3)

Problematize energy conservation. Show **slide Q.** Have students turn and talk before discussing the prompts as a class.

Suggested prompt	Sample student response
Why would energy be conserved?	It has to go somewhere. It has to come from somewhere.
How is energy transferring?	It transfers from particle to particle and spreads out.
How could we know for sure that energy is conserved?	We would have to measure it.
How have we measured energy in the past, like in biology?	Calories.
What could help us see what is happening with particles or energy?	A microscope. A simulation.

9 · INTRODUCE A SIMULATION

4 min

MATERIALS: computer, https://www.youtube.com/watch?v=f74iIJtGrtg&list=PLSLDxqPb5NQlFczx8-5QZIRw3xp0NGTRS&index=6

Introduce a particle-level simulation. Show **slide R.** Say, *I have a simulation that might be able to help us out. This video explains the basic functions in the simulation we will be using today.*

Orient to the simulation. Play https://www.youtube.com/watch?v=f74iIJtGrtg&list=PLSLDxqPb5NQlFczx8-5QZIRw3xp0NGTRS&index=6. Point out any sliders, buttons, switches, graphs, or monitors within the simulation that will help students either manipulate or measure different variables.

10 · CARRY OUT AN INITIAL INVESTIGATION

6 min

MATERIALS: https://www.openscied.org/general/energytransfersolids/, computer

Consider the value of the simulation. Present **slide S.** Lead a brief discussion of the prompts on the slide.

Suggested prompt	Sample student response
What happens when two substances of different temperatures touch each other?	One gets warmer and the other gets cooler.
What affects how or how quickly this process occurs?	How hot or cold they are to start with. How much mass they have. How well they are touching.
What happens if the two substances have very different temperatures? ✱	The temperature change will happen quickly, but might take a while to finish.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
Students should make a prediction regarding the simple limit case that temperatures will change rapidly in a system where the two objects have very different initial temperatures but take a while to reach a final temperature. (SEP: 5.4)

What to do: Push students to think about the extreme temperature difference in the example in steps, if they are struggling to think about it. Begin with thinking about if two objects are similar temperatures (like an ice cube and refrigerator air) and then move to greater extremes (like a hand and a hot pan, or a piece of paper and a burning log).

Building toward: 10.B.1 Use simple limit cases to test a simulation of a closed system in which energy and matter are conserved that shows how an uncontrolled system with two different-temperatures objects eventually reaches uniform energy distribution. (SEP: 5.4; DCI: PS3.B.5; CCC: 5.1)

✱ SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Using extreme situations to test if a model "makes sense" in that range is called a limit case. Highlight to students that by comparing the simulation's behavior to what we know about a hot and cold substance in contact in the "real world," we can ensure that the model is reflecting actual behavior under the conditions that we care about.

✱ SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Investigations are not always experiments. Play and tinkering are important parts of investigative activity and figuring out for students of all ages, not just young children. This step is an important strategy for equity to ensure your students have a chance to figure out the relationship between the movement of the particles and the flow of energy between them before homing in on a more routinized approach to exploring the behavior space of the simulation.

Tinker with the particle-level simulation.✱ Show **slide T.** Allow students time to explore the simulation as they wish. Remind them that they can get creative and do not need to follow a procedure yet. Say, *The goal of this initial investigation is to get a sense of how the simulation works and to start to notice and wonder about what you see the energy doing in the system*. Ask students to prepare to share one thing they noticed or wondered while tinkering with the simulation.

11 · SHARE OBSERVATIONS FROM THE INITIAL INVESTIGATION

8 min

MATERIALS: *Summarizing Our Investigations*, Key ideas chart paper

KEY IDEAS

Purpose of this discussion: This discussion will allow students to re-establish the middle-school idea that the energy transfer is occurring through particle collisions, and to name this process *conduction*.

Listen for these ideas:

4. Conduction is the transfer of energy through direct contact as particles collide.

Report on observations from the simulation.✱ Show **slide U.** Ask students to share with the class their observations from tinkering with the simulation. Accept all responses right now; the goal for students at this stage is to identify variables that they can test later to see if their ideas are accurate.

Suggested prompt	Sample student response
What did you notice?	Particles vibrated. The objects in the sim are solid. Energy flowed from the warmer solid to the cooler solid. The total energy stayed constant.
What did you notice about what affected the energy in the objects?	There was more energy if the objects were larger or hotter.
Did your observations make sense with what you see in the world?	Yes. Usually a hot object cools down when it touches hot stuff, and vice versa. Maybe. I am not sure if real objects with different temperatures really come to the same temperature after touching.
How did you decide when to click "stop"?	When the temperatures were within a certain number of degrees. After a certain amount of time.
What did the particles have to do to prompt you to click "stop"?✱	They were vibrating a similar amount. The temperature was the same throughout. The energy was spread throughout both objects, instead of mainly in one.

✱ STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

In this discussion, continue to push students to share evidence from their investigation to support their ideas. Have the simulation ready to show ideas to the class as needed.

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Students are bringing to table practical knowledge of the computational model they are using, along with observations of the particles. If it is unclear from student responses, follow up by asking, *If the temperature is the same, how is the energy spread or distributed?* Use the simulation to show that it is spread evenly. Use examples like cooling coffee and refrigerators to highlight that this spread happens in uncontrolled systems, but not in controlled systems.

Suggested prompt	Sample student response
What affected how quickly energy flowed?	The masses. The temperatures. The area in contact.
What had to happen for the energy to flow?	The particles had to be in contact so that they could pass along the vibration.
Did the contact area affect how much energy flowed in the end?	No, it just took longer if less area was in contact.

Say, *This contact between particles sounds like an important way to transfer energy. Is it the same thing as convection or radiation?*

When students say it is not, note that this is a third way to transfer energy. Add key idea #4 to the chart paper: *Conduction is the transfer of energy through direct contact as particles collide.*

Tell students that when a process reaches this balance in which there might be changes happening at a small scale but the system seems stable at larger scales, scientists say that the system has reached an *equilibrium.*

Emphasize energy conservation. Display **slide V.**

Suggested prompt	Sample student response
Was energy conserved in your investigations?	Yes.
Was matter conserved in your investigations?	Yes.
How do we know?	There was no way for the energy and matter to get in and out in the lab, and in the simulation we saw that the energy and matter stayed constant.
(Refer students to the conservation equation on the Key Ideas chart paper or in prompt 3 of the handout.) *We said that $m_a \cdot \Delta T_a - m_b \cdot \Delta T_b = 0$. Was that true in this simulation?* *(Run the simulation and plug the results into the equation above as a class if students are unsure.)*	Yes.

Say, *This supports our idea that mass times temperature change represents how much energy is flowing. Scientists call energy flow through conduction "heat" and represent it with the letter Q.* Cross out "energy?" on the chart paper and replace it with "*Q* (heat)".

Point out that scientists have a name for a system where matter is conserved, a *closed system*. Emphasize that energy can leave a closed system, but matter cannot. Elicit examples of closed systems where energy can still transfer in or out, like a coffee cup with a lid or the bottles in Lesson 3.

Have students complete prompt 5 on *Summarizing Our Investigations*. They will need this handout again on day 3.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should acknowledge that the simulation behaved as expected based on the simple limit case and other knowledge of the "real world." (SEP: 5.4)
- Students should determine that a system with two objects touching will result in energy being spread throughout the two objects, and energy and matter were conserved (not created or destroyed) in the investigations. (DCI: PS3.B.5; CCC: 5.1)

What to do: Direct students back to the simulation regularly as they make claims. If there is uncertainty about any of these ideas, have students help you figure out how to set up the conditions in the simulation to provide evidence for or against the claim.

Building toward: 10.B.2 Use simple limit cases to test a simulation of a closed system in which energy and matter are conserved that shows how an uncontrolled system with two different-temperatures objects eventually reaches uniform energy distribution. (SEP: 5.4; DCI: PS3.B.5; CCC: 5.1)

12 · NAVIGATE

5 min

MATERIALS: None

Return to the glacier system. Display **slide W** and discuss the prompts.

Suggested prompt	Sample student response
What have we figured out about energy transfer to a glacier?	We have figured out that mass times temperature change is the heat flow. We figured out that energy is conserved.
What have we not figured out about energy transfer to a glacier?	We have not looked at energy transfer between a solid and a liquid, like the glacier and water, or what happens at the air interface either.
What do we actually need to measure to show that heat is mass times temperature change when energy is transferring to a glacier?	Mass. Temperature change. Energy (for both substances).

Offer to bring an updated version of the simulation that can do some of this work.✱

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

The model students will see on day 3 includes functionality to test a solid-gas interface, but not a solid-liquid interface. This is due to computational difficulties in modeling liquids interacting with other materials. If students are concerned about this, highlight this limitation of the model and suggest that we conduct an investigation after we have figured out what we can from the simulation.

13 · HOME LEARNING

2 min

MATERIALS: None

Introduce the home learning activity.✱ Show **slide X**. Say, *We want to consider whether an updated simulation can actually explain different situations in our world.* Revisit the phenomena shared during the class period as a starting point, then ask students to document additional phenomena that the updated simulation could explain. Students should be ready to share their work with a partner at the beginning of day 3.

ALTERNATE ACTIVITY

Extension opportunity: Encourage students who have access to a thermometer at home to observe what happens when the two objects they document come into contact. If you have small, inexpensive thermometers, you may wish to loan them out to students who do not have one at home.

✱ ATTENDING TO EQUITY

This home learning assignment is used to broaden students' thinking related to everyday phenomena and to leverage the science experiences students have outside of school to augment the learning that happens in the classroom. Locating the anchoring and related phenomena in the context of their home or community helps these phenomena become more personally meaningful to each student and provides an opportunity for discussion with family members and other community members.

End of day 2

14 · NAVIGATE

4 min

MATERIALS: completed home learning assignment

Discuss the home learning. Show **slide Y.** Give students two minutes to turn and talk about the prompts on the slide, then discuss as a class.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:
Students should articulate additional ways in which they expect the simulation to behave based on the phenomena they captured. (SEP: 5.4)

What to do: If students do not identify particular ways that the simulation should behave, ask students to "tell the story" of the phenomena they captured. As students share their stories, identify places where they are highlighting variables included in the simulation. Leverage this thinking to move toward a more complete prediction of how the simulation might behave.

Building toward: 10.B.3 Use simple limit cases to test a simulation of a closed system in which energy and matter are conserved that shows how an uncontrolled system with two different-temperature objects eventually reaches uniform energy distribution. (SEP: 5.4; DCI: PS3.B.5; CCC: 5.1)

15 · INTRODUCE UPDATED SIMULATION

4 min

MATERIALS: https://www.openscied.org/general/energytransfersubstances/, computer

Introduce the new simulation. Load the simulation at: https://www.openscied.org/general/energytransfersubstances/. Tell students that we have a more complex version of the simulation from last class that includes the option to change the state of matter between gas and solid. Share your screen so that students can see how to do this.

Show **slide Z.** Prompt students to consider how we can use this updated simulation to our advantage.

Suggested prompt	Sample student response
In addition to the state of matter, what are some new variables that can or cannot be changed in this version of the simulation?	Gas-solid interaction compared to solid-solid interaction. Masses. We can no longer change the area of the matter in contact.
What can we still measure that we might be interested in?	The energy. The changes in energy and temperature.

16 · PLAN AN INVESTIGATION

8 min

MATERIALS: science notebook, chart paper or whiteboard, copy of https://docs.google.com/spreadsheets/d/1UpxdUAbBWQsi1WxT0JKhUJA26XRssZ97xR-mcdIBlw0/copy, "Rules for Energy Transfer" anchor chart, Investigation Anchor Chart

Document an investigation plan. Show **slide AA.**

Use a poster board or whiteboard for this activity. Validate the importance of investigating all of these relationships, and emphasize the need to keep track of them in an organized manner so that we can clearly see how each variable affects energy transfer and to what degree.✱ Establish the question(s) that the class is trying to answer first and record this on the board, then have students title a page of their notebook with the question you land on as a class. This will be something like:

- How do mass and temperature change affect energy transfer when two objects of different temperatures come into contact?

Refer to the Investigation Anchor Chart from Lesson 3 to support students' thinking. Have students record the ideas that the class decides on.

✱ SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

Though students have started to become relatively fluent in planning an investigation, this is likely to be one of the first times that students are working with two independent variables and performing the calculations required to obtain additional information. For this reason, the default direction in the teacher guide is to plan this investigation as a class.

If students have completed the middle-school units *OpenSciEd Unit 7.2: How can we use chemical reactions to design a solution to a problem? (Homemade Heater Unit)* and *OpenSciEd Unit 8.1: Why do things sometimes get damaged when they hit each other?*

Suggested prompt	Sample student response
What are our independent, dependent, and controlled variables?	The independent variables are the mass and the state of matter. The dependent variables are the amounts of temperature change and energy change. The controlled variables can include the starting temperatures and the amount of contact between the substances, since we have already investigated those variables. We should also keep one mass constant for each investigation.
How do we organize our collected data to distinguish between the solid-solid and gas-solid interactions?	Segment out the data tables and label each section. Add a column.
How will we identify/record a quantitative change in the temperature?	Subtract final temperature from initial temperature. There's a box on the simulation that shows the change. Pause it and record that number.

Provide a data table. Share the class copy of https://docs.google.com/spreadsheets/d/1UpxdUAbBWQsi1WxT0JKhUJA26XRssZ97xR-mcdIBlw0/copy and work with students to assign four specific conditions to each pair (group). Show students that they can simply enter numbers in the spreadsheet and the change calculations and graphing will be automatically carried out for them.

Add rows if you wish to have students conduct more trials when tweaking a given object's mass. If students wish to have one set of groups alter the mass of A while others alter the mass of B, copy the existing spreadsheets to make new ones for the other groups.

ADDITIONAL GUIDANCE

Extension opportunity: If you would like students to get more practice making graphs to build on what they learned in Lesson 9, consider having them graph manually using graph paper. However, this step has been de-emphasized here to help students focus on interpreting the results.

(Collisions Unit), they will have already experienced two opportunities to plan an investigation with multiple independent variables, but without calculations. If so, you may wish to modify this step so that students plan the investigation in small groups rather than as a whole class.

Students will return to more small-group investigation planning in Lesson 11.

17 · CARRY OUT AN INVESTIGATION WITH THE SIMULATION

9 min

MATERIALS: science notebook, computer, https://www.openscied.org/general/energytransfersubstances/

Carry out the investigation. Show **slide BB.** Emphasize that students should record all of their data using the spreadsheet.

Summarize investigation findings. After about seven minutes for students to collect data, show **slide CC**. Say, *In a Scientists Circle, we will consider how we can generalize our findings about the impact of mass on temperature change and energy flow, and we will try to build toward a consensus. It is important to first collect your own thoughts so that you can come to the Scientists Circle with some initial ideas.* Shift to showing the graphs that were produced as students entered data. Give students two minutes to jot down their small group's investigation findings with all devices off.

18 · HAVE A BUILDING UNDERSTANDINGS DISCUSSION

15 min

MATERIALS: science notebook, copy of https://docs.google.com/spreadsheets/d/1UpxdUAbBWQsi1WxT0JKhUJA26XRssZ97xR-mcdIBlwO/copy, Key ideas chart paper

KEY IDEAS

Purpose of this discussion: This discussion will allow students to establish an equation for energy transfer through conduction.

Listen for these ideas:

5. $Q = c \cdot m \cdot \Delta T$

Make sense of investigation findings. Assemble students in a Scientists Circle with the class's data table visible on screen and display **slide DD.** Tell students you are listening for each of them to contribute to our conclusions. Take this opportunity to celebrate how many students were called out in the exit ticket at the end of Lesson 9, and encourage students to follow our Community Agreements throughout the discussion. Use *Discussion Mapping/Assessment Template* to document the discussion as formative assessment.✱

Compare energy transfers with different masses and temperature changes. Begin by having students share the patterns they observed within their investigations.

Suggested prompt	Sample student response
What patterns did you observe on the graphs showing change in energy (heat) vs. mass · ΔT?	The graphs were the same for solid-solid, but not for the other states of matter. The graphs were always linear.
Why would the flow of energy into or out of an object vary even though its mass stayed the same?	If the other object is bigger or smaller, more or less energy can transfer from the object which has a constant mass.
Were there any differences between the trends in the solid-solid and solid-gas tests?	It looks like the trends are similar. It is hard to say without somehow looking at the trend lines more specifically.
Do we have enough information to predict the energy transfer if we know the mass and the temperature change?	Yes, but we would have to think about the best-fit lines carefully.

Find the best-fit lines. Divide students into smaller groups to find each best-fit line, as they did in Lesson 9. Students may use any method, including just calculating the slope. Then discuss these lines as a class.

Suggested prompt	Sample student response
How did the best-fit lines and equations compare?	They were the same, except they had different slopes.
What are the units of the slope?	calories per gram · °C

✱ ATTENDING TO EQUITY

Building classroom culture: If desired, take this opportunity to more deeply check in on classroom culture, particularly if the responses to the Lesson 9 survey reflected some concerns. Even if community culture-building is going well, it is recommended to pause the discussion part-way through to allow students to see *Discussion Mapping/Assessment Template* and adjust their mode of participation accordingly.

Suggested prompt	Sample student response
What does the slope mean?	It is kind of confusing. The energy or heat that transfers when the mass and temperature change shift by a certain amount.
Why are the slopes different?	Different materials or states of matter must transfer different amounts of energy, along with differences in mass or temperature changes.
What is the intercept?	It is about 0, so we can ignore it.
Do we know enough about the best-fit line to think about it like an equation? What would that equation tell us?	Yes, since we know what the variables, slope, and intercept are. It would tell us about the heat or energy flow.

ADDITIONAL GUIDANCE

If students do not accept that the intercepts are near zero, encourage them to compare the intercepts to the most positive or negative *y*-values. They will note a drastic difference.

Introduce specific heat. Show **slide EE.** Say, *Scientists describe how much energy it takes to change the temperature of a substance as its specific heat, and it is different for every substance. It is represented here as c.* Add key idea #5, the equation $Q = c \cdot m \cdot \Delta T$, to the chart paper and discuss its different parts. For example, for specific heat, say *The specific heat of a substance or mixture tells us how much energy in calories is needed to change 1 gram of it by 1 °C. Notice that for water this is about 1 calorie, but for these other substances in the table it is less. We can use the specific heat in an equation to help us calculate how much energy is transferred between substances.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should apply techniques of algebra and functions to identify that a best-fit line can be used to compare similar graphs and the slope of the best-fit line has units of calories per gram · °C and represents the amount of energy it takes to raise the temperature of 1 gram of a substance by 1 degree Celsius, and
- Students should determine that we have enough information to mathematically model and quantify energy. (SEP: 5.3; DCI: PS3.B.3; CCC: 4.3)

What to do: If students do not mention using a best-fit line as a possibility, ask how we figured out an equation for density in Lesson 9. You may wish to have students discuss how that process worked before thinking about what the best-fit line means.

Building toward: 10.C.1 Apply techniques of algebra and functions to quantify, describe, and mathematically model the energy flows that result in measurable temperature changes in order to quantify conserved energy. (SEP: 5.3; DCI: PS3.B.3; CCC: 4.3)

ADDITIONAL GUIDANCE

If students are surprised or find it suspiciously convenient that water's specific heat capacity is 1 cal / (g · °C), you may wish to share that this is because the definition of a calorie was based on the amount of energy required to heat up 1 gram of water by 1 °C.

Update personal glossaries. Display **slide FF** and give students a few minutes to update their personal glossaries. They may want to include *specific heat*, *equilibrium*, *conduction*, *heat, closed system,* or the heat transfer equation they just developed.

19 · NAVIGATE

5 min

MATERIALS: *Summarizing Our Investigations*

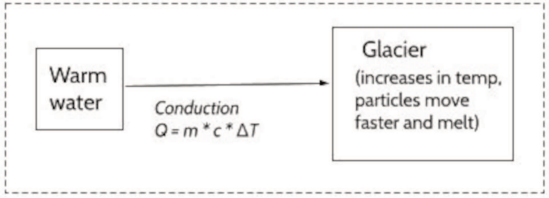
Highlight our new quantitative model. Say, *We have seen this model in all of the interactions we observed. Let's reflect on what we figured out, so we can think about where to go next.*

Exit ticket. Display **slide GG** and give students a few minutes to complete prompts 6–9 on *Summarizing Our Investigations*. These prompts will help students navigate into Lesson 11.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' energy transfer models should show that energy is conserved (all of it is transferred between the objects), and the mathematical model $Q = c \cdot m \cdot \Delta T$ quantifies the energy transfer. (DCI: PS3.B.3; CCC: 4.3)
- Students should state that we do not know *c* for ice, so we need to figure it out to quantify energy in this particular model. (DCI: PS3.B.3; CCC: 4.3)



What to do: If many students do not have these ideas in their exit tickets, you may wish to share out particular canonical responses at the beginning of Lesson 11, so all students can visualize what this might look like. If most students have the right idea, a brief discussion may instead suffice.

Building toward: 10.C.2 Apply techniques of algebra and functions to quantify, describe, and mathematically model the energy flows that result in measurable temperature changes in order to quantify conserved energy. (SEP: 5.3; DCI: PS3.B.3; CCC: 4.3)

Additional Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HSN.Q.A.2: Define appropriate quantities for the purpose of descriptive modeling.

CCSS.MATH.CONTENT.HS.S-ID.7: Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of the data.

CCSS.MATH.CONTENT.HSF.LE.A.2: Construct linear ~~and exponential~~ functions ~~including arithmetic and geometric sequences,~~ given a graph ~~a description of a relationship,~~ or two input-output pairs (include reading these from a table).

CCSS.MATH.CONTENT.HSF.IF.B.6: Calculate and interpret the average rate of change of a function (presented symbolically or as a table) over a specified interval. ~~Estimate the rate of change from a graph.~~

CCSS.MATH.CONTENT.HS.S-ID.6b: Represent data on two quantitative variables on a scatter plot, and describe how the variables are related: Informally assess the fit of a function by plotting and analyzing residuals.

CCSS.MATH.CONTENT.HS.S-ID.6c: Represent data on two quantitative variables on a scatter plot, and describe how the variables are related: Fit a linear function for a scatter plot that suggests a linear association.

CCSS.MATH.CONTENT.HS.S-ID.7: Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of the data.

Students use these practices as they develop mathematical expressions that describe the relationships between objects' masses, changes in temperature, and energy transfer.

LESSON 11: How does heat affect the amount of ice melt?

PREVIOUS LESSON

We planned and carried out an investigation to figure out if we could measure energy transfer between warm and cool water. From graphs, we gained some additional evidence that energy is conserved. We used a simulation to figure out more about energy conservation at the particle level and developed a mathematical model of energy transfer through conduction.

THIS LESSON

INVESTIGATION

1 day

We reflect on where our new heat equation fits into our energy transfer model. We realize that we do not know what affects the amount of ice melt other than incoming heat, so we plan and conduct an investigation in which we measure both the temperature change of the water and the mass change of the melting ice. We figure out from the slope of the best-fit line of the data that 80 calories of energy are required to melt 1 gram of ice. We consider how this understanding might help us in addressing glacier melt and sea level rise.

NEXT LESSON

We will develop a Gotta-Have-It Checklist and mathematical model that can help us further evaluate the berm solution. We will use the model to calculate the berm's impact on ice melt. We will brainstorm ideas for an expanded computational model that includes the Earth system beyond the glacier.

BUILDING TOWARD NGSS

HS-PS3-1, HS-PS3-4, HS-ESS2-2, HS-ESS2-4, HS-ESS3-1, HS-ESS3-5, HS-ESS3-6, HS-ESS2-7

WHAT STUDENTS WILL DO

11.A Ask questions based on an existing model around how energy causes matter cycling in a system with conserved and transferred energy. (SEP: 1.2; DCI: PS3.B.1; CCC: 5.4)

11.B Make a directional hypothesis about how much energy transfer must be prevented as part of a system design. (SEP: 3.5; DCI: PS3.B.1; CCC: 4.1)

WHAT STUDENTS WILL FIGURE OUT

- Because energy is conserved, the heat that transfers out of the water in our investigation flows to the ice.
- 80 calories of energy are required to melt 1 gram of ice ($Q = 80 \cdot m$).
- We can use our mathematical model to predict the amount of ice melt when we know the mass and temperature of the water it is in contact with.

Lesson 11 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	8 min		**NAVIGATE** Reorient students to calculating the energy transfer the berm prevents.	A-B	*Summarizing Our Investigations*
2	5 min		**DEVELOP AN INVESTIGATION QUESTION** Give students time to brainstorm and decide on an investigation question.	C	*Investigation Question Development*, *Water-Ice Investigation Procedure*
3	7 min		**PLAN AN INVESTIGATION TO COMPLETE OUR MATHEMATICAL MODEL** Review the investigation procedure and co-construct a modified spreadsheet to collect class data.	D-F	*Water-Ice Investigation Procedure*, copy of https://docs.google.com/spreadsheets/d/1FjEL64clNekP794iL0xvZo3DU53u-trj0CO7gNwU_P0/copy
4	12 min		**COLLECT AND SHARE DATA** Carry out the investigation and share results in the class data table.	G-H	computer, copy of https://docs.google.com/spreadsheets/d/1FjEL64clNekP794iL0xvZo3DU53u-trj0CO7gNwU_P0/copy, Water-Ice Investigation
5	8 min		**MAKE SENSE OF THE RESULTS** Construct a line of best fit and discuss what its slope means.	I	copy of https://docs.google.com/spreadsheets/d/1FjEL64clNekP794iL0xvZo3DU53u-trj0CO7gNwU_P0/copy, Key ideas poster from Lesson 10
6	5 min		**NAVIGATE** Have students update their Progress Tracker to support navigation to the next lesson.	J-K	

End of day 1

Lesson 11 • Materials List

	per student	per group	per class
Water-Ice Investigation materials	• *Water-Ice Investigation Procedure* • indirectly vented chemical splash goggles • nitrile gloves • non-latex apron	• 2 foam cups with lids • 2 large ice cubes in individual plastic bags or on paper towels • 1 digital thermometer with metal probe • 1 digital scale	• 4 water baths at different temperatures (hot • warm • cool • and cold) • 30-qt insulated cooler
Lesson materials	• *Summarizing Our Investigations* • *Investigation Question Development* • *Water-Ice Investigation Procedure* • copy of https://docs.google.com/spreadsheets/d/1FjEL64clNekP794iL0xvZo3DU53u-trj0CO7gNwU_P0/copy • science notebook	• computer • copy of https://docs.google.com/spreadsheets/d/1FjEL64clNekP794iL0xvZo3DU53u-trj0CO7gNwU_P0/copy	• copy of https://docs.google.com/spreadsheets/d/1FjEL64clNekP794iL0xvZo3DU53u-trj0CO7gNwU_P0/copy • Key ideas poster from Lesson 10

Materials preparation (50 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Making ice will take at least two days if you do not have access to a large number of trays or an icemaker, so start the process well ahead of time. To make enough ice for all of your classes, you will need to make multiple batches of ice cubes, taking them out approximately every 4 hours and then refilling the trays

For example, for six classes, you will need to make 2 cubes per group x 7 groups per class x 6 classes = 86 ice cubes. If each tray holds 8 cubes and you have 2 trays you will need to make 6 batches of ice cubes.

Store each ice cube in its own plastic snack bag in the freezer to prevent the ice cubes from sticking to each other. If you do not have a freezer in the classroom, store the ice cubes in an insulated container that you can transport to and from each class.

Create a copy of this Google Sheet to use as a template to share with your students:
- https://docs.google.com/spreadsheets/d/1FjEL64clNekP794iL0xvZo3DU53u-trj0CO7gNwU_P0/copy

If you cannot access the Google Sheet and/or you want to recreate the layout from scratch, the images in *Spreadsheet References* provide a snapshot of what that layout should look like.

Water-Ice Investigation
- **Group size:** 5 students
- **Setup:**
  - Prepare the 4 water baths. For the hot-water bath, use a hot plate or kettle to heat the water to almost boiling. For the warm-water bath, you can use room-temperature water from the faucet. For the cool-water bath, chill the water in a refrigerator. For the cold-water bath, chill the water in a refrigerator with a few ice cubes in the container.
  - Test to make sure that the maximum mass of water you are assigning to a group (e.g., 75 g) from the warmest water you are making available, still leaves some ice in the cup after the final temperature reaches ~1-2 °C. Water that is too hot may completely melt the ice and may not stabilize at a temperature range of ~1-2 °C. That condition is problematic for the type of simpler relationships we are trying to derive in this lesson and should therefore be avoided.
  - Gather a set of the following materials for each group:

        - 2 large ice cubes, each in its own plastic bag or on its own paper towel
    - Set aside the following materials to distribute and collect from groups for reuse:
        - 2 foam cups with lids
        - 1 digital thermometer with metal probe
        - 1 digital scale
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*. Discuss with students how to transport the water for the hot-water bath to prevent burns. If you are heating water in a beaker on a hot plate, it is recommended that you transport and dispense the water for the hot-water bath to groups. In addition:
    - Wear indirectly vented chemical splash goggles, nitrile gloves and non-latex apron during the setup, hands-on, and takedown segments of the activity.
    - Secure loose clothing, wear closed-toe shoes, and tie back long hair.
    - Immediately wipe up any spilled liquids - slip/fall hazard.
    - Follow procedures set up by your instructor for disposal of materials.
    - Use only GFI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
    - Any electrical cords must be off the floor to prevent trip/fall hazards.
    - Use caution when working with glassware or plasticware - can break and cut/puncture skin.
    - Wash hands with soap and water or use hand sanitizer wipes immediately after completing this activity.
    - Use caution when working with hot liquids. They can splash and burn skin.
    - Direct supervision will be required during all aspects of this activity.
- **Disposal:** None
- **Storage:** The liquid can be poured down the drain. Retain all other materials. Make sure to allow the foam cups to dry before storage.

Lesson 11 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build ideas related to the following disciplinary core idea:

- **PS3.B.1: Conservation of Energy and Energy Transfer.** Conservation of energy means that the total change of energy in any system is always equal to the total energy transferred into or out of the system.

A procedure is provided for the investigation in this lesson. Although students developed fluency in planning investigations based on their experiences in Lessons 3, 4, 6, 9, and 10, the planning focus in this lesson is on asking questions (SEP: 1.2) and making directional hypotheses (SEP: 3.5). These practices are scaffolded as students are doing them more independently than in the past. Students also build on thinking from Lesson 11 as they see again how energy drives matter cycling within a system (CCC: 5.4). They expand their understanding of systems as they begin to more explicitly consider how the berm actually prevents melting, not just energy transfer (CCC: 4.1).

Data analysis and mathematical modeling are not assessed in this lesson, but students will leverage the understandings of these practices built in Lessons 9 and 10 to make sense of their data. You may wish to have students construct the graphs on their own if you wish to emphasize the use of data tables.

Students will develop a relationship for the amount of energy needed to melt 1 gram of ice. 80 calories per gram is the assumed relationship, but it is okay if students' values fall anywhere in the range of 70-90 calories per gram. Have students use the value they derived rather than the published, known value.

In this lesson, the class determines that all known energy transfers are now accounted for at the Ilulissat Glacier site, and that those through convection and conduction are quantified. Lesson 12 gives students an opportunity to apply the mathematical model to the use of a berm to prevent energy transfer.

Where We Are NOT Going

In the main lesson, students do not define the relationship they figure out between heat and ice melt as "latent heat of melting." However, this is done in the optional extension found in *Other Substances*.

The idea that energy is conserved in every process is one that will be developed further in this course. *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)* will develop this idea in chemical reactions. Physics will develop this idea in electrical systems in *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*.

Students' questions in this lesson result from examining their models, rather than a theory. Students will have opportunities to ask questions from theory later in the course.

LEARNING PLAN for LESSON 11

1 · NAVIGATE

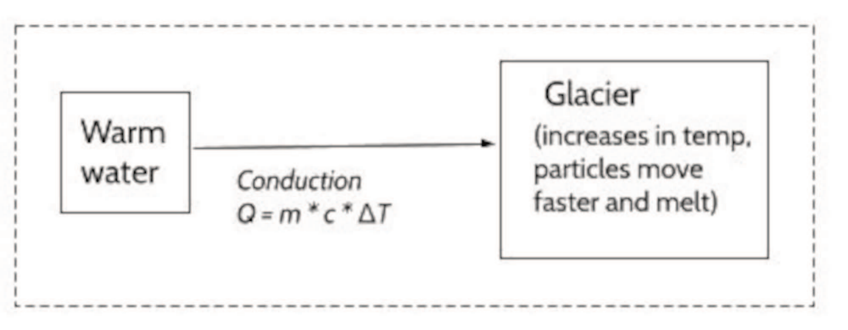
8 min

MATERIALS: *Summarizing Our Investigations*

Hand back the Lesson 10 exit tickets. Show **slide A**. Have students discuss the prompts on the slide using their exit tickets as a guide.

Suggested prompt	Sample student response
How is energy flowing between water and the glacier with no berm present?	It is being transferred by conduction until the temperature is the same. Particles collide with each other until they are at the same speed.
How does that energy affect the glacier?	The glacier ice heats up and melts into the ocean.
Where would we use our new equation in the model?	We could use it to calculate how much energy transfers from the water to the ice, if we knew the temperature change and mass of water.
Where could we actually put our equation on our energy transfer model?	We could put it over the conduction arrow between the water and the ice.
What information would we need to calculate the effect of heat flowing from water to the glacier?	We probably need to know something about the ice, like its specific heat capacity. We would need to figure out how much energy was transferred from the water.

You may draw this energy transfer model on the board, as shown below.✱



✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

This model is necessarily incomplete, as this navigation is intended to help students problematize the fact that they cannot explain how much ice melt results from the energy transfer to the glacier.

Try calculating the amount of ice melt. Say, *Let's practice doing that on a smaller scale.* Show **slide B.** Give students a few minutes to turn and talk with a partner to discuss the prompts, then discuss them as a class.

Suggested prompts	Sample student responses	Follow-up questions
How much heat flows out of the water?	About 1,000 calories.	*How did you figure that out?*
How much ice would that heat melt?	It is hard to say. We need more information about the ice.	*What types of information would be helpful?*
Let's break this down. How much of this energy would actually go into melting the ice?	Probably all of it.	*What evidence do we have for that?*
The ice at the edge of the glacier is already at about the melting point, 0°C or 32°F, so it does not have to change in temperature much to melt. So, what other factor could affect how much ice is melted by the heat?	The mass of the ice. How much energy is transferred from the water. Specific heat, or some other property of the ice.	*Would a mass of ice melt differently than the same mass of another material, like a concrete berm?* *Why do you think that?*

ADDITIONAL GUIDANCE

Building prerequisite understandings: In Lesson 12, students will use their understanding and the mathematical tools from this unit to calculate the impact of a berm on energy transfer in the glacier system. You may wish to prepare students for this task using the heat transfer equation on **slide B**. If so, replace the problem with one where students must calculate the water's mass based on its density and the dimensions of the container.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should identify that energy transfer from water to ice causes the ice to melt into the water. (CCC: 5.4)
- Students should conclude that because energy is conserved, the energy lost by the water must be transferred to the ice and cause it to melt. (DCI: PS3.B.1)

What to do: If students do not make explicit connections between ice melt and energy transfer between systems, ask them to think about what we figured out in Lesson 4 through the land ice–sea ice investigation. If students do not identify energy conservation as a reason why all, or nearly all, of the heat from the water would flow to and melt the ice, refer them back to the Key Ideas poster from Lesson 10.

Building toward: 11.A.1 Ask questions based on an existing model around how energy causes matter cycling in a system with conserved and transferred energy. (SEP: 1.2; DCI: PS3.B.1; CCC: 5.4)

2 · DEVELOP AN INVESTIGATION QUESTION

5 min

MATERIALS: *Investigation Question Development*, *Water-Ice Investigation Procedure*

Problematize the material. Display **slide C**. Say, *We are trying to figure out how much matter is affected or melted when energy transfers from the water to the glacier. Based on what we have figured out, what would be a good question to investigate to complete our model?* Give students a few minutes to brainstorm questions using *Investigation Question Development*, then discuss.✱ Listen for these ideas:

- How is a mass of ice affected by incoming heat flow?
- What factors affect how much ice melts?
- What is the relationship between heat and mass of ice melted?

