Unit Storyline

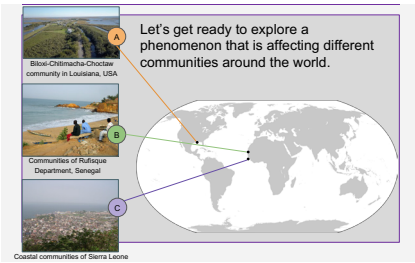
Lesson Set 1: Why and how is the sea level rising?

LESSON 1

How are sea levels rising and forcing people to move?

Anchoring Phenomenon 3 days

Phenomenon or design problem	What we do and figure out	How we represent it
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. • 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.	speed up from energy from sun, melt go into water ocean rises Key ice particles movement Energy Sun Particles speed up & melt Ice



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.

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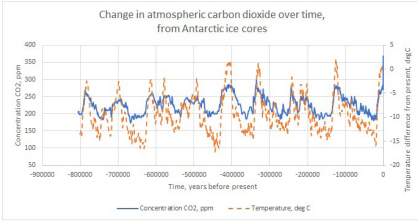
LESSON 2

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

Anchoring Phenomenon, Investigation **3 days**

Phenomenon 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.

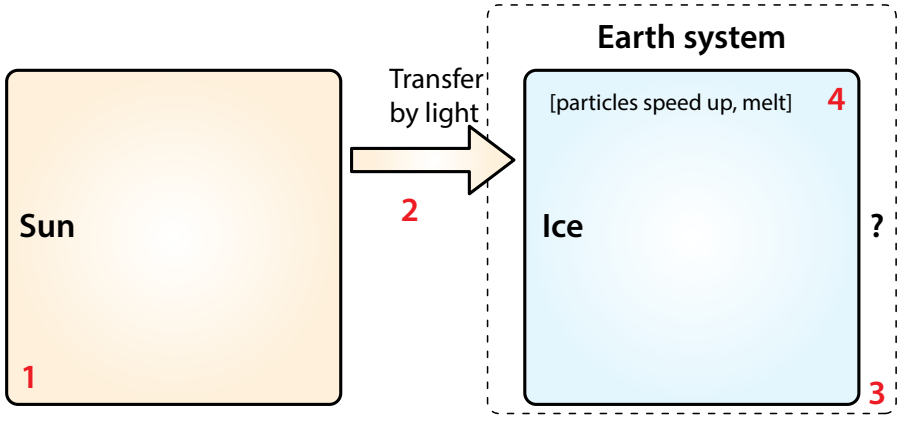


What we do and figure out

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.

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LESSON 3

How does carbon dioxide contribute to climate change?

Investigation **3 days**

Phenomenon or design problem

In the closed water bottle system, bottles containing more CO_2 see a greater increase in temperature under a heat lamp.

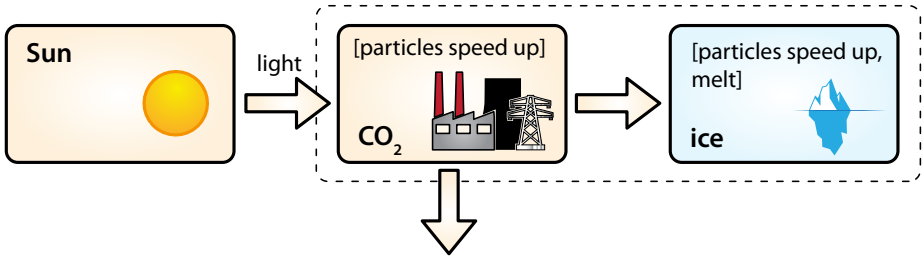


What we do and figure out

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.

How we represent it



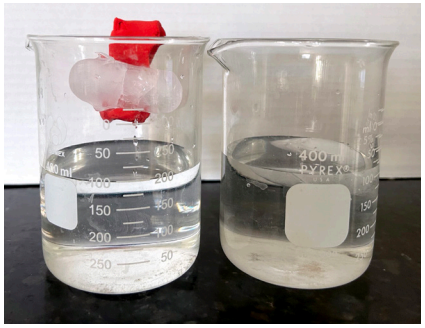
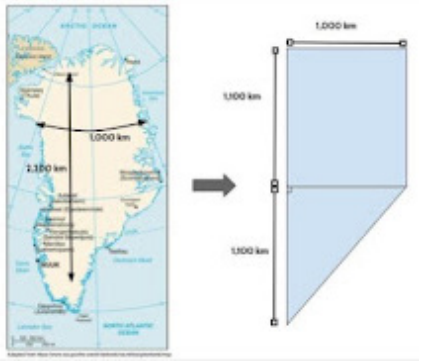
Navigation to Next Lesson: We figure out that carbon dioxide has a substantial impact on atmospheric temperatures and sea level rise, both in terms of the amount of warming and how long Earth will continue to warm up. We wonder how we can address the reality of rising sea levels in the short term.

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LESSON 4

What would happen if Earth's ice melted?

Investigation, Putting Pieces Together **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
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.

