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

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

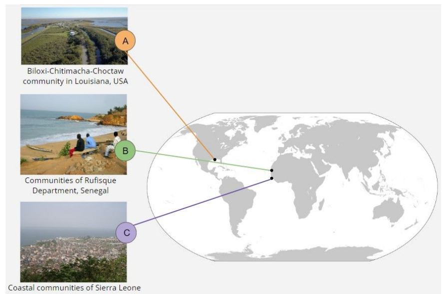
LESSON 1
Lesson Set 1

3 days

How are sea levels rising and forcing people to move?

Anchoring Phenomenon

Phenomena or Design Problem



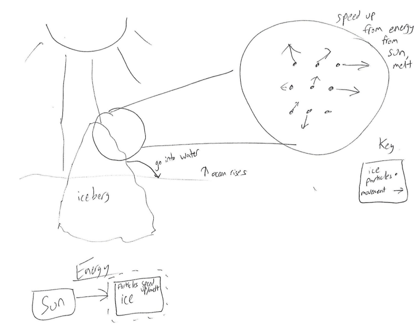
Coastal locations are noticing sea level rise due to local and global causes, which are forcing some communities to move.

What we do and figure out

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.

How we represent it



⇓ **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.

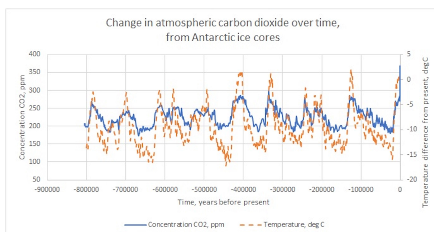
LESSON 2
Lesson Set 1

3 days

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

Anchoring Phenomenon, Investigation

Phenomena or Design Problem



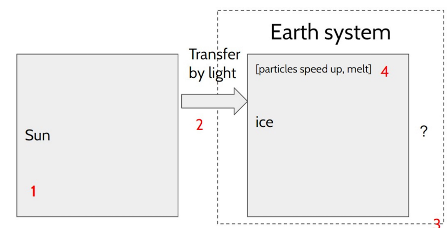
Sea level tends to increase as temperature increases and polar ice melts. Various factors can affect Earth's climate, but only carbon dioxide can impact it at the timescales we observe.

What we do and figure out

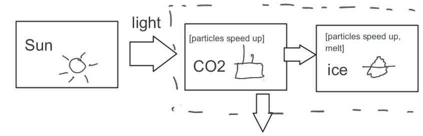
We look at historical data of temperature, polar ice volume, sea level, and different possible causes. We discuss and model the likely cause of current ice melt and sea level rise. We figure out:

- 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.

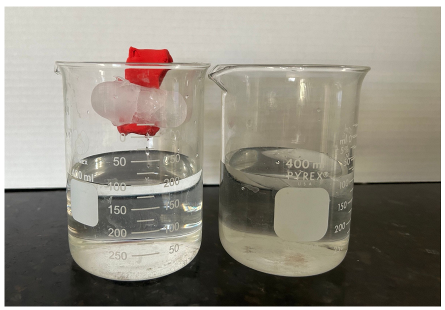
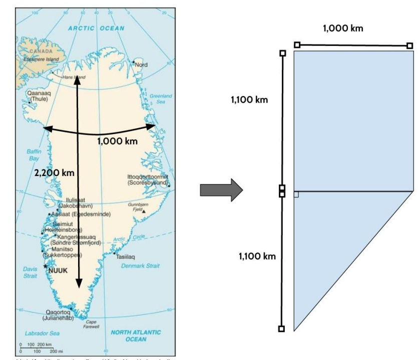
How we represent it



⇓ **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.	

⇓ **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.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
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 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

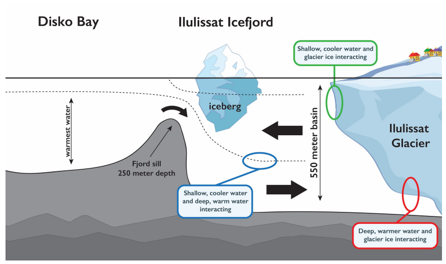
LESSON 5
Lesson Set 2

2 days

How can we best slow or stop the land ice melt?

Problematizing

Phenomena or Design Problem



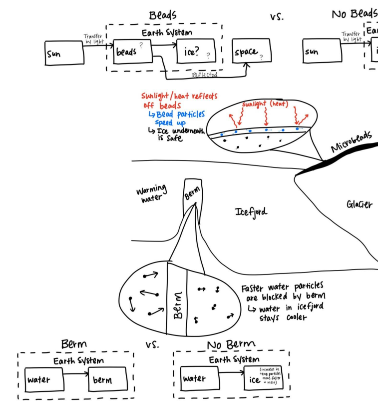
The Ilulissat Glacier has lost a lot of ice mass and has visibly retreated over the past few decades. Scientists have proposed two potential geoengineering solutions to slow the rate of melting at this location – building an underwater berm, or spreading thin layers of microbeads on ice during the summer.

What we do and figure out

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.

How we represent it



⇓ **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.

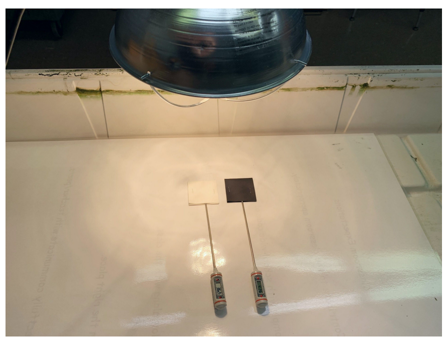
LESSON 6
Lesson Set 2

2 days

Why would some engineers want to sprinkle glass microbeads on the Arctic?