Accept all responses that indicate a relationship between mass of ice melt and heat. Once this has been established as the purpose of the investigation, distribute *Water-Ice Investigation Procedure* and have students record or indicate their preferred investigation question.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should ask questions that clarify the energy transfer model's unclear mathematical relationship between heat and ice melt. (SEP: 1.2; CCC: 5.4)

What to do: *Investigation Question Development* can be used to provide extra support if students are not sure what to investigate based on their existing model. If students' questions do not clearly establish a relationship between ice melt and heat, help students recall what they said might affect ice melt generated on **slide A**.

Building toward: 11.A.2 Ask questions based on an existing model around how energy causes matter cycling in a system with conserved and transferred energy. (SEP: 1.2; DCI: PS3.B.1; CCC: 5.4)

✱ SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

Lessons 11 and 13 both provide opportunities for students to ask questions differently than they have before. Here, students are given time to individually consider investigation questions that have the explicit purpose of refining their model, rather than deciding on this question as a group or class. In Lesson 13, students will ask questions of a computational model.

3 · PLAN AN INVESTIGATION TO COMPLETE OUR MATHEMATICAL MODEL

7 min

MATERIALS: *Water-Ice Investigation Procedure*, copy of https://docs.google.com/spreadsheets/d/1FjEL64clNekP794iL0xvZo3DU53u-trj0CO7gNwU_P0/copy

Review the water-ice investigation procedure. Show **slide D**. Distribute *Water-Ice Investigation Procedure*. Give students a few minutes to read the investigation procedure and underline things that are different between this procedure and the liquid-liquid investigation in Lesson 10. Then ask students to share some of the things they noticed. These might include:

- We are only measuring the temperature change of the water, not of the ice.
- After we combine the two substances, we separate them again.
- We are documenting the mass change of the water and the ice and taking the average.

Explain that taking the average of the water's mass increase and the ice's mass decrease, which should be about the same, will help us get a more accurate reading.

Display **slide E**. Discuss the questions on the slide as a class.

Suggested prompt	Sample student response
What will these changes in the procedure allow us to figure out?	How much energy transferred from the water to the ice to make it melt. How much ice melted.

Suggested prompt	Sample student response
What is our independent variable?	The amount of heat transfer from the water.
What is our dependent variable?	The mass of ice that is melted.
(Show students the Google Sheet.)	It has space for the data we need to collect.
How would the spreadsheet allow us to easily record our data?	It already has a graph that shows the amount of heat transfer and mass of ice melt, so we will be able to see the relationship easily.
*Why can we graph the heat transfer **from** the water with the mass of ice melted? Shouldn't we graph the heat transfer **to** the ice instead?*	They should be the same amount of heat because energy is conserved.

ADDITIONAL GUIDANCE

Students may be surprised or confused by the fact that the independent variable, heat, is on the *y*-axis, while the dependent variable, mass, is on the *x*-axis. Tell them that this is sometimes done to make the equation easier to work with later.

Assign each lab group to a particular condition.

Make a directional hypothesis. Show **slide F**. Have students finish the hypothesis statement on *Water-Ice Investigation Procedure*. Then discuss the prompt on the slide as a class. Listen for these ideas:

- More ice will melt when more heat is transferred to it.
- This fits with our experiences, but we do not have evidence to say if the relationship will be linear or not.

ADDITIONAL GUIDANCE

Highlight to students that by making a directional hypothesis, we will be able to easily tell whether or not the experimental results support our current thinking.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should make hypotheses that clearly state the direction in which increased heat will affect ice melt mass. (SEP: 3.5)
- Students should state that the heat flowing out of water is the same as the heat flowing into ice because energy is conserved. (DCI: PS3.B.1)

What to do: At this point, students do not have to predict the shape of the graph, but it is fine if they do. Allow students to use arrows to represent their hypothesis or state it verbally if they initially struggle to write it in words. Then, work with these students or have their peers help them figure out how to record their ideas in words.

Building toward: 11.B.1 Make a directional hypothesis about how much energy transfer must be prevented as part of a system design. (SEP: 3.5; DCI: PS3.B.1; CCC: 4.1)

4 · COLLECT AND SHARE DATA

12 min

MATERIALS: Water-Ice Investigation, computer, copy of https://docs.google.com/spreadsheets/d/1FjEL64clNekP794iL0xvZo3DU53u-trj0CO7gNwU_P0/copy

Review safety guidelines. Do so by displaying and discussing **slide G**.

Carry out the investigation. Display **slide H**. Check to see that students are following the investigation procedure correctly and recording their data in the data table on *Water-Ice Investigation Procedure*. Remind them to use the "tare" button to eliminate the mass of the cup and lid, and to measure the temperature of the water right before adding the ice to get the most accurate measurement. Demonstrate how to flip the lid and pour out the water, if needed. Consult *Water-Ice Investigation Procedure* for step-by-step instructions.

Record class results. Have students complete the prompts below the data table on *Water-Ice Investigation Procedure*, then add their group's results to the class data table.

Collect cups, lids, digital thermometer with metal probes, and scales to reuse across classes.

5 · MAKE SENSE OF THE RESULTS

8 min

MATERIALS: copy of https://docs.google.com/spreadsheets/d/1FjEL64clNekP794iL0xvZo3DU53u-trj0CO7gNwU_P0/copy, Key ideas poster from Lesson 10

Analyze the data. Display **slide I.** Lead the class in discussing the prompts on the slide.

Suggested prompt	Sample student response
What do we notice in the data? How does this fit with our hypothesis?	More ice melted when more heat was transferred to it.✱ This is what most of us thought would happen.
(Construct the best-fit line for students.) *What is the slope of the best-fit line?*	It is about 80.
What are the units of the slope?	Calories per gram.
What does the slope mean?	This means that when 80 calories of energy are transferred from the water to the ice, 1 gram of ice melts.
How could we write this as an equation?	Q = 80 * m
(Add the equation to the poster under the label "heat required to melt a mass of ice.") *If we knew the heat transfer but not the mass, how could we figure out the mass?*	We could divide the heat transfer by 80.

Add this equation to the Key ideas poster.

✱ SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

As in Lesson 10, it may help students to represent the relationship with arrows: when $Q \uparrow$, m (of ice melt) $\uparrow$.

ADDITIONAL GUIDANCE	To produce a line of best fit in Google Sheets: 1. Double-click the chart. 2. Click Customize. 3. Click Series. 4. Scroll down to click Trendline. 5. Under Label, select "Use Equation."
ALTERNATE ACTIVITY	**Extension opportunity:** The slope of this graph represents the latent heat of fusion, which is a material property that indicates how much energy is required to melt a certain mass of a substance. If you wish for students to generalize this knowledge to other substances, you may assign *Other Substances* as home learning.

6 · NAVIGATE

5 min

MATERIALS: science notebook

Update Progress Trackers. Show **slide J**. Give students a moment to update their Progress Tracker in their notebook.

Question	What we figured out in words/pictures
How does heat affect the amount of ice melt?	*We figured out that Q = 80 · m. This means that if you add a certain amount of heat to the ice, you divide it by 80 to figure out the mass of ice that melts.*

Navigate back to the glacier system. Display **slide K**. Discuss the questions on the slide as a class.

Suggested prompt	Sample student response
What does our new equation help us explain in this system?	It can tell us how much ice would melt if a certain amount of energy gets to the glacier. It can tell us how much energy we need to stop from getting to the glacier if we want to prevent it from melting.
How can it help us in addressing glacier melt and sea level rise?	It tells us how good our berm has to be. It tells us how much energy transfer the berm has to stop. It can help tell us if the berm is "worth it" to prevent ice melt and sea level rise.

Say, *It sounds like we have figured out a lot about the berm! We are probably ready to put all those pieces together.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should state that our knowledge of energy transfer could be used to determine if a change to the water-glacier system would have the desired effect of slowing polar ice melt and sea level rise. (DCI: PS3.B.1; CCC: 4.1)

What to do: If students are unsure how our new ideas could be applied, you may wish to have them review prior rows in their Progress Tracker. Additionally, use the diagram on **slide I** to help students think about the role of the berm in the system.

Building toward: 11.B.2 Make a directional hypothesis about how much energy transfer must be prevented as part of a system design. (SEP: 3.5; DCI: PS3.B.1; CCC: 4.1)

Additional Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HSN.Q.A.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; ~~choose and~~ interpret the ~~scale and the~~ origin in graphs and data displays.

CCSS.MATH.CONTENT.HSN.Q.A.2: Define appropriate quantities for the purpose of descriptive modeling.

CCSS.MATH.CONTENT.HS.S-ID.7: Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of the data.

CCSS.MATH.CONTENT.HSF.LE.A.2: Construct linear ~~and exponential~~ functions ~~including arithmetic and geometric sequences,~~ given a graph ~~a description of a relationship,~~ or two input-output pairs (including reading these from a table).

CCSS.MATH.CONTENT.HS.S-ID.6b: Represent data on two quantitative variables on a scatter plot, and describe how the variables are related: Informally assess the fit of a function by plotting and analyzing residuals.

CCSS.MATH.CONTENT.HS.S-ID.6c: Represent data on two quantitative variables on a scatter plot, and describe how the variables are related: Fit a linear function for a scatter plot that suggests a linear association.

CCSS.MATH.CONTENT.HS.S-ID.7: Interpret the slope (rate of change) and the intercept (constant term) of a linear model in the context of the data.

As in Lesson 10, students use graphical information and a line of best fit to construct an equation that can be used in modeling a phenomenon.

LESSON 12: How can we slow the flow of energy on Earth to protect vulnerable coastal communities?

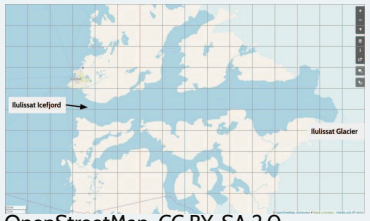
PREVIOUS LESSON

We realized that we do not know all the factors that affect the amount of ice melt, so we planned and conducted an investigation to measure how heat and mass are related. We figured out that 80 calories of energy are required to melt 1 gram of ice, and we considered how this understanding might help us in addressing glacier melt and sea level rise.

THIS LESSON

PUTTING PIECES TOGETHER, PROBLEMATIZING

2 days



OpenStreetMap, CC BY-SA 2.0

We develop a Gotta-Have-It Checklist of ideas to include in a mathematical model that can help us further evaluate the berm solution. We develop this mathematical model, then use it to calculate the berm's impact on ice melt. We recognize that this model does not reflect all the ideas we figured out or the solutions we examined in the unit, so we brainstorm ideas for an expanded computational model that includes the Earth system beyond the glacier.

NEXT LESSON

We will read about how scientists model climate. We will use this understanding to develop and test questions with our unit computational model. We will discuss and reflect on our results. We will close out our Driving Question Board and complete a transfer task focused on indoor heating in a changing climate.

BUILDING TOWARD NGSS

HS-PS3-1, HS-PS3-4, HS-ESS2-2, HS-ESS2-4, HS-ESS3-1, HS-ESS3-5, HS-ESS3-6, HS-ESS2-7

WHAT STUDENTS WILL DO

12.A Use multiple types of models of changes in energy and matter flows in order to predict the impact of a berm. (SEP: 2.4; DCI: ESS3.D.1; CCC: 5.2)

12.B Support a claim with mathematical models, including unit conversions involving quantified changes in sea level, using energy conservation as a tool. (SEP: 5.2, 5.5; DCI: PS3.A.1; CCC: 7.2)

12.C Create a checklist for a computational model that can predict how a defined system is influenced by resource availability and use by humans. (SEP: 5.1; DCI: ESS3.A.1; CCC: 4.2)

WHAT STUDENTS WILL FIGURE OUT

- We can build a mathematical model that will allow us to figure out how much ice melt the berm can prevent.
- About 3.35 x 10^{18} calories of energy are being transferred into the Ilulissat Glacier system to cause the amount of ice melt that produces the yearly amount of meltwater coming off the Ilulissat Glacier.
- About 5 x 10^{18} calories of annual energy flow into the Ilulissat Glacier system could be prevented by the proposed berm solution, so the berm could theoretically stop glacier melt at that location.
- We can expand our model to include a larger system (i.e., on the global scale, rather than the scale of a particular glacier).

Lesson 12 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	4 min		**NAVIGATE** Orient students back to the big-picture problem that the class has been investigating and motivate putting together a consensus model of the proposed berm solution.	A	
2	18 min		**BUILD A GOTTA-HAVE-IT CHECKLIST** Support students in compiling ideas from Lesson Set 3 into a Gotta-Have-It Checklist to use to build a mathematical model of the berm's impact.	B-C	materials from Lessons 8-11, *Berm Model*, Key Ideas poster from Lesson 10, Gotta-Have-It Checklist, consensus model chart paper
3	8 min		**DEVELOP A MATHEMATICAL MODEL** Give students time to develop a mathematical model to figure out how much energy transfer and sea level rise a berm would prevent.	D	*Berm Model*, consensus model chart paper, Gotta-Have-It Checklist
4	15 min		**BUILD A CONSENSUS MODEL** The class conducts a Consensus Discussion and builds a model in a Scientists Circle to explain and quantify how the berm works to prevent glacial melt.	E	*Berm Model*, consensus model chart paper, chart paper markers, Gotta-Have-It Checklist
					End of day 1
5	20 min		**USE THE MATHEMATICAL MODEL** Support students as they work with a partner to calculate whether the proposed berm solution at the Ilulissat Glacier site would have a meaningful impact on sea level rise.	F	*Calculating Berm Impact*, Mathematical Consensus Model
6	5 min		**DISCUSS AND PROBLEMATIZE THE RESULTS** Verify for students the results they should have found and help them navigate back to other proposed solutions.	G	*Calculating Berm Impact*
7	15 min		**BUILD A UNIT GOTTA-HAVE-IT CHECKLIST** Give students time to brainstorm ideas to include in a unit-long computational model.	H-I	*Unit Gotta-Have-It Checklist*, chart paper
8	5 min		**COMPLETE AN EXIT TICKET** Give students time to complete an exit ticket.	J	*Vehicle Exit Ticket*
					End of day 2

Lesson 12 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • materials from Lessons 8-11 • *Berm Model* • *Calculating Berm Impact* • *Unit Gotta-Have-It Checklist* • *Vehicle Exit Ticket*		• Key Ideas poster from Lesson 10 • Gotta-Have-It Checklist • consensus model chart paper • chart paper markers • Mathematical Consensus Model • chart paper

Materials preparation (30 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Prepare two pieces of chart paper--one for a class Gotta-Have-It Checklist for the berm model, and a second with an outline for the mathematical consensus model. The *Berm Model Key* key provides an example of the outline you may want to draw, as well as a sample Gotta-Have-It Checklist and consensus model.

Lesson 12 • Where We Are Going and NOT Going

Where We Are Going

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **ESS3.D.1: 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.
- **PS3.A.1: Definitions of Energy.** Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. ~~That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as,~~ within the system, energy is continually transferred from one object to another ~~and between its various possible forms.~~
- **ESS3.A.1: Natural Resources.** Resource availability has guided ~~the development of~~ human society.

This lesson completes the mathematical model for energy transfer in the berm solution that students have been developing throughout Lesson Set 3. Students build a model that shows the equations they have developed in the context of energy transfer models mapped onto the berm solution diagram from Lesson 5. This is also an excellent opportunity to include particle-level representations as a reminder to students of the continuing importance of particle-level modeling in chemistry.

Students use several different models, developed throughout Lesson Set 3, as they develop a class consensus model (SEP: 2.4) to aid their own mathematical modeling. Here, they show changes in energy and matter (CCC: 5.2). Students quantify and model change over time (CCC: 7.2), using mathematical representations, including ratios and unit conversions (SEP: 5.5), to support claims (SEP: 5.2). In doing so, students build on mathematical modeling practices from Lessons 4 and 6. The Mathematics Anchor Chart can serve as a reminder of how different techniques are used. Students also carefully identify system boundaries and conditions (CCC: 4.2) as they create a Gotta-Have-It Checklist for a computational model of the Earth system (SEP: 5.1).

As students calculate the impact of the berm, they are considering the Learning in Places ethical decision-making question, *How does the natural world impact this decision? How is the natural world impacted by this decision?*

The average melt flux of 1.4 x 10^9 grams per second used for the calculations in *Calculating Berm Impact* and *Berm Calculations Key* was measured from the front of the glacier. However, this is not the only source of water flowing from the glacier into the fjord. Calving accounts for an additional ~20 billion tons of ice added to the ocean as water per year. Some icebergs breaking off from the glacier are too tall (up to 1 km in height) to float down the fjord and remain stuck in its shallower areas, sometimes for years, until they are broken up by the force of the glacier and icebergs farther up the fjord. The energy transfers to this ice and the resulting melt flux were not included in the average melt flux used in the handout.

Where We Are NOT Going

This lesson does not include a comprehensive unit model incorporating ideas from Lesson Sets 1 and 2. Students spec out such a model at the end of the lesson, then utilize a prebuilt computational model in Lesson 13.

Students already established energy conservation in Lessons 3, 6, and 10, and use it here in their mathematical modeling. Students do not consider rates of change (as they did in Lesson 1) or irreversibility of certain system changes (as they will in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*). Students explicitly use models to make predictions in subsequent units and similarly have opportunities to use algorithmic representations to support explanations later in the course. Rates and percentages are not addressed in this lesson or unit, nor are revisions of a computational model of a phenomenon or designed device.

As in previous lessons, allow students to celebrate that they have figured out how the berm solution could help prevent glacier melt, but keep in mind that it is neither a panacea or necessarily desirable in every local context. Students use the acknowledgement that scaling up berms seems challenging to help motivate a holistic examination of the Earth system in Lesson 13.

Students are introduced to the idea, for the first time in the OpenSciEd High School Chemistry course, that resource *availability* is an important consideration as we explore solutions to major problems like climate change, and that it could have an impact on where society goes in the future. This idea is more completely developed in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*.

LEARNING PLAN for LESSON 12

1 · NAVIGATE

4 min

MATERIALS: None

Navigate to today's work. Display **slide A.** Say, *We have spent a lot of time thinking about how energy transfers to the bottom of Ilulissat Glacier and how the proposed berm solution could prevent this.*

Have students turn and talk about the questions on the slide and then discuss as a class.

Suggested prompt	Sample student response
What have we been trying to figure out in this unit?	How can we slow the flow of energy on Earth to protect vulnerable coastal communities?
How does the proposed berm solution fit into that picture?	It is supposed to prevent warm water from getting to the glacier, so it won't melt and contribute to sea level rise.
Would the berm solution be a good one? How could we tell?	It makes sense. We do not know how much it would actually help with sea level rise. We need to actually calculate how the berm would help with ice melt, like we did with the microbeads.

Transition to the need to build a consensus model for what the class has figured out. Say, *We have figured out so much about how this potential solution works. Let's put these pieces together.*

2 · BUILD A GOTTA-HAVE-IT CHECKLIST

18 min

MATERIALS: science notebook, materials from Lessons 8-11, *Berm Model*, Key Ideas poster from Lesson 10, Gotta-Have-It Checklist, consensus model chart paper

ADDITIONAL GUIDANCE

In Lessons 10 and 11, students developed the following key ideas and are used as students build the model (along with other ideas from Lesson Set 3)✱:

1. Energy transfer between two objects/samples initially at different temperatures will cause both to eventually reach the same final temperature, which will be between the initial temperatures.
2. The mass and temperature of each sample affect where the final temperature stabilizes (ΔT depends on m).
3. Energy is conserved. It flows between objects but is not created or destroyed. $m_a \cdot \Delta T_a - m_b \cdot \Delta T_b = 0$
4. Conduction is the transfer of energy through direct contact as particles collide.
5. $Q = c \cdot m \cdot \Delta T$
6. $Q = 80 \cdot m$

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

In constructing a model, we are laying out some of the particular computations that students will need to carry out to move from a general understanding of the glacier system to estimating the actual amount of ice melt that occurs with no berm present. The Gotta-Have-It Checklist will get ideas on the table, including useful equations, which

Brainstorm ideas for a Gotta-Have-It Checklist with a partner. Display **slide B**. Say, *We have a pretty good idea of how a berm works, but we have not actually figured out* ***how much*** *impact it will have on ice melt. To do that, it helps to have an idea of what mathematical model we will need to use for our calculations.*

In this class, when we develop a complex model or mathematical model, it is helpful to use a Gotta-Have-It Checklist. This is where we decide what information is important for us to answer our questions.

Have students turn to the area of their notebooks where they recorded work related to the berm, and remind them to refer to the Key Ideas poster. Distribute *Berm Model* and give students 8 minutes to work with a partner to review the materials and brainstorm ideas that would be helpful to include in our mathematical model.

Build a class Gotta-Have-It Checklist. Display **slide C.** Have pairs share ideas that they included in their brainstorming.✱ Use the prompts on the slide to help guide this Consensus Discussion. Record decided-upon ideas on the Gotta-Have-It Checklist chart paper, and ask students to add them to their own Gotta-Have-It Checklists. Example checklist ideas are shown below.

Once a checklist has been agreed upon, celebrate it, and indicate that we have the pieces we need to build a mathematical model.

KEY IDEAS

Purpose of this discussion: In this discussion, students develop a class Gotta-Have-It Checklist for all the ideas needed to mathematically model the impact of the berm solution on sea level rise. Students can add these ideas to *Berm Model* as a support as they develop a mathematical model of this phenomenon.

Your role in this discussion is to get as many students as possible to weigh in on the ideas being shared. Do not write every idea on the chart paper right away. Let students determine whether an idea is really needed to explain a part of the system. If you see that any critical ideas are missing, be sure to prompt students so that the list is complete at the end of this Consensus Discussion.

Listen for these ideas: See the key for *Berm Model Key* for sorting by category.

- Energy comes from the warm salty water that is moving toward the ice.
- Increased density due to increased mass helps explain why the warm salty water does not rise to the top as warm water normally does.
- The energy moves with the water to the glacier through convection.
- Increased density due to increased mass helps explain why the warm, salty water does not rise to the top as it normally does.
- The energy transfers from the warm salty water to the ice via conduction.
- We can calculate how much energy transfers with $Q = c \cdot m \cdot \Delta T$.
- If a berm is in place, it blocks the warm salty water and energy will transfer to the berm instead of to the glacier.
- The energy transferred to the ice causes it to melt.
- The amount of ice melt can be calculated using $Q = 80 \cdot m$.
- We can use tools from earlier in the unit to calculate how much of the sea level rise would result from this ice melt.

can then be mapped to the physical features of the glacier system on the provided diagram in *Berm Model*.

✱ ATTENDING TO EQUITY

To promote equitable discussion, allow each group to share at least one idea before any groups repeat. You may wish to select groups with fewer ideas on the page to share first, so they have the opportunity to share something before the ideas on their page are "taken." Or, in subsequent rounds, encourage students to promote or echo a point that has already been proposed, if they do not have a new idea to share.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- See the *Berm Model Key* key for what to look for in the Gotta-Have-It Checklist.

What to do: It is important to surface all the ideas that are included in the sample Gotta-Have-It Checklist so that students may use them in their mathematical models if they wish. Refer back to the investigations in which these ideas were developed as needed.

Building toward: 12.A.1 Use multiple types of models of changes in energy and matter flows in order to predict the impact of a berm. (SEP: 2.4; DCI: ESS3.D.1; CCC: 5.2)

3 · DEVELOP A MATHEMATICAL MODEL

8 min

MATERIALS: *Berm Model*, consensus model chart paper, Gotta-Have-It Checklist

Develop a mathematical model with a partner. Display **slide D.** Have students shift to the modeling portion of *Berm Model*. Give students a block of time to work with a partner.✱

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- See the *Berm Model Key* key for what to look for in students' models.

What to do: It is okay if an individual student's model does not include every idea described in the "Organized Understanding" section of the key. Encourage students who are stuck to add to particular areas of the provided diagram, asking them, *What did we figure out is happening here?*

If you suspect that many students will have to significantly revise their models during class discussion, plan to ask them to make these revisions in a different color.

This three-dimensional assessment opportunity is a chance for students to use mathematical, particle, and system models together to track energy and matter flows as part of understanding humans' ability to manage their impacts (in this case, specifically how the berm affects this ability). Even after consensus modeling, it is useful to collect students' individual models to provide feedback on the use of all three dimensions together, as well as individual elements of the dimensions.

Building toward: 12.A.2 Use multiple types of models of changes in energy and matter flows in order to predict the impact of a berm. (SEP: 2.4; DCI: ESS3.D.1; CCC: 5.2)

✱ SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Consider posting the Mathematical Anchor Chart to support students in this task, particularly if it contains an example unit conversion calculation.

4 · BUILD A CONSENSUS MODEL

15 min

MATERIALS: *Berm Model*, consensus model chart paper, chart paper markers, Gotta-Have-It Checklist

KEY IDEAS

Purpose of this discussion: In this discussion, the class develops a mathematical consensus model that students can use to help them calculate the impact of the berm solution.✱

Listen for these ideas: See the *Berm Model Key* key for a sample consensus model, as well as in-development models that students may bring to the discussion.

Organized understanding should show:

- how energy is transferred into the system by warm water, and eventually to ice, through the mechanisms of convection and conduction and how this impacts matter at the particle level.
- how relevant equations could be used to predict the impact of the berm solution as compared to the normal flow of warm water.

Form a Scientists Circle to build a consensus model.✱ Display **slide E**. Ask students to bring *Berm Model* and gather them so that the model chart paper and class Gotta-Have-It Checklist are visible. Use the prompts on the slide to help students construct the mathematical consensus model.

COLLABORATION

Before students build a class consensus model, you may wish to give them an opportunity to share and sharpen their work through peer feedback. Have pairs meet with other pairs and examine each others' work using the protocols in the *OpenSciEd High School Teacher Handbook,* then begin whole-class discussions.

Suggested prompt	Sample student response
How should we model where the energy comes from?	We can show warm salty water moving into the icefjord. We could represent that this water is denser than the cooler water above because it is so salty.
How should we model or predict how the energy moves or flows?	We could draw an energy transfer model that shows this movement as part of convection. We could draw a second arrow and box showing that the energy transfers to the ice by conduction. We could write $Q = m \cdot c \cdot \Delta T$ by this arrow. We could do a second possible path for the warm water from the energy transfer diagram, showing it hitting the berm and energy transferring there instead.

✱ SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Although this model is being used primarily for mathematical purposes, it in fact incorporates different types of models to provide different types of context. Highlight this idea for students, along with the advantages that the different pieces of the model provide and the limitations that they present.

Suggested prompt	Sample student response
How should we mathematically model how the energy affects the matter as it transfers?	We could model melting at the particle level if we wish. We could add the equation Q = 80 · m next to the ice to show that it can be used to calculate the mass of ice that melts. We can write "unit conversions" next to this to remind ourselves that we can calculate the amount of sea level rise based on this ice melt.
Which energy transfers are we choosing not to model here?	Energy transferred directly from the Sun or the air.

Add these ideas to the consensus model chart paper.

Follow up by asking the following prompts.

Suggested prompt	Sample student response
How can we use this model?	We can figure out the impact of a berm on ice melt. We could figure out the impact on sea level rise after that. We could figure out the impact of other solutions that change the amount of heat transfer to ice.
Why is it useful to map our equations onto a diagram and include non-mathematical parts?	It helps us put our mathematical models into context. It shows us how the different ideas in our model work together more effectively.

Celebrate students' progress and say that we seem ready to carry out calculations like these.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- See the key for *Berm Model Key* for what to look for in students' models.

What to do: Listen for ideas that indicate how the berm would affect the system. If you do not hear these ideas, follow up by asking, *How is this different when the berm is in place?*

You may wish to collect individual students' models once they have had a chance to revise them. If so, the recommendations provided on the key for *Berm Model Key* may be helpful for providing feedback.

Building toward: 12.A.3 Use multiple types of models of changes in energy and matter flows in order to predict the impact of a berm. (SEP: 2.4; DCI: ESS3.D.1; CCC: 5.2)

End of day 1

5 · USE THE MATHEMATICAL MODEL

20 min

MATERIALS: *Calculating Berm Impact*, Mathematical Consensus Model

Navigate into the assessment. Say, *We have the tools to figure out if the berm would really prevent glacier melt as much as we hope it would.* Distribute *Calculating Berm Impact*. Tell students, *You will have about 20 minutes to work through these problems on your own and with a partner.✱ All the resources you need are on this handout and our class model.* Display **slide F**.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should accurately utilize unit conversions in their calculations. (SEP: 5.5)
- Students should be able to apply their mathematical model throughout the calculations to quantify changes and make a reasonable claim based on the results. (SEP: 5.2; CCC: 7.2)
- Students should be able to articulate how energy conservation is consistent with their claim. (DCI: PS3.A.1)

What to do: Remember that errors early in *Calculating Berm Impact* may propagate throughout students' calculations. Encourage students to make a claim based on their results so that this element can be assessed, even if the calculations do not yield the expected answers. See the key for *Berm Calculations Key* for detailed solutions and additional guidance.

It is important to ensure that students are leveraging all three dimensions in their claims about the impact of the berm, as they will be asked to use this disciplinary core idea as they complete the unit transfer task in Lesson 13.

Building toward: 12.B Support a claim with mathematical models, including unit conversions involving quantified changes in sea level, using energy conservation as a tool. (SEP: 5.2, 5.5; DCI: PS3.A.1; CCC: 7.2)

✱ ATTENDING TO EQUITY

To combat math anxiety, encourage students to try some parts together, and some parts on their own. When a pair is stuck, encourage them to check in with others. Pause the class to get on the same page if needed. The goal is to help students figure out the effectiveness of the berm solution while practicing some math, not to test students on their ability to do unit conversions.

6 · DISCUSS AND PROBLEMATIZE THE RESULTS

5 min

MATERIALS: *Calculating Berm Impact*

Summarize the assessment takeaway. Say, *You should have found that about 5 x 10^{18} calories of energy would be blocked by the berm each year, which is more than the approximately 3.35 x 10^{18} calories of energy that are currently being transferred from the warm water to the glacier.. This means all the ice melt occurring each year at this location could be stopped, and many people's lives could be tremendously impacted by the berm.*

Display **slide G**. Say, *Let's think more about this solution.* Lead students in a brief discussion beginning with the prompt on the slide, then continue with the additional prompts below.

ADDITIONAL GUIDANCE

You might be surprised to see the Problematization Routine appear in the penultimate lesson. However, it is necessary to help students move beyond the berm solution that was the emphasis in Lesson Set 3 to making meaning of the unit as a whole.

Suggested prompt	Sample student response
Would the berm solution always work? Why or why not?	Maybe, but we would need more data. No, because it might not be supported by local people. No, because it might be harder to stop the water in certain locations. No, because in some places, more of the melting might be due to the air, the ground, or the Sun. No, because it might be too expensive. No, because there might be scenarios where it affects wildlife.
Even if it worked, would it be able to make the sea level go down again? Or would it work quickly enough to make a difference?	It probably would not make the sea level go down again, just keep it from rising more. It is hard to say if it would work quickly enough to make a difference.
What other proposed solutions have we discussed in this class?	Spreading microbeads on ice. Just releasing less CO_2 or somehow getting rid of it.
If all these solutions were implemented, how might this affect the biosphere (human and non-human)?	The sea level would not rise as quickly. People would have to produce less carbon dioxide and burn less fossil fuel.
Why are any of these solutions needed in the first place?	The temperature rise is due to CO_2 added to the atmosphere by people.
Can we account for other solutions or effects besides sea level rise with our current model?	No, we need to expand it.
How would the system in an expanded model be different from the system we modeled when we were calculating the berm's impact?	It would cover more of the world. It would include new components like the Sun, carbon dioxide, and places other than Ilulissat.

Say, *We should identify what these ideas are, so we know what we would want in this expanded model. It sounds like we want to account for lots of different human activities and their effects, beyond just sea level rise.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should conclude that implementing solutions that would functionally affect resource (fossil fuel) availability would also affect daily life. (DCI: ESS3.A.1)
- Students should identify that the system in the proposed model includes many more components than the system in the previously developed mathematical model. (CCC: 4.2)

What to do: These ideas are only being initially developed at this point, so there is no need to push if students do not articulate them fully. They will have another opportunity to consider these concepts in *Vehicle Exit Ticket* at the end of the lesson.

Building toward: 12.C.1 Create a checklist for a computational model that can predict how a defined system is influenced by resource availability and use by humans (SEP: 5.1; DCI: ESS3.A.1; CCC: 4.2)

7 · BUILD A UNIT GOTTA-HAVE-IT CHECKLIST

15 min

MATERIALS: *Unit Gotta-Have-It Checklist*, science notebook, chart paper

Brainstorm additional items. Display **slide H** and distribute *Unit Gotta-Have-It Checklist*. Give students seven minutes to work with their partner to brainstorm ideas to include in a full-unit model.

Build a class checklist.✱ Display **slide I.** On chart paper, add the Gotta-Have-It Checklist items that would be useful to include in a computational model that answers the question, *What are the intended and unintended impacts of human activity on polar ice melt and sea level rise?*

Listen for the following ideas. The list does not have to be comprehensive, as an initial model will be provided to students in Lesson 13.

- Sea level rise affects people in coastal communities.
- Volcanic activity, Earth's position in orbit, and solar activity all impact the amount of energy that reaches Earth.
- Land ice contributes to sea level rise, but sea ice does not.
- The berm and microbeads solutions could affect humans and non-humans in the areas where they are implemented.
- Clean snow and ice have a greater albedo than most other materials, so they reflect more light.
- When low-albedo materials absorb visible light they emit infrared light.
- Visible light passes through carbon dioxide and other greenhouse gases but infrared light is absorbed, keeping the energy in Earth's system.
- People in coastal communities would have to move if the land they live on becomes unavailable or unusable.
- People in the areas where solutions are implemented would have to change their lives to adjust to the solutions.

Summarize. Thank students for their ideas. Say that you will bring a model that includes these ideas for students to use in the next lesson.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING SYSTEMS AND SYSTEM MODELS

In this checklist, students are essentially identifying the different components that they want to include in the computational model; that is, in the system. Encourage students to skim their Progress Trackers and other course materials to identify these different pieces.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should create a checklist that could be used to build a computational model that uses ideas from the unit to predict human impacts on the Earth system. (SEP: 5.1)

What to do: Encourage students to review their Progress Tracker and materials used throughout the unit during the brainstorming phase. It is okay if not every idea on the sample Gotta-Have-It Checklist above or in the Lesson 13 model is represented, as long as the majority are. This is also an opportunity to help students review the unit as a whole.

Building toward: 12.C.2 Create a checklist for a computational model that can predict how a defined system is influenced by resource availability and use by humans (SEP: 5.1; DCI: ESS3.A.1; CCC: 4.2)

8 · COMPLETE AN EXIT TICKET

5 min

MATERIALS: *Vehicle Exit Ticket*

Assign the exit ticket. Display **slide J** and distribute *Vehicle Exit Ticket*. Have students complete the exit ticket and turn it in.

EXIT TICKET

The first prompt in this exit ticket is used as a Social and Emotional Learning (SEL) check-in. As mentioned in Lesson 1, climate anxiety can have a real effect on students' mental health. Use this opportunity to see how students are doing. There will be another SEL check-in again in Lesson 13.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should recognize that the availability of materials for electric vehicles could impact where people live. (DCI: ESS3.A.1)
- Students should identify other Earth systems that would be impacted by increased lithium mining and electric vehicle usage. (CCC: 4.2)

What to do: Review the exit tickets to support navigation into Lesson 13. You may wish to provide feedback that asks probing questions that help students identify gaps in their reasoning that can be investigated using the computational model in Lesson 13.