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

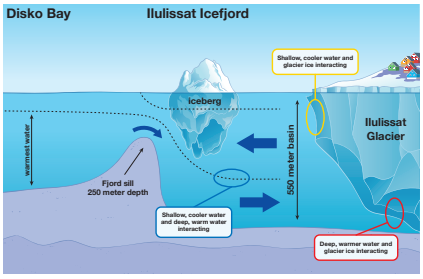
LESSON 5

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

Problematizing 2 days

Phenomenon 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.

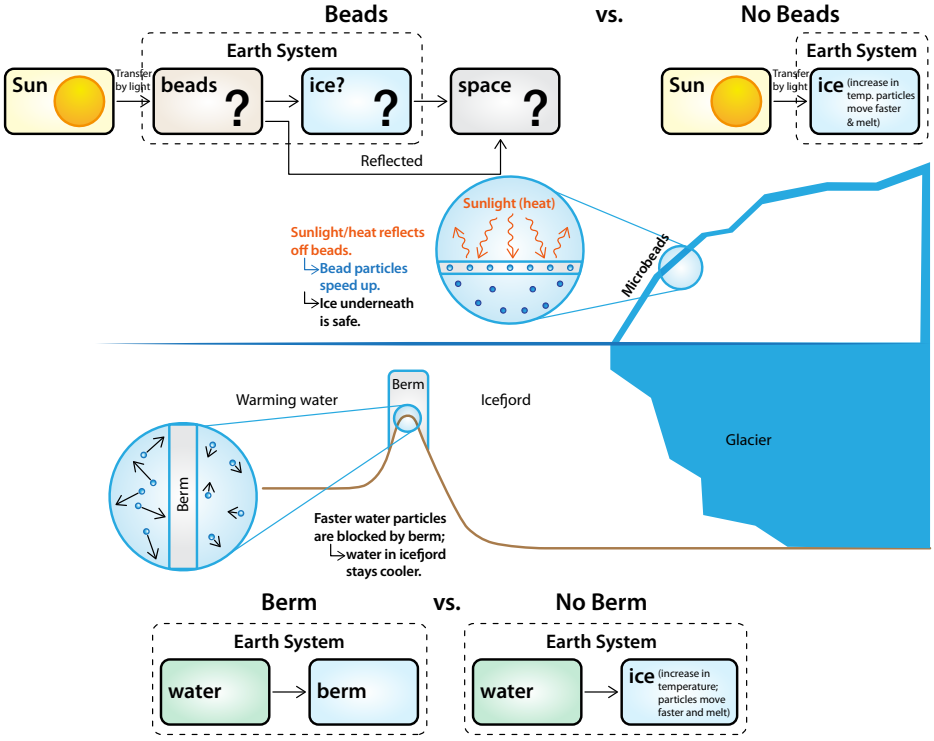


What we do and figure out

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.

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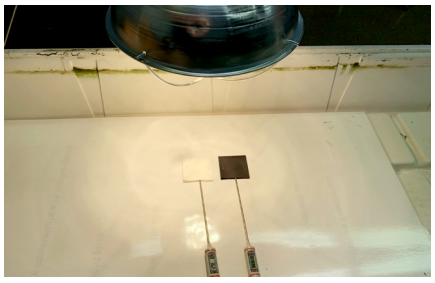
LESSON 6

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

Investigation **2 days**

Phenomenon or design problem

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

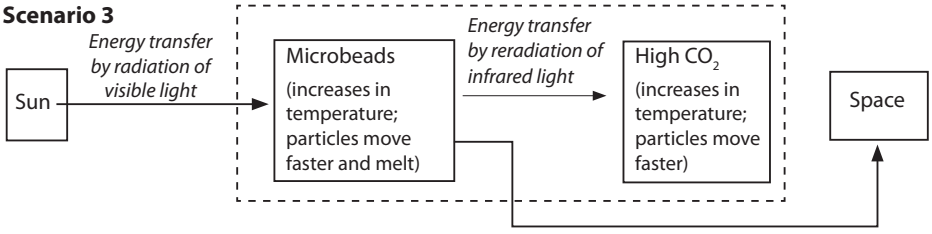


What we do and figure out

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.

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LESSON 7

How do feedback loops affect Earth's systems?

Putting Pieces Together 1 day

Phenomenon or design problem

Many changes in Earth systems, like increased warming due to melting ice and permafrost releasing CO_2 that speeds warming, are due to feedback loops.