Investigation

Phenomena or Design Problem



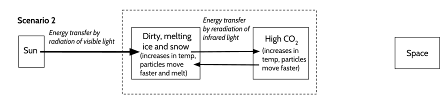
Different colors of construction paper increase in temperature differently under a heat lamp.

What we do and figure out

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.

How we represent it



⇓ **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

Phenomena or Design Problem

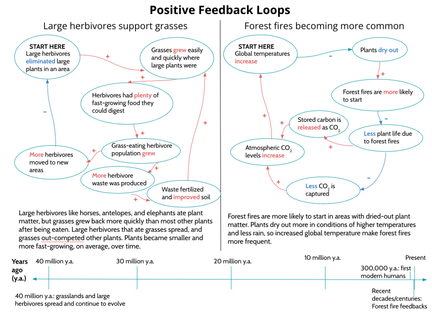
Many changes in Earth systems, like increased warming due to melting ice and permafrost releasing CO2 that speeds warming, are due to feedback loops.

What we do and figure out

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.

How we represent it



⇓ **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

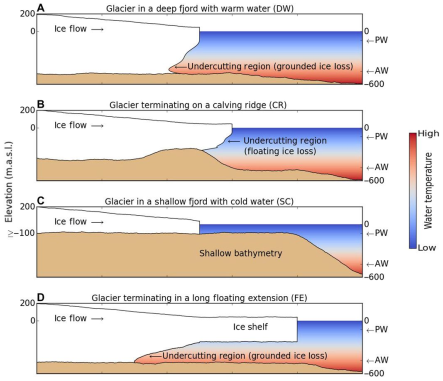
Lesson Set 3

1 day

What is going on where the ice meets the water?

Investigation, Problematizing

Phenomena or Design Problem



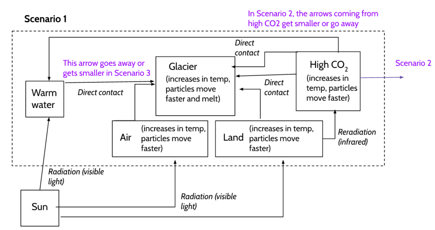
Data from Inuit hunters and fishers and NASA scientists suggest that warming oceans contribute to glacial melt

What we do and figure out

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.

How we represent it



⇓ **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

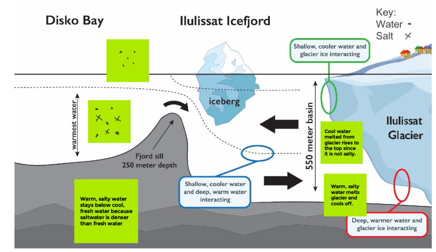
Why does warm salty water sink to melt a glacier?

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.



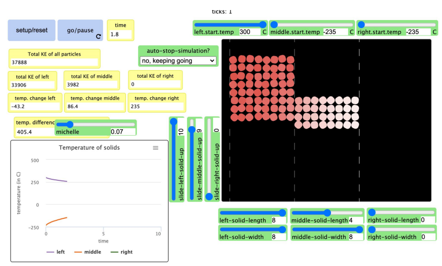
⇓ **Navigation to Next Lesson:** Though we now see how creating a barrier at the bottom of the ocean would prevent warmer saltwater from coming into contact with the bottom of Ilulissat Glacier, we are unsure about how this melting process works.

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:

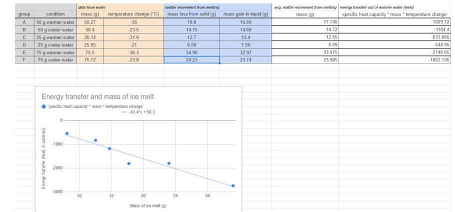
- Energy transfer between two objects/samples initially at different temperatures will cause both to eventually reach the same final temperature, which will be between the initial temperatures.
- The mass of each sample affects where the final temperature stabilizes (ΔT depends on m).
- Energy is conserved. 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.

$$Q = c_p \cdot m \cdot \Delta T$$

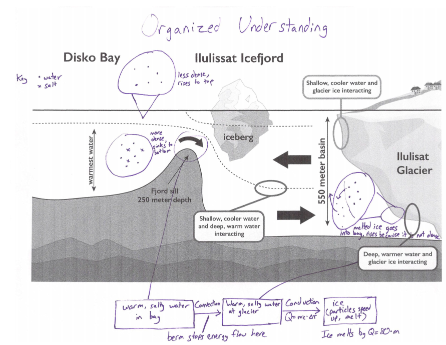
Energy transferred (calories) = c_p · mass (grams) · temperature change (°C)

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

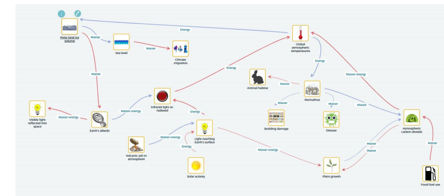
⇓ **Navigation to Next Lesson:** We have an equation to calculate the heat transfer to a glacier from warm water, but we may not have the information we need to apply this equation in the context of Ilulissat Glacier.

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.	

⇓ **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.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
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 5×10^{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 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