Building toward: 12.C.3 Create a checklist for a computational model that can predict how a defined system is influenced by resource availability and use by humans. (SEP: 5.1; DCI: ESS3.A.1; CCC: 4.2)

Additional Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH	CCSS.MATH.CONTENT.HSN.Q.A.2: Define appropriate quantities for the purpose of descriptive modeling. CCSS.MATH.CONTENT.HSN.Q.A.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; ~~choose and~~ interpret ~~scale and~~ the origin in graphs and data displays. Students define appropriate quantities when building the Gotta-Have-It Checklist and use units and interpret expressions as they determine the impact that a berm has on polar ice melt and sea level rise.
SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.WHST.9-10.1: Write arguments focused on discipline-specific content. Students make and support a claim using their mathematical model.

LESSON 13: How can we model what will happen to Earth's climate if humans make changes?

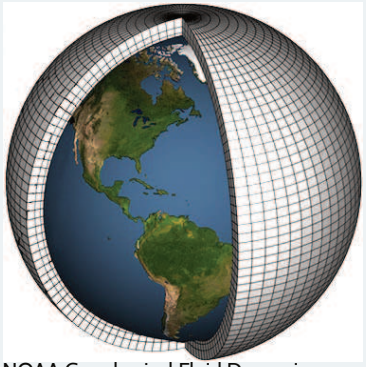
PREVIOUS LESSON

We developed a Gotta-Have-It Checklist of ideas to include in a mathematical model that could help us further evaluate the berm solution. We developed and used this mathematical model to calculate the berm's impact on ice melt. We brainstormed ideas for an expanded computational model that includes the Earth system beyond the glacier.

THIS LESSON

PUTTING PIECES TOGETHER

3 days



NOAA Geophysical Fluid Dynamics Laboratory

We return to our Gotta-Have-It Checklist for the unit computational model and realize that the model is fairly complicated, so we need to think more about how climate modeling works. We read about how scientists carry out and use climate modeling. We use this understanding to develop questions we can ask of our computational model, then test them. We discuss our results and reflect on how they make us feel. We close out our Driving Question Board and complete a transfer task focused on indoor heating in a changing climate.

NEXT LESSON

There is no next lesson.

BUILDING TOWARD NGSS

HS-PS3-1, HS-PS3-4, HS-ESS2-2, HS-ESS2-4, HS-ESS3-1, HS-ESS3-5, HS-ESS3-6, HS-ESS2-7

WHAT STUDENTS WILL DO

13.A Ask questions to determine relationships in a predictive but limited model considering that new discoveries are always being made and that climate models suggest average global temperatures will continue to rise. (SEP: 1.3; DCI: ESS3.D.2, ESS2.D.4; CCC: 4.4)

13.B Use a computational model to support claims about the impacts of energy and matter flows amid complexity. (SEP: 5.2; DCI: ESS2.D.4; CCC: 4.3)

13.C Plan an investigation to identify a problem with energy transfer in the geothermal heating system. (SEP: 3.5, 3.2; DCI: PS3.B.2, PS3.B.5, PS3.D.1; CCC: 4.2)

WHAT STUDENTS WILL FIGURE OUT

- Climate models work using equations for energy and matter transfer like those we developed.
- They are based on assumptions and are therefore not perfectly predictive.
- Models are improved as scientists get new information.
- Climate models agree that Earth will continue to warm significantly if no changes are made.
- Our computational model shows that solutions that decrease carbon dioxide in the atmosphere or energy reaching Earth's surface could prevent some sea level rise and its negative impacts on people.
- Heat pumps provide a possible solution to help limit carbon dioxide emissions while keeping homes safe and comfortable.

Lesson 13 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	6 min		**NAVIGATE** Return to the Gotta-Have-It Checklist for the unit computational model and show the model that was built to these specifications.	A-B	computational model Gotta-Have-It Checklist from Lesson 12, https://www.openscied.org/general/earthsystemmodel/
2	18 min		**READ ABOUT AND DISCUSS CLIMATE MODELING** Give students time to read about, then briefly discuss, climate modeling, with an emphasis on how the information impacts how we think about our computational model.	C-D	*Modeling the Climate*
3	12 min		**GET TO KNOW THE COMPUTATIONAL MODEL** Watch an introductory video and take time to try some basic runs of the model.	E-F	https://www.openscied.org/general/earthsystemmodel/, https://youtu.be/C953LUnpo8Y
4	9 min		**ASK QUESTIONS THAT CAN BE ANSWERED USING THE MODEL** Give students time to develop questions that can be tested using the model.	G	*Modeling the Climate*, https://www.openscied.org/general/earthsystemmodel/
					End of day 1
5	3 min		**NAVIGATE** Remind students of their goals for the computational model.	H	
6	7 min		**TEST QUESTIONS THAT CAN BE ANSWERED USING THE MODEL** Give students time to develop questions that can be tested using the model, then test them.	I	https://www.openscied.org/general/earthsystemmodel/
7	13 min		**SHARE RESULTS FROM THE COMPUTATIONAL MODEL** Discuss what students saw in their tests.	J	
8	20 min		**REFLECT ON WHAT WE HAVE ACCOMPLISHED** Revisit the DQB as a class and take stock of all of the questions we have now answered.	K-L	*DQB Questions*, Driving Question Board
9	2 min		**NAVIGATE** Assign an exit ticket focused on social-emotional learning.	M	blank sheet of paper
					End of day 2
10	45 min		**COMPLETE AN INDIVIDUAL ASSESSMENT** Students individually complete a transfer task.	N	*Heat Pumps Transfer Task*
					End of day 3

Lesson 13 • Materials List

	per student	per group	per class
Lesson materials	• *Modeling the Climate* • science notebook • *DQB Questions* • blank sheet of paper • *Heat Pumps Transfer Task*	• https://www.openscied.org/general/earthsystemmodel/	• computational model Gotta-Have-It Checklist from Lesson 12 • https://www.openscied.org/general/earthsystemmodel/ • https://youtu.be/C953LUnpo8Y • Driving Question Board

Materials preparation (30 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

You should have already created the handout *DQB Questions* for your class. If a significant number of student questions have been added to the DQB since then, you should create an updated version with those new questions and prepare to distribute that to students in addition to their original copy.

Have the Driving Question Board posted and visible to students.

Lesson 13 • Where We Are Going and NOT Going

Where We Are Going

This lesson has three main purposes:

1. to help students apply the conceptual understanding they have built throughout the unit to the whole Earth system,
2. to remind students that even though climate change is a significant hazard, we can make predictions that help us make decisions about how we can address it, and
3. to assess students on key DCIs, SEPs, and CCCs from the unit.

This lesson is designed to coherently build ideas related to the following disciplinary core ideas:

- **ESS3.D.2: Global Climate Change.** Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to human activities.
- **ESS2.D.4: Weather and Climate.** Current models predict that, although future regional climate changes will be complex and varied, average global temperatures will continue to rise. The outcomes predicted by global climate models strongly depend on the amounts of human-generated greenhouse gases added to the atmosphere each year and on the ways in which these gases are absorbed by the ocean and biosphere.
- **PS3.B.2: Conservation of Energy and Energy Transfer.** Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems.
- **PS3.B.5: Conservation of Energy and Energy Transfer.** Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., ~~water flows downhill~~, objects hotter than their surrounding environment cool down).
- **PS3.D.1: Energy in Chemical Processes.** Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment.

Students build the first two of these ideas as they ask questions of a computational model (SEP: 1.3) and use it to support claims (SEP: 5.2). This is students' first assessed opportunity to ask questions about the relationships between variables in the course, although they have previously formulated hypotheses about the relationships between variables (in Lessons 3 and 11) and will do so again in the transfer task. Students previously used structured mathematical modeling as the basis for claims in Lesson 12, and do so again here with a less structured task using a computational model.

This lesson also helps students build on thinking about systems and system models developed throughout the course. Students build on the idea from Lesson 9 that models are not always perfectly reliable due to differences in measurements by considering how climate models are built on assumptions (CCC: 4.4), yet are in general agreement about the reality of climate change even with these differing assumptions. Students also consider which interactions occur due to energy and matter flows in the Earth system (CCC: 4.3).

In this lesson, students are asked to consider questions about how humans impact the climate, including ways that we can work to address climate change. This thinking leverages a variety of areas of the Learning in Places Ethical Deliberation and Decision-Making Framework.

The transfer task provides opportunities for students to demonstrate their understanding of the remaining elements as they reason about how heat pumps work and troubleshoot a faulty system. In doing so, they leverage elements of systems and system modeling and planning investigations built throughout the unit.

Where We Are NOT Going

This lesson is not about evaluating all possible solutions to glacier melt in all locations, or addressing other effects of climate change. Additional effects and solutions will be addressed in *Oysters Unit*, *Fuels Unit*, and *Electricity Unit*.

Although this lesson contains a transfer task, it is not intended to be replaced by an assessment focused on decontextualized "problems." The transfer task was carefully developed to address all three dimensions of the NGSS in a context that is meaningful to students' experiences in and outside of this unit.

LEARNING PLAN for LESSON 13

1 · NAVIGATE

6 min

MATERIALS: computational model Gotta-Have-It Checklist from Lesson 12, https://www.openscied.org/general/earthsystemmodel/

Return to the Gotta-Have-It Checklist. Post the checklist from the end of Lesson 12 and display **slide A**. Use the prompt on the slide to help students re-articulate several key ideas we identified at the end of Lesson 12. Listen for these ideas:

- We wanted different factors that affect how much energy reaches Earth's surface.
- We wanted carbon dioxide.
- We wanted temperature, polar land ice, and sea level.
- We wanted albedo.
- We wanted impacts on people.

Share the model. Open https://www.openscied.org/general/earthsystemmodel/. Give students a minute to look at it, pointing out the matter and energy flows. Then display **slide B** and discuss the prompts on the slide.

Suggested prompt	Sample student response
What impressions do you have of the model?	It looks really complicated.✱
	It looks like it has most of the ideas we wanted.
	The lines are confusing. What are red and blue?
What questions do you have about the model?	How did they decide how the lines work?
	What do you actually control?
	How can you adjust the "up and down" of the fuels?

Say, *This is complicated. In general, modeling climate is something that is pretty complicated. Let's think about how scientists actually model climate before we work with this model ourselves.*

✱ SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

This introduction to the computational model may seem unnecessarily complicated; however, it is intended to help students realize that there is actually a lot they do not know about how climate modeling works. This motivates the need for *Modeling the Climate*.

2 · READ ABOUT AND DISCUSS CLIMATE MODELING

18 min

MATERIALS: *Modeling the Climate*

Give students time to read. Display **slide C** and distribute *Modeling the Climate*. Encourage students to focus on what the reading can tell us that is relevant to our computational model. Give students about ten minutes to read and respond to the prompts in the handout.

Discuss the reading. Display **slide D** and discuss the prompts on the slide.

Suggested prompt	Sample student response
What are the strengths and limitations of climate models like ours?	They are useful for answering questions about long-term climate. They cannot tell us what will happen in a particular place on a particular day.
What does this section tell us about how climate models like ours work?	They use equations to track matter and energy flows. They make assumptions about what these equations are.✱
What does this section tell us about climate models generally?	They show the impacts of different human activities or decisions. They can be updated as we learn more. They predict that average temperatures will continue to rise on average. They predict more storms and other dangerous conditions in most places.
What are three questions you would like to test in our new computational model?	Responses will vary.

Thank students for their questions. Ask, *If we tested these questions using our climate model, in what ways would we be acting as climate scientists do?* Listen for these ideas:

- We would be trying to understand the impacts of human actions on different parts of the Earth system.
- We would be using our models to make predictions about what might happen and learn more about how the different parts of the system interact.
- We would be accounting for new discoveries that we have made in this unit.

✱ SUPPORTING STUDENTS IN DEVELOPING AND USING ENERGY AND MATTER

You may wish to pull out the "Rules for Energy Transfer" and Mathematical Anchor Charts and highlight these ideas from prior lessons as they appear.

ADDITIONAL GUIDANCE

Emphasize to students that scientists do not just say "I think the system will do this" and put it into the model. They use data to develop the model and frame the assumptions, then they test back around that data. It is a constant process to test and revise the model with new data sets. This contributes to confidence in the model. There is variation because scientists test the model in different ways and explore different aspects of the Earth system. Scientists are careful not to say they are certain of what will happen, but the deliberate process, along with general agreement between models, gives confidence that global temperatures will continue to rise without intervention. You may add that an additional limitation of our model is that we did not quantify most of the relationships presented, so we would need more data to know if it represents a highly accurate description of our current climate.

ALTERNATE ACTIVITY

Extension opportunity: Give students an opportunity to return to the climate models they have already encountered in this course: https://sealevel.nasa.gov/ipcc-ar6-sea-level-projection-tool, https://coast.noaa.gov/slr/, and https://sealevel.nasa.gov/vesl/web/sea-level/slr-eustatic/. Let them explore these models in more depth, paying particular attention to the background information accessible in each. Emphasize these questions:

- How are the models similar? How are they different?
- Are the differences only surface-level, or are they based on different data, mathematical models, and assumptions?
- Do any of these tools give access to multiple different sets of climate models or assumptions?

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should identify limitations of their model, including its role in modeling climate rather than weather and its assumptions about the equations that describe energy flow. (CCC: 4.4)
- Students should articulate that:
    - models can be changed as new information is being discovered, (DCI: ESS3.D.2)
    - and climate models generally agree that global average temperatures will continue to rise, although exact predictions vary based on unknowns. (DCI: ESS2.D.4)

What to do: If conversation is slow to start, have students share what they read with a partner before discussing it as a class. Emphasize to students that even though climate models have limitations, scientists constantly work to make them better. Also emphasize that climate models agree on the general outlines of how the climate will change, even though they may disagree somewhat on details. Scientists address this by being honest about their assumptions. Students will have an opportunity to further consider that climate models show continued temperature increases without significant action, so you should plan to re-emphasize this point when students work with the models if the general statement in the reading does not yet resonate with students.

Building toward: 13.A.1 Ask questions to determine relationships in a predictive but limited model considering that new discoveries are always being made and that climate models suggest average global temperatures will continue to rise. (SEP: 1.3; DCI: ESS3.D.2, ESS2.D.4; CCC: 4.4)

3 · GET TO KNOW THE COMPUTATIONAL MODEL

12 min

MATERIALS: https://www.openscied.org/general/earthsystemmodel/, https://youtu.be/C953LUnpo8Y

Watch a video about the computational model. Say, *I think we are ready to dive into how this computational model works.* Display **slide E.** Play https://youtu.be/C953LUnpo8Y. Tell students they will have time to use the model in a moment, and you will take questions then.

Play with the computational model. Display **slide F.** Give students five minutes to explore the model with a partner. Encourage them to use the prompts on the slide for framing if they are unsure what to do.

Take a few minutes to answer students' questions on using the model. Then say, *The reading gave a number of examples of questions that the computational model could help us answer. I bet you have some of your own, too. Let's identify those questions so we can work to answer them using the model.*

4 · ASK QUESTIONS THAT CAN BE ANSWERED USING THE MODEL

9 min

MATERIALS: *Modeling the Climate*, science notebook, https://www.openscied.org/general/earthsystemmodel/

Set up the task. Say, *Like most climate models, our computational model is good at a number of things. If we think of a change that people can make, we can represent that by increasing or decreasing an independent variable — the variables with the sliders on them. Then, our model should be able to tell us not only how that will affect a dependent variable, but approximately how much it should affect it. We want to frame questions that can give us somewhat quantitative answers.*✱

Give students time to develop questions. Display **slide G**. Give students five to six minutes to brainstorm questions with their partner, then settle on one.

After this time, take a minute for a few pairs to share the question they plan to test. If you have time you may also elicit suggestions from the class.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should ask questions that seek to understand a semi-quantitative relationship between an independent and dependent variable. (SEP: 1.3)

What to do: Encourage students to use the scaffold on the slide if it is helpful. This sentence starter was written to help students recall the definitions of independent and dependent variables while developing a question that the computational model is positioned to answer.

Building toward: 13.A.2 Ask questions to determine relationships in a predictive but limited model considering that new discoveries are always being made and that climate models suggest average global temperatures will continue to rise. (SEP: 1.3; DCI: ESS3.D.2, ESS2.D.4; CCC: 4.4)

✱ SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

Students have had opportunities throughout the unit to measure and even predict changes in a dependent variable when an independent variable is changed, but they have never modified their questions to so specifically target these relationships. The sentence stem provided is intended to give the necessary support to help students see that they can ask directed questions about these types of relationships.

End of day 1

5 · NAVIGATE

3 min

MATERIALS: science notebook

Navigate into testing our questions. Display **slide H**. Lead a brief discussion using the prompts on the slide. Accept all responses.

6 · TEST QUESTIONS THAT CAN BE ANSWERED USING THE MODEL

7 min

MATERIALS: science notebook, https://www.openscied.org/general/earthsystemmodel/

Test the questions. Show **slide I**. Give students a few minutes to test their ideas with partners and record the results in their notebooks. Tell them to test more questions, even if they are not well-refined, if they have time.

7 · SHARE RESULTS FROM THE COMPUTATIONAL MODEL

13 min

MATERIALS: None

Discuss students' results. Display **slide J**. Have as many pairs as possible share their results, using the prompts on the slide to guide their responses. Accept all responses that support claims using the model, tie back to matter and energy flows, and support the idea that the effects of climate change will continue if humans do not make changes in behavior.

Tie back to the anchoring phenomenon. Ask, *What do our findings tell us about the communities affected by sea level rise that we saw at the start of the unit, and climate migrants more generally?* Listen for these ideas:

- The communities are still in danger if people do not make changes that could slow global temperature increases, polar ice melt, and climate change.
- They are an example of a much wider problem of negative impacts from climate change.
- Climate migrants deserve empathy and support.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should make claims that are supported by use of the computational model and describe the key energy and matter flows observed. (SEP: 5.2; CCC: 4.3)
- Students should identify continued warming without changes in this complex system. (DCI: ESS2.D.4)

What to do: This activity is intended to build hope. Encourage students to focus on how different interventions can have positive effects, if carried out. Encourage students to identify particular observations from the model that support their claim and to use the energy and matter labels to track flows through the system when a change is made.

Building toward: 13.B Use a computational model to support claims about the impacts of energy and matter flows amid complexity. (SEP: 5.2; DCI: ESS2.D.4; CCC: 4.3)

8 · REFLECT ON WHAT WE HAVE ACCOMPLISHED

20 min

MATERIALS: *DQB Questions*, Driving Question Board

Prepare to return to the Driving Question Board.✱ Display **slide K.** Have students take out *DQB Questions* and provide them with an updated version, if you made one. Have students work in pairs for 10 minutes to mark questions they think the class has answered using the symbols on the handout, replicated here.

- We did not answer this question or any parts of it yet: o
- Our class answered some parts of this question, *or* I think I could now answer some parts of this question: ✓
- Our class answered this question, *or* Using the ideas we developed, I could now answer this question: ✓+

Mark questions on the DQB, individually. Display **slide L.** Ask individual students to come to the DQB and mark questions that the class has answered in whole or in part through our investigations. Have as many students as possible participate until all the questions that the class has answered have been marked. Ask students to share evidence that we have answered the questions as each one is checked off. At the end, you may ask students to summarize which groups of questions have and have not been answered. Thank students again for all their hard work on this unit and celebrate just how much we have figured out through our efforts.

ALTERNATE ACTIVITY

Extension opportunity: Many of the questions on the Driving Question Board may relate to the communities introduced in Lesson 1. If some of these questions have not been answered explicitly but could be answered using the computational model in this lesson, assign these questions to groups of students to test using the model or investigate them as a class.

✱ ATTENDING TO EQUITY

Revisiting the Driving Question Board is important for students to feel as though their questions are valued and recognized. While not all questions will have been addressed (it is more likely that 60–75 percent will be at least partially answered), this activity helps students see the hard work they have done to answer many of their own questions.

9 · NAVIGATE

2 min

MATERIALS: blank sheet of paper

Assign the exit ticket. Display **slide M**. Have students complete the exit ticket on a blank sheet of paper and hand it in for an SEL check-in. Make sure to read these and respond appropriately with students before closing out the unit.

End of day 2

10 · COMPLETE AN INDIVIDUAL ASSESSMENT

45 min

MATERIALS: *Heat Pumps Transfer Task*

Navigate into the transfer task. Display **slide N**. Say, *We have figured out a lot of great chemistry ideas in this unit, but we have mostly only applied these ideas to polar ice melt and sea level rise. Today you will have a chance to look at a different phenomenon that has a lot in common with the ice melt we examined in this unit. This phenomenon involves using an increasingly popular technology called heat pumps. You will focus on how these devices heat homes, but they also can be used to cool homes.✱*

✱ ATTENDING TO EQUITY

Supporting Universal Design for Learning: The scenario associated with the transfer task may be intimidating for some students due to the reading involved. It is recommended you read this scenario as a class before engaging in the transfer task, printing it off on a separate handout for students if desired. Alternatively, give

ALTERNATE ACTIVITY

Extension opportunity: This transfer task may not take the whole class to complete. Consider providing one or more of the following opportunities to students who finish early:

- Have students reflect on how asking questions helped us figure out important ideas about sea level rise and polar ice melt in this unit.
- Have students reflect on how we planned and carried out investigations to help us answer our questions.
- Have students reflect on how we worked together to make progress in answering our questions.
- Collect students' celebrations about the classmate(s) they worked with most throughout the unit, such as most common partners or lab groups.
- Identify questions on the DQB that we were not able to answer in this unit and are unlikely to answer in other units. Have students pick one of these questions and research it.

Once all students are finished, students can share and reflect on these ideas as a class.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- See *Heat Pumps Key* for what to look for in the transfer task.

What to do: See *Heat Pumps Key* for guidance on what to do in response to students' ideas in the transfer task.

Building toward: 13.C Plan an investigation to identify a problem with energy transfer in the geothermal heating system. (SEP: 3.5, 3.2; DCI: PS3.B.2, PS3.B.5, PS3.D.1; CCC: 4.2)

students an opportunity to read the scenario individually or with a partner, then have a few students summarize what they learned from the scenario.

Additional Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

Students summarize the ideas in the reading and consider their application to the climate model that students developed.

Unit C.1 Teacher Reference Materials

ASSESSMENT SYSTEM OVERVIEW

Each OpenSciEd unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the "Assessment Icon" in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

Overall Unit Assessment

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 1	Initial Models Driving Question Board	**Pre-Assessment** The student work in Lesson 1 should be considered a pre-assessment. It is an opportunity to learn more about the ideas your students bring to this unit. Hearing these ideas early on can help you be more strategic in how to build from and leverage student ideas across the unit. The initial model developed on day 2 of Lesson 1 is a good opportunity to pre-assess students' understanding of which parts of the system are important for explaining what is causing sea-level rise, as well as the roles of energy and matter. Collect these models if you do not have time to look at them in the lesson and use them to gauge how students are using models to show three-dimensional thinking; that is, that they are able to model changes in matter and energy to explain the mechanisms behind and impacts of natural hazards like sea level rise. Feedback around these dimensions can also help support student thinking as they begin to use energy transfer models in subsequent lessons. The Driving Question Board is another opportunity for pre-assessment. For example, your class may add a section of questions on anthropogenic climate change, showing they understand its causes, so you may need less time in Lessons 2 and 3. Reinforce that students should generate open-ended questions, such as *how* and *why* questions, and post them to the board. However, any questions students share, even if they are close-ended questions, can be valuable. Make note of any close-ended questions and use navigation time throughout the unit to have your students practice turning these questions into open-ended questions when they relate to the investigations underway. Although students may ask a variety of questions, use this opportunity to assess students' use of crosscutting concepts, especially Stability and Change, as a lens to ask questions that help better understand the particular problem of sea level rise. Throughout these tasks, attend to students' social emotional learning. Check-ins are embedded in discussions throughout the unit and individual check-ins are explicitly built into Lessons 12 and 13, but add more as necessary.
Lesson 2	*Exit Ticket* *Data Analysis*	**Formative** In Lesson 2, *Exit Ticket* is provided between days 2 and 3. This exit ticket not only assesses students' individual reactions to the work done on the Chalk Talk poster, but also provides an opportunity to identify students' thoughts about the idea of anthropogenic climate change due to the release of carbon dioxide. **Formative** Students record their arguments for the most likely cause of temperature increase and sea-level rise based on the timing and rate of change of different factors. Students' on-paper and whole-class work should fully establish that carbon dioxide is the most likely cause of the recent global temperature increase. You should collect *Data Analysis* to better understand the thinking of students who do not share in the oral argumentation. This is an important moment to gather evidence of students' argument-based evidence, using pieces of disciplinary core ideas from their readings, with Stability and Change as a lens.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 3	*Carbon Dioxide Investigation*	**Formative** Students record different parts of the investigation plan that were developed as a class, so this investigation plan can be checked. Students also summarize their investigation findings, providing an opportunity to assess students' thinking about energy transfer and its effects.
	Driving Question Board	**Formative** This first, relatively informal Driving Question Board check-in is an opportunity for students to identify questions that were answered in the first two lessons. They should also add new questions, with at least some of them centering around the discovery that carbon dioxide remains in – and can heat – Earth's atmosphere for a long time, even after we stop new emissions.
Lesson 4	*Sea Level Calculations*	**Formative** Students have an opportunity to apply unit conversions at different scales in the context of the global hazard of glacial ice melt and sea-level rise. They can demonstrate their understanding of using mathematics and computational thinking to calculate the predicted sea-level rise if all of Greenland's and Antarctica's land ice were to melt. The optional *Conversions Home Learning* provides additional practice and assessment opportunities on this topic, if desired.
	Lesson 4 Exit Ticket (Electronic Exit Ticket)	**Summative + Community Building** The first Electronic Exit Ticket allows relatively quick individual assessment of students on a key LLPE. Teachers can quickly check students' understanding of unit conversions to determine whether more practice with this aspect of Using Mathematics and Computational Thinking is necessary. If it is, teachers can provide *Conversions Home Learning* as described above, in preparation for further work with unit conversions in Lessons 6 and 12. Additional targets in this assessment center around the human impacts on climate change and the effects of resulting natural hazards on humans and the role of Scale, Proportion, and Quantity in students' thinking. This assessment also provides summative evidence of students' use of pairs of NGSS elements together. Students also have an opportunity here to reflect on why it is important to address sea-level rise, as well as to engage with metacognitive questions around their own lives, and the value of their classmates in supporting their learning.
Lesson 5	*Discussion Mapping Tool*	**Formative + Community Building** *Discussion Mapping Tool* is a tool to be used to track students' thoughts during the lesson's Consensus Discussion. Although this discussion allows teachers to gauge student thinking around the key features of the two proposed solutions, it is also the unit's first built-in opportunity to systematically examine the classroom culture in the context of a whole-class discussion. A discussion in which only a few students share, or the students who do share are responding only to the teacher or to the same small set of classmates, indicates a need to return to the Community Agreements.
	Driving Question Board	**Formative** This second Driving Question Board check-in allows students to clear additional questions from the first lesson set and add questions deriving from the microbeads and berm solutions. The microbeads questions are particularly important because they will drive instruction throughout Lesson Set 2. In addition, the questions students ask in this question should be three-dimensional: focused on the suitability of the proposed designs, concerned with managing impacts, and with a Systems lens that emphasizes interactions between potentially disparate components. If students' questions are not three-dimensional, you encourage them to re-write them as such or develop new questions that are. This feedback will be beneficial as students are responsible for asking three-dimensional questions in the assessment task in Lesson 7.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 6	*Revising Prior Models*	**Formative** Students independently complete energy transfer models. Collecting these handouts after the lesson also allows teachers to see whether students modified their models to include the "reradiation arrow" from CO_2 back to the surface, which indicates that a feedback loop is occurring.
Lesson 7	*Thawing Permafrost Transfer Task*	**Summative** This mid-unit transfer task uses permafrost melt as a proximal context in which to assess students' understanding of feedback loops, interactions between Earth systems, and the practice of asking questions. It is intentionally designed around a compelling phenomenon to generate questions that students might take forward with them or apply to berms. Part 2 of the assessment provides an opportunity to assess students' three-dimensional thinking around the practice as they ask questions about feedback loops involving varied Earth systems, inspired by the problem of thawing permafrost releasing large amounts of carbon dioxide into the atmosphere.
	Driving Question Board	**Formative** This Driving Question Board check-in gives students a chance to ask new questions related to feedback loops and the complex interactions between Earth systems, while also aiding navigation into Lesson Set 3 by reminding students that many of their unanswered questions relate to the berm solution.
Lesson 8	*Revisiting Questions*	**Formative** This assessment opportunity aids students in applying the ideas they heard from Inuit hunters and fishers and NASA scientists to complex energy transfer models that represent the berm system under different scenarios. Students also use these revised models to generate hypotheses. This thinking is also intended to highlight that the berms prevent warm water at the bottom of the bay from reaching the glacier, problematizing this notion and aiding navigation into Lesson 9.
Lesson 9	Lesson 9 Exit Ticket (Electronic Exit Ticket)	**Summative + Community Building** This second and final Electronic Exit Ticket focuses on function fits to data, which students will use again in Lessons 10 and 11. It also provides an opportunity for students to share their thinking about error in models developed from experimental data, tie the concept of convection to situations in their own lives, and reflect on the role of data analysis and system modeling in their sensemaking. Finally, students again celebrate a classmate who has helped their thinking. Although it assesses different NGSS elements than the Lesson 4 Exit Ticket, this exit ticket can provide useful evidence of students' use of pairs of dimensions. It is early in the year, but if students' responses to the open-ended follow-ups are one-dimensional, you should highlight to the class moments where two or three dimensions are being used together.
Lesson 10	*Discussion Mapping/Assessment Template*	**Formative + Community Building** In this assessment, students have a Building Understandings Discussion to use the data collected from the computer simulations to generate an equation that describes energy transfer out of or into a sample of matter. This equation, $Q = c_p \cdot m \cdot \Delta T$, will be used in sensemaking in Lessons 11 and 12. Additionally, the use of discussion mapping in this lesson allows for a second opportunity to see which students are talking, how much, about what, and to whom, opening the door to additional discussions of how our Community Agreements support our sensemaking.
	Exit ticket (questions 6-9 on *Summarizing Our Investigations*)	**Formative** These prompts allow assessment of students' understanding of energy transfer models and the new equation developed in this lesson, as well as the interaction between the two different models. These prompts support navigation into Lesson 11 as students recognize a gap in their model, and will also support the model building on day 1 of Lesson 12.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 11	*Investigation Question Development*	**Formative** Lessons 11 and 13 both provide opportunities for students to ask questions differently than they have before. Here, students are given time to individually consider investigation questions that have the explicit purpose of refining their model, rather than deciding on questions as a group or class. In Lesson 13, students will ask questions of a computational model, and they will need to develop their own questions with less scaffolding provided., so attend to and provide additional support to students who struggle here.
Lesson 12	*Berm Model* and Class Consensus Model	**Summative** The class consensus model and supporting handout allow students to put together information from Lesson Set 3, particularly the models from Lessons 9-11. This task serves as a celebration of what the class has figured out together, provides students with the tools they need to perform the calculations in *Calculating Berm Impact*, and reinforces ideas about energy transfer going into the end-of-unit transfer task. This task is designed to focus on the berm, as students will identify pieces from the unit that are missing in this model at the end of the lesson. This three-dimensional assessment opportunity is a chance for students to use mathematical, particle, and system models together to track energy and matter flows as part of understanding humans' ability to manage their impacts (in this case, specifically how the berm affects this ability). Even after consensus modeling, it is useful to collect students' individual models to provide feedback on the use of all three dimensions together, as well as individual elements of the dimensions.
	Calculating Berm Impact	**Summative** In this task, students calculate the impact that a berm could have on Ilulissat Glacier. In doing so they leverage mathematical thinking built in Lesson 4, returned to in Lesson 6, and added to in Lessons 9-11. This task is recommended to be completed in pairs but is summative in the sense that it is the last major, dedicated opportunity to assess students' understanding of unit conversions–an idea that will return in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)* as students not only use basic unit conversions, but also apply similar ideas in stoichiometric calculations. It is important to ensure that students are leveraging all three dimensions in their claims about the impact of the berm, as they will be asked to use this disciplinary core idea as they complete the unit transfer task in Lesson 13.
	Vehicle Exit Ticket	**Formative** This informal exit ticket serves as an SEL check-in, with the hope that because they have seen that both microbeads and berms (along with carbon dioxide emission reductions) are workable solutions, students might exhibit lower anxiety. For students who still experience climate anxiety, the exit ticket also opens the door to other potential solutions, asks students to think about the impacts of using resources while implementing these solutions, and navigates into the last lesson by asking students to think about how we could systematically use a computational model to investigate impacts of different solutions or human activities.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 13	Exit ticket (SEL check-in) Driving Question Board *Heat Pumps Transfer Task*	**Formative** This final SEL check-in gives students an opportunity to share how thinking about potential solutions and scientists' ability to model climate has impacted their feelings around climate change. Remind students that there is hope as long as human beings work together to take steps to address polar ice melt and sea-level rise, as well as the underlying issue of carbon dioxide emissions. Students will have additional opportunities to engage with potential solutions to climate issues in *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*, *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*, and *OpenSciEd Unit P.1: How can we design more reliable systems to meet our communities' energy needs? (Electricity Unit)*. **Formative** The final Driving Question Board check-in allows students to celebrate everything they have figured out in the unit. Students can also identify questions that were not answered in this unit, which may be addressed in later units or courses, or can serve as areas of independent research. Finally, this Driving Question Board check-in acts as a review of the units' ideas before students engage with the final transfer task. **Summative** This end-of-unit transfer task engages students with the novel phenomenon of heat pumps, which can be explained using ideas from the unit. It assesses students on HS-PS3-4: Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). Onboarding prompts in Part 1 help students trace energy and matter throughout the system. Then, Part 2 gives students an opportunity to plan an investigation into why a broken heat pump is, in fact, broken, using thinking about the system and energy transfer within it. Part 2, in particular, represents a vital culminating three-dimensional assessment opportunity as students use physical science ideas from throughout the unit to investigate the effectiveness of a repair to a broken heat pump system.
After each lesson	Lesson Performance Expectation Assessment Guidance	**Formative Assessment** Use this document to see which parts of lessons or student activity sheets can be used as embedded formative assessments.
Occurs in several lessons	Progress Tracker	**Formative and Student Self-Assessment** The Progress Trackers are thinking tools designed to help students keep track of important discoveries that the class makes while investigating phenomena. They help students figure out how to prioritize and use those discoveries to develop a model to explain phenomena. It is important that what the students write in the Progress Trackers reflects their own thinking at that particular moment in time. In this way, the Progress Trackers can be used to formatively assess individual student progress or for students to assess their own understanding throughout the unit. Because the Progress Trackers are meant to be a thinking tool for students, we strongly suggest that it not be collected for a summative "grade" other than for completion. Students add to their Progress Trackers in Lessons 2, 4, 6, 9, and 11.

When	Assessment and Scoring Guidance	Purpose of Assessment
Occurs in several lessons	Teacher Background Information	**Self-Assessment** This resource is available in the *OpenSciEd Teacher Handbook: High School Science*. The student self-assessment discussion rubric can be used any time after a discussion to help students reflect on their participation in the class that day. Choose to use this resource at least once per week or once every other week. Initially, you might give students ideas for what they can try to improve for the next time, such as sentence starters for discussions. As students gain practice and proficiency with discussions, ask for their ideas about how the classroom and small-group discussions can be more productive. Opportunities for individual self-assessment and reflection outside of this tool may be found in the Electronic Exit Tickets in Lessons 4 and 9 and the exit tickets in Lessons 12 and 13.
Occurs in several lessons	Teacher Background Information	**Peer-Assessment** This resource is available in the *OpenSciEd Teacher Handbook: High School Science* and should be used as needed. Facilitating opportunities for students to give each other feedback is valuable to their three-dimensional learning. Additionally, peer feedback can support teachers in managing the time-intensive demands of individualized feedback. We suggest that peer review take place at least two times per unit. Peer feedback is most useful when there are complex and diverse ideas visible in student work. That is, peer feedback works best when not all work is the same. Student models and explanations are good times to use a peer feedback protocol. They do not need to be final pieces of student work. Rather, peer feedback will be more valuable to students when they have time to revise after receiving the feedback. It should be a formative, not summative, type of assessment. It is also necessary for students to have prior experience with investigations, observations, and activities so that they can use these experiences as evidence for their feedback. Recommendations for opportunities to use the peer assessment tool may be found in Lessons 2, 4, 9, and 12.