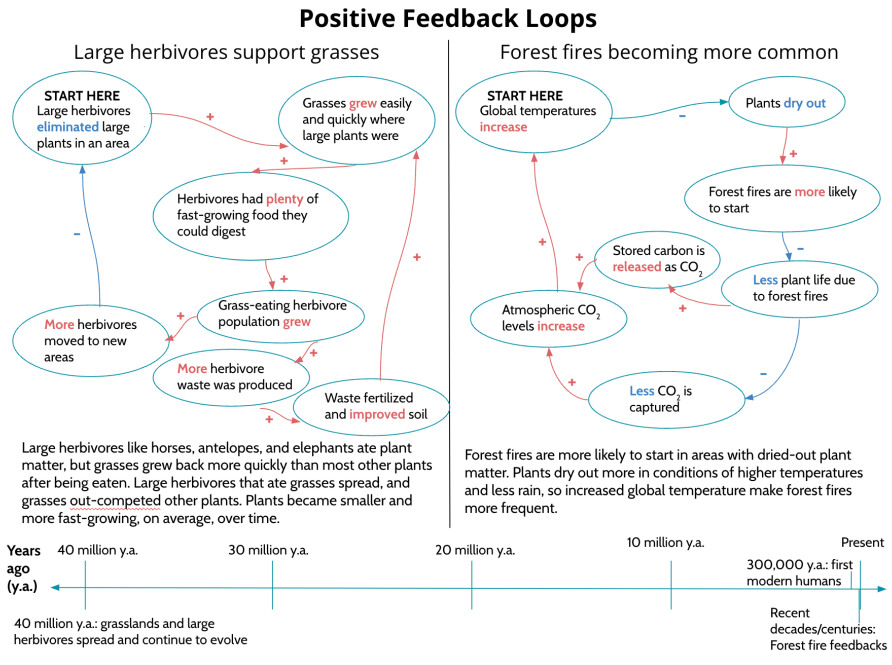
USGS, B. Jones

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.

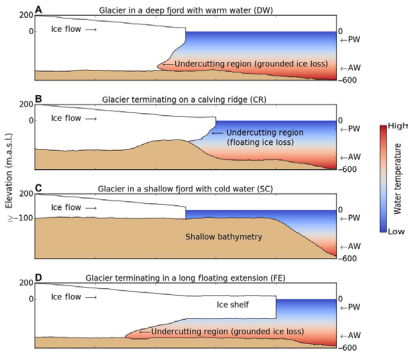
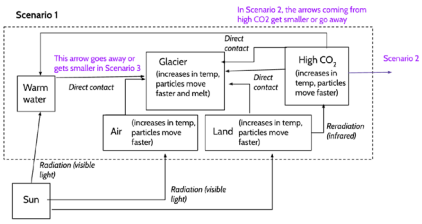
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Lesson Set 3: How well would the berm solution work in the context of Earth systems?

LESSON 8

What is going on where the ice meets the water?

Investigation, Problematizing **1 day**

Phenomenon or design problem	What we do and figure out	How we represent it
Data from Inuit hunters and fishers and NASA scientists suggest that warming oceans contribute to glacial melt  Wood, M. et al. (2021)	We pose questions about the interface where glacial ice meets ocean water, and we 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.

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LESSON 9

Why does warm salty water sink to melt a glacier?

Investigation **3 days**

Phenomenon or design problem

Samples of water of different temperatures and amounts of salt form layers when they first come into contact with one another.

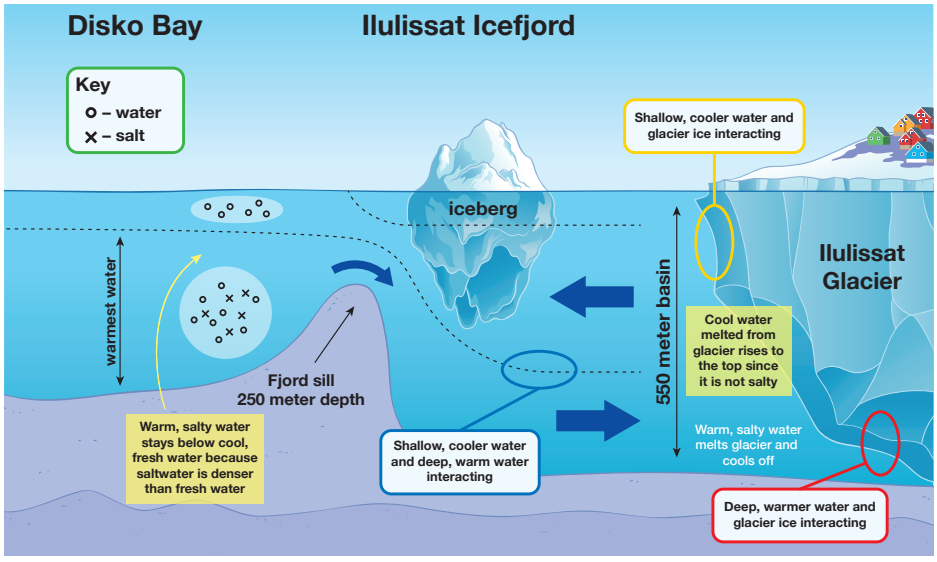


What we do and figure out

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, the fluids 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.

How we represent it



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.

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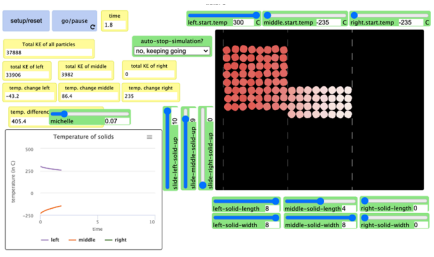
LESSON 10

How can we measure the energy transfer a berm prevents?