For more information about the OpenSciEd approach to assessment and general program rubrics, visit the OpenSciEd Teacher Handbook.

Lesson-by-Lesson Assessment Opportunities

Every OpenSciEd lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to Science and Engineering Practice(s), alignment to Cross-Cutting Concept(s), and alignment to the Disciplinary Core Ideas.

The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 1	**1.A** Ask questions that arise from examining models to clarify and seek additional information about changes and rates of change in sea levels and the resulting impact on human migration. (SEP: 1.2; DCI: ESS3.B.1; CCC: 7.2) **1.B** Develop a model based on evidence to illustrate energy and matter flows in the Earth system that result in changes in human migration. (SEP: 2.3; DCI: ESS3.B.1; CCC: 5.2, 4.2)	**1.A When to check for understanding:** 1. On day 1 when students make a T-chart and list noticings and wonderings (**slides B-C**). 2. On day 1 when students examine the average rate of sea level rise over time (**slide F**). 3. On day 3 when students generate and share questions for the Driving Question Board (**slides V-W**). **What to look/listen for across opportunities 1-3:** • Students ask questions that consider why changes in sea level rise are occurring. (SEP: 1.2; CCC: 7.2) • Students ask questions that consider how sea level rise is impacting human migration. (SEP: 1.2; DCI: ESS3.B.1) • Students indicate that sea levels are rising and the rate of sea level rise is increasing, and this will increase rates of human migration. (DCI: ESS3.B.1; CCC: 7.2) • Students ask questions that consider why changes in sea level rise are occurring and whether they can be prevented or reversed. (SEP: 1.2; CCC: 7.2) • Students ask questions that consider how sea level rise is impacting human migration. (SEP: 1.2; DCI: ESS3.B.1) • Students' questions should seek to clarify confusing portions of their models. (SEP: 1.2) **1.B When to check for understanding:** 1. On day 2 as students create their initial models about what could be causing sea level rise (**slide O**). 2. On day 3 as students think about energy and matter flow in the system (**slide U**). **What to look/listen for across opportunities 1-2:** • Students' models are supported by evidence for the components that were included. (SEP: 2.3) • Students' models show changes in and flows of energy and matter. (SEP: 2.3; CCC: 5.2) • Students' models explain how changes in sea level that cause human migration could occur. (SEP: 2.3; DCI: ESS3.B.1) • Students present an accurate description of changes in and flows of energy and matter using the model. (SEP: 2.3; CCC: 5.2) • Students identify their system of interest on the model. (SEP: 2.3; CCC: 4.2)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 2	**2.A** Evaluate the impact of new data showing indirect evidence of energy flows of changes in Earth's orbit, the Sun's energy output, volcanic activity, vegetation, and carbon dioxide on a working model of sea level rise. (SEP: 4.5; DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 3.2, 5.2) **2.B** Construct an oral argument of how changes in Earth's orbit, the Sun's energy output, volcanic activity, vegetation, and carbon dioxide affect changes in climate over different timescales. (SEP: 7.4; DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 7.2)	**2.A When to check for understanding:** 1. On day 1 when students share their responses to the analysis questions (**slide B**). 2. On day 1 when students discuss how data drawn from geological and other sources could help us learn more about what causes temperature changes (**slide F**). 3. On day 3 as students share their energy transfer models (**slide S**). **What to look/listen for across opportunities 1-3:** • Students evaluate how new data showing slow system changes impact their sea level rise model. (SEP: 4.5; CCC: 3.2) • Students should identify that long-ago changes in Earth's orbit, volcanic activity, and atmosphere left indirect evidence, which can be studied today to build a picture of the past. (DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 3.2) • Students' models should represent energy flows within, into, and out of Earth systems based on the data students engaged with throughout the lesson. (SEP: 4.5; CCC: 5.2) • Students should accurately represent energy flows using a basic understanding of changes in Earth's orbit, the Sun's energy output, volcanic activity, vegetation, and carbon dioxide. (DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 5.2) **2.B When to check for understanding:** 1. On day 2 when students submit their exit tickets (**slide L**). 2. On day 3 during the Building Understandings Discussion (**slide P**). **What to look/listen for across opportunities 1-2:** • Students' exit tickets include an initial idea that changes in carbon dioxide are more likely than other factors to be causing current sea level rise because carbon dioxide and sea levels changes have mirrored each other historically. (DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2; CCC: 7.2) • Students' arguments are based on evidence from the data focusing on the timing of changes and rates of change in sea level and their possible causes. (SEP: 7.4; CCC: 7.2) • Students' arguments should reflect understanding of how changes in Earth's orbit, the Sun's energy output, volcanic activity, vegetation, and carbon dioxide affect climate. (SEP: 7.4; DCI: ESS1.B.2, ESS2.A.3, ESS2.D.2)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 3	**3.A** Collaboratively outline the variables and test an investigation to identify the directional relationship between the amount of carbon dioxide and temperature change in a defined model atmospheric system. (SEP: 3.1, 3.5; DCI: ESS2.D.3; CCC: 4.2) **3.B** Develop a model based on evidence to predict how energy flows between the Sun, the atmosphere, and the cryosphere and how its absorption impacts climate. (SEP: 2.3; DCI: ESS2.D.1, PS3.B.2; CCC: 4.3) **3.C** Ask questions about the unexpected result that conservation of energy and matter lead to models that predict that global temperatures will continue to rise on average even if carbon dioxide emissions stop. (SEP: 1.1; DCI: ESS2.D.4; CCC: 5.1)	**3.A When to check for understanding:** 1. On day 1 when students consider a central question for the investigation to answer based on their predictions about the relationship between carbon dioxide and temperature (**slide C**). 2. On day 1 when students use a sentence stem to indicate the directional relationship they predict to see in the investigation between carbon dioxide and temperature (**slide F**). 3. On day 1 when students define the boundaries of the system (**slide G**). **What to look/listen for across opportunities 1-3:** • Students develop an investigation question that is able to test the relationship between the amount of carbon dioxide present and increased temperature (SEP: 3.1; DCI: ESS2.D.3). • Students write a hypothesis that outlines a directional relationship between the amount of carbon dioxide and temperature change. (SEP: 3.5; DCI: ESS2.D.3) • Students define the boundaries of the water bottle system as a model for the atmospheric system and identify changes in inputs and outputs of energy and matter. (CCC: 4.2) **3.B When to check for understanding:** On day 2 when students discuss ideas about energy flows and build a class consensus model (**slides N-O**). **What to look/listen for during the opportunity:** • Students describe energy flowing from the Sun to the atmosphere and the atmosphere to the cryosphere in the outlined boxes. (DCI: ESS2.D.1; CCC: 4.3) • Students mention evidence from the investigation that the energy stayed in the atmosphere when more CO_2 was present. (SEP: 2.3; DCI: PS3.B.2) **3.C When to check for understanding:** 1. On day 3 when students turn and talk to consider new questions that extend from ideas that arose during the previous two days (**slide P**). 2. On day 3 when the class shares questions they have about the effects of CO_2 staying in Earth's atmosphere (**slide U**). **What to look/listen for across opportunities 1-2:** • Students' questions focus on the impact of energy and matter flows taking place within Earth's systems. (SEP: 1.1; CCC: 5.1) • Students indicate that conservation of energy and matter within Earth's systems causes global temperatures to continue to rise on average even if carbon dioxide emissions stop. (DCI: ESS2.D.4; CCC: 5.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 4	**4.A** Apply ratios and unit conversions at different scales to make predictions about the impact of human-caused ice melt on sea levels and human populations. (SEP: 5.5; DCI: ESS3.B.1, ESS3.D.1; CCC: 3.1) **4.B** Plan and carry out an investigation to revise a model to reflect that sea ice is in the ocean system (hydrosphere) and therefore does not change sea level, though losing it might have other negative effects. (SEP: 3.1; DCI: ESS3.D.2; CCC: 4.2)	**4.A When to check for understanding:** 1. On day 1 as students calculate the volume of Antarctic ice (**slide K**). 2. On day 2 as students calculate the predicted sea level rise if all Antarctic ice were to melt (**slide P**). 3. On day 3 as students discuss human impacts of sea level rise (**slide FF**). 4. On day 3 as students complete an Electronic Exit Ticket (**slide JJ**). **What to look/listen for across opportunities 1-4:** • Students should use appropriate unit conversions with consideration of which label should be written in the denominator of the fraction to cancel out unwanted units. (SEP: 5.5) • Students' calculations show that Antarctica has approximately 2.77 x 10^7 km^3 of ice. (SEP: 5.5) • Students' calculations show that if all Antarctica's ice melted, sea levels would rise by approximately 76.5 m. (SEP: 5.5) • Students' calculations show that if sea levels rose by 0.5 m, approximately 4 million people in the United States would be flooded out and have to move. (SEP: 5.5; CCC: 3.1) • Students should recognize that the scale of sea level rise matters for human migrations. (DCI: ESS3.B.1; CCC: 3.1) • Students should recognize that our ability to make predictions about human impacts on climate allows people to prepare for effects. (DCI: ESS3.D.1) • See *Exit Ticket Key* for using the Electronic Exit Ticket for assessment. **4.B When to check for understanding:** 1. On day 2 as students build a data table (**slide V**). 2. On day 3 as students make sense of their results (**slide BB**). 3. On day 3 as students collaboratively revise their model of Earth's cryosphere melting (**slide CC**). **What to look/listen for across opportunities 1-3:** • Students identify land ice vs. sea ice as an independent variable and water level rise as a dependent variable. (SEP: 3.1) • Students' data tables that allow for systematic collection of data. (SEP: 3.1) • Students identify that sea ice does not affect sea level rise because its matter is already in the ocean system (hydrosphere). (DCI: ESS3.D.2; CCC: 4.2) • Students acknowledge that there may be negative effects we are still learning about if sea ice melts. (DCI: ESS3.D.2) • Students propose a change to the model to reflect that only land ice affects sea level rise, while sea ice does not. (SEP: 3.1) • Students model how matter from land ice moves into the ocean, while matter from sea ice is already in the ocean but changes state. (SEP: 3.1; CCC: 4.2)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance

Lesson 5	**5.A** Ask questions to refine a model of the energy transfer into, out of, and within the system if proposed solutions prevent glacier ice melt in Disko Bay. (SEP: 1.4; DCI: PS3.B.2; CCC: 4.1)
	
	5.B Use energy transfer consensus models to ask questions that challenge the suitability of the design solutions based on their current and future impacts. (SEP: 1.7; DCI: ESS3.D.1; CCC: 4.3)
		5.A When to check for understanding
		On day 2 when students go public with their ideas and ask questions to refine the class consensus model (**slide R**).
		What to look/listen for during the opportunity:
		• Students' questions seek to:
		  • clarify or refine a portion of their model. (SEP: 1.4)
		  • refine how energy moves into the system. (SEP: 1.4; DCI: PS3.B.2)
		  • refine where energy is moving from one place to another. (SEP: 1.4; DCI: PS3.B2)
		• Students wonder:
		  • how energy would move within the system without any proposed solution. (DCI: PS3.B2; CCC: 4.1)
		  • how energy would move within the system if the proposed solution prevents ice melt. (DCI: PS3.B2; CCC: 4.1)
		  • about specific design features of the proposed solutions. (CCC: 4.1)
		
		5.B When to check for understanding
		On day 2 when students are writing their new questions for the DQB (**slide T**).
		What to look/listen for during the opportunity:
		• Students' questions:
		  • challenge the suitability of the proposed design. (SEP: 1.7)
		  • grapple with predicting and managing current and future impacts of the design solution. (SEP: 1.7; DCI: ESS3.D.1)
		  • are inspired by the class consensus model that simulates energy flows within and between systems. (SEP: 1.7; CCC: 4.3)
		• Students wonder about the magnitude of human impacts in consideration of these design solutions. (DCI: ESS3.D.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 6	**6.A** Plan and conduct a safe investigation with controlled variables and well-defined system boundaries to figure out how the reflection, absorption, storage, and reradiation of energy from the Sun affect climate. (SEP: 3.1, 3.3; DCI: ESS2.D.1, PS3.D.1; CCC: 4.2) **6.B** Use mathematical representations to support a claim about whether the changes in energy flows and disrupted feedback loops caused by microbeads make them a viable solution to help prevent polar ice melt. (SEP: 5.2; DCI: ESS2.A.1; CCC: 5.3)	**6.A When to check for understanding:** 1. On day 1 when students plan the investigation (**slide E**). 2. On day 1 when students conduct the investigation (**slide F**). 3. On day 1 when students discuss the results of the investigation (**slide G**). 4. On day 2 as students discuss the reading (**slide I**). **What to look/listen for across opportunities 1-4:** • Students identify distance and angle between the samples and heat lamp as confounding variables due to possible differential energy flow between systems and propose a solution to control the experiment. (SEP: 3.1; CCC: 4.2) • Students identify type of paper and placement around thermometers as confounding variables and propose a solution to control the experiment. (SEP: 3.1) • Students recall appropriate heat lamp-specific safety measures from Lesson 3 and make suggestions on modifications in light of the new experimental setup. (SEP: 3.3) • Students follow planned measures to control variables and carry out the investigation safely. (SEP: 3.1, 3.3) • Students establish energy flows into and out of the boundaries of the systems that vary based on different colored materials' interactions with radiation. (DCI: ESS2.D.1; CCC: 4.2) • Students propose that darker colors absorb more light energy, causing melt, and/or that lighter colors reflect more light energy. (DCI: ESS2.D.1) • Students verify that different colored materials have different albedos, causing differences in how they absorb and reflect radiation. (DCI: ESS2.D.1) • Students should state that carbon dioxide and other greenhouse gases prevent energy flow across the boundaries of the Earth system by preventing reradiation into space, causing temperature increases. (DCI: ESS2.D.1; CCC: 4.2) • Students identify that once energy is transferred to carbon dioxide molecules, it cannot be used for any particular purpose besides promoting melting. (DCI: PS3.D.1) **6.B When to check for understanding:** 1. On day 2 when students use their model to make a prediction (**slide M**). 2. On day 2 as students use their mathematical model to make a claim (**slide P**). **What to look/listen for across opportunities 1-2:** • Students' predictions are based on the idea that energy cannot be created or destroyed, and if trapped continues to flow between Earth systems. (CCC: 5.3) • Students propose a chain of events consistent with a feedback loop between ice melt, decreasing albedo, increased energy absorption/temperatures, and ice melt. (DCI: ESS2.A.1) • Students' claims are based on calculations and note that unknown feedback loops could result in other unintended effects to either action or inaction. (SEP: 5.2; DCI: ESS2.A.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance

Lesson 7	**7.A** Ask questions to clarify the role of positive and negative feedback loops involving the co-evolution of plants and other organisms with other Earth systems. (SEP: 1.4; DCI: ESS2.E.1, ESS2.D.2, ESS2.A.1; CCC: 7.3)	**7.A When to check for understanding:**
		1. As students discuss the reading (**slide D**).
		2. In the assessment (**slide E**).
		3. As students ask questions about the impacts of feedback loops in the context of the berm solution (**slide G**).
		What to look/listen for across opportunities 1-3:
		• Students should state that:
		  • positive feedback loops tend to cause changes while negative feedback loops promote stability; neither type is inherently good or bad. (CCC: 7.3)
		  • the evolution of plants and other photosynthetic organisms caused the development of our current atmosphere, which stabilized in a negative feedback loop. (DCI: ESS2.D.2; CCC: 7.3)
		  • the evolution of grasslands and their rich soils was promoted by and helped promote the evolution of large herbivores in a positive feedback loop. (DCI: ESS2.E.1; CCC: 7.3)
		• See *Thawing Permafrost Key* for guidance on *Thawing Permafrost Transfer Task*.
		• Students ask questions that seek to clarify how feedback loops would influence the berm solution. (SEP: 1.4; DCI: ESS2.A.1)

Lesson 8	**8.A** Ask questions about the changing ice, waters, and lands of the circumpolar region that could be investigated in the field (using Indigenous Inuit and/or NASA methodologies) to frame a hypothesis about changes in energy and matter where glacial ice meets the ocean water at Ilulissat. (SEP: 1.6; DCI: ESS2.A.3; CCC: 5.2) **8.B** Read and listen to scientific and technical information from two authoritative sources--Inuit Indigenous Knowledge and research from the NASA OMG Project--and consider the usefulness of describing and analyzing the boundaries, initial conditions, inputs, and outputs of the Arctic system from these different perspectives. (SEP: 8.3; DCI: ESS2.A.3; CCC: 4.2)	**8.A When to check for understanding:** 1. When students generate their initial questions (**slide C**). 2. When students revisit their questions and frame hypotheses (**slide L**). **What to look/listen for across opportunities 1-2:** • Students' questions require evidence from the field to answer and are focused on the interface between ocean water and glacial ice. (SEP: 1.6; DCI: ESS2.A.3) • Students' hypotheses are consistent with models and rules of energy transfer from previous lessons and with evidence from the field. (SEP: 1.6; CCC: 5.2) **8.B When to check for understanding:** 1. When students identify the features, purposes, and methodologies of the Indigenous Knowledge and NASA systems. (**slides H** and **K**). 2. When students reflect on the results of drawing system boundaries and defining system inputs and outputs from these different methodological perspectives (**slide K**). **What to look/listen for across opportunities 1-2:** • Students should share specific examples of differences in how Inuit hunters and fishers and NASA researchers define system boundaries, inputs, and outputs; e.g., animal movement within and into Inuit Nunaat vs. water temperature readings in sampling grids. (DCI: ESS2.A.3; CCC: 4.2) • Students should share specific examples of differences in how authorities of Indigenous Knowledge and the NASA OMG project approach building knowledge; e.g., passing knowledge through lessons and from generation to generation vs. publication. (SEP: 8.3) • Students reflect on the consequentiality of defining systems boundaries, inputs, and outputs in different ways; e.g., considering the impact of including or not including humans and animals in the model on knowledge construction and conceptualization of potential courses of action. (CCC: 4.2)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 9	**9.A** Evaluate a question about the energy circulation in the ocean to see if it is testable and select appropriate tools to collect and record data in an investigation, considering predicted energy flows within the ocean system. (SEP: 1.5, 3.4; DCI: ESS2.D.1; CCC: 5.4) **9.B** Apply function fits to data, consider limitations of data analysis, and consider model reliability to identify density as altering expected patterns of energy circulation in the ocean. (SEP: 4.2, 4.3; DCI: ESS2.D.1; CCC: 4.4)	**9.A When to check for understanding:** 1. As students model different liquids (**slides C-D**). 2. As students evaluate potential investigation questions (**slide E**). 3. As students identify the tools that would be most useful to measure mass and volume in the investigation (**slide G**). 4. As students revise their initial models (**slides U-V**). **What to look/listen for across opportunities 1-4:** • Students should show that matter behaves differently based on the energy stored within it and energy originates from the Sun before reaching the ocean. (ESS2.D.1; CCC: 5.4) • Students' responses should reflect the ideas that question C is both testable in the classroom and relevant to our investigation, and it is relevant because it addresses how it defies our expectations about the behavior that matter should have based on its energy. (SEP: 1.5; CCC: 5.4) • Students should select the graduated cylinder and scale because they are appropriate to the investigation (i.e., they measure the desired variables). (SEP: 3.4) **9.B When to check for understanding:** 1. As students find and discuss the lines of best fit (**slide N**). 2. As students consider limitations on their model (**slide O**). 3. As students decide on the need for more care in performing calculations and discuss how they would use significant figures in this context (**slide P-Q**). 4. As students complete an Electronic Exit Ticket at the end of day 3 (**slide AA**). **What to look/listen for across opportunities 1-4:** • Students should be able to fit the function to data with support and identify that the slope from any one of the graphs shows us the relationship between changes in mass to changes in volume for water (for that water condition). (SEP: 4.2) • Students should reason that the *y*-intercept represents the mass when the volume is 0 and should therefore be 0. (SEP: 4.2) • Students should reason that our model is limited because our calculated answers would be more precise if we had used similar rounding procedures, and that other sources of error exist and are influencing our model. (SEP: 4.3; CCC: 4.4) • Students should identify that error could affect our ability to explain the motion of water. (SEP: 4.3; ESS2.D.1) • See *Lesson 9 Exit Ticket Key* for guidance on what to look for in the Electronic Exit Ticket.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 10	**10.A** Plan and conduct investigations of energy transfer between objects in order to quantify conserved energy. (SEP: 3.2; DCI: PS3.A.1; CCC: 5.3) **10.B** Use simple limit cases to test a simulation of a closed system in which energy and matter are conserved that shows how an uncontrolled system with two different-temperature objects eventually reaches uniform energy distribution. (SEP: 5.4; DCI: PS3.B.5; CCC: 5.1) **10.C** Apply techniques of algebra and functions to quantify, describe, and mathematically model the energy flows that result in measurable temperature changes in order to quantify conserved energy. (SEP: 5.3; DCI: PS3.B.3; CCC: 4.3)	**10.A When to check for understanding:** 1. On day 1, as students plan the first investigation (**slides D-F**). 2. On day 2, as students make sense of the equal areas on the mass vs. temperature change graphs for the warmer and cooler liquids (**slide P**). **What to look/listen for across opportunities 1–2:** • Students should articulate investigation plans that consider what data to collect (mass and temperature) , how much data to collect (more trials or more conditions), and how keeping lids on improves the accuracy of data. (SEP: 3.2) • Students should explicitly consider trade-offs between the number of trials and cost or time. (SEP: 3.2) • Students should state that energy transfers between the warm and cool water, the areas of the graphs resemble quantities of energy, and energy is conserved within the closed system of the cup as energy transfers between warm and cool water. (DCI: PS3.A.1; CCC: 5.3) **10.B When to check for understanding:** 1. On day 2, as students posit how they expect the simulation to behave based on their experiences (**slide S**). 2. On day 2, as students discuss what they observed in the simulation (**slides U-V**). 3. On day 3, as students share their home learning assignments (**slide Y**). **What to look/listen for across opportunities 1–3:** • Students should make a prediction regarding the simple limit case that temperatures will change rapidly in a system where the two objects have very different initial temperatures but take a while to reach a final temperature. (SEP: 5.4) • Students should acknowledge that the simulation behaved as expected based on the simple limit case and other knowledge of the "real world." (SEP: 5.4) • Students should determine that a system with two objects touching will result in energy being spread throughout the two objects, and energy and matter were conserved (not created or destroyed) in the investigations. (DCI: PS3.B.5; CCC: 5.1) • Students should articulate additional ways in which they expect the simulation to behave based on the phenomena they captured. (SEP: 5.4) **10.C When to check for understanding:** 1. On day 3, as students make sense of their investigation using the updated simulation (**slides DD-EE**). 2. On day 3, as students complete an exit ticket (**slide GG**). **What to look/listen for across opportunities 1–2:** • Students should apply techniques of algebra and functions to identify that a best-fit line can be used to compare similar graphs and the slope of the best-fit line has units of calories per gram · °C and represents the amount of energy it takes to raise the temperature of 1 gram of a substance by 1 degree Celsius, and • Students should determine that we have enough information to mathematically model and quantify energy. (SEP: 5.3; DCI: PS3.B.3; CCC: 4.3) • Students' energy transfer models should show that energy is conserved (all of it is transferred between the objects), and the mathematical model $Q = c \cdot m \cdot \Delta T$ quantifies the energy transfer. (DCI: PS3.B.3; CCC: 4.3) • Students should state that we do not know c for ice, so we need to figure it out to quantify energy in this particular model. (DCI: PS3.B.3; CCC: 4.3)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 11	**11.A** Ask questions based on an existing model around how energy causes matter cycling in a system with conserved and transferred energy. (SEP: 1.2; DCI: PS3.B.1; CCC: 5.4) **11.B** Make a directional hypothesis about how much energy transfer must be prevented as part of a system design. (SEP: 3.5; DCI: PS3.B.1; CCC: 4.1)	**11.A When to check for understanding:** 1. As students use their existing quantitative energy transfer model (**slides A-B**). 2. As students develop an investigation question (**slide C**). **What to look/listen for across opportunities 1–2:** • Students should identify that energy transfer from water to ice causes the ice to melt into the water. (CCC: 5.4) • Students should conclude that because energy is conserved, the energy lost by the water must be transferred to the ice and cause it to melt. (DCI: PS3.B.1) • Students should ask questions that clarify the energy transfer model's unclear mathematical relationship between heat and ice melt. (SEP: 1.2; CCC: 5.4) **11.B When to check for understanding:** 1. As students plan their investigation and make a directional hypothesis (**slides E-F**). 2. As students consider the implications of the ice melt equation we developed (**slide J**). **What to look/listen for across opportunities 1–2:** • Students should make hypotheses that clearly state the direction in which increased heat will affect ice melt mass. (SEP: 3.5) • Students should state that the heat flowing out of water is the same as the heat flowing into ice because energy is conserved. (DCI: PS3.B.1) • Students should state that our knowledge of energy transfer could be used to determine if a change to the water-glacier system would have the desired effect of slowing polar ice melt and sea level rise. (DCI: PS3.B.1; CCC: 4.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 12	**12.A** Use multiple types of models of changes in energy and matter flows in order to predict the impact of a berm. (SEP: 2.4; DCI: ESS3.D.1; CCC: 5.2) **12.B** Support a claim with mathematical models, including unit conversions involving quantified changes in sea level, using energy conservation as a tool. (SEP: 5.2, 5.5; DCI: PS3.A.1; CCC: 7.2) **12.C** Create a checklist for a computational model that can predict how a defined system is influenced by resource availability and use by humans. (SEP: 5.1; DCI: ESS3.A.1; CCC: 4.2)	**12.A When to check for understanding:** 1. On day 1, as students share their ideas for the class Gotta-Have-It Checklist (**slide C**). 2. On day 1, as students develop a mathematical model with a partner (**slide D**). 3. On day 1, as the class develops a mathematical consensus model (**slide E**). **What to look/listen for across opportunities 1-3:** • See the key for *Berm Model Key* for what to look for in the Gotta-Have-It Checklist and students' models. **12.B When to check for understanding:** 1. On day 2, as students complete *Calculating Berm Impact* with a partner (**slide F**). **What to look/listen for in the moment:** • Students should accurately utilize unit conversions in their calculations. (SEP: 5.5) • Students should be able to apply their mathematical model throughout the calculations to quantify changes and make a reasonable claim based on the results. (SEP: 5.2; CCC: 7.2) • Students should be able to articulate how energy conservation is consistent with their claim. (DCI: PS3.A.1) **12.C When to check for understanding:** 1. On day 2, as students discuss the meaning of their calculation results (**slide G**). 2. On day 2, as students brainstorm and build a Gotta-Have-It Checklist for the unit computational model (**slide I**). 3. On day 2, as students complete an exit ticket (**slide J**). **What to look/listen for across opportunities 1-3:** • Students should conclude that implementing solutions that would functionally affect resource (fossil fuel) availability would also affect daily life. (DCI: ESS3.A.1) • Students should identify that the system in the proposed model includes many more components than the system in the previously developed mathematical model. (CCC: 4.2) • Students should create a checklist that could be used to build a computational model that uses ideas from the unit to predict human impacts on the Earth system. (SEP: 5.1) • Students should recognize that the availability of materials for electric vehicles could impact where people live. (DCI: ESS3.A.1) • Students should identify other Earth systems that would be impacted by increased lithium mining and electric vehicle usage. (CCC: 4.2)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance

Lesson 13	**13.A** Ask questions to determine relationships in a predictive but limited model considering that new discoveries are always being made and that climate models suggest average global temperatures will continue to rise. (SEP: 1.3; DCI: ESS3.D.2, ESS2.D.4; CCC: 4.4)
	
	13.B Use a computational model to support claims about the impacts of energy and matter flows amid complexity. (SEP: 5.2; DCI: ESS2.D.4; CCC: 4.3)
	
	13.C Plan an investigation to identify a problem with energy transfer in the geothermal heating system. (SEP: 3.5, 3.2; DCI: PS3.B.2, PS3.B.5, PS3.D.1; CCC: 4.2)
		13.A When to check for understanding:
		1. On day 1 as students discuss the reading (**slide D**).
		2. On day 1 as students develop questions to test using the model (**slide G**).
		What to look/listen for across opportunities 1-2:
		• Students should identify limitations of their model, including its role in modeling climate rather than weather and its assumptions about the equations that describe energy flow. (CCC: 4.4)
		• Students should articulate that:
		  • models can be changed as new information is being discovered, (DCI: ESS3.D.2)
		  • and climate models generally agree that global average temperatures will continue to rise, although exact predictions vary based on unknowns. (DCI: ESS2.D.4)
		• Students should ask questions that seek to understand a semi-quantitative relationship between an independent and dependent variable. (SEP: 1.3)
		
		13.B When to check for understanding:
		On day 2 as students share results from the computational model (**slide J**).
		What to look/listen for in the moment:
		• Students should make claims that are supported by use of the computational model and describe the key energy and matter flows observed. (SEP: 5.2; CCC: 4.3)
		• Students should identify continued warming without changes in this complex system. (DCI: ESS2.D.4)
		
		13.C When to check for understanding:
		On day 3 as students complete the transfer task (**slide N**).
		What to look/listen for in the moment:
		• See *Heat Pumps Key* for what to look for in the transfer task.

Lesson-Specific Teacher Materials

Lesson 1 Teacher Reference

Energy Anchor Chart

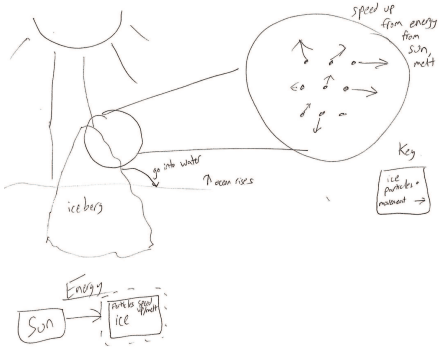
Throughout *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* and the OpenSciEd High School Chemistry and Physics courses, students utilize an energy transfer model based on that developed by Fortus et al. (2019). This approach "differs substantially from more traditional approaches to energy instruction in that it does not require energy forms and it emphasizes connections between energy, systems, and fields that mediate interaction-at-a-distance." Students will not address fields and interaction-at-a-distance until *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*, but students will still use energy transfer models in this unit for two main reasons:

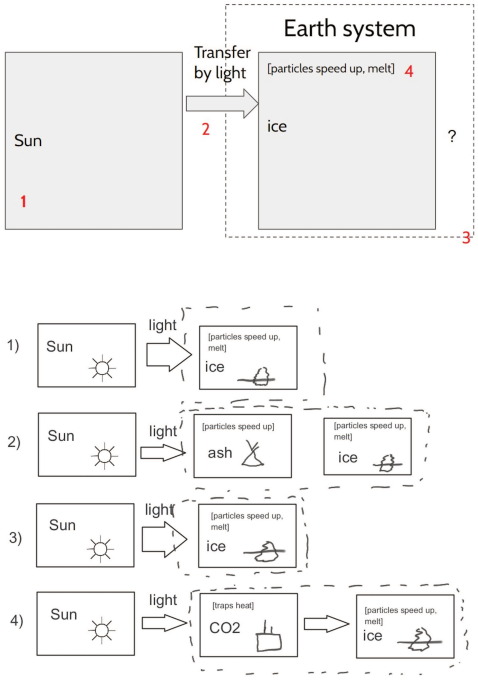
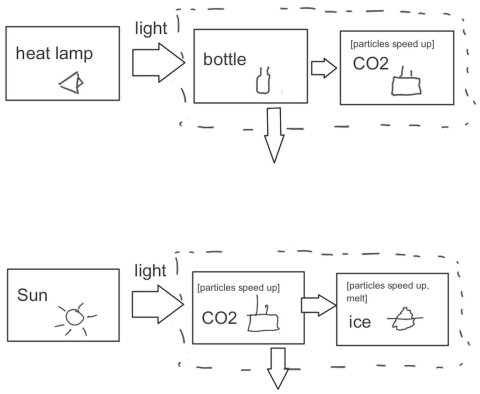
1. to promote a coherent student model of energy across the program
2. to allow for students to organically discover feedback loops in Lesson 6 using this powerful representation

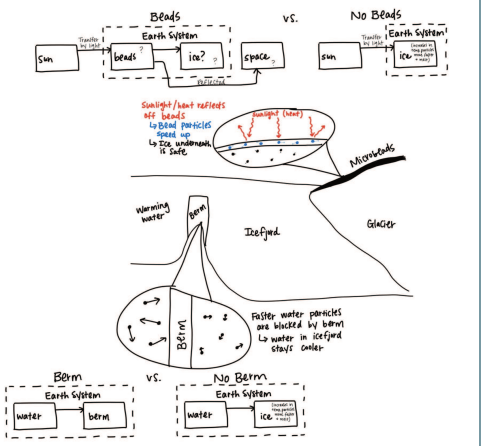
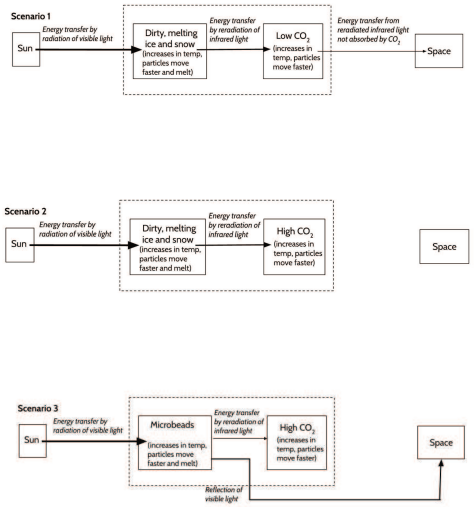
This unit *does not* intentionally develop the practice of Developing and Using Models, but *does* intentionally develop the Crosscutting Concepts of Systems and System Models and Energy and Matter. For this reason, students are not expected to draw full energy transfer models independently until Lesson 6, and even then the emphasis is more on students' thinking rather than their use of any particular representation. Instead, in early lessons students are engaged with systems and energy flows through written prompts and classroom discourse through which energy transfer models are co-constructed. The class also co-constructs a "Rules for Energy Transfer Models" anchor chart which identifies best practices for thinking about and modeling energy. This anchor chart will support students as they move toward more independent modeling of energy transfer.

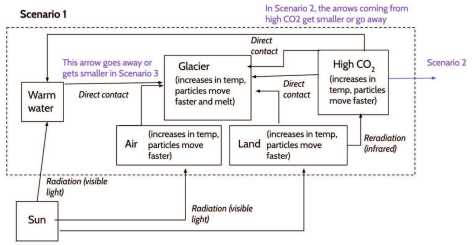
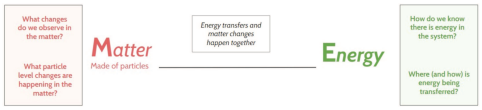
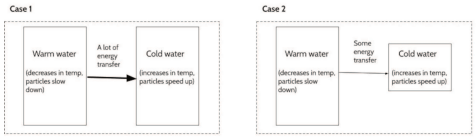
Throughout the unit, energy due to the motion of particles is called "energy," rather than "kinetic energy," because there is no reason to contrast it with energy stored in a field. However, it is appropriate to talk about the "kinetic energy of particles" or the "thermal energy" if you so choose.

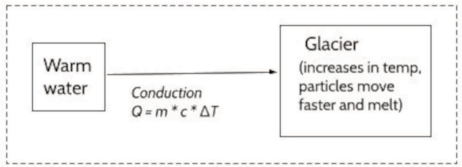
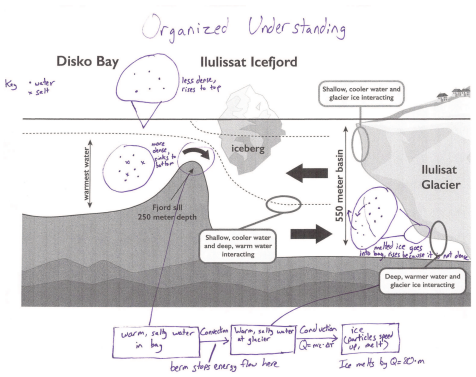
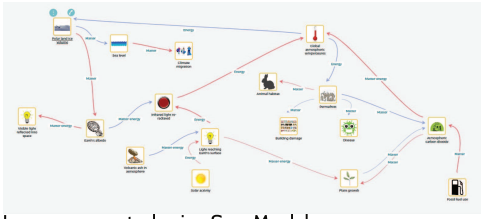
The table below shows how this energy transfer model is built and used in each lesson.

Lesson	Model Question(s)	Sample Model(s)	Phenomenon-Specific Ideas	"Rules for Energy Transfer Models" Additions The most important additions are **bolded**.
1	Draw a model to show what you think is happening at the particle level to cause the sea level to rise. Make sure your model shows any changes or flows of matter (particles) and energy. (Completed individually, but an energy transfer model is added by the teacher based on student ideas.)		Possible causes of sea level rise involve large-scaled changes in and flows of matter and energy. Energy transfers result in changes in particle motion. All student ideas should be considered and areas of disagreement highlighted in order to problematize what the group needs to investigate. The system, or collection of objects that we most care about, is defined by a dotted line.	None - chart established in Lesson 2.

2	Let's think about how energy "normally" flows to Earth to melt ice. How would our energy transfer model change if... 1. Earth's tilt was greater than it is now? 2. there was a major volcanic eruption? 3. the sun had greater activity than it does now? 4. there was more atmospheric carbon dioxide than there is now? (Discussed as a class without modeling, then a model is added by the teacher using students' ideas and the Rules.)		Under "normal" circumstances, light transfers energy from the Sun to ice, which causes the particles to speed up and melt. Different potential causes of ice melt change the energy transfer in different ways.	*Chart established* Boxes represent objects. **Arrows represent energy flows/transfers.** **A dotted line shows which objects are in the system** We can use text to say what happens to the particles in an object when energy transfers to or away from it. We can use prompts about where energy comes from and goes (and how it moves) to help us think through energy flows. We can draw separate energy transfer models to show situations where energy transfer is different.
3	According to what you wrote in Carbon Dioxide Investigation, how did energy flow in the investigation? How would the energy transfer model be different if we wanted to show how atmospheric CO2 affects ice melt on Earth? (Individual response to prompts, then modeled as a class as students share their ideas)		Carbon dioxide absorbs energy transferred from the Sun, causing an increase in global temperatures.	We can change arrow line widths to show that the energy that came into the system does not disappear (energy is conserved).

5	What do you think is happening at the *particle level* to make your assigned solution work? What questions do we need to ask to also model the energy transferring into, out of, and within the system? (Student ideas are added to the model by the teacher)		Develop questions such as the following: • Where does the energy in the system come from? • Without any design solution, how does the energy normally transfer to the ice to melt it? • How does the berm prevent the energy from transferring to the ice? • Where would the energy from the sun move if the beads were spread over the ice?	None.
6	How does energy normally move in Earth's systems? (Low CO2, no microbeads) How does increased atmospheric CO2 affect polar ice melt? (High CO2, no microbeads) This model is a revision of your Lesson 3 model. How can microbeads help slow polar ice melt as atmospheric CO2 causes temperature increases? (High CO2, with microbeads) This model is a revision of your Lesson 5 model. (Modeled by students in pairs, using a template)		• When dark materials absorb visible light, their particles speed up and re-emit infrared light over time. • Carbon dioxide and other greenhouse gases transmit visible light, but absorb infrared light, trapping it in the Earth system. • A feedback loop could occur as additional carbon dioxide causes increased temperatures, which would melt ice, which would decrease the albedo of Earth's surface, which would cause more energy to be absorbed.	We can label transfer by light with the particular type of radiation involved.

8	How might decreased atmospheric CO2 affect polar ice melt below the glacier? (low CO2, no berm) How might the berm help slow polar ice melt as atmospheric CO2 causes temperature increases? (high CO2, with berm) (Students annotate this complex model)		Both the berm solution and cutting carbon emissions could slow the transfer of energy at the interface between warm ocean water and glacial ice, through different mechanisms and on different timescales.	None--anchor chart not presented in lesson as to give students the opportunity to modify a complex energy transfer model without that support.
9	How do energy and matter work together to affect glacier melt? What are some of the questions we have asked ourselves about energy? What are similar questions we could ask ourselves about matter? (Students add to Lesson 8 models in pairs before developing a model as a class)		Matter changes from solid to liquid when energy is transferred to it. Particles speed up when they have more energy. Warmer substances are usually less dense, unless they have heavier matter in them. Density differences allow energy to transfer through conduction.	**The diagram at left**. This is the beginning of the "Matter-Energy-Forces triangle," or M-E-F triangle, which will be further built on in *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit).* Optionally, you may also add a note that convection, like radiation, is an energy transfer mechanism.
10	How does energy transfer in the cases of a high temperature object and low temperature object in two scenarios? (equal size, different sizes) (Completed individually as an exit ticket)		Added to a separate "Key Ideas" poster that is appended to the main anchor chart. 1. **Energy transfer between two objects/samples initially at different temperatures will cause both to eventually reach the same final temperature, which will be between the initial temperatures.** 2. The mass and temperature of each sample affect where the final temperature stabilizes (ΔT depends on m). 3. **Energy is conserved. It flows between objects but is not created or destroyed.** $m_a \cdot \Delta T_a - m_b \cdot \Delta T_b = 0$ 4. Conduction is the transfer of energy through direct contact as particles collide. 5. $Q = c \cdot m \cdot \Delta T$	

11	Where could we actually put our equation on our energy transfer model (of warm water transferring energy to a glacier)? (Discussed as a class based on the Lesson 10 exit ticket)		Added to the "Key Ideas" poster from Lesson 10. • $Q = 80 \cdot m$ (Optional): Students read about how "80" here represents the latent heat of fusion, a material property.	
12	How much would the berm solution impact energy flows and sea level? (Completed in pairs based on a class-generated Gotta-Have-It Checklist, then used to build a consensus model)		We can build a mathematical model that will allow us to figure out how much ice melt the berm can prevent.	None, but may be used to support student use of energy transfer models.
13	Students generate individual questions that can be answered using their computational model, which was originally specified in Lesson 12 based on work in pairs.	 Images generated using SageModeler (https://sagemodeler.concord.org/), developed at the Concord Consortium and Michigan State University.	Climate models work using equations for energy and matter transfer like those we developed.	None., but ideas from prior lessons may be highlighted (particularly around the use of equations.)

References

Fortus, D., Kubsch, M., Bielik, T., Krajcik, J., Lehavi, Y., Neumann, K., Nordine, J., Opitz, S., & Touitou, I. (2019). Systems, transfer, and fields: Evaluating a new approach to energy instruction. *Journal of Research in Science Teaching*, 56(10), 1341–1361. https://doi.org/10.1002/tea.21556

Lesson 1: Answer Key 1

Initial Model Key

This key is provided as guidance for the types of responses students may have on *Initial Model*. Do not grade these items, as they represent students' initial ideas that will be built upon, adjusted, or supported throughout the unit.

Question 1 Where do you think the water is coming from to cause sea level rise all around the world?
Many students will identify "polar ice" or "melting ice." Others may focus on rain or other bodies of water.

Question 2 How do you think the water that causes sea level rise gets to the ocean?
Many students will identify that "ice melts into the ocean." Others may say that additional rain causes sea levels to rise, ocean water is expanding, or water is flowing into the ocean from other bodies of water.

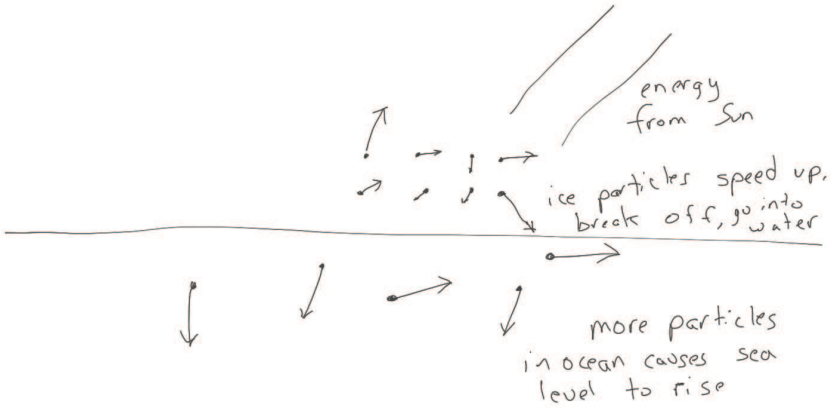
Question 3 Draw a model that explains why the sea level is rising all around the world.
Make sure your model includes:

- different components (parts), including ocean water
- lines, arrows, or other symbols to show relationships between different components
- a key that shows what any colors or symbols mean

Although all models are to be accepted, the example student model below represents the canonical explanation that ice melts, transferring matter into the ocean. However, this ice is in the ocean, rather than on land, and therefore will not affect sea level when it melts. Scientifically inaccurate features such as this are fine in early lessons. Throughout the unit students will be motivated to gather evidence that will allow them to improve their models.

Question 4 Draw a model to show what you think is happening at the *particle level* to cause the sea level to rise. Make sure your model shows any changes or flows of matter (particles) and energy.

This model shows a particle-level view of the sample model under Question 3. Student models should include middle school ideas about particle motion, state changes, and energy flows, but may represent them in a variety of ways. Students are not expected to know the chemical composition of water, although you may draw an example water molecule for students if they are hesitant to start because they do not know how to draw it "correctly."



Question 5 Explain why you included the components in your models that you did.

Student responses will vary and may reference the videos and data students have examined in Lesson 1, as well as related phenomena and students' personal and cultural experiences.

Lesson 2 Teacher Reference

UDL for Jigsaw Readings

Engagement	Representation	Action & Expression
Purposeful & Motivated	Resourceful & Knowledgeable	Strategic & Goal-Directed
Recruit interest: Allow students to choose readings. **Sustaining effort:** Jigsaws are social, and all participants are treated as experts.	**Perception**: Electronic format supports screen reading; images support background knowledge. **Language & Symbols:** We pay attention to structure and text features. **Comprehension:** Students access key information relevant to the big question.	**Physical action:** Using computers optimizes access to translation/screen readers. **Expression & Communication:** The lesson encourages use of text features. **Executive Function:** Students have a distinct goal/purpose for reading and use handouts to organize ideas.

Here are some text structures and design features that benefit **all readers** in this lesson, and can be applied to other texts your students may encounter:

1. **Images & graphics:** There is a reason "a picture is worth a thousand words." Images help readers engage with the text on a sensory level before the reading activity begins. An image that is closely related to the text's main content can activate sensemaking that includes students' previous experiences, cultural funds of knowledge, and their curiosity.
2. **Short sentences and paragraphs:** If a reader has to decode a lot of words in a sentence, it is hard to remember the concepts from previous parts of a sentence to string together. One way to alleviate this is with shorter sentences that maintain the meaning of an idea or paragraph.
3. **Titles, subtitles, and other section names:** Titles highlight the purpose of the text and "set the stage" for students to make conceptual connections to the text. Students can use their background knowledge and cultural funds of knowledge to connect with the reading right away.
4. **Language register**: Science articles can take on different registers of language depending on the audience and purpose. Articles written for youth may have more colloquial language, while articles written for professionals will have more highly specialized language. While specificity is important, it should not come at the expense of general comprehension for any audience. One general guideline is the 90% rule: If 1 in 10 words is unfamiliar to students, the reading or text is not easily comprehensible.

The Google versions of these articles are accessible to screen-reading technology and online translator services. The articles have the following embedded features:

Reading	Universal Design Features	Differentiation Guidance
Geological Data	• Images • Section titles	The topic sentence of each paragraph in this reading will help students navigate to relevant information. This reading is organized in order of the lesson prompts: *How is data collected?* is answered in the middle paragraph and *What types of data can be collected?* is answered in the final paragraph.

Ice Cores	• Images • Relatively concise sentences • Short paragraphs • Short overall length • Section titles	While ice cores may be new to students, they are probably familiar with tree rings. Encourage students to make this background knowledge connection prior to reading. This article is organized in order of the lesson prompts: *How is data collected?* is answered in the 2nd and 3rd paragraphs, and *What types of data can be collected?* is answered in the final paragraph.
Clues from Humanity	• Maps and images • Section titles	This reading is comparatively long, and contains multiple examples to answer the lesson prompts. Some new terms are presented, but the overall language is accessible and not highly specialized.

References

(2018). Universal Design for Learning Guidelines version 2.2. CAST. Retrieved December 14, 2022, from https://udlguidelines.cast.org/

Lesson 2: Answer Key

Data Analysis Key

This key is provided as guidance for the types of responses students may have on *Data Analysis*. It is not suggested that you grade these items, as students use the data to build an argument for the most likely cause of current temperature increases/polar ice melt/sea level rise.

Possible Cause	How does this phenomenon cause increased temperatures?	TIMESCALE OF CHANGE Did it change at the right time to cause recent temperature increases? Explain.	PROPORTION OF CHANGE Did it change in the right way (direction/rate) to cause recent temperature increases? Explain.
Orbital changes (Milankovitch cycles)	Evening out the seasons makes summers cooler and winters warmer, so ice forms but does not melt as much.	No, because these cycles take place over thousands of years and the temperature increases have been fairly recent. Yes, because something related to them caused us to come out of the last ice age.	It is difficult to say, but we have a pretty circular orbit right now and are not that tilted, so probably not.
Volcanic activity	Mostly causes decreases in the short term, but also releases CO_2 so lots of volcanic eruptions might cause temp increases.	No, there have not been that many volcanic eruptions recently.	No, there have not been that many volcanic eruptions recently.
Solar activity	More solar activity/a brighter Sun sends more energy to Earth.	No, as it is on an 11-year cycle and temperatures have been increasing for longer than that.	No, because the overall trend has been toward a dimmer Sun, which would decrease temperatures.
Carbon dioxide	More CO_2 increases temperatures.	Yes, CO_2 has been increasing for a long time, but especially recently.	Yes, CO_2 has been increasing at a high rate.

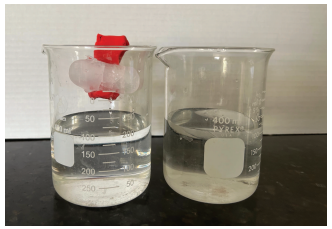
Complete the argument: I think _____ is the most likely cause of current temperature increases/polar ice melt/sea level rise, because the data show....
Student responses will vary.

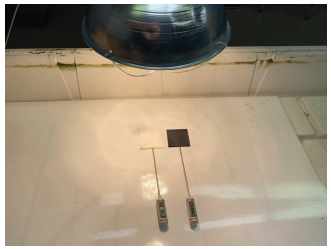
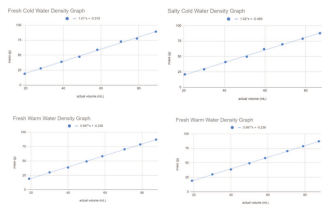
Explain how changes you saw in the data tell you the most likely cause.
Student responses will vary.

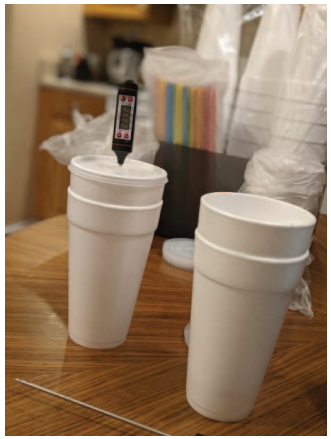
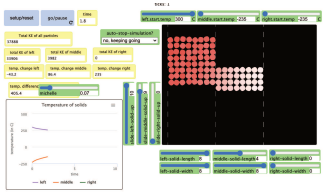
Lesson 3 Teacher Reference

Investigation Anchor Chart

Throughout this unit, students will use an Investigation Anchor Chart to track and support their thinking around planning and conducting investigations. This table summarizes the investigation in the unit and what, if anything, is added to the chart in each lesson. Anytime the class adds ideas to or references the Investigation Anchor Chart, you may also have students return to *Carbon Dioxide Investigation*.

Lesson	Investigation(s)	Investigation Description	Investigation Anchor Chart Additions
3	**Carbon Dioxide Investigation** 	The temperature in a closed bottle increases more when there is more carbon dioxide in the bottle. This investigation is planned as a class.	Ideas seen in *CO2 Investigation Key*, with an emphasis on: • Investigation questions • Hypotheses • Independent, dependent, and controlled variables • Setting up data tables
4	**Land Ice vs. Sea Ice Investigation** 	Ice melting off of land (land ice) increases the water level, while ice that is already in the water (sea ice) does not. This investigation is planned partially as a class and partially in groups.	• Recording procedures and system diagrams can make it easier to return to or repeat our investigation in the future.

6	**Light Investigation** 	Darker-colored paper gets warmer under a heat lamp than lighter-colored paper. Students individually evaluate a proposed investigation plan before discussing it as a class.	• Note about safety (either general or class-specific)
9	**Mass and Volume Lab**  **Water-Density Layering Demonstration** 	Different water conditions have different amounts of mass for a given volume (different densities). This investigation is planned partially independently and partially as a class. Different conditions of water layer based on density.	None, but the lesson emphasizes refining investigation questions and using graduated cylinders and scales.

10	**Liquid-Liquid Investigation**  **Investigation with Simulation** 	Energy transfer between two samples of water initially at different temperatures will cause both to eventually reach the same final temperature, which will be between the initial temperatures. This represents students' first individual investigation plan. We can find a relationship between energy transfer through conduction, mass, and temperature change. This investigation is planned mostly as a class due to its complexity.	(Optional): Record the class consensus about whether data collection should focus on testing more conditions or conducting more trials of each condition.

11	**Water-Ice Investigation** 	We can use our equation from Lesson 10 and an investigation similar to the Liquid-Liquid Investigation in Lesson 10 to determine how much ice melts when a given amount of energy transfers to it. This investigation is mostly pre-planned with some classwide modifications, as the focus is on students making a directional hypothesis.	None, but the lesson emphasizes making a directional hypothesis.

Lesson 3: Answer Key

CO2 Investigation Key

This key is provided as guidance for the types of responses students may have on *Carbon Dioxide Investigation*. It is **not suggested** that you grade these items.

Investigation Question: Look for something like, "How does CO_2 in the atmosphere affect temperature?"

Hypothesis: Complete the statement below.

IF	*the amount of carbon dioxide in the system increases ↑*	THEN the temperature of the system will	increase. ↑

Reasoning 1:

How does matter (CO_2) flow into and out of the water bottle system, if at all?

Matter cannot get into the system from the outside, only from the tablets in the bottle. Matter might be able to get out of the system if the bottle is not fully sealed.

Reasoning 2:

Where does the energy come from?

It comes from the heat lamp.

How does the energy get to the water bottle?

It passes through the air and into the bottle because it is clear.

What does the energy do in the bottle if there is CO_2? If there is no CO_2?

If there is CO_2, then the energy will somehow stay in the bottle and make the temperature go up. If there is no CO_2, then the energy will pass through.

Where does the energy go after getting into the water bottle? Is the answer different if CO_2 is present or absent?

If there is CO_2, then the energy will stay in the bottle. If there is no CO_2, then the energy will mostly go through to whatever is behind the bottle.

Data Table Title:
When coming up with a title for a data table, describe the relationship you are keeping track of when collecting data.

Look for something like, "Temperature Over Time in Systems with No, Low, and High CO_2".

Column goes top to bottom ↓

Row goes left to right →

Row setup considerations:
- **When do you need to take measurements?**
- **If you are looking for changes over time, how frequently will you take measurements?**

Time (min)	Temperature of control/no CO_2 (^oF)	Temperature of low CO_2 (^oF)	Temperature of high CO_2 (^oF)
0	93	91.9	110
2	103.8	100.9	131.5
4	113.9	110.1	148.1
6	114.8	119.2	148.1
8	114.9	123	148.2
10	115.7	124.7	149.5
12	116.7	125.2	151.1
14	118	125.7	151.8
16	118.9	125.6	152.4
18	119.3	124.7	151.8
20	120	124.1	151.7

Column setup considerations:
- **What are you changing?**
- **What are you measuring?**
- **What units will you measure in?**
- **Will you track changes over time?**
- **Will you need multiple data tables to track changes over time?**

Observations:
Record any other observations that you cannot put directly into your data table.
Look for observations related to the experimental setup (e.g., clay was not immediately added to one of the bottles) and to other changes that occur during the experiment (e.g., condensation forms in the bottle).

Summarize Investigation Findings:
Look back at your hypothesis and the evidence you collected from the investigation. Summarize your findings by answering the following prompt and completing the provided sentence stems.

How did the increased carbon dioxide affect the temperature in the bottles?

The temperature increased in all the bottles, but increased more when there was more carbon dioxide.

In this investigation, the energy came from ___the heat lamp____ as ___light and heat____.
It went to __the gas in the bottle_____.
This caused the particles to __speed up_____.

Then ___some ___ (some/all) energy _____stayed in the bottle_____.

If not all energy flowed/transferred in the same way, what did the rest do?

Especially in the no-CO_2 bottle, not all the energy stayed in the bottle. Some transferred out into the environment. We can see some of this as light on the other side of the bottle.

Lesson 4 Teacher Reference

Mathematical Anchor Chart

The Mathematical Anchor Chart is intended to record different strategies to support mathematical and computational modeling, as well as specific examples of these tools in action. When building this chart throughout the course, keep the following in mind:

- **Go for usability over comprehensiveness.** Record only the strategies that you most want students to hang onto, not every idea below whether they bring it up or not.
- **Show examples.** Record a quick example of scientific notation instead of a sentence, if you feel that is more useful for your students.

Like all the anchor charts in this unit, this is intended to be a collective student product, not a set of teacher-dictated notes.

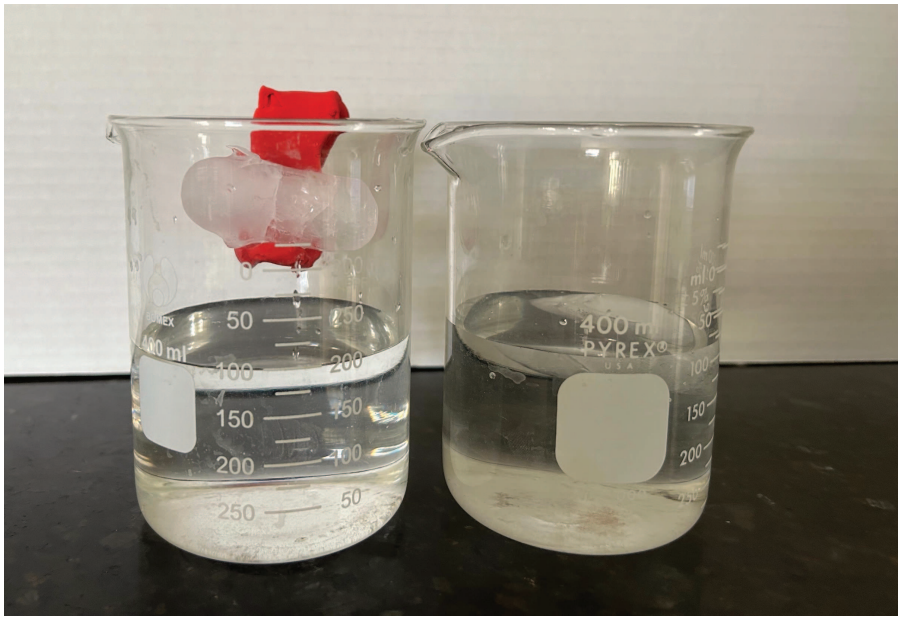
Lesson	How Mathematical and Computational Modeling Is Used	Mathematical Anchor Chart Additions Use **student** language as much as possible. The most important additions are **bolded**.
4	Predict the sea level rise if all the ice in Greenland and Antarctica melted. This work is done first as a class, then with a partner. Additional opportunities for pair or individual work are provided.	Include **examples** that show key ideas as necessary. • Physical models help us plan. • We can estimate area using simple shapes and areas formulas. • **Scientific notation** allows us to represent big numbers. • We can convert between different units using **conversion factors.** • We can predict how big our answers will be and check if they make sense. • Different approaches can get to the same answer. • **Assumptions** help simplify the problem to get a pretty good answer.
6	Students calculate the cost of implementing the microbeads solution. This is done with a partner or individually.	None, but available for support with unit conversions.
9	Remind students about making predictions of how big our answers will be and checking if they make sense.	• Optional: Add a sample equation with the slope and *y*-intercept labeled. • Significant figures help eliminate a source of error from our models. • **The greater the slope, the more the variable on the y-axis changes when the variable on the x-axis changes.**
10	Students consider if their computational model of conduction "makes sense" by comparing it to the "real world" and develop an algebraic representation of energy transfer through conduction. This is done with a partner.	None, but available for support in interpreting graphs.
11	Students mathematically model how much ice melts when a given amount of energy is transferred to it. This is done with a partner.	None, but available for support in interpreting graphs.
12	Students mathematically model how much ice melt, and therefore sea level rise, the berm could prevent. This is done with a partner with some whole-class planning.	None, but available for supporting students' mathematical model development.

13	Students use a computational model that allows them to manipulate different variables to identify the impacts on Earth systems. This is done with a partner or individually.	None, but available to identify the strategies from Lesson 4 as they return.

Sample Investigation Procedure

1. Add 100 mL of water to two different 250 mL beakers.
2. Make clay into a small platform and place at the top of one beaker. Make sure it is tilted so that water does not pool on it.
3. Place an ice cube on top of the platform. This represents land ice (as shown).
4. Place a second ice cube in the second beaker. This represents sea ice.
5. Place tape at the water level on each and mark the current level.
6. Label containers. Cover for overnight melting if necessary.

Other sizes of containers or different amounts of water may be used. However, remember that the water level change from a single ice cube will be most visible with a relatively small amount of water and a relatively narrow container.



Lesson 4 Teacher Reference

Electronic Exit Ticket

What are Electronic Exit Tickets?

These are short **formative** assessments that occur 2-3 times per unit, in between other assessments. They include items to check for understanding of lesson-level PEs, to make connections between content and students' lives, and to elicit information about their experiences and to help students reflect on their own progress in focal SEPs and CCCs. They are built in Google Forms, but can be ported to any survey software.

How to create Electronic Exit Tickets

In *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, the two Electronic Exit Tickets in this unit are found:

- at the end of Lesson 4 (**slide JJ**);
- and at the end of Lesson 9 (**slide AA**).

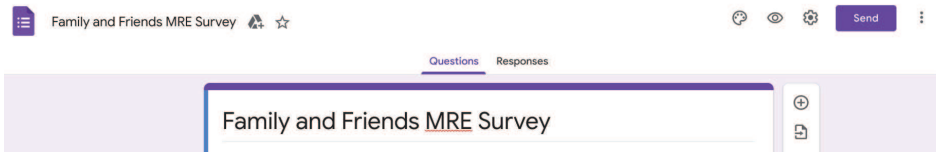
Select the link for the Electronic Exit Ticket that corresponds with the lesson you are teaching.
https://docs.google.com/forms/d/1jvpWOSDPElhPiwg1jzX96kVWPgkedGGmRnBGQErvozo/copy
https://docs.google.com/forms/d/1kAZBHTqV9mI57xxp-GgkoGeYvt-aYWD1TpzGgdsRDDU/copy

Spanish versions are available here:
https://docs.google.com/forms/d/1F6CY8vXgQNc3gklvroUDEPuJea2r2oeqW2A5fUDpuUo/copy
https://docs.google.com/forms/d/1F6CY8vXgQNc3gklvroUDEPuJea2r2oeqW2A5fUDpuUo/copy

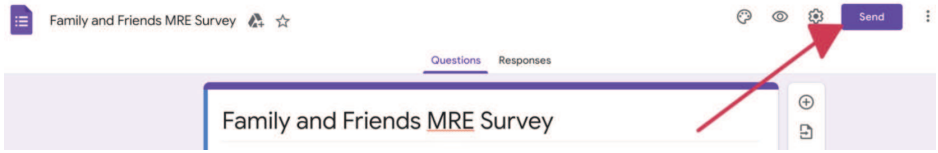
Attending to Equity
Some students may benefit from completing the Electronic Exit Tickets on a printed version. Complete the steps below to create a copy of the Electronic Exit Ticket. Once you have created a copy in your own Google Drive, click on the 3 dots in the upper right side of the form next to the SEND button. This should give you an option to print a paper copy of the Electronic Exit Ticket.

When you select the link, it will ask you to make a copy in your own Google Drive.

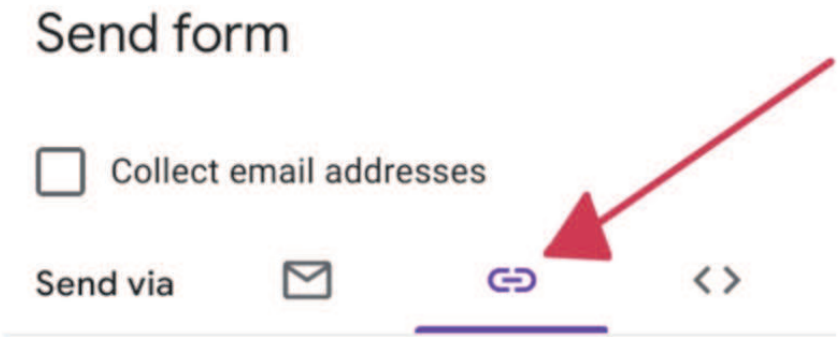
The student Electronic Exit Ticket will open in your own Google Drive.



Select the “Send” button in the upper right corner to get a link to give to students.

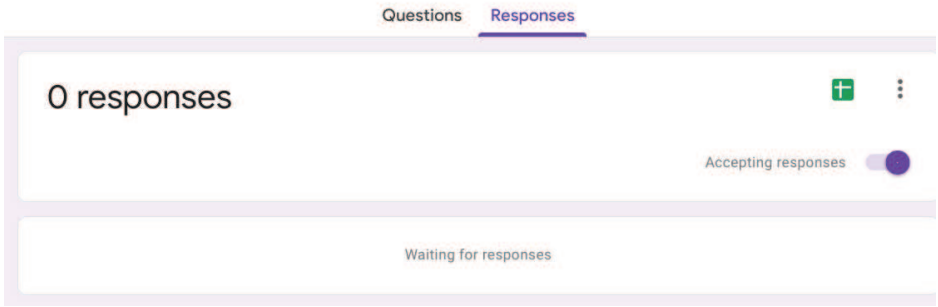


In the “Send via” panel select the middle icon in order to choose to send the Electronic Exit Ticket via a link.



Copy the link it provides you or select the “Shorten URL” box then copy the link. This second option creates a link that will be easier for students to type.

Once people submit responses they will show up in your Google Form under "Responses". Google will automatically provide you with some visualizations of these responses.



If you want to see the data in a spreadsheet format, click the sheet icon to create a Google Sheet of your data. It will automatically populate when people respond to the Electronic Exit Ticket.

For each Electronic Exit Ticket, you will need to repeat the process above. You can choose to make a copy of the Electronic Exit Ticket for each of your classes or choose to have one Electronic Exit Ticket for all your classes.

Lesson 4: Answer Key

Exit Ticket Key

4.A Apply ratios and unit conversions at different scales to make predictions about the impact of human-caused ice melt on sea levels and human populations. (SEP: 5.5; DCI: ESS3.B.1, ESS3.D.1; CCC: 3.1)

Where these elements are addressed in this assessment	**5.5 Using Mathematics and Computational Thinking** Apply ratios, ~~rates, percentages,~~ and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m3 , acre-feet, etc.).	**ESS3.B.1: 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.D.1: 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.	**3.1 Scale, Proportion, and Quantity** The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.
Q1a and Q1b	X		X	
Q2a and Q2b		X	X	X
Q3				
Q4a and Q4b	X			X
Q5				

Questions 1a and 1b

The simulation indicated that if all the ice in Greenland melted, the sea level would rise by about 7 m. We found that this corresponds to about 2,500,000 km^3 of ice melted. How much would the sea level rise if "only" 500,000 km^3 of ice melted? (You can use 7 m sea level = 2,500,000 km^3 ice as a conversion factor.)

- 35 meters
- 5.0 meters
- 2.5 meters
- **1.4 meters**

Describe the steps you used in your calculation. How is a calculation like the one done here useful as we think about sea level rise?

Correct response: 1.4 meters
500,000 km^3 x (7 m / 2,500,000 km^3) = 1.4 meters

I set up a unit conversion so that km^3 canceled out. The conversion factor had 7 m on the top and 2,500,000 km^3 on the bottom. A calculation like this one allows us to predict the impact of sea level rise, so we can better understand how people or the environment are affected and potentially do something to protect them.

Rationale for distractors:
35 meters is achieved if students multiply 7 m by 2,500,000 km^3 and divide by
5.0 meters is achieved if students divide 2,500,000 km^3 by 500,000 km^3 or just use the first digit of 500,000 km^3 of ice melted.
2.5 meters is achieved if students just use the initial digits of 2,500,000 km^3 of ice melted.

What to do:
Ensure the student is using the context to treat their solution as a prediction: Ask, *How much of this room would be covered with water if it was about 1/5 of 7 meters? Why would we care about that number compared to a higher or lower one?*

Support students in using unit conversions. Ask, *Did you set up a unit conversion problem with your conversion factor? Were you able to cancel out units?* If students need additional practice, assign *Conversions Home Learning* to individuals who would benefit from it. This aspect of Using Mathematics and Computational Thinking returns in Lessons 6 and 12.

Follow up with students who consistently attend to only one dimension at a time throughout this assessment. For example, highlight the use of mathematics to support understanding of impacts in this prompt, then ask students to explain their use of different dimensions together in other prompts.

Questions 2a and 2b

Scientists predict that a 0.5 m sea level rise is likely, with more possible. We calculated that about 4,000,000 people would have to move if the sea level rose by this amount. If the sea level rose by even 1/10th this amount, about how many people would likely have to move? (Assume the population is distributed evenly across the affected areas.

- 40,000 people
- **400,000 people**
- 2,000,000 people
- 40,000,000 people

Describe how reasoning about scale, proportion, and quantity like this helps you understand the impacts of climate change on human populations, like migration.

Correct response: 1/10th of 4,000,000 people is 400,000 people.

We realized that sea levels would rise incredibly high if polar land ice melted. The amount would not be great compared to the sea level, but it would cover a lot of land. Math like this helps us figure out that even a fraction of the expected sea level rise would affect a significant number of people who would have to move..

Rationale for distractors:
40,000 represents 1/100th of 4,000,000.
2,000,000 represents half the original 4,000,000, indicating that the student just multiplied the numbers in the prompt.
40,000,000 represents 10 times the original 4,000,000.

What to do:
Ensure the student is using the context to treat their solution as a prediction regarding migration: Ask, *Which pieces of information in this problem are important to help us make a prediction about the number of people who migrate?*
Support students in using unit conversions. Ask, *How much better or worse is the problem of sea level rise in this scenario? How would that change in scale affect the scale of migration?*
Ask students to describe their strategies to each other. Some students may benefit from drawing out a coastline diagram, or thinking about 4,000,000 people.
If students are having difficulty answering 2b, you may rephrase "scale, proportion, and quantity" with other common names for proportional thinking, such as fractions, amounts, or parts of a whole.

Question 3

In this lesson, we brainstormed different possible solutions to help slow or stop sea level rise. Why might these solutions be important to you, whether you live near the ocean or not?

What to look for in response:
Encourage students to think globally and connect to patterns of human migration that affect your local community.

What to do:
Accept all responses. Validating these responses engages students in activating the **relevance** and **interest** in these issues, which can motivate future questions.

Questions 4a and 4b

What types of benefits would result if we implemented a solution that could prevent even half of the polar ice melt and sea level rise that would otherwise happen?