Investigation **3 days**

Phenomenon or design problem

Two computer simulations help model how energy transfers from a warmer object to a cooler one.



What we do and figure out

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 or 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 initial temperature 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 degree Celsius.
- Heat transfer Q into or out of a substance can be found by multiplying the specific heat, mass, and temperature change.

How we represent it

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

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

Substance or Mixture	Specific heat, c calories / (g · °C)
Dry air	0.24
Limestone	0.22
Sand	0.20
Copper	0.09
Water	1.00

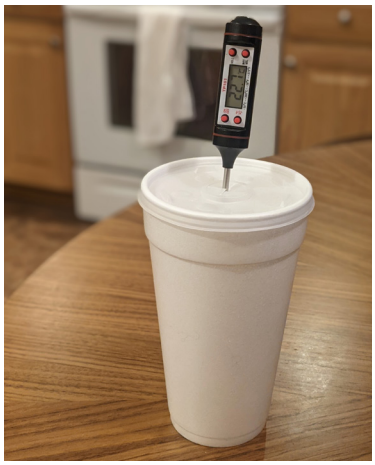
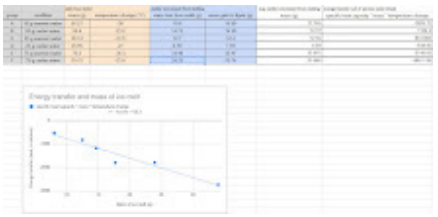
Navigation to Next Lesson: We have an equation to calculate the heat transfer to a glacier from warm water, but we may not have the information we need to apply this equation in the context of Ilulissat Glacier.

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LESSON 11

How does heat affect the amount of ice melt?

Investigation **1 day**

Phenomenon or design problem	What we do and figure out	How we represent it
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. • Eighty 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.	

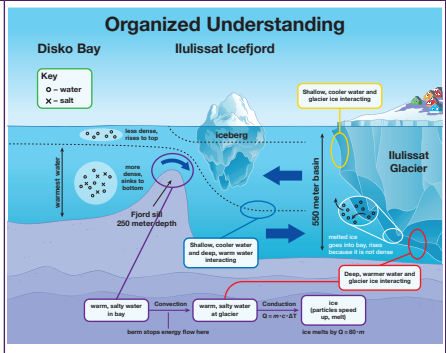
Navigation to Next Lesson: We have the information we need to figure out how much energy transfer a berm prevents as we consider this proposed solution.

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LESSON 12

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

Putting Pieces Together, Problematizing **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
We can predict how a berm might affect the ice melt at Ilulissat Glacier.  OpenStreetMap, CC BY-SA 2.0	We develop a model that can help us further evaluate the berm solution. We develop this mathematical model and 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).	

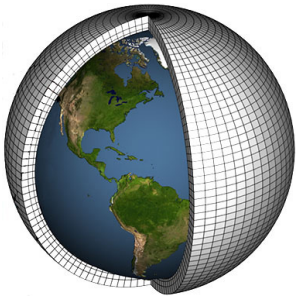
Navigation to Next Lesson: We figured out what impact the berm has, but we want an extended computational model that can help us consider the many impacts that humans have had or could have on the environment.

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LESSON 13

How can we model what will happen to Earth's climate if humans make changes?

Putting Pieces Together **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
We can build models that help us predict how different human actions will affect climate.  NOAA Geophysical Fluid Dynamics Laboratory	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 and 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**

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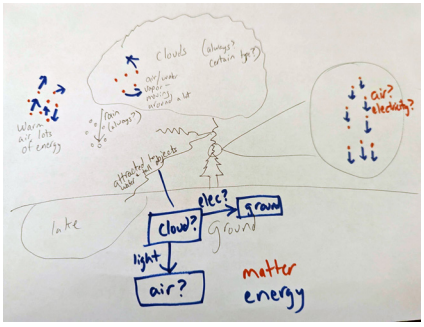
Unit Storyline

Lesson Set 1: What is lightning?

LESSON 1

When and where does lightning occur and what are its impacts?

Anchoring Phenomenon **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Slow-motion videos of lightning strikes show patterns we cannot see in real time. Lightning strikes more often and causes more harm in some places than others.  Mike Lewinski, Unsplash	We watch videos, engage with stories, and analyze patterns in data to try to determine how lightning forms and why some places are safer than others. We figure out: • People have looked at lightning in many different ways, but agree that it is dangerous, powerful, and accompanies rainstorms. • Lightning does not strike evenly across the earth. Lightning strikes more frequently in warmer and wetter locations and in the summer months. • Lightning can cause significant injury and death, but not always in the places with the most lightning. • We have many questions and ideas to investigate around what causes lightning and why some places seem safer than others during lightning storms.	