- Fewer people who live near coasts would have to move.
- Some coastal environments would be protected.
- Some polar ecosystems would be preserved.
- **All of the above.**

Briefly explain how calculations from the lesson supported your thinking about the scale of sea level rise and its impacts.

What to look for in response:
The correct answer is **All of the above**. All answers are correct, as preventing polar ice melt and sea level rise would have many positive impacts.

Unit conversions helped us move between what we knew about the ice and the water, showing that a lot of land will be affected by sea level rise. We also used unit conversions to help us think about how many people might be affected by sea level rise. Even half the sea level rise would affect many people, but many would be protected if we could somehow slow sea level rise.

What to do:
The first part of this prompt is intended to help students think about why their work in Lesson 5 will be important, and should not be for a grade except for completion. The second portion may be graded, as it asks students how their work in Lesson 4 informed their response.

Encourage students to think about how mathematical reasoning like this scale-focused work is relevant to their work as scientists and in their daily lives.

Question 5

Name one student who helped you learn today. What did they do to help you learn?

What to look for in response:
- Students identify another student that helped them.
- Students articulate how that student helped them.

What to do: Depending on student responses, it may be beneficial to revisit the Community Agreements.
- If many students do not name another student, spend time revisiting the Community Agreements to ensure that students are using the agreements as they work together to make progress on figuring out science and engineering ideas.
- If many students do not explain what the other student did to help them, revisiting the Community Agreements may encourage students to think about what specific agreement the classmate was adhering to that caused them to be helpful.

Lesson 4: Answer Key 1

Sea Level Calculations

You have significant information about where, and how much, ice can be found in portions of Earth's cryosphere.
(See *Sea Level Calculations* for supporting images.

This chart summarizes what we know and what we need to figure out. Work with your partner, using the clay as an aid, to add to this chart. Show your work in the boxes below.

Ice		Ocean	
Dimensions of Greenland's ice sheet	1,500 m tall Irregular shape; see image	Area of Earth's oceans	3.619×10^8 km^2
Dimensions of Antarctica's ice sheet	2,000 m tall Radius approximately 2,100 km		
Need to figure out: Volumes of the ice sheets		**Need to figure out:** Sea level rise Volume of melted water	

Sea Level Rise If Greenland's Ice Melted	1. Find the total area. Calculate the area of the rectangle first: 1,100 km x 1,000 km = 1,100,000 km^2. Then find the area of the triangle, which equals half the area of the rectangle: 1,100,000 km^2 / 2 = 550,000 km^2 Add the areas of the rectangle and triangle to find the TOTAL AREA: 1,650,000 km^2. 2. Find the volume. To calculate the volume of ice in Greenland, students multiply the area by the thickness of the ice. The ice's thickness was given in meters rather than kilometers, so convert the meters to kilometers: 1,500 m x (1 km / 1,000 m) = 1.5 km. Now find the VOLUME of the ice: 1.5 km x 1,650,000 km^2 = 2,475,000 km^3 (See https://www.nationalgeographic.org/encyclopedia/ice-sheet/ for more details on the nature of the ice sheets.) STOP--Finish the problem on day 2. 3. Find the sea level rise. METHOD 1 (USING SPATIAL GEOMETRY) 1. We imagine there is a 1-km-tall bucket large enough to cover all the Earth's oceans, and we are trying to determine how "full" that bucket would be if Greenland's ice melted. We can assume that it would be less than 1 km "full". 2. To represent the volume of the bucket, multiply the total area of Earth's oceans by 1 km and use km^3 as the units. 3. To find the height of the water level in the bucket if Greenland's ice melted, divide Greenland's ice volume, 2.475 million km^3, by the base area of the bucket, 3.619 x 10^8 km^2. 4. This yields 0.00684 km, which we can convert to meters: 0.00684 km * (1,000 m / 1 km)= 6.84 m METHOD 2 (USING ALGEBRA) 1. We know that the total area of Earth's oceans is 361,900,000 km^2 and that area = length x width. We can use the volume formula, V = length x width x height, to solve for height because we want to know how high the sea level would rise if a certain volume of water were added. • l x w = 361,900,000 km^2 • V = 2,475,000 km^3 (volume of ice in Greenland) • h = unknown 2. Set up an equation: 361,900,000 km^2 x h = 2,475,000 km^3 3. Divide each side by 361,900,000 to solve for height: 2,475,000 km^3 / 361,900,000 km^2 = 0.00684 km 4. Finally, convert kilometers to meters: h = 6.84 m

Sea Level Rise If Antarctica's Ice Melted	1. Find the approximate area of Antarctica. For a circle, $A = \pi r^2$, where r is the radius. Therefore, $A \approx \pi(2100 \text{ km})^2 \approx 13{,}850{,}000 \text{ km}^2$ 2. Find the volume of ice in Antarctica by multiplying the area by the ice's thickness in km. Convert meters to kilometers: 2,000 m x (1 km / 1,000 m) = 2.00 km Volume of ice: 2.00 km x 13,850,000 km^2 = 27,700,000 km^3 STOP--Finish the problem on day 2. 3. Find the sea level rise. METHOD 1 (USING SPATIAL GEOMETRY) 1. We imagine there is a 1-km-tall bucket large enough to cover all the Earth's oceans, and we are trying to determine how "full" that bucket would be if Antarctica's ice melted. We can assume that it would be less than 1 km "full". 2. To represent the full volume of the bucket, multiply the total area of Earth's oceans by 1 km and use km^3 as the units. 3. To find the height of the water level in the bucket if Antarctica's ice melted, divide Antarctica's ice volume, 27.7 million km^3, by the base area of the bucket, 3.619×10^8 km^2. 4. This yields .0765 km, which we can convert to meters: 0.0765 km * (1,000 m / 1 km) = 76.5 m METHOD 2 (USING ALGEBRA) 1. We know that the total area of Earth's oceans is 361,900,000 km^2 and that area = length x width. We can use the volume formula, V = length x width x height, to solve for height because we want to know how high the sea level would rise if a certain volume of water were added. • l x w = 361,900,000 km^2 • v = 27,700,000 km^3 (volume of ice in Antarctica) • h = unknown 2. Set up an equation: 361,900,000 km^2 x h = 27,700,000 km^3 3. Divide each side by 361,900,000 to solve for height: 27,700,000 km^3/3.619×10^8 km^2 = .0765 km 4. Finally, convert kilometers to meters: h = 76.5 m

Lesson 4: Answer Key 2

Home Learning: Conversions Key

Chemists often have to look at a simpler version of a complicated system before they can learn more about the more complicated system itself. **Unit conversion,** or dimensional analysis, allows scientists to easily move among systems of different sizes or complexities, or between related quantities that measure different properties of a material.

To answer a question like HOW MUCH of something will make HOW MUCH of something else, you need to know two things:

1. Initial amount, with units
2. Conversion factor (ratio between the initial and final units that is equal to 1)

The example below shows how a ratio can be used to predict the eventual volume of a substance with an INITIAL volume of 10 cm^3 and that is expected to GROW 4 times in volume:

$$\frac{10\ cm^3}{1} \times \frac{4\ new\ cm^3}{1\ cm^3} = 40\ cm^3$$

initial amount	x	conversion factor	= final amount

Notice how in this example, we start with the initial amount we already know. We write 1 in the denominator, which does not change the number. That is where we get 10 cm^3/1.

To write the conversion factor, we create a ratio that matches the unit we are starting in (cm^3 in this case), to represent how many cm^3 the final (new) volume will have for every 1 cm^3 of the initial (old) volume. We always use the number 1 in this ratio. The cm^3 labels cancel each other in the numerator and denominator of the conversion factor, leaving cm^3 as our final units in the product.

Let's Practice:

Let's say you analyze a 10-mL water sample and find that the sample contains 1.36 mg of calcium carbonate, but you have to report the amount in **milligrams per liter.** How do you do that? The first question you should have is, **how many milliliters are in one liter?**

First, write the original amount of calcium carbonate in the sample: 1.36 mg / 10 mL.

Since mL is in the denominator, write your conversion factor with 1000 mL in the numerator so that the mL units will cancel each other. Then multiply:

$$\frac{1.36\ mg}{10\ \cancel{mL}} \times \frac{1000\ \cancel{mL}}{1\ L} = \frac{1.36 \times 100\ mg}{1\ L} = 136\ mg/L$$

What do these numbers *mean*?
Can you use unit conversions to explain sea level rise?

6.84 meters was our calculated rise in sea level if all the ice on Greenland melted.

1. How much is this rise in feet, to the nearest tenth? Show your work. *(Hint: 1 m = 3.28 ft.)*

6.84 m x (3.28 ft / 1 m) ≈ 22.4 ft

2. Would this amount of water rise cover a house currently at sea level? How much water is this in terms of stories of buildings? *(Hint: 1 story = 14 ft; 1 m = 3.28 ft.)*

22.4 ft x (1 story / 14 ft) = 1.6 stories
This amount of water rise would cover a 1-story house at sea level.

3. The Maldives is an island nation in South Asia situated in the Indian Ocean. The Maldives lies southwest of Sri Lanka and India, about 700 kilometers (430 miles) from the Asian continent's mainland. The island chain is home to over 540,000 people and is known for its coral reefs and natural beauty. The population density is 1,802 people per km^2. How many people is that per mi^2? *(Hint: 1 mi = 1.609 km, but 1 mi^2 is not equal to 1.609 km^2. It may help to diagram the shape of a square kilometer conversion first.)*

(1,802 people / 1 km^2) x (1.609 km / 1 mi) x (1.609 km / 1 mi) = 4,665 people / mi^2

4. The Maldives is currently 72 inches above sea level. Is this more or less than 6.84 meters? Use a unit conversion of 39.4 in. = 1 m. What would happen to the Maldives if Greenland's ice melted completely?

72 in. x (1 m / 39.4 in.) = 1.83 m
That is 5.1 m below sea level, so the Maldives would be completely covered.

5. What would happen in these situations if Greenland's ice melted only 25%?

A house at sea level: With 25% of Greenland's ice melting, 25% of the sea level rise would occur. 0.25 x 22.4 ft = 5.6 ft, which is not a full building story. A house at sea level would not be completely covered.

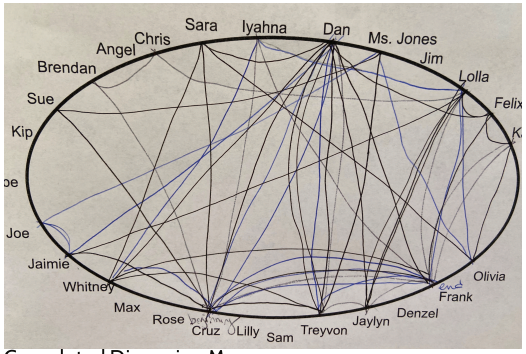
The Maldives: 0.25 x 6.84 m = 1.71 m. The Maldives is 1.83 m above sea level, so almost all of its land would be covered by the ocean.

Lesson 5 Teacher Reference

Discussion Mapping Tool

Instructions

1. Print one copy of the second page of this tool for each class section.
2. Add students' names to the circle in the order that students are sitting. You may want to do this ahead of time and then ask students to sit according to the map.
3. Write the question that students are trying to answer at the top of the page.
4. Select a student recorder who will map the discussion as it happens. Decide ahead of time if you will have multiple students take turns mapping and when you will move the map to a new student recorder.
5. If this is the first time you are using a discussion map, explain to students that each time someone speaks, the recorder will draw a line from the previous speaker to the new speaker's name. You may want to mark where the conversation begins and ends, but the goal is to map the overall conversation patterns rather than to be able to retrace the entire conversation.
6. Once the discussion begins, allow students to take the lead on moving the discussion forward. Sit in the circle as a participant rather than standing in front of the class as a facilitator. This will allow students to practice building on each other's ideas directly.
7. Be mindful of group dynamics, especially when displaying the map and discussing patterns of contributions. Avoid focusing on the contributions of single students and instead redirect the class to notice class-level patterns.



Completed Discussion Map

Discussion Mapping Codes

The key at the bottom of the discussion map contains codes that can be used to label the types of student contributions. The first few times that you create a discussion map with your students, you should focus only on recording the flow of the conversation. This allows students to get comfortable with the process. Once students have experience recording and interpreting those initial patterns, you can add discussion mapping codes to future discussion maps. Start by adding "low risk" or more accessible codes first such as claim given, evidence added, agreed, or disagreed. There is an extra column where you can add your own discussion codes as needed based on individual class needs and agreements. You may also choose to just use some of the discussion codes, based on the type of discussion that your students are having. In this case, be sure to cross out the codes that you are not using so that student recorders know not to include them.

Key Ideas

There is space to list up to three key ideas that emerge from the discussion on the tool itself so that the class can keep track of the ideas that are raised in the discussion. If you choose to use codes to annotate student contributions, you can also use the codes "1", "2", and "3" to map when those ideas are talked about.

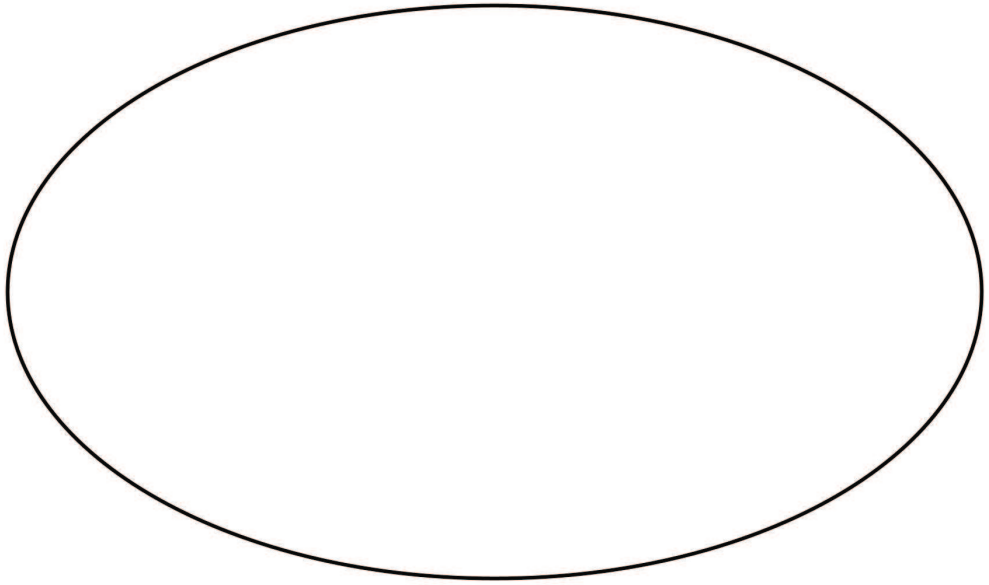
Adaptations

- For a large class, map discussions using a fishbowl structure. Arrange students in an inner and outer circle. Have the inner circle discuss the question while the students in the outer circle map the discussion.
- Consider having sentence frames displayed on a slide or poster to support multilingual learners.

Question we are trying to answer:

Date:_____
L#: _____
Period: ___

Key Ideas



Discussion Codes (Choose up to 3)				
C- claim given	**CL**- clarified idea	**?**- asked question	**T**- tied ideas together	**I**- interrupted
E- gave evidence	**A**- affirmed/agreed	**NI**- new idea added	**RP**- related phenomena	
OT- off topic	**D**- disagreed	**R**- repeated idea	-- idea ended	

Lesson 6: Answer Key

Revising Prior Models Key

This key is provided as guidance for the types of responses students may have on *Revising Prior Models*. These items should not be scored for correctness, as they represent students' ideas in progress.

Consider our findings from the investigation and reading from this lesson to answer the prompts below.

1. What did we figure out from the investigation in this lesson that could be used to revise your energy transfer models?

We figured out that darker colors do seem to absorb more light energy than lighter colors.

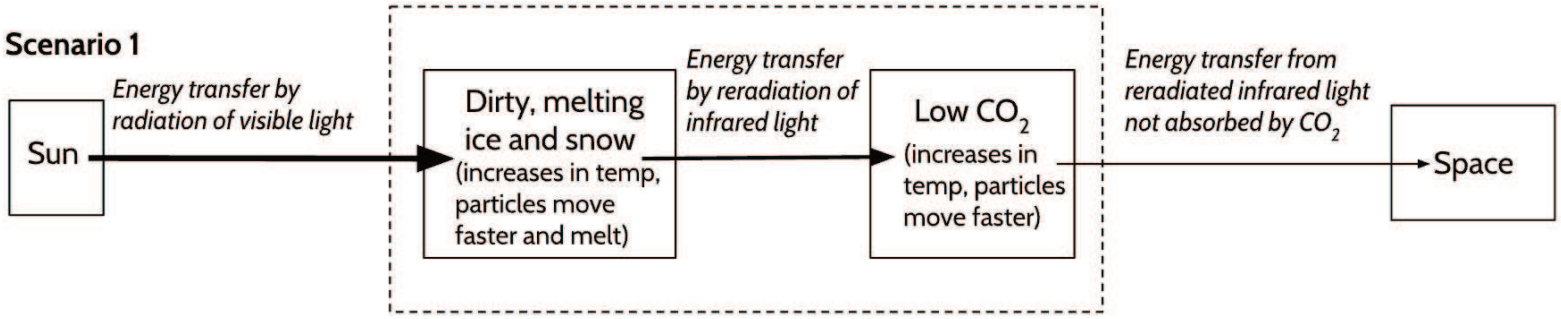
2. What did we figure out from the reading in this lesson that could be used to revise your energy transfer models?

Darker colors absorb visible light and reradiate infrared light, while lighter colors reflect more visible light.

CO_2 transmits visible light and absorbs infrared light.

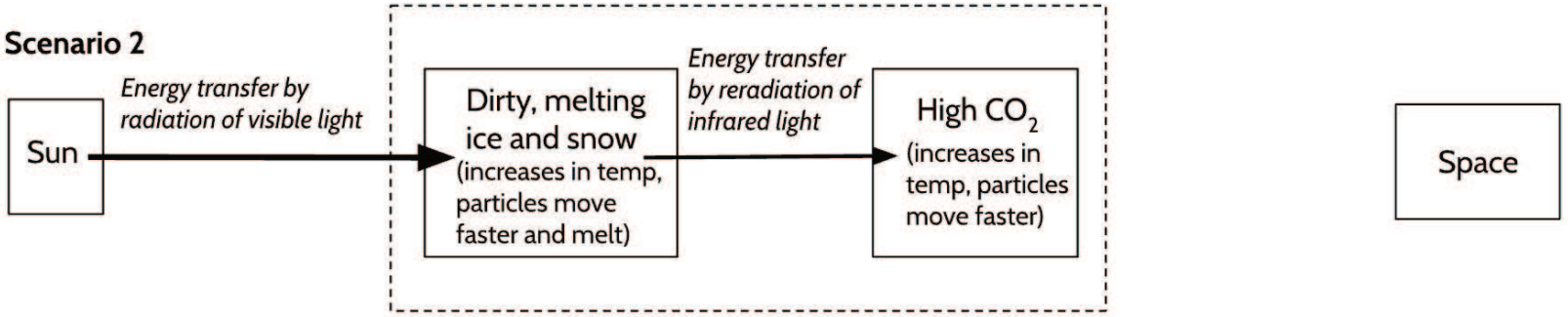
Use the template below to model three different scenarios for how energy flows in Earth's systems. The first model has been completed for you. *Light and Materials* may be helpful.

Scenario 1: *How does energy normally move in Earth's systems?* (Low CO_2, no microbeads)



Scenario 2: *How does increased atmospheric CO_2 affect polar ice melt?* (High CO_2, no microbeads)

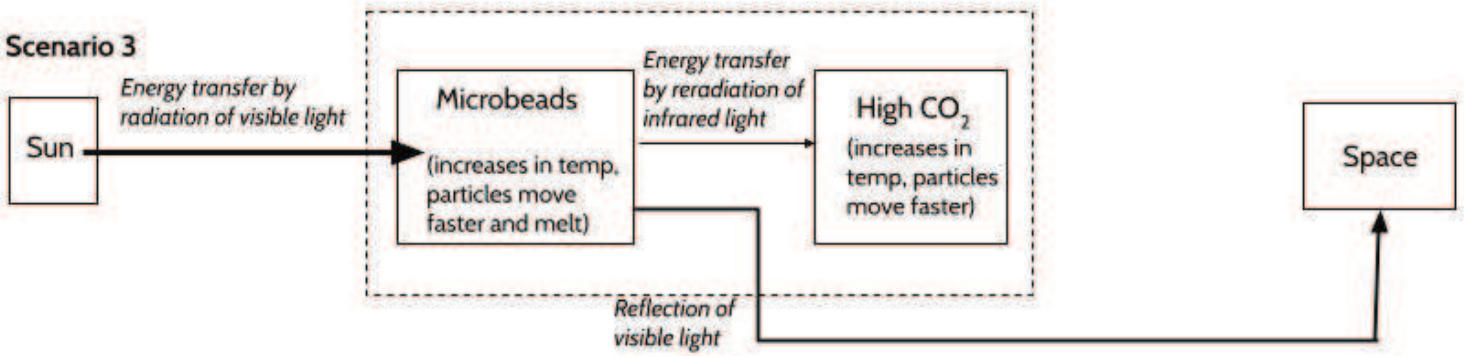
- This model is a revision of your Lesson 3 model.



Both the Scenario 2 and Scenario 3 models intentionally left out the reradiation arrow from CO_2 back to the ice and snow or microbeads. Students may decide to add that arrow at this step, but they may not come to agreement that CO_2 is reradiating back to the surface until making predictions later in the lesson.

Scenario 3: *How can microbeads help slow polar ice melt as atmospheric CO_2 causes temperature increases?* (High CO_2, with microbeads)

- This model is a revision of your Lesson 5 model.



Lesson 7: Answer Key

Thawing Permafrost Key

Building toward 7.A. Ask questions to clarify the role of positive and negative feedback loops involving ~~the co-evolution of plants and other organisms with other~~ Earth systems. (SEP: 1.4; DCI: ~~ESS2.E.1, ESS2.D.2,~~ ESS2.A.1; CCC: 7.3)

ESS2.E.1 and ESS2.D.2 are assessed as students discuss the reading earlier in Lesson 7.

3D Elements	Question #					
	1a	1b	1c	1d	2a	2b
Asking Questions and Defining Problems. Ask questions to clarify and refine a model, ~~an explanation, or an engineering problem~~. (SEP: 1.4)					X	X
ESS2.A: Earth Materials and Systems Earth's systems, being dynamic and interacting, cause feedback effects that can increase or decrease the original changes.		X	X	X	X	
Stability and Change. Feedback (negative or positive) can stabilize or destabilize a system. (CCC: 7.3)			X	X		X

Scoring Guidance. The elements described below would be considered an exemplary response at this point in the unit. These are shown as purple text or in purple diagrams below the related question. In some cases different elements of the response are identified with a separate + symbol These + 's are not meant to be all inclusive; they are suggestions for what you may see your students include.

The following scoring guidance provided can help you identify different ideas that students should (or could) include in their responses.

- If several of the ideas marked with a + are missing from a student's response, this may indicate the student has not mastered the science ideas or that the student may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking with oral or written feedback that requires a response can provide insight about whether the student is struggling with a science practice or science idea, or both.
- If all or almost all of the ideas marked with a + are present in a student's response, this likely indicates that the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.
- Some "additional elements" are listed for some prompts. Students should not be penalized if these items are not included.

Much of the surface in and near the Arctic that is not ice-covered is covered by a mixture of soil and ice. This mixture is called *permafrost* because, historically, it did not thaw during the summer and remained permanently frozen. Today, however, it is beginning to thaw, as you will see in the video: https://youtu.be/a_d3uqoYxR0.

Part 1a: What did the video show? What does it remind you of?

This question is intended to help students make sense of the phenomenon. Accept all responses.

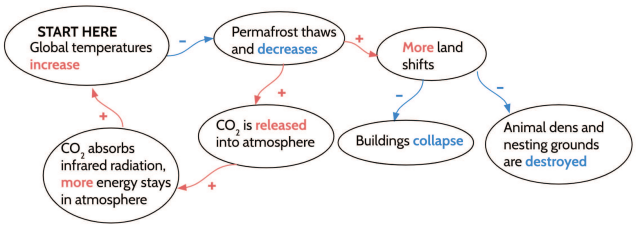
Permafrost thaw is a major problem because it impacts other Earth systems in possibly harmful ways, similar to polar ice melt.

When permafrost thaws, land can change drastically, among other effects. The table below lists some of the effects of thawing permafrost the Earth has experienced already. How will Earth be impacted as permafrost continues to thaw? Answer the questions below.

See *Thawing Permafrost Transfer Task* for associated images.

Burrowing animals and birds that nest on slopes lose habitat as burrows and slopes collapse.	Buildings warp and become unusable, like historic St. Andrew's Presbyterian Church in Dawson City, Yukon, Canada. Modern buildings are also impacted, unless they are built with special, more expensive design features.	Permafrost contains carbon dioxide, which has been trapped for thousands of years and can be released as the permafrost thaws.

The model below shows the impacts of permafrost thaw. The arrows represent cause-and-effect relationships, with or without energy transfer.



Part 1b: What feedback loop(s) do you see in the model? Use **all of the relevant pieces** of the model to *completely* describe the ways how the feedback loop(s) affect the original change, "Global temperatures increase."

Key elements:
+ global temperature increase causes permafrost to thaw
+ thawing permafrost releases carbon dioxide into the atmosphere
+ the new carbon dioxide in the atmosphere absorbs infrared light
+ increased atmospheric carbon dioxide increases global temperatures
+ because of the initial change of increased temperatures, even more permafrost thaws, repeating the cycle

Additional accurate element not essential to this item:
+ further explanation of the mechanism by which carbon dioxide and infrared light interact in order to raise global temperatures

Sample student response:
In the main feedback loop, global temperatures increase. This causes permafrost to thaw, releasing carbon dioxide into the atmosphere. The carbon dioxide absorbs infrared light or radiation, which causes global temperatures to increase further, starting the cycle over again.

Part 1c: Are the feedback loop(s) that affect(s) permafrost *positive feedback loops* or *negative feedback loops*? Explain your thinking using words and/or pictures and connect your response to the specific changes in Earth systems that are described in the diagram.

Key elements:
+ identifies the feedback loop shown as a positive feedback loop
+ provides a rationale that indicates positive feedback loops reinforce original changes or tend to destabilize the system
+ provides a rationale that because the original change (global temperature increase) continues as a result of the feedback loop, it is being reinforced

Additional accurate element not essential to this item:
+ further examples of ways in which positive or negative feedback loops impact their systems

Sample student responses:
The feedback loop shown is a positive feedback loop, because it keeps having a greater and greater impact over time as increases in temperature cause effects that make temperature even greater. A negative feedback loop would be if the original change had effects that counteracted it. The arrow coming off temperatures rising, to permafrost thawing and then from there, all cycle back to temperatures increasing. That makes it a positive feedback loop.

Part 1d: Describe a feedback loop involving permafrost thaw that includes **at least two Earth systems (spheres)** from the list below.

- Your response may include multiple feedback loops, if that helps you talk about two systems more easily.
- You can use ideas we have built as a class throughout the unit as part of your thinking.
- You may annotate on the model to support your response.

atmosphere	biosphere	cryosphere	geosphere	hydrosphere

Key elements:
+ one or more feedback loops is identified or described
+ portions of this feedback loop are explicitly connected to at least two different Earth systems

Additional accurate element not essential to this item:
+ multiple feedback loops are identified or described
+ suggest feedback loops that have not been explicitly identified as such in class or involve different systems in novel ways

Sample student responses:
All five systems/spheres: Increased atmospheric carbon dioxide would cause more ice in the cryosphere to melt, exposing dark ground. The low albedo of the ground would cause more light to be absorbed and reradiated as infrared light, which would be absorbed by CO_2 in the atmosphere and cause even more warming. This warming would increase ocean temperatures (hydrosphere) and harm different organisms (biosphere).

Atmosphere and biosphere: Additional carbon dioxide in the atmosphere would increase plant growth (biosphere). Plants use carbon dioxide, so they would be able to decrease the amount of carbon dioxide in the atmosphere, decreasing plant growth, allowing levels of carbon dioxide to increase again. Populations of animals (biosphere) that eat these plants would rise and fall as plant populations rise and fall.

Geosphere and hydrosphere: Thawing permafrost (geosphere) falls into the ocean (hydrosphere) all around the world. This would raise the sea level, which could cause the permafrost at the edge to thaw more quickly as it is exposed to warm water. *(Note: responses like this, that reflect theoretically possible but naive or incomplete understandings of interactions between Earth systems, are welcome for this prompt as long as they reflect an understanding of feedback loops.)*

Some scientists have argued that permafrost thaw could be even more damaging than the model above predicts. This is because thawing permafrost can allow chemical reactions that combine carbon in the soil (C) with oxygen in the air (O_2) to make carbon dioxide (CO_2).

Part 2a: What questions would you need to ask about the scientists' idea to find out if it would change the feedback loops in the first permafrost thaw model?

Part 2b: How would answering your questions allow you to better predict the effects of permafrost thaw in a system with many feedback loops?

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	What to look for in students' questions and discussions of their use in clarifying the model: • The question clearly identifies at least one component of feedback loops in Earth systems. • The question could help make progress in feedback loops or permafrost as a phenomenon generally. • The student begins to explain how the question relates to feedback loops and their impacts.	What to look for in students' questions and discussions of their use in clarifying the model: • The question clearly identifies at least one component of feedback loops in Earth systems with an incomplete interaction. • The question could help make progress in understanding feedback loops in the permafrost model. • The student explains how the question relates to feedback loops and their impacts.	What to look for in students' questions and discussions of their use in clarifying the model: • The question clearly identifies at least one component and interaction found in feedback loops in Earth systems. • The question would help make progress in understanding feedback loops in the permafrost model. • The student explains how the question relates to *particular* feedback loops and their impacts.

Example	2a. What does the carbon dioxide do? How is permafrost affected? 2b. **What does the carbon dioxide do?** If we know what the carbon dioxide does then we understand how it affects feedback loops. **How is permafrost affected?** If we know how the permafrost is affected then we understand it and feedback loops better.	2a. Where is the carbon dioxide coming from? What impact would the carbon dioxide have on the permafrost? 2b. **Where is the carbon dioxide coming from?** If we know where the carbon dioxide is coming from, maybe we can prevent harmful feedback loops that result in more sea level rise. **What impact would the carbon dioxide have on the permafrost?** If we know what impact the carbon dioxide has on the permafrost, we understand how it impacts lots of different feedback loops in the system that result in more sea level rise.	2a.What are these chemical reactions that make carbon dioxide? How much carbon dioxide is released because of the permafrost thaw? How can we prevent these reactions from taking place? 2b. **What are these chemical reactions that make carbon dioxide?** If we know what this chemical reaction is, we might be able to somehow figure out how to change or stop it so that carbon dioxide is not formed from this source and cannot negatively affect the atmosphere through increased temperatures. **How much carbon dioxide is released because of the permafrost thaw?** If we know how much carbon dioxide is released, we can better determine the effects on the feedback loop of carbon dioxide in the atmosphere. We could predict what or how much land and which or how many people might be affected because of the sea level rise that results, and we can take steps to protect them.
Feedback / What to Do	*Linking:* Invite students to generate focused questions about different, specific aspects of the models. Challenge them to generate a question about each arrow or each circle.	*Organizing:* Invite students to clarify the language of their questions. Invite students to more explicitly share how their questions would help them better understand specific aspects of feedback loops in the permafrost system.	*Extending:* Encourage students to identify how different answers to their questions would have different implications for the energy and matter flows in feedback loops in the permafrost system.

	Foundational Understanding	Linked Understanding	Organized Understanding
Ideas for Instruction	Review *Earth's Feedback Loops* with students and help them identify patterns in the types of interactions between different components. Review the purpose of questions when focused on a model--to investigate and learn more about specific ideas.	Review the assessment with students to foster students making connections between different aspects of feedback loops and the ways in which they affect or can affect Earth systems.	Invite students to investigate other feedback loops in Earth's systems and ideate solutions to polar ice melt based on them.

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Lesson 8: Answer Key 1

Revisiting Questions Key

Consider Indigenous Knowledge of Inuit hunters and fishers and NASA OMG findings to answer the questions below.

1. How might what we have learned help to answer the questions you had at the start of this lesson?

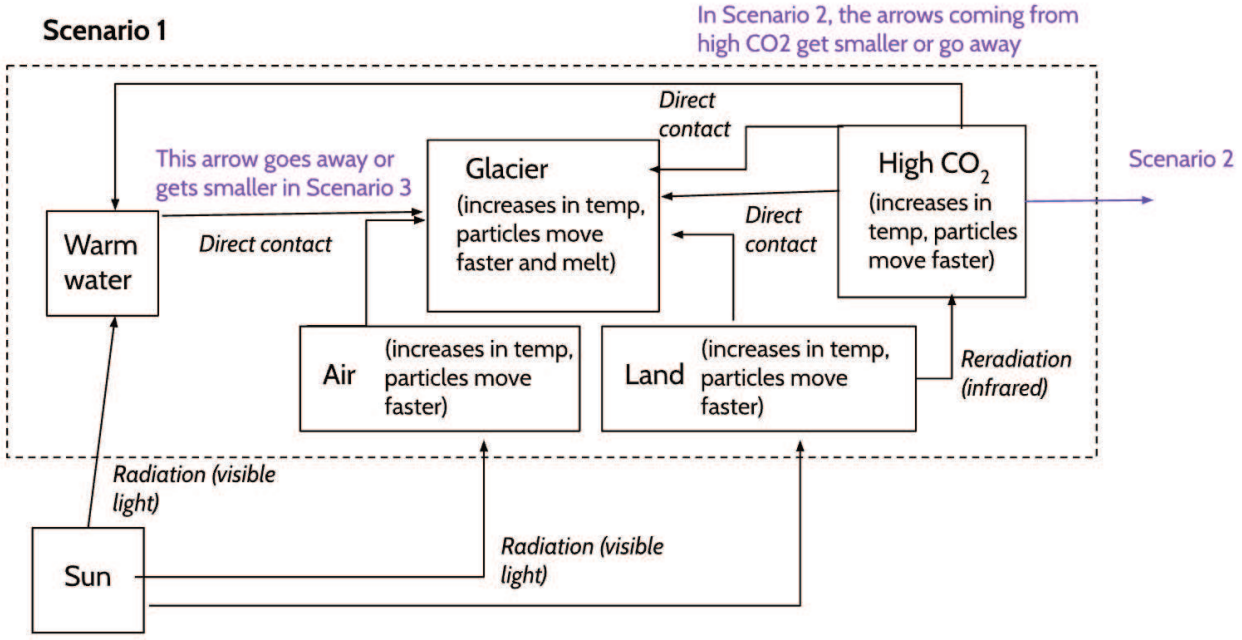
Answers will vary.

2. What have we figured out that could be used to revise our energy transfer models?

The berm prevents water from reaching the glacier.

Warm water is the main cause of glacier melt at Ilulissat.

The model below shows how energy is currently moving in Earth's systems (high CO_2, no berm).



Instructions for additional scenarios: Show on the model (using words or pictures) how it would change in each scenario, then write a hypothesis in the suggested format for what would happen to polar ice and sea level in this scenario.

Scenario 2: *How might decreased atmospheric CO_2 affect polar ice melt below the glacier?* (low CO_2, no berm)

- This model is a revision of and addition to your Lesson 6 model.

Hypothesis: If the amount of carbon dioxide in the system decreases, then...
polar ice melt decreases and the sea level will not rise as much

...because:
less carbon dioxide means less infrared light is absorbed by the atmosphere and its energy transferred to ice.

Scenario 3: *How might the berm help slow polar ice melt as atmospheric CO_2 causes temperature increases?* (high CO_2, with berm)

- This model is a revision of your Lesson 5 model.

Hypothesis: If a berm is built on top of the fjord sill in front of the Ilulissat glacier, then...
polar ice melt decreases and the sea level will not rise as much

...because:
the berm prevents energy from being transferred from water to the ice.

Lesson 9 Teacher Reference

Preparing Water Containers

Saltwater Mixture Preparation

To prepare the saltwater mixture, add 410 g of salt to a 1-gallon container (108 g of salt per liter of water). Then fill the container almost to the top with water. Leave a small air gap. Cap the container and shake for three minutes. This will produce salty water with a density of approximately 1.11 g/mL (due to a slight decrease in the overall density of solute that occurs when the salt is dissolved). This is approximately three times the salinity of ocean water (~35 g of salt per liter of water). This increased salinity will help make density differences stand out in the experimental results students gather so that the slopes of the lines comparing mass and density will differ by at least 10%.

You have now made enough saltwater for one class. It is recommended that you divide this single gallon of saltwater into two containers (e.g., two empty 2-L bottles or two empty 1-gallon containers), labelling one container "warmer saltwater for period #" and the other "colder saltwater for period #". Put the "colder saltwater" in the refrigerator and leave the "warmer saltwater" out in the classroom. This process ensures that both saltwater containers will have identical salinity but different temperatures for the class that uses them. If you have additional gallons available, dividing the saltwater into another set of containers will allow more students to access the pouring station area during lab time.

Repeat this preparation process for each class.

Fresh Water Preparation

Set aside two gallons of distilled water for every two classes you have. Label one container "warmer fresh water for all periods" and leave it out in the classroom. Label the other "colder fresh water for all periods" and put in the refrigerator until it is ready for class. These fresh water sources can be used across multiple classes. If you do not have a refrigerator, you can keep the base of the containers submerged in an ice bath.

Repeat this preparation process for every two classes.

Lesson 9 Teacher Reference

Spreadsheet References

A Google Sheet is available for you to copy each of the next three lessons. They are located in the Lesson Resources folders. If you cannot access these spreadsheets and want to recreate them from scratch, the images below provide snapshots of what the layouts should look like, along with sample data.

Lesson 9, https://docs.google.com/spreadsheets/d/1l2ArHNHy0TItwCW6BYqfx7wmBN52Uw4Wbky7FUxvqOA/copy

	A	B	C	D	E	F	G	H	I	J
1			*data from fresh cold water*						*data from salty cold water*	
2	group	target volume (mL)	actual volume (mL)	mass (g)			group	target volume (mL)	actual volume (mL)	mass (g)
3	A	20	19.5	19			A	20	20.5	21
4	B	30	28	27.9			B	30	30	29.2
5	C	40	39	38.9			C	40	40.5	41
6	D	50	48.5	47.3			D	50	51	49.7
7	E	60	58	58.9			E	60	59.5	61.9
8	F	70	70.5	72.6			F	70	68.5	69.8
9	G	80	79	77.7			G	80	78.5	78.9
10	H	90	89	89.2			H	90	87	87.8
11										
12										
13										
14										
15										
16										
17			*data from fresh warm water*						*data from salty warm water*	
18	group	target volume (mL)	actual volume (mL)	mass (g)			group	target volume (mL)	actual volume (mL)	mass (g)
19	A	20	19	19.2			A	20	19	19.4
20	B	30	30	30.1			B	30	27.5	28
21	C	40	40	38.6			C	40	40.5	41.3
22	D	50	50	49.2			D	50	49	48.5
23	E	60	58.5	58.2			E	60	60.5	61.6
24	F	70	70.5	70.3			F	70	71	72.3
25	G	80	79	78.7			G	80	78.5	79.4
26	H	90	87.5	87.1			H	90	89	88.8
27										

Lesson 10

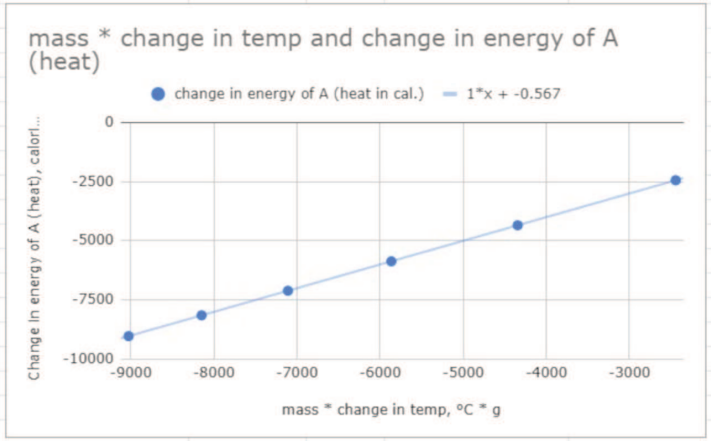
Liquid-Liquid Investigation, https://docs.google.com/spreadsheets/d/1jHmpxoaOSwF2EwqD4X6vThS5_9mzO83hJZBeNzUTPw8/copy

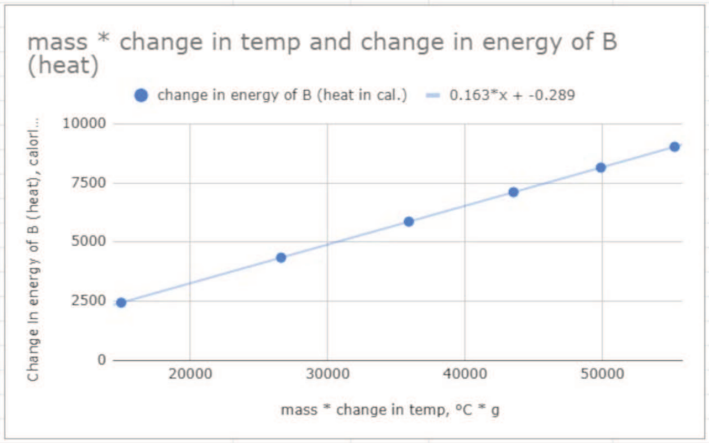
	A	B	C	D	E	F
1			*data from warmer water*		*data from cooler water*	
2	group	condition	mass (g)	temp. change (°C)	mass (g)	temp. change (°C)
3	A	1	100.18	-17.4	50.53	31
4	A	2	75.64	-10.1	76.84	9.6
5	A	3	100.59	-14.1	101.59	14.2
6	B	1	49.45	-26.2	51.45	23.4
7	B	2	50.89	-32.5	100.48	16.7
8	B	3	102.28	-14.2	50.39	27.6
9	C	1	52.54	-22.6	53.2	19.7
10	C	2	75.91	-22.9	76.36	21.6
11	C	3	101.68	-28	101.25	28.9
12	D	1	150.46	-15.8	49.54	43.2
13	D	2	52.02	-39.8	152.27	14
14	D	3	101.77	-25.6	100.96	26.1
15	E	1	101.59	-32.9	199.46	17.1
16	E	2	201.12	-12.8	99.36	26
17	E	3	100.39	-16.3	100.12	16.6
18	F	1	52.54	-33	101.92	17.6
19	F	2	75.12	-34	149.08	17
20	F	3	100.16	-29.8	199.81	14.9
21	G	1	101	-12.3	51.33	24.3
22	G	2	151.44	-12.2	75.49	24
23	G	3	199.91	-12.9	99.36	25

Second Simulation, https://docs.google.com/spreadsheets/d/1UpxdUAbBWQsi1WxT0JKhUJA26XRssZ97xR-mcdIBlwO/copy
Because no data has been entered, the class data sheet will show no graphs when first opened. The data sheet with sample data is shown below.

This sample data, https://docs.google.com/spreadsheets/d/1fMxhrOOT24K8O7KXhi2MiyUb-iItaKnD3dElUksZ_zg/copy is shown for one spreadsheet (Solid-Solid). There is a second spreadsheet, Solid-Gas. Students should only modify the mass of either sample A OR B in a given sheet. Add rows or create new sheets as necessary.

	A	B	C	D	E	F	G	H	I	J	K
1	Before run			After run	Calculated	After run	Before run		After run	Calculated	After run
2	Responsible Scientist(s)	A start-temp (°C)	A mass (g)	A temperature change (°C)	A mass * change in temp	change in energy of A (heat in cal.)	B start-temp (°C)	B mass (g)	B temperature change (°C)	B mass * change in temp	change in energy of B (heat in cal.)
3		300	7	-349.2	-2444.4	-2444.1	-100	49	49.9	14970	2444.1
4		300	14	-310.4	-4345.6	-4345	-100	49	88.7	26610	4345
5		300	21	-279.3	-5865.3	-5865.6	-100	49	119.7	35910	5865.6
6		300	28	-253.9	-7109.2	-7109	-100	49	145.1	43530	7109.8
7		300	35	-232.8	-8148	-8146.4	-100	49	166.3	49890	8146.4
8		300	42	-214.9	-9025.8	-9024.1	-100	49	184.2	55260	9024.1

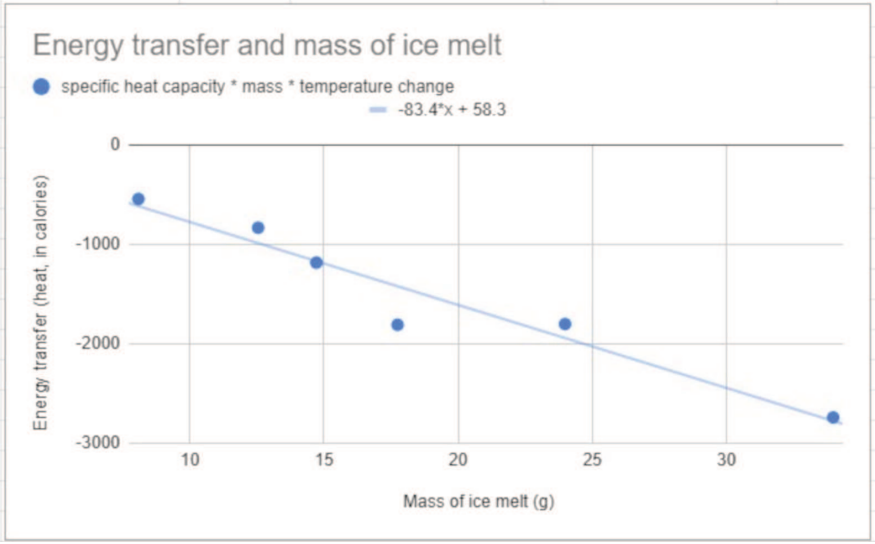




Lesson 11

Water-Ice Investigation, https://docs.google.com/spreadsheets/d/1FjEL64clNekP794iL0xvZo3DU53u-trjOCO7gNwU_PO/copy

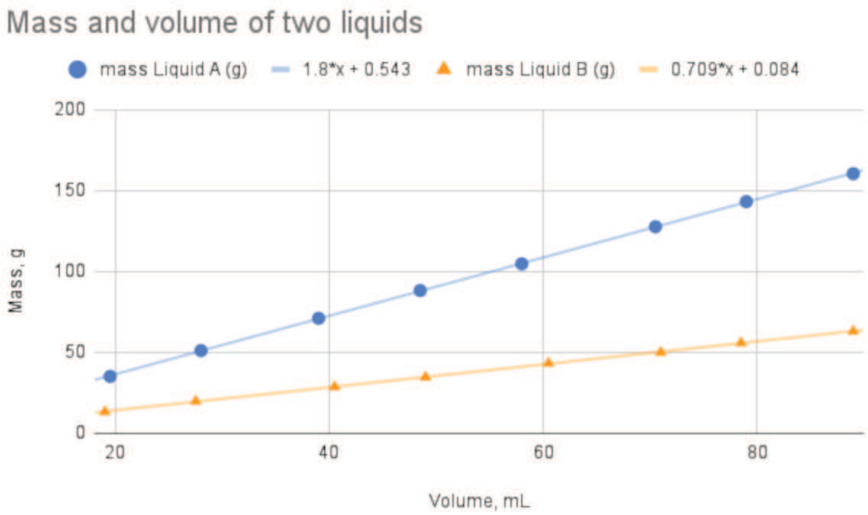
		data from water		*matter movement from melting*		*avg. matter movement from melting*	*energy transfer out of warmer water (heat)*
group	condition	mass (g)	temperature change (°C)	mass loss from solid (g)	mass gain in liquid (g)	mass (g)	specific heat capacity * mass * temperature change
A	50 g warmer water	50.27	-36	19.8	15.69	17.745	-1809.72
B	50 g cooler water	50.4	-23.5	14.75	14.69	14.72	-1184.4
C	25 g warmer water	26.14	-31.9	12.7	12.4	12.55	-833.866
D	25 g cooler water	25.95	-21	8.59	7.59	8.09	-544.95
E	75 g warmer water	75.5	-36.3	34.98	32.97	33.975	-2740.65
F	75 g cooler water	75.72	-23.8	24.23	23.74	23.985	-1802.136



Lesson 9 Exit Ticket Key

9.B Apply function fits to data, consider limitations of data analysis, and consider model reliability to identify density as altering expected patterns of energy circulation in the ocean. (SEP: 4.2, 4.3; DCI: ESS2.D.1; CCC: 4.4)				
Where these elements are addressed in this assessment	**4.2 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.	**4.3 Analyzing and Interpreting Data** Consider limitations of data analysis (e.g., measurement error, sample selection) when analyzing and interpreting data.	**ESS2.D.1 Relationship between Energy and Forces** 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.~~	**4.4 Systems and System Models** Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to ~~the assumptions and~~ approximations inherent in models.
Q1	X		X	
Q2			X	X
Q3				
Q4		X		X
Q5	X			
Q6		X		X
Q7				

Question 1



Analyze the graph of two liquids. Which statement best describes and explains which liquid would sink to the bottom if both were placed in a container?

- **Liquid A would sink to the bottom, because it has a slope (and density) of 1.8 g/mL.**
- Liquid A would sink to the bottom, because it has a slope (and density) of 0.543 g/mL.
- Liquid B would sink to the bottom, because it has a slope (and density) of 0.709 g/mL.
- Liquid B would sink to the bottom, because it has a slope (and density) of 0.084 g/mL.

Correct response: Liquid A would sink to the bottom, because it has a slope (and density) of 1.8 g/mL.

Rationale for distractors:
Students must correctly identify the slopes from the best-fit lines and reason that an object with a greater slope, and therefore density, will tend to sink.

0.543 g/mL is the intercept of the best-fit line for Liquid A.
0.709 g/mL is the correct slope (and density) for Liquid B, but this density is lower than that of Liquid A, so Liquid B would tend to rise to the top.
0.084 g/mL is the intercept of the best-fit line for Liquid B.

What to do:
Have students review their slope calculations and reflect on how we connected the slope to density. Ask, "How much would the mass of one liquid INCREASE for every gram, 1.8 or 0.543?"

Encourage students to return to their definition of density and results from the Water-Density Layering Demonstration.

Question 2

What could be a source of error in our model of energy transfer through convection as warm salty water flows into Disko Bay?

- We average multiple measurements.
- Different groups used different-sized containers, but made sure they were only measuring the water.
- **The water samples we used may not match the water in Disko Bay in terms of temperature or saltiness.**
- Our containers were not tested near Ilulissat Glacier.

Correct response: The water samples we used may not match the water in Disko Bay in terms of temperature or saltiness.

Rationale for distractors:
Averaging multiple measurements would only have a positive impact. Container size would only matter if students did not account for the containers in their measurements. The proximity to Ilulissat Glacier is not relevant to the experiment as long as the water samples matched those of Disko Bay.

What to do:
Review which types of investigative changes improve an experiment and resulting model, negatively impact the results, or have no effect.

Return to the particle-level model as updated at the end of class. Ask students, Which of these selections are represented in our model in a way that would impact density?

Question 3

What is a situation where energy transferring through convection might appear in and matter in your life or future?

What to look for in response: Accept all responses.

What to do:
If many students cannot identify situations, ask those who can to share their ideas with the class.

Question 4

Sharita and Antoine are scientists who are calculating the amount of energy transferred into Disko Bay by warm water every hour. They take measurements together and are using the same mathematical model, but their answers end up being off from each other by just a tiny amount. What is the most likely source for this apparent error?

- Their measurements are incorrect.
- Their mathematical model (equation) is based on bad assumptions or data.
- They did not collect enough samples.
- **Only one of them used the correct rules for significant figures.**

Correct answer: Only one of them used the correct rules for significant figures.

Rationale for distractors:
None of the additional possibilities explain why they obtained different answers. Based on what we know about mathematical modeling, we cannot tell from the answers Sharita and Antoine obtained if their measurements are incorrect because of problems with their investigation or model.

What to do:
Review the sources of error discussed in class. Have students re-examine *Significant Figures* so they can review the ways in which proper use of significant figures accounts for approximation.

Question 5
How did using a line of best fit help you figure out why the berm is placed at the bottom of Disko Bay, instead of the top?
What to look for in response: Note: These could be different for each student. • Students should discuss how they used the line of best fit to figure out the densities of different water conditions. • Students may further explain how the "steepest" slope shows the highest density. **What to do:** If students are struggling to articulate how they used a line of best fit in the lesson, have them reflect on how we figured out that the densities of water conditions were different in the first place. Alternatively, use the Mathematical Anchor Chart to remind students of this takeaway.

Question 6
How did we work with errors in the experiment or calculations that affected our data and model in order to figure out why the berm is placed at the bottom of Disko Bay, instead of the top?
What to look for in response: • Students should identify that they were able to rule out different errors causing differences in their results because they were working from the same data. • Students should also identify that using significant figures correctly helps get more accurate answers so our models make the same predictions. **What to do:** If students do not discuss these ideas, use the Mathematical Anchor Chart to remind students of the role that significant figures play.

Question 7
Name one student who helped you learn today. What did they do?
What to look for in response: • Students identify another student that helped them. • Students articulate how that student helped them. **What to do:** Depending on student responses, it may be beneficial to revisit the Community Agreements. • If many students do not name another student, spend time revisiting the Community Agreements to ensure that students are using the agreements as they work together to make progress on figuring out science and engineering ideas. • If many students do not explain what the other student did to help them, revisiting the Community Agreements may encourage students to think about what specific agreement the classmate was adhering to that caused them to be helpful.

Liquid-Liquid Investigation Notebook Example

1. Obtain 50 g of hot water and 50 g of cool water. Record the exact mass of each.
2. Find the temperature of each sample.
3. Pour each water sample into the same cup. Immediately place the lid on the cup.
4. Swirl for 2 minutes.
5. Record the final temperature.
6. Repeat with the other combinations (50 g of hot water and 25 g of cool water, 25 g of hot water and 50 g of cool water).

Mass of A (g)	Starting temperature of A (°C)	Mass of B (g)	Starting temperature of B (°C)	Final temperature (°C)

Lesson 10 Teacher Reference

Discussion Mapping/Assessment Template

10.C Apply techniques of algebra and functions to quantify, describe, and mathematically model the energy flows that result in measurable temperature changes in order to quantify conserved energy. (SEP: 5.3; DCI: PS3.B.3; CCC: 4.3)

Science and Engineering Practices
5.3 Apply techniques of algebra and functions to represent and solve scientific and engineering problems.

Crosscutting Concepts
4.3 Models (e.g., physical, mathematical, computer models) can be used to simulate systems and interactions--including energy, matter, and information flows--within and between systems at different scales.

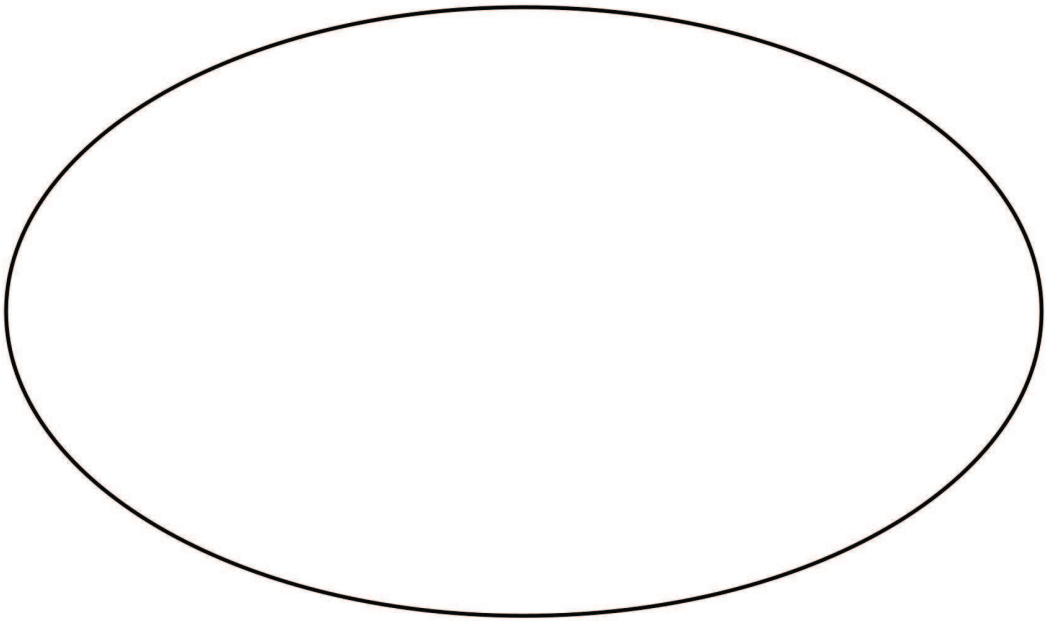
Disciplinary Core Ideas
PS3.B.3: Conservation of Energy and Energy Transfer.

- Mathematical expressions, which quantify how the stored energy in a system depends on ~~its configuration (e.g. relative positions of charged particles, compression of a spring) and how kinetic energy depends on mass and~~ speed, allow the concept of conservation of energy to be used to predict and describe system behavior.

Question we are trying to answer:

Date:_____
L#: _____
Period: ___

Key Ideas



Discussion Codes (Choose up to 3)				
C- claim given	**CL**- clarified idea	**?**- asked question	**T**- tied ideas together	**I**- interrupted
E- gave evidence	**A**- affirmed/agreed	**NI**- new idea added	**RP**- related phenomena	
OT- off topic	**D**- disagreed	**R**- repeated idea	-- idea ended	

Lesson 11: Answer Key

Investigation Question Development Key

Sometimes when we need more information, it is helpful to take stock of where we are to help us develop our question. Use this sheet to help brainstorm questions.

Consideration	Where we are
What do we know about energy transfer between water and ice?	Water particles transfer energy to the ice particles. This is called conduction. The final temperature will be between those of the ice and the water. We can calculate energy transfer or heat flow using $Q = m \cdot c \cdot \Delta T$.
What are we ultimately trying to figure out?	We want to know if the berm can slow enough heat transfer to be worth doing.
What question could help us complete our model, if we investigated it?	How much ice melts when heat is transferred to it from water? How is a mass of ice affected by incoming heat flow? What affects how much ice melts? What is the relationship between heat (energy transfer) and mass of ice melted?

Lesson 12: Answer Key 1

Berm Model Key

Building toward 12.A. Use multiple types of models of changes in energy and matter flows in order to predict the impact of a berm. (SEP: 2.4; DCI: ESS3.D.1; CCC: 5.2)

3D Elements Addressed in This Assessment	
SEP	~~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. (SEP: 2.4)
DCI	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. (DCI: ESS3.D.1)
CCC	Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (CCC: 5.2)

Brainstorm a Gotta-Have-It Checklist that could be used to build a model that answers the question, ***How much would the berm solution impact energy flows and sea level?*** Because this model is answering a question about amount, it will need to have mathematical components.
Several sub-questions are provided to help structure our thinking. Consider how we might include ideas that are best represented with equations, energy transfer models, or particles.

Gotta-Have-It Checklist Items
Where does the energy to melt the ice come from? Energy comes from the warm salty water that is moving toward the ice. Increased density due to increased mass helps explain why the warm salty water does not rise to the top as warm water normally does.
How does the energy move or flow? How can we calculate the amount of energy flow? The energy moves with the water to the glacier through convection. Increased density due to increased mass helps explain why the warm, salty water does not rise to the top as it normally does. The energy transfers from the warm salty water to the ice via conduction. We can calculate how much energy transfers with the equation $Q = c \cdot m \cdot \Delta T$. If a berm is in place, it blocks the warm salty water and energy will transfer to the berm instead of to the glacier.

How does the energy affect matter as it transfers?
How can we calculate the amount of ice melt due to energy transfer?

The energy transferred to the ice causes it to melt.

The amount of ice melt can be calculated using $Q = 80 \cdot m$.

We can use tools from earlier in the unit to calculate how much of the sea level rise would result from this ice melt.

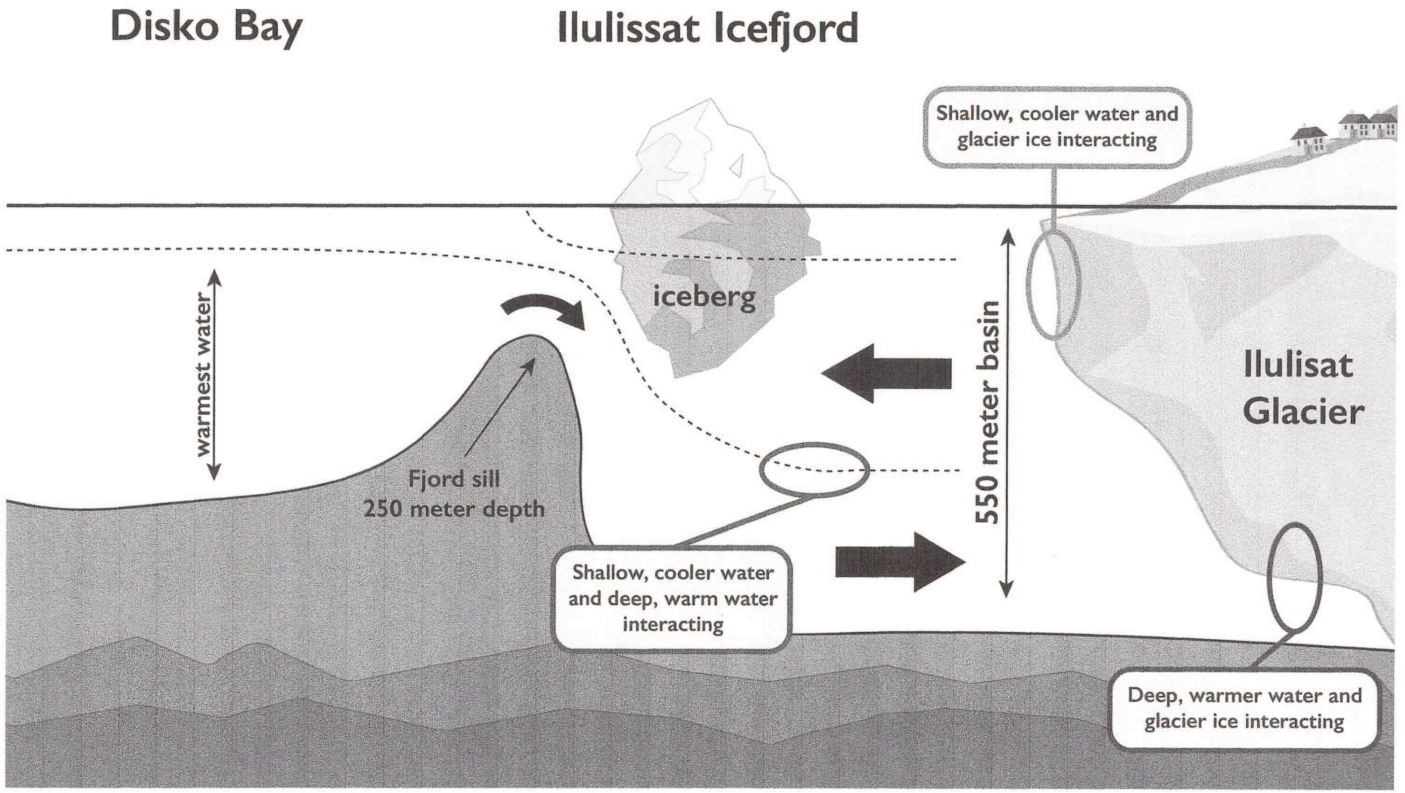
Develop a model that would allow us to answer the question, ***How much does the berm solution impact energy flows and sea level?***

Be sure to include all the ideas on your class's Gotta-Have-It Checklist.

It may be helpful to show energy transfers and equations on or near the parts of the diagram they describe.

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	What to look for in this mathematical model: • The model focuses on the role of warm water in bringing energy to the system and includes relevant equations, but they cannot be used to predict the impact of this water or of the berm solution. • Students should show that energy is transferred into the system by warm water, and eventually to the ice.	What to look for in this mathematical model: • The model ties relevant equations to where they might fall on the model, but they can only be used to predict the impact of warm water or of the berm solution with interpretation. • Students should show how energy is transferred into the system by warm water, and eventually to the ice, through the mechanisms of convection and conduction.	What to look for in this mathematical model: • The model shows how relevant equations could be used to predict the impact of the berm solution as compared to the normal flow of warm water. • Students should show how energy is transferred into the system by warm water, and eventually to the ice, through the mechanisms of convection and conduction, and how this impacts matter at the particle level.
Example	See below.	See below.	See below.
Feedback/ What to Do	*Linking:* Revisit the class Gotta-Have-It Checklist and ask students to consider where different mathematical ideas connect to the physical environment. Support students in seeing how over the last few lessons, we added different pieces that can be used together when making calculations about the impact of the berm solution. Ask students to explicitly compare their own mathematical models to the class model and then revise their models accordingly.	*Organizing:* Review how different mathematical models from the unit relate to each other. Review how conduction results in changes at the particle level. Support students in seeing how the equations not only build on one another, but would be applied differently in systems with or without a berm present. Ask students to revise their models after review.	*Extending:* Ask students to add the microbeads solution or other potential solutions to the mathematical model. Ask students to predict how we would have to account for matter and energy flows in that system.

Foundational Pieces

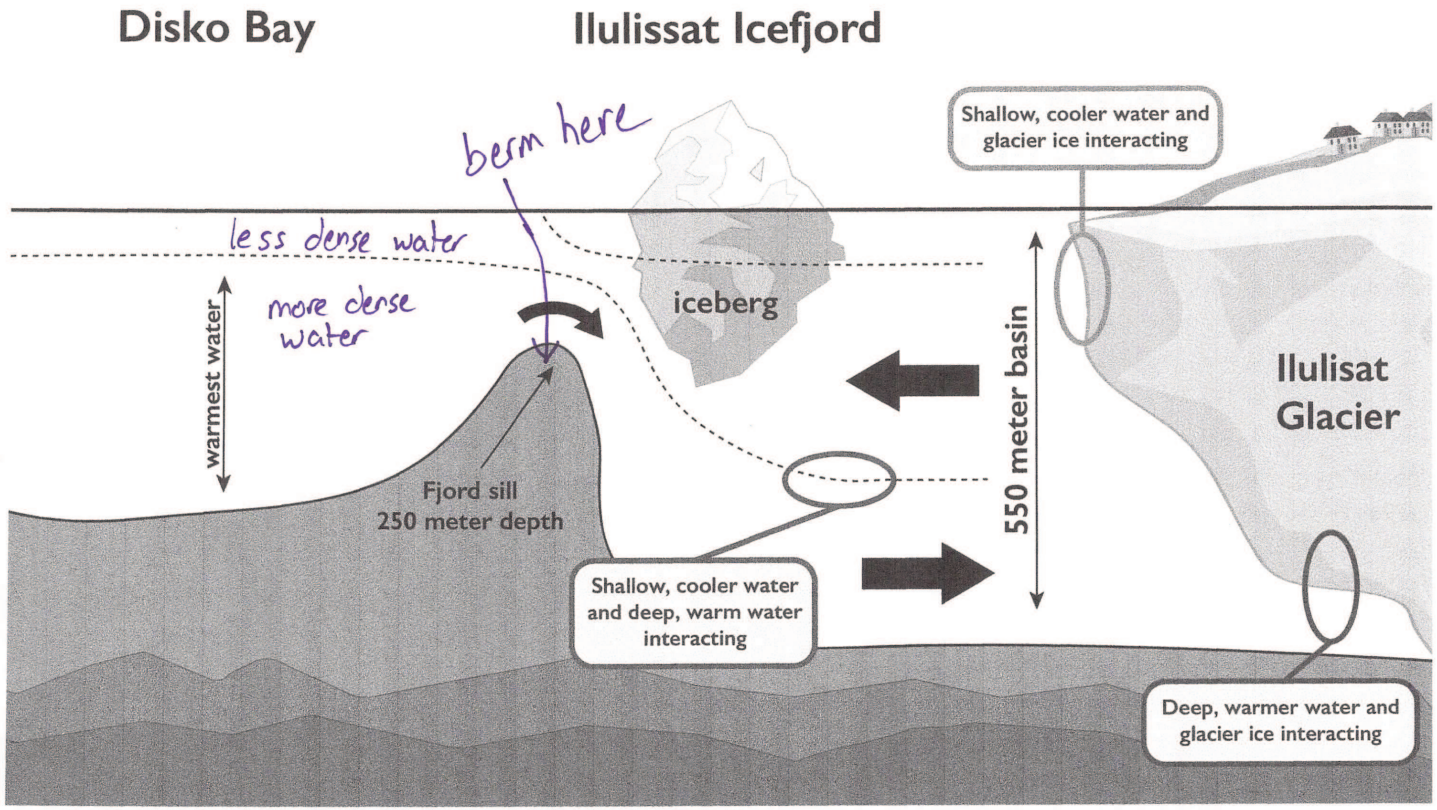


$Q = c \cdot m \cdot \Delta T$

$Q = 80 \cdot m$

warm water in bay → warm water at glacier → ice (melts)

Linked Understanding

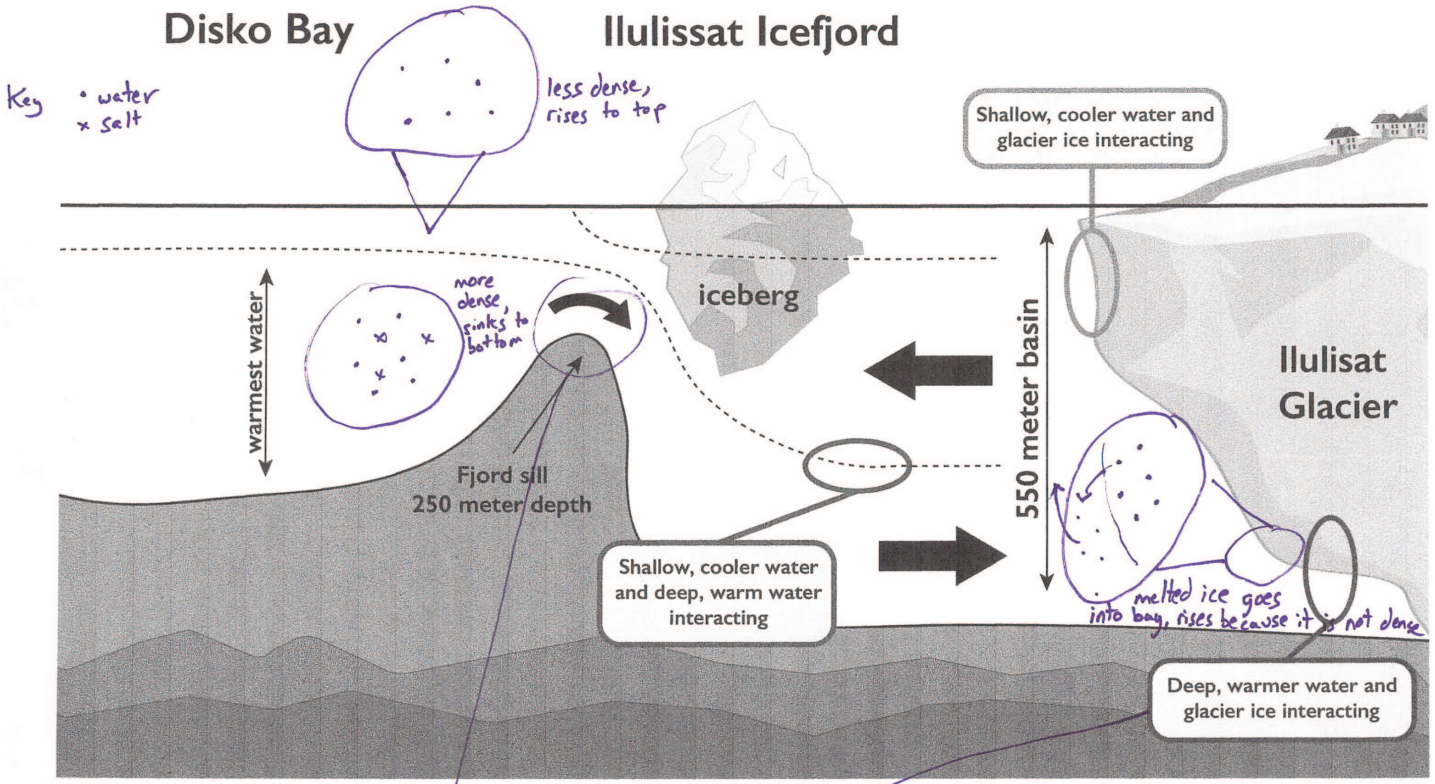


warm, salty water in bay → convection → warm, salty water at glacier → Conduction → ice (particles speed up, melt)

$Q = c \cdot m \cdot \Delta T$

$Q = 80 \cdot m$

Organized Understanding



	Foundational Understanding	Linked Understanding	Organized Understanding
Ideas for Instruction	Review the mathematical models developed in Lessons 9-11. Ask students what these different mathematical models tell us about the berm system.	Review the connections between energy transfer models and the mathematical models that students have developed	Invite students to reflect on what type of information they would need to mathematically model the microbeads solution.