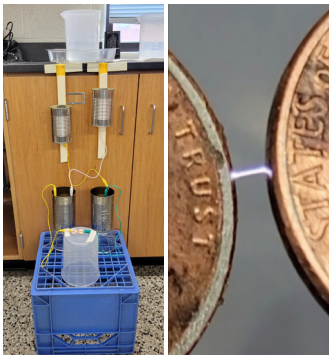
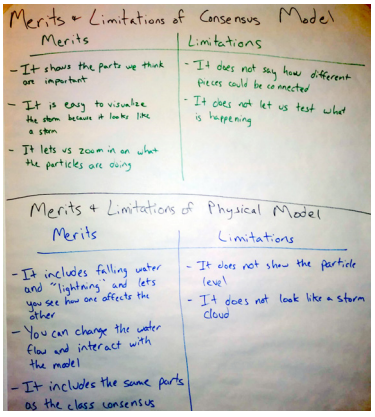
Navigation to Next Lesson: We have so many connected questions about lightning and the damage it causes that we could start investigating anywhere and make progress on our questions. We will take stock of areas of agreement to help determine next steps.

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LESSON 2

What parts of the (smaller-scale) system might be causing the (smaller-scale) lightning?

Investigation **1 day**

Phenomenon or design problem	What we do and figure out	How we represent it
A system with water drops falling creates lightning-like sparks without a power source. 	We analyze graphical data and examine a physical model to consider whether there is a causal relationship between falling water and lightning formation. We figure out: • Rain from clouds is correlated with lightning from clouds. • Water drops falling can create a lightning-like spark in the lab.	

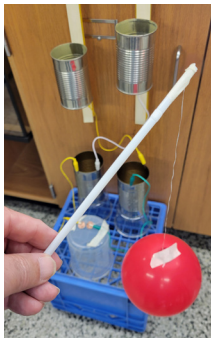
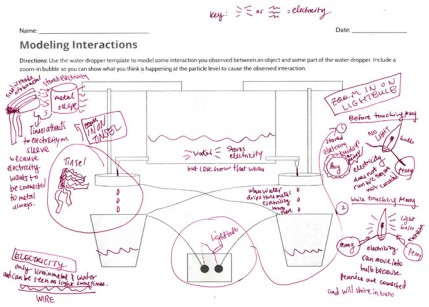
Navigation to Next Lesson: We figure out that water likely plays a role in the formation of lightning, or at least it does in the water dropper system. We decide to investigate this physical model further by seeing how different objects interact with it.

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LESSON 3

What is the spark in the water dropper system and what else is happening in the system before it appears?

Investigation **1 day**

Phenomenon or design problem	What we do and figure out	How we represent it
In the water dropper system, a neon light bulb glows briefly when touched to metal surfaces, a balloon sticks to these surfaces until the system produces a spark, and strings of tinsel and floss are pulled or pushed different amounts depending on where they are held in space and how long it has been since the last spark.  	We carry out two rounds of investigations by adding different test objects to the water dropper system. We record what we notice and wonder and develop a model to illustrate the patterns in forces acting on the test objects. We discuss the patterns in forces and energy transfer that we noticed. We identify related phenomena (static) that we think would produce similar interactions. We figure out: • The water dropper system acts on different objects/materials by either pushing them away (repulsive) or pulling them toward (attractive) the system. • The water dropper system allows us to make observations at a smaller scale that help explain the lightning phenomenon, which occurs at a different, larger scale. • Changes in the strength of these forces seem related both to where the objects are in space as well as to when energy is transferred out of the water dropper system (as light and sound in the form of a spark).	

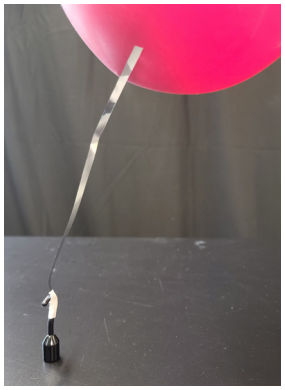
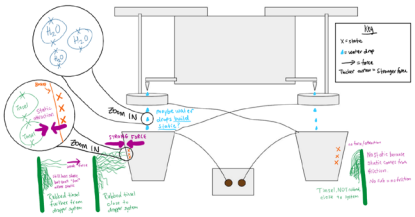
Navigation to Next Lesson: We think static electricity would also generate some of the same kinds of interactions between objects that we detected in the water dropper system. We want to test whether static electricity produces the same types of interactions.

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LESSON 4

What happens when we produce static electricity?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
We try various methods to produce static electricity with different objects or materials, then make observations of the resulting forces between objects. 	We use several objects to investigate attractions and repulsions in different materials when we rub them together. We figure out: • Attractive and repulsive forces seem to be stronger at closer distances and weaker at greater distances. • Some type of contact or friction seems needed for objects to become attractive or repulsive to other objects at a distance. • Electrostatic forces are likely responsible for the phenomena we have been observing. • Objects with charges generate electric fields. Fields generated by matter result in forces.	

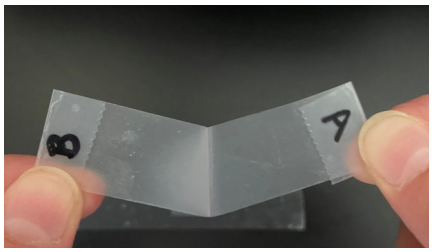
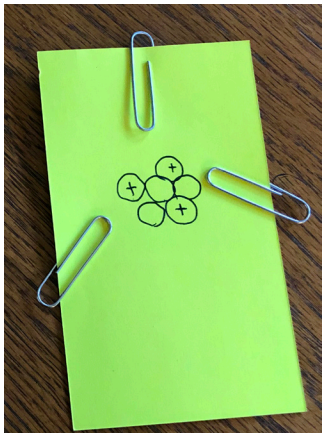
Navigation to Next Lesson: We are not sure how friction causes matter to become charged. We also want to find out if something similar happens before or during lightning strikes.

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LESSON 5

What is happening at a particle level to produce static effects?

Investigation, Putting Pieces Together **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
People have reported hair standing on end, crackling noises, and sparks right before a lightning strike happens. 	We investigate more static interactions. We use a reading and a simulation to develop models of atomic structure to help explain the interactions we observed. We figure out: • All atoms are made of different combinations of the same three subatomic particles: positively charged protons, uncharged neutrons, and negatively charged electrons. The relative number of protons and electrons determines the atom's overall (net) charge. • Subatomic particles are organized in the atom with protons and neutrons in the nucleus and electrons surrounding the nucleus. The type of atom is based on the number of protons in it. • As objects in contact produce static, a small amount of matter in the form of electrons is removed from one object and accumulated on another. This movement changes the net charge on each object.	

Navigation to Next Lesson: We developed a model to explain how moving electrons create static interactions, but now we are wondering what is causing electrons to move before a lightning strike.

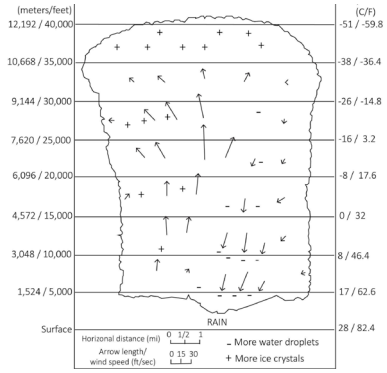
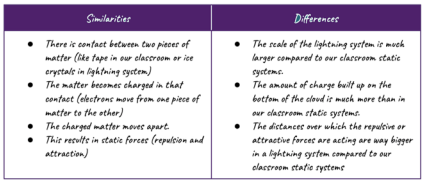
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Lesson Set 2: What causes a lightning strike?

LESSON 6

What causes static in a lightning system?

Investigation **1 day**

Phenomenon or design problem	What we do and figure out	How we represent it
Collisions between ice crystals and water molecules occur within a cloud.  Data Source: U.S. Weather Bureau	We use information from a reading to compare the lightning system to our in-class static systems. We figure out: • Collisions between ice crystals and water molecules inside clouds cause the top of the cloud to be positively charged and the bottom of the cloud to be negatively charged. • Thunderclouds grow very tall due to warm, moist air rising very high in the atmosphere. • There is a massive buildup of electrons, far greater than people experience in everyday static interactions, that eventually causes those electrons to flow from the cloud to the ground. • Electricity is the movement of charges (i.e., electrons).	 **Similarities** • There is contact between two pieces of matter (like tape in our classroom or ice crystals in lightning system) • The matter becomes charged in that contact (electrons move from one piece of matter to the other) • The charged matter moves apart. • This results in static forces (repulsion and attraction) **Differences** • The scale of the lightning system is much larger compared to our classroom static systems. • The amount of charge built up on the bottom of the cloud is much more than in our classroom static systems. • The distances over which the repulsive or attractive forces are acting are way bigger in a lightning system compared to our classroom static systems

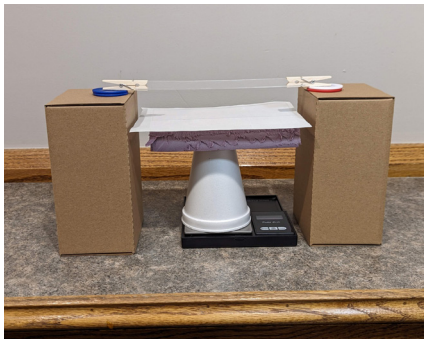
Navigation to Next Lesson: By comparing the static interactions in the lightning system to those in our classroom investigations, we identify that the scale of forces within both systems might explain the differences we see in the distances over which these static forces occur. We decide to dig deeper into the relationship between force, distance, and the amount of charge next.

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LESSON 7

How are electrostatic forces between objects affected by the amount of charge and the distance between them?