Lesson 12: Answer Key 2

Berm Calculations Key

Building toward 12.B. Support a claim with mathematical models, including unit conversions involving quantified changes in sea level, using energy conservation as a tool. (SEP: 5.2, 5.5; DCI: PS3.A.1; CCC: 7.2)

3D Elements	Question #						
	1	2	3	4	5	6	7
Using Mathematics and Computational Thinking. Use mathematical, ~~computational, and/or algorithmic~~ representations of phenomena or design solutions to describe and/or support claims ~~and/or explanations~~. (SEP: 5.2)		X					X
Using Mathematics and Computational Thinking. Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m^3, acre-feet, etc.). (SEP: 5.5)			X	X	X	X	
PS3.A: Definitions of Energy Energy is a quantitative property of a system that depends on the motion and interactions of matter and radiation within that system. That there is a single quantity called energy is due to the fact that a system's total energy is conserved, even as, within the system, energy is continually transferred from one object to another and between its various possible forms. (DCI: PS3.A.1)		X	X	X	X	X	X
Stability and Change. Change and rates of change can be quantified and modeled over very short or very long periods of time. ~~Some system changes are irreversible.~~ (CCC: 7.2)		X			X		X

In the previous lessons, you have been considering a design solution for slowing the ice melt that is occurring at Ilulissat Glacier. This is a site that has contributed 6.5% of the total Greenland ice-sheet loss over the past few decades.

1) Make a prediction. Would the design solution you have been evaluating stop enough energy transfer to prevent **all** future ice melt occurring at this glacier?

- Accept all answers.

2) What other information do you need to be able to use the mathematical models we developed in class to answer this question?

- The mass of ice that typically melts in a certain amount of time (rate of ice melt).
- The mass of water that makes contact with the ice, and how much that water drops in temperature.

Make sure to help students reason about which mathematical models should be considered here and what information is included in each.

Determine how much energy it takes to melt the ice:

3) Each second, 1.4×10^9 grams of ice from the Ilulissat Glacier melt into the icefjord. Use this information and our mathematical model to calculate the amount of energy (in calories) that is needed to cause this ice melt every **second**.

From Lesson 11: about 80 calories are needed to melt every 1 gram of ice

$(80 \text{ cal/g}) \cdot (1.4 \times 10^9 \text{ g/s})$

$= 1.1 \times 10^{11}$ cal/s

Attend to students' use of unit conversions. Ensure that they are properly multiplying, with 80 calories and 1.4×10^9 g on top of each fraction, so that the grams cancel out.

4) Use unit conversions to figure out how much energy (in calories) is transferred to the glacier each **year**.

1 year = 365 days 1 day = 24 hours 1 hour = 60 minutes 1 minute = 60 seconds

$(1.1 \times 10^{11} \text{ cal/s}) \cdot (60 \text{ s/min}) \cdot (60 \text{ min/hr}) \cdot (24 \text{ hr/d}) \cdot (365 \text{ d/yr}) = 3.5 \times 10^{18}$ cal/yr

If students are not sure how to string all these unit conversions together, suggest that they complete them one at a time.

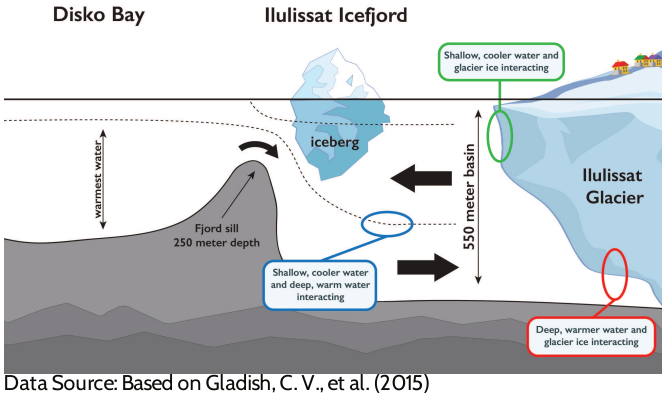
Determine how much warm water is flowing into the icefjord, bringing energy into the ice/water system:

A relatively large amount of warm water flows from Disko Bay over the underwater sill and into the Ilulissat Icefjord. This water then cycles back out to the Bay, closer to the surface.

Every 24 days, this water flow is equivalent to the entire volume of water already in the Ilulissat Icefjord.

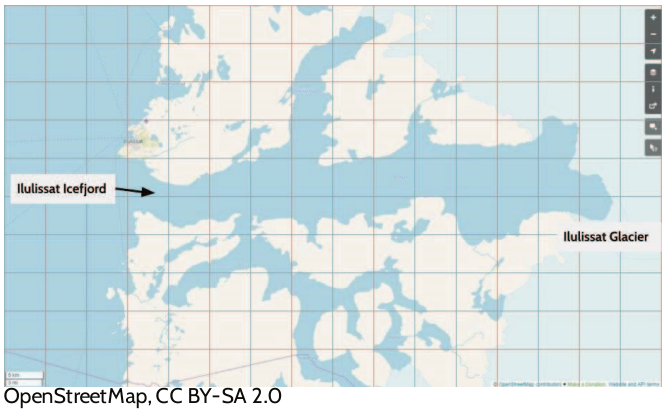
5a) Use the map and the average depth of the icefjord (550 m) to calculate the volume of liquid water that flows into and out of the icefjord (in cubic centimeters) every **24 days**.

1 km = 1 x 10^5 cm
1 m = 100 cm



Data Source: Based on Gladish, C. V., et al. (2015)

Each square shown in the map is 5.0 km x 5.0 km.



OpenStreetMap, CC BY-SA 2.0

volume of water in bay = # of squares · area of each square · depth of water
= (~16 squares) · (5.0 x 10^5 cm) · (5.0 x 10^5 cm) · (550 m) · (100 cm/m)
= ~2.2 x 10^{17} cm^3

Refer students back to their reasoning from Lesson 4's area calculations as they complete this task.

5b) Use the calculation above to determine the volume of liquid water (in cm^3) that flows into and out of the icefjord every **year**.
(2.2 x 10^{17} cm^3) / (24 d) · (365 d/yr)
= 3.4 x 10^{18} cm^3/yr

Check that students are setting up the conversion factor (2.2 x 10^{17} cm^3) / (24 d) correctly. If they are not, suggest they think about what their answer in (5a) is actually telling them.

5c) How many **grams** of water is this per year?
You may choose either of these densities of water for your calculations. Be sure to indicate whether you are assuming the water is freshwater or saltwater.

- Density of freshwater: 1.00 g/cm^3
- Density of saltier water at the bottom of the icefjord: 1.04 g/cm^3

Assuming freshwater: (1.00 g/cm^3) · (3.4 x 10^{18} cm^3/yr) = 3.4 x 10^{18} g/yr
Assuming saltwater: (1.04 g/cm^3) · (3.35 x 10^{18} cm^3/yr) = 3.5 x 10^{18} g/yr

Determine how much energy is transferred out of the warm water:
6) The warm water flowing over the sill into and along the Ilulissat Icefjord has a temperature of about 4.0 °C. Assuming that the water's temperature drops to 2.5 °C as a result of energy transfer to the glacier, how much total energy transfer would be prevented with the berm in place in one year?

Use the specific heat for the type of water you chose in part 5c:

- The specific heat of freshwater is 1.00 cal/(g * °C).
- The specific heat of saltwater is 0.93 cal/(g * °C).

calories transferred from liquid water into the ice = specific heat *mass *temperature change

Freshwater: 1.5 °C · (1 cal/(g · °C)) · (3.4 x 10^{18} g/yr) = 5.0 x 10^{18} cal/yr

Saltwater: $1.5\ ^{o}C \cdot (0.93\ cal/(g \cdot\ ^{o}C)) \cdot (3.5 \times 10^{18}\ g/yr) = 4.9 \times 10^{18}\ cal/yr$

Make an evidence-based claim:

7) Would the design solution you have been evaluating to block the flow of warm water into the icefjord stop enough energy transfer to prevent **all** of the melt occurring at Ilulissat Glacier, or only **some** of it? Explain how each of the following support your claim:

- your calculations
- energy conservation

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	What to look for in students' claims: • The calculations (quantified changes) that support the claim are implied. • The claim is supported by general, partial descriptions of energy conservation. • The claim references the change that the berm would cause (or prevent) in the system.	What to look for in students' claims: • The calculations (quantified changes) that support the claim are described qualitatively. • The claim is supported by specific, partial descriptions of how energy is conserved in the system. • The claim references the change that the berm would cause (or prevent) in the system.	What to look for in students' claims: • The specific calculations (quantified changes) that support the claim are explicitly stated. • The claim is supported by specific, complete descriptions of how energy is conserved in the system. • The claim ties back to the change that the berm would cause (or prevent) in the system.
Example	The claim below is **bolded**. **The berm will help protect the glacier because it blocks enough energy from reaching it.** Energy is conserved, meaning that it is not created or destroyed, so stopping from moving means that it cannot cause melting.	The claim below is **bolded**. I calculated that the berm keeps more energy from reaching the glacier than it would take to melt the glacier. This means that the glacier is p**rotected from melt.** Energy is conserved so since the energy that would otherwise melt the glacier is blocked, no other energy will be created at the glacier in order to cause it to melt.	The claim below is **bolded**. The answer to part 6 (5.0×10^{18} cal/yr or 4.9×10^{18} cal/yr) is more energy than is currently being transferred to the glacier to produce all of the ice melt that is occurring (3.5×10^{18} cal/yr). **The proposed berm solution, therefore, would block more than enough energy flow to the glacier to prevent ALL future melt happening at this location.** Energy conservation also supports this claim because even though the energy carried by the warm salty water does not disappear, it is unable to transfer directly to the glacier because the berm blocks it.
Feedback / What to Do	*Linking:* Invite students to expand on how their calculations helped them develop a claim. Invite students to reflect on how energy conservation applies in this particular system.	*Organizing:* Invite students to specifically reference the calculations that support their claim. Invite students to expand on the role of energy conservation on different components in the system.	*Extending:* Encourage students to expand beyond Disko Bay and consider energy transfers between this system and other components of the Earth system discussed in the unit.

	Foundational Understanding	Linked Understanding	Organized Understanding
Ideas for Instruction	Return to the Mathematical Anchor Chart and consensus mathematical model and review different procedures and operations. Help students map different steps in their calculations to ideas from the mathematical model.	Give students an opportunity to compare calculations and identify errors. Put up a representative claim and workshop how it could be made more thorough and specific to the problem at hand.	Invite students to scale the problem up, reflecting on what estimates would be required to develop a similar claim for the impact of berms of all similarly situated glaciers in Greenland or the world.

Lesson 13: Answer Key

Heat Pumps Key

Performance expectation being assessed: HS-PS3-4. Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics).

In addition to the SEP, CCC, and DCI associated with this PE, this assessment also addresses two additional SEP elements and one additional CCC element. Developing and Using Models (SEP 2.4) is incorporated so that students have an opportunity to develop and show understanding of the heat pump system before they plan an investigation to troubleshoot the system. An additional Planning and Carrying Out Investigations element (SEP 3.5) is also built in so that students have an opportunity to share their reasoning about the functioning of the system. Similarly, students leverage an additional Systems and System Models element (CCC 4.1) to support their reasoning about how the system is designed and functions.

3D Elements Addressed in this assessment	Question #						
	1	2	3	4	5	6	7
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. (SEP: 2.4)	X	X	X	X			
Planning and Carrying Out Investigations. Plan ~~and conduct~~ an investigation individually ~~and collaboratively~~ to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (SEP: 3.2)						X	
Planning and Carrying Out Investigations. Make directional hypotheses that specify what happens to a dependent variable when an independent variable is manipulated. (SEP: 3.5)					X		
PS3.B: Conservation of Energy and Energy Transfer Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-4)		X		X	X	X	
PS3.B: Conservation of Energy and Energy Transfer Uncontrolled systems always evolve toward more stable states—that is, toward more uniform energy distribution (e.g., ~~water flows downhill~~, objects hotter than their surrounding environment cool down). (HS-PS3-4)		X	X				X
PS3.D: Energy in Chemical Processes Although energy cannot be destroyed, it can be converted to less useful forms—for example, to thermal energy in the surrounding environment. (HS-PS3-4)		X					
Systems and System Models. Systems can be designed to do specific tasks. (CCC: 4.1)	X		X	X	X	X	X
Systems and System Models. When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. (CCC: 4.2)		X				X	

Scoring Guidance. The elements described below would be considered an exemplary response at this point in the unit. These are shown as purple text or in purple diagrams below the related question. In some cases different elements of the response are identified with a separate + symbol These + 's are not meant to be all inclusive; they are suggestions for what you may see your students include. The following scoring guidance provided can help you identify different ideas that students should (or could) include in their responses.

- If several of the ideas marked with a + are missing from a student's response, this may indicate the student has not mastered the science ideas or that the student may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking can provide insight about whether the student is struggling with a science practice or science idea, or both.
- If all or almost all of the ideas marked with a + are present in a student's response, this may indicate that the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.

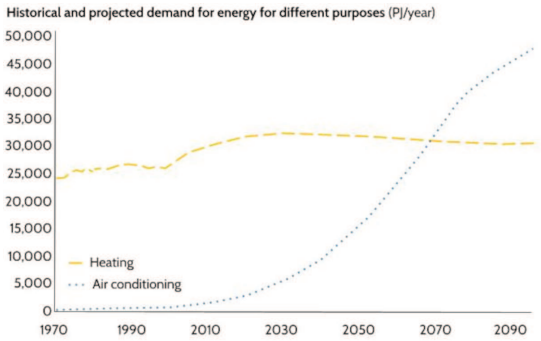
- Some “additional elements” are listed for some prompts. Students should not be penalized if these items are not included.

Students can respond to questions on this assessment in writing, using illustrations, gestures, and languages other than English.

Scenario: Heat Pumps

As global climate changes, people who never needed indoor cooling before are feeling the heat. Increasing temperatures are expected to bring increased demand for air conditioning (AC). This is partially about comfort, but also about survival. High temperatures can make people sick and can even be deadly. Since much of the electricity that powers AC today still comes from fossil fuels and has associated carbon emissions, there is serious concern about how increased need for cooling could fuel a fearsome feedback loop -- more demand for cooling driving more fossil fuel use, increasing emissions and causing higher temperatures, and driving even more demand for cooling.

But the emissions associated with indoor cooling are still small compared to those from indoor **heating**. While the electricity that powers AC may come indirectly from burning fossil fuels, some electricity already comes from renewable sources like wind, hydroelectric, and solar power. On the other hand, the energy used to heat buildings often comes directly from burning natural gas, oil, or propane. This, combined with the current greater global demand, means that indoor heating is now a bigger contributor to climate change than indoor cooling.



There is currently greater demand for heating than cooling globally. Energy demand for cooling in buildings will overtake demand for heating in the future. Data Source: van Vuuren, D.P. (2009)

But the surge in demand for AC might actually help to change that. As people buy AC units for the first time, there is an opportunity to change how indoor spaces are **heated** too. Electric heat pumps are systems designed to work like a two-way air conditioner, using a refrigerant and electricity to transfer heat either into or out of a building. Instead of burning oil, gas, or propane to generate heat, an electric heat pump uses electricity to efficiently transfer heat with the use of a chemical refrigerant. Refrigerants are substances that change from liquid to gas at very low temperatures, and can be forced to change back to liquid using a technology called a compressor. Heat pumps take advantage of these phase changes and the law of conservation of energy to efficiently heat and cool indoor spaces.

If heat pumps are widely adopted, they could eventually make a major dent in global carbon emissions by reducing direct emissions from indoor furnaces. As electric grids shift from fossil fuel power plants to renewables, more heat pumps could mean slashed emissions from both heating and cooling. Installing an electric heat pump can be expensive up front, but in the United States, new legislation is making it easier for consumers to make the switch. But electric heat pumps are not totally free of issues.

Use this task to figure out:

- how heat pumps work to heat indoor spaces;
- how you might troubleshoot a problem with a heat pump system.

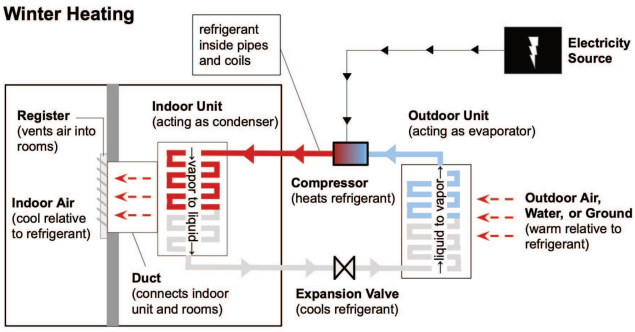
References

Haubursin, C. (2021, September 24). *Why heaters are the future of cooling*. Vox. Retrieved December 12, 2022, from https://www.vox.com/videos/2021/9/24/22691392/heat-pumps-cooling-air-conditioner-heating

Isaac, M., van Vuuren, D.P., 2009. "Modeling global residential sector energy demand for heating and air conditioning in the context of climate change". Energy Policy 37, 507–521.

The United States Government. (2022, October 26). *Clean energy for all*. The White House. Retrieved December 12, 2022, from https://www.whitehouse.gov/cleanenergy/

PART 1:
The diagram shows how a typical heat pump system works.



1. Consider what you already know about how homes or buildings are heated. **Briefly** explain in your own words or draw a **quick** sketch of how this works.

Key Elements:
+ Proposes an initial model of how a home heating system works

What to do:
Accept all responses. Validating these responses engages students in activating their existing knowledge about home heating systems and builds **relevance** and **interest** in the task.

2. *See Heat Pumps Transfer Task for the diagram and text, which have been omitted from this document to save space.*
Referencing the diagram and text, take a moment to notice how energy flows through the heat pump system and between the system and the surroundings.

A. Define the system. Draw or describe the boundary between the heat pump system and its surroundings.
What parts of the diagram show the heat pump itself and what parts show the environment around it?
B. Where and how is energy coming into and out of the heat pump?
C. Might there be other places not shown in the diagram where energy comes into the system or where energy exits the system? If so, add those places to the diagram and explain how this would affect the usefulness of the system.
Key elements:
+ draws or describes the boundary between the heat pump system and the surroundings
+ shows or describes energy transfer from the electricity source
+ uses the heat pump diagram to provide a mechanistic account in which energy flows from warmer to cooler substances (from the outdoor air to the refrigerant in the outdoor unit and from the indoor unit to the cool indoor air)
+ shows or describes energy exiting the system through the walls of the duct or the sides of the pipes
+ indicate that there are ways for energy to leave the system
+ indicate that energy outside the system is not useful

Additional accurate element not essential to this item:
+ includes how temperature differentials between surrounding air and refrigerant result in energy transfer that causes phase changes

Sample student responses:
A. The heat pump system includes the outer unit, the interior unit, the compression and expansion valves, and the pipes and coils connecting the units, ducts, and vents. The surroundings include the air, ground or water outside, the home as well as the air inside the home. The electricity source is also in the surroundings.

B. Energy comes into the heat pump system through the electricity source. Energy also comes into the heat pump system through the outdoor air, water, or ground, which is warmer than the refrigerant in the system. Energy leaves the system inside the house through the duct.

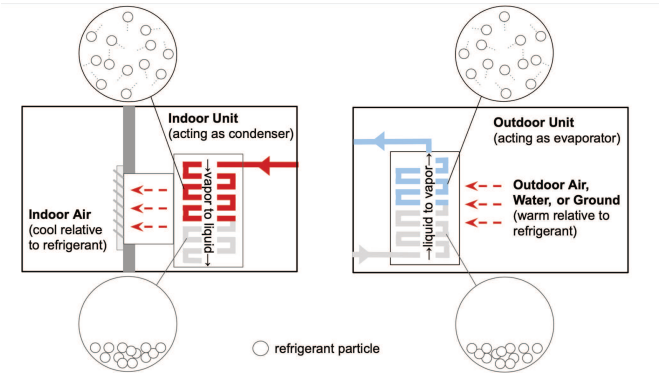
C. Energy transfers will happen when matter at different temperatures comes into contact. Some energy would transfer to the surrounding environment as the refrigerant moves through the pipes, coils, and ductwork. This "escaped" energy outside the system would not be useful to heat the home. [Diagram is updated with arrows pointing outward from the hot pipe and coil.]

What to do:
Support students to identify system boundaries. Ask, *What are the key parts of the heat pump?* Or suggest, *Draw a line or box to indicate what is inside and outside of the system.*

Support students to describe how energy is moving toward more uniform distribution. Ask, *What forms of energy are involved in this system? Where does the heat pump get its energy / lose its energy? What energy is entering, staying in, or leaving the system? What evidence is there that energy is being conserved in this system?*

Support students to consider limitations of the diagram as it relates to modeling energy flows. Ask, *Where else might energy be entering, staying in, or leaving the system that is not shown in the diagram? How would you revise this model to give a more complete picture of how energy is likely flowing in the heat pump system and between the system and the surroundings?*

3. Consider the following particle models of the refrigerant flowing through the coils inside the indoor unit and the outdoor unit.



A. What happens to the matter (refrigerant) as it moves through the unit that is acting as an evaporator? How and why does this happen?

- If you wish, you may draw an illustration or energy transfer model to show your thinking.

B. What happens to the matter (refrigerant) as it moves through the unit that is acting as a condenser? How and why would this result in **heating** of the surroundings?

- If you wish, you may draw an illustration or energy transfer model to show your thinking.

Key elements:

+ uses the heat pump diagram and particle models to provide a mechanistic account
+ shows how the evaporator transfers energy from outside to inside through conduction or particle motion
+ shows how the condenser transfers energy from outside to inside through conduction or particle motion
+ makes a connection between energy transfer and indoor heating from the system
+ indicates that temperature should even out in the system as as energy transfers in ways that cause it to become more evenly distributed

Additional accurate element not essential to this item:

+ includes how temperature differentials between surrounding air and refrigerant result in energy transfer that causes phase changes

Sample student response:

A. Refrigerant particles start to speed up as they move through the evaporator. This happens because energy is transferred from the warm outside air/water/ground to the cold refrigerant. As the particles bump into each other, the outdoor particles transfer energy to the refrigerant particles, causing them to speed up, so that the energy is spread evenly.
B. Refrigerant particles start to slow down as they move through the condenser. As energy leaves the refrigerant particles, it is transferred to the cooler surroundings, which causes the surroundings to heat up, so that the energy is spread evenly..

What to do:

Support students in relating the models to each other. Ask students to compare the two models to identify common features and differences.

Support students to think through transformations of matter and energy transfer. Ask, *What does the particle model suggest is happening to matter as it moves within [part of system]? Where does the refrigerant get its energy? Where does the refrigerant's energy go?*

4A. Put the pieces together. Use the text, diagrams, and models to explain how the heat pump systems are designed to transfer energy from the outside to the inside.
In other words, how does a heat pump heat indoor spaces in the winter?
4B. Why was it important to use multiple models and diagrams in answering 4A? Give specific examples.

Key elements:

+ uses the heat pump diagram and particle models to provide a mechanistic account
+ the different models provide different pieces of information or have different strengths and limitations
+ includes examples of why particular models were useful or had specific strengths and limitations
+ traces energy transfer into, out of, and within the system at a particle level
+ makes a connection between energy transfer and indoor heating from the system

Additional accurate element not essential to this item:

+ includes how temperature differentials between surrounding air and refrigerant result in energy transfer that causes phase changes

Sample student response:

A. The outside particles are warm (fast moving), and the refrigerant particles are cold (slow moving). When they bump into each other energy transfers from the outside particles to the refrigerant particles, making them move faster (heating them up). These fast refrigerant particles move through the heat pump system until they reach the condenser.

At the condenser, the fast moving (hot) refrigerant particles come in contact with the cool (slow moving) inside air particles. As they bump into each other, energy transfers from the refrigerant particles to the inside air particles, making them move faster (heating them up). The refrigerant particles cool down and cycle through the system to start the process over again.

B. The different models provide different pieces of information. For example, the particle model shows what is happening in the coils, while the system model gives a better understanding of how energy is getting into the system without showing what is happening at the particle level.

What to do:

Support students to think through energy conservation and energy transfer in the scenario. Ask, *How is energy driving the cycling of refrigerant in the heat pump system? What is needed to cause particles to move?*

Support students to think about the models comparatively. Ask, *What is the difference between the models in this assessment? What does each one tell us that the others do not?*

PART 2:

HVAC technicians (who work on **H**eating, **V**entilation, and **A**ir **C**onditioning) install, repair, and maintain heating, ventilation, air conditioning, and refrigeration systems that control the temperature and air quality in buildings.

Imagine you are an HVAC technician who has been called to repair a heat pump system that has malfunctioned. Below are some notes and photos you took on site after talking with the customer.

Notes *- Outdoor unit is on, but inside temp is still cold (64°F, thermostat set to 72°F)* *- Outdoor temp is 43°F* *- Unit installed in 2007, home built in 1901* *- No visible moisture near indoor or outdoor coils* *- No leaves or other debris obstructing outdoor unit* *- Filter is new and clean* *- Large gaps between ducts and opening of registers / air vents.* *-Register full of pet hair*	See *Heat Pumps Transfer Task* for example images.

As a trained HVAC technician, you know that there are a few common reasons a heat pump might not heat in the winter.

	Possible Causes	Possible Fixes
1	Thermostat problems	Clean thermostat, ensure power supply, replace thermostat
2	Dirty air filters	Replace filter
3	Outside unit blocked or dirty	Remove debris
4	Leaking or clogged air ducts	Ensure seal (no gaps) between duct and vent, remove debris

5A. Based on your notes and observations on site, construct a hypothesis about which part of the system is causing the problem, what repair is needed, and why.

"The likely cause of the problem is... because..."
"If I..., it will fix the problem because..."

5B. In your hypothesis, underline the independent variable and *put stars around or next to the dependent variable*.

Key elements:

+ identifies a repair (sealing gaps and removing pet hair) as a the independent variable needed for the system to provide indoor heating
+ specifies the expected effect on temperature and/or air flow as a dependent variable
+ does so in a manner consistent with principles of energy conservation and transfer

Sample student response:
The likely cause of the problem is leaking and clogged air ducts because there are large gaps between the ducts and the opening of the air vents, and the register is full of pet hair. If I seal the gaps, it will fix the problem because *less energy will be transferred to the surroundings through the gap and more energy will be transferred to the air inside the room*. If I clean the register to eliminate the pet hair, it will fix the problem because air can move more easily through the duct, allowing more air to be heated.

What to do:
Support students to think through their hypothesis. Ask, *What would you fix to get the heat pump working again? How does the fix you are proposing increase the energy transferred from the system to the home?*

6. As an HVAC technician, you commonly carry the following specialty tools in addition to your hand tools (screwdrivers, wrenches, pipe cutters, metal shears, safety glasses, black markers, etc):

Specialty Tool	What it measures
Handheld thermometer	Temperature
Multimeter	Electricity Flow
Refrigerant gauge	Pressure
Anemometer	Air Flow

Using your available resources, create an investigation plan to test if your repair to the system worked.

a. Which of your available specialty tools will be most useful to you in your investigation? Why?
The thermometer will be most useful in my investigation because I need to determine whether my fix results in the heat pump increasing the temperature inside the house.

The air flow sensor will be most useful in my investigation because it will allow me to see whether my repair to the gap between the ducts and registers increases the amount of warm air that can enter the home.

b. What observations/measurements will you record and how frequently? Where in the system will you take these measurements? (e.g., Near vents, in middle of living area, outside, etc.)
I will take temperature measurements in the middle of the living area every 30 minutes.

I will take airflow readings before and after the repair near the register.

c. Each of your specialty tools has a degree of error (see the table below). In the unit we accounted for this error by saying that the last significant digit of a measurement, like a graduated cylinder reading, was estimated or uncertain. How will you be certain that changes in your readings are due to your repair, and not measurement error?

Tool	Typical Margin for Error	Example
Handheld Thermometer	±2°F (±0.5°C)	If the thermometer registers a reading of 96°F, the real temperature may be anywhere between 94°F and 98°F.
Multimeter	±2% of the full scale value	If the multimeter registers a reading of 20 amps, the real current may be between 19.6 amps and 20.4 amps.
Refrigerant Gauge	±1% of the full scale value	If the gauge registers a refrigerant pressure of 101.6 PSIG, the real pressure may be between 100.6 PSIG and 102.6 PSIG.

Anemometer	+/- 0.2% of the full scale value	If the anemometer registers airflow at 3518 ft/min, the real airflow may be between 3511 and 3525 ft/min.

I will only decide that the repairs have been successful if the measurements are greater than the error in the instruments.

d. What variables will you control to decrease their impact on experimental error? How will you control them? (Name at least three.)
Opening or closing windows or doors can change temperature, changing the setting on the thermostat, or using the oven or a fireplace could cause temperature changes in the house. These variables can be controlled by keeping windows and doors shut, using the same setting on the thermostat, and making sure ovens or other heat sources are turned off.

e. How will you explain what you are doing to the customer? How will you minimize any disruption to the client's use of the space that might be caused by your repair or test?
I will explain that I am sealing the connection between the ducts and the vents, and cleaning out pet hair, to ensure that energy is transferred from the coils to the air and into the home and prevent warm air from flowing behind the walls or floor. To make sure this addresses the problem, I will measure the initial temperature in the living area, then after making the repair, measure the temperature in the main living area every 30 minutes to ensure temperature is rising and that the interior temperature meets the desired indoor temperature of 72°F.

To minimize disruption I will work in one area of the house at a time to make the repairs, then enter the home only to take my measurements. The measurements will be taken in the same place.

f. Describe the pattern of evidence that would support the claim that your repair was successful and the heat pump system is again operating as it was designed to operate.

What changes in energy would you need to see for you to know that the data you collected is enough to help you support or disprove your hypothesis in question 5A?
See the rubric below for key elements and sample responses.

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	What to look for in students' investigation plans and patterns of evidence: The investigation plan does SOME of the following: • 6a. selects thermometer or air flow sensor as a specialty tool and includes a rationale • 6b. specifies a reasonable method to determine if the system is performing as expected • 6c. Explains how to account for measurement error in the experiment. • 6d. Identifies at least 3 possible confounders in the system or surroundings and provides a reasonable plan to control for them • 6e. specifies a reasonable method to determine if the system is performing as expected, including strategies for limiting impact on the client. 6f. The student begins to identify how the results would show changes in only inputs or outputs in a way somewhat consistent with understanding of energy conservation and transfer.	What to look for in students' investigation plans and patterns of evidence: The investigation plan does MOST of the following: • 6a. selects thermometer or air flow sensor as a specialty tool and includes a rationale • 6b. specifies a reasonable method to determine if the system is performing as expected • 6c. Explains how to account for measurement error in the experiment. • 6d. Identifies at least 3 possible confounders in the system or surroundings and provides a reasonable plan to control for them • 6e. specifies a reasonable method to determine if the system is performing as expected, including strategies for limiting impact on the client. 6f. The student partially identifies how the results would show changes in inputs and outputs in a way consistent with understanding of energy conservation and transfer.	What to look for in students' investigation plans and patterns of evidence: The investigation plan does ALL of the following: • 6a. selects thermometer or air flow sensor as a specialty tool and includes a rationale • 6b. specifies a reasonable method to determine if the system is performing as expected • 6c. Explains how to account for measurement error in the experiment. • 6d. Identifies at least 3 possible confounders in the system or surroundings and provides a reasonable plan to control for them • 6e. specifies a reasonable method to determine if the system is performing as expected, including strategies for limiting impact on the client. 6f. The student identifies how the results would show changes in inputs and outputs in a way consistent with understanding of energy conservation and transfer, with an emphasis on energy transferring throughout the space when the system is functioning properly.

Example	See above for examples of 6a-6e. 6f. The temperature of the room would go up, meaning the energy is going to different parts of the home.	See above for examples of 6a-6e. 6f. The temperature of the room continues to go up at every reading until it reaches 72 degrees, which means the energy is spreading to all different parts of the home.	See above for examples of 6a-6e. 6f. If the temperature of the room does not change within the first two readings, I will conclude that the repair was not successful and there is another problem somewhere else in the system. If the temperature of the room does change within the first two readings, I will continue to monitor it until it gets close to the desired indoor temperature (72 degrees). The temperature of the room continues to go up at every reading until it reaches 72 degrees. This means that energy is now flowing from the duct to the room, without escaping the system entirely or being blocked from reaching the actual home by pet hair.
Feedback / What to Do	*Linking:* Support students to think through their investigation plan. Ask, *What kinds of things normally change in a home like the one presented in the scenario? How might you make sure those changes are not impacting your test?* Support students to think through what data they would need to see to be confident that their repair was successful. Ask, *What reading are you looking for? Why would this reading indicate the system is working as desired? What does this reading tell you about how the unit is operating? If the reading can be off by [margin of error] what number would you look for to be sure the reading is in the right range?* Invite students to think about how energy transfers in regular patterns (from hot to cold) in all systems and consider how that idea can be leveraged to more carefully analyze the heat pump system.	*Organizing:* Invite students to think about how defining our heat pump system in a certain way allows us to identify relationships between components of the system and track energy transfers and conservation more carefully. Invite students to think about how their plan can be refined to be more replicable by another HVAC technician in a similar situation.	*Extending:* Encourage students to consider how other problems in heat pumps could be addressed.

7. What is happening at the particle level that explains why allowing warm air into one part of the room from the heat pump system causes the whole room to heat up?

- Use both matter and energy thinking in your response.
- You may use illustrations or drawings to support your response, if you wish.

Key elements:

+ traces energy transfer at a particle level
+ makes a connection between energy transfer and indoor heating from the system
+ includes the process continuing until energy is evenly distributed and temperature is consistent throughout the room

Sample student response:

The warm air particles coming into the room from the heat pump system are fairly fast-moving. They will collide with other air particles in the room, transferring energy through conduction, until all particles are moving at the same speed. This means the energy is spread out and the temperature is consistent throughout the room.

What to do:

Have students reflect on why it is that all the air in the room increases in temperature due to the action of the heat pump. Ask, *How is the heat pump heating up air in the duct? What causes the air particles to eventually all reach the same speed?* Students may conflate temperature and energy. If the student just talks about the temperature becoming even without discussing energy distribution, ask, *What does it mean about the energy of particles if the temperature is even throughout the room?*

	Foundational Understanding	Linked Understanding	Organized Understanding
Ideas for Instruction	Review the simulations from Lesson 10 and explicitly consider how particle motion leads to energy transfer as represented in energy transfer models.	Review the assessment with students to foster students making connections between features of the heat pump, investigative methods we could use, and the roles of energy conservation and transfer in systems.	Invite students to investigate and compare the energy transfer mechanisms found in different home heating systems.