Investigation 3 days

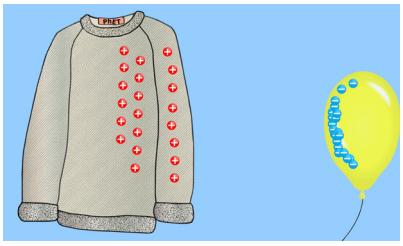
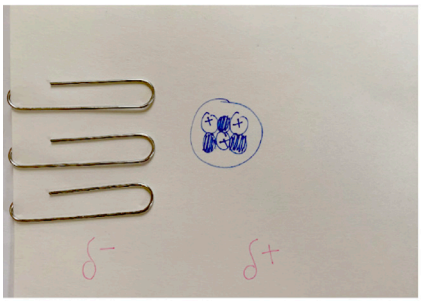
Phenomenon or design problem	What we do and figure out	How we represent it
When two charged surfaces are moved apart, they produce less force between them as measured by a digital scale, but when more charges are added to the system, they produce more force. 	We carry out an investigation to determine how electrostatic forces between objects are affected by the amount of charge and the distance between them. We compare graphs of our results and identify patterns in how different variables affect these forces. We evaluate a mathematical model for how these variables are related and use algebraic methods to predict the effects of larger-scale changes in the amount of charge and distance between charges in a system. We figure out that: • When like or unlike charges are moved farther apart, they produce significantly less force. • The strength of the electrostatic forces on any two amounts of charge, separated by a distance, can be predicted using Coulomb's law.	Coulomb's law: $F = k \cdot \left(\frac{q_1 \cdot q_2}{r^2} \right)$

Navigation to Next Lesson: While we can quantitatively predict the strength of forces between any two amounts of charge separated by any distance, we are not sure what is causing objects near the ground to experience electrostatic force interactions if the ground is neutral long before a lightning strike.

LESSON 8

How can something that is neutral have an attractive or repulsive interaction with another object without any contact?

Investigation 1 day

Phenomenon or design problem	What we do and figure out	How we represent it
The attraction between neutral objects and charged objects is due to the induced polarization of atoms in neutral objects.  PhET interactive Simulations, University of Colorado Boulder	We use a simulation and our paper-clip models to explain what we think is happening in atoms of neutral objects when they interact with charged objects. We figure out: • Atoms can be temporarily polarized, meaning a partial negative and partial positive charge can be induced through the movement of electrons to one "side" of the atom. • Electrons are not transferred to or from the atom when atoms are polarized. • Polarization can occur over distance; contact between objects is not required.	

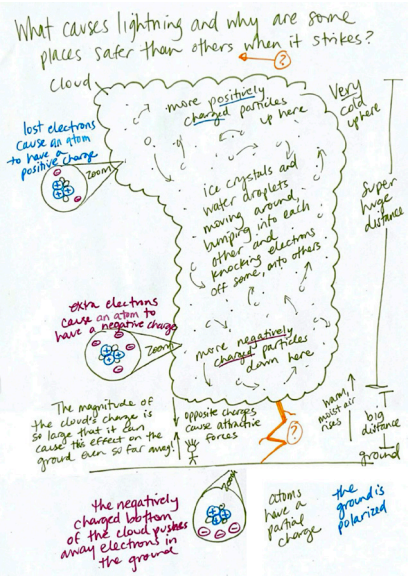
Navigation to Next Lesson: We have figured out a lot about how lightning works and what makes lighting move from the cloud to the ground. We should check our DQB and see which questions we have answered.

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LESSON 9

How can we revise our models to explain what we have figured out about the lightning system?

Putting Pieces Together, Problematizing **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
All previous phenomena. 	We create Gotta-Have-It Checklists and use them to develop updated models to answer the question, "What causes lightning to strike at a particular place and time?" We take stock of the Driving Question Board and then complete an assessment task to demonstrate our understanding of static interactions and Coulomb's law. We figure out: • Causes of lightning can be explained using the matter perspective (the change in charges in the cloud). • Causes of lightning can be explained using the forces perspective (the attractive forces between the bottom of the cloud and ground). • Our remaining DQB questions are directing us to pursue the investigation of lightning from an energy perspective.	

Navigation to Next Lesson: While we have made a lot of progress on figuring out connections between changes in the matter and changes in the forces in the lightning system, many of our remaining DQB questions are about the energy involved in lightning strikes.

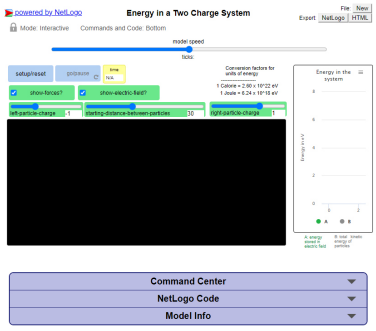
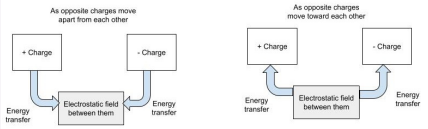
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Lesson Set 3: How and why does a lightning strike transfer so much energy?

LESSON 10

Where does the energy come from for lightning to strike across miles of air?

Problematizing, Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Lightning transfers a huge amount of energy, but it is unclear where this energy comes from.  Images generated by the Interactions Project (https://concord.org/our-work/research-projects/interactions/) at the Concord Consortium.	We analyze data that show that lightning transfers a LOT of energy. We use a computational model that shows energy storage between charges. We figure out: • Energy is stored in the electric field that exists between charged particles. • The electric field exists because of attractive and repulsive forces between charged particles. • Energy transfers to or from particles to or from the electric field as charged particles are moved toward or away from one another.	

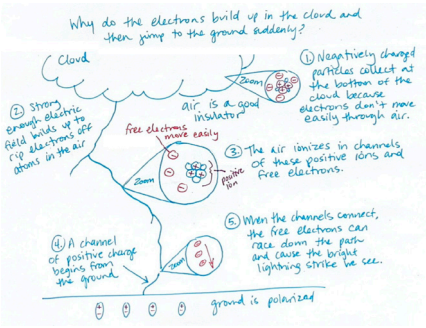
Navigation to Next Lesson: We know that negative charges are gathered on the bottom surface of the cloud before a lightning strike, but we do not understand why they build up there rather than being pulled toward the ground constantly.

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LESSON 11

Why do the electrons build up in the cloud and then jump to the ground suddenly?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Before a lightning strike, channels of ionized air form between the cloud and the ground. When a channel connects with the ground, those free electrons can speed down it.  Jakub Halun, CC BY-SA 4.0	We consider what we know about air to figure out that there is no easy path for electrons to move through it. We conduct research online and evaluate our sources to explain how charges move through air to cause the lightning we can see. We figure out: • Air is a good insulator because it does not let electrons move through it easily. • The electric field created by a storm cloud can rip electrons off nearby air molecules, creating ions. • Channels of ionized air branch out in segments from the cloud toward the ground. • When one of those channels connects with a channel of positive charge from the ground, electrons move easily and rapidly through the path, causing the intense lightning strike we see. • Light flashes, thunder, and nitrate formation all result from energy transfers out of strong electric fields.	

Navigation to Next Lesson: We figured out that air is a good insulator, but when it becomes ionized, the free electrons move through it very easily. We still have questions about why some places or materials are safer from lightning than others.

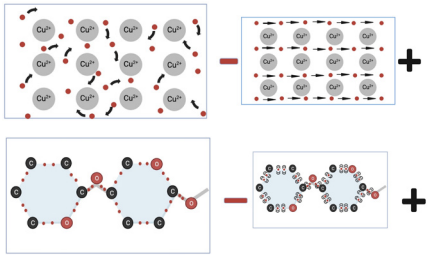
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Lesson Set 4: What makes some places safer than others when lightning strikes?

LESSON 12

Why are some structures safer than others (and safer than being outside)?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Certain structures or materials are safer than others when there is lightning.  NOAA	We look at data about lightning safety, read about how lightning rods work, and examine models of metals and nonmetals. We compare two models of lightning rods and identify the merits and limitations of each. We figure out: • Metals have "free" electrons that allow them to conduct electricity relatively easily. We call these materials conductors. • Materials that are insulators do not have free electrons that can transfer energy through them. • These differences in the structures of matter help to explain differences in electrical conductivity and why some materials are safer than others during lightning.	

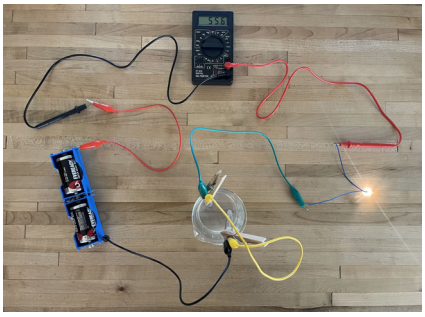
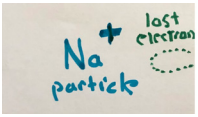
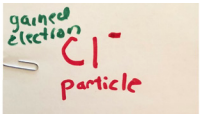
Navigation to Next Lesson: We figured out why metal is a good conductor of electricity, but we still don't know why being near water is dangerous. We are wondering, why does water conduct electricity?

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LESSON 13

Why are you supposed to get away from water when there is lightning nearby?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
An autopsy of 50 Canada geese revealed small lesions in their hearts which indicated electrocution as the cause of death. A light bulb glows and an ammeter reports a current when saltwater bridges a gap in a circuit, but not when that water is pure (distilled). 	We determine that pure water does not conduct electricity. We argue that the salt found in different water sources conducts electricity. We plan an investigation to determine whether this is true. We evaluate different models to determine which one best explains the results of our investigations. We explain how a lightning strike on water would cause the death of a group of geese floating on it. We figure out: • Solid table salt (sodium chloride) is an ionic compound, which means it is made of positive and negative ions that form by gaining or losing an electron. • Water molecules have permanent partially positive and partially negative sides (polarity). • When water molecules make contact with solid salt they pull individual ions off, causing the salt to break apart (dissolve) and the ions to spread throughout the solution. • Ions in solution can conduct electricity. • Water in living things contains dissolved salts and other electrolytes.	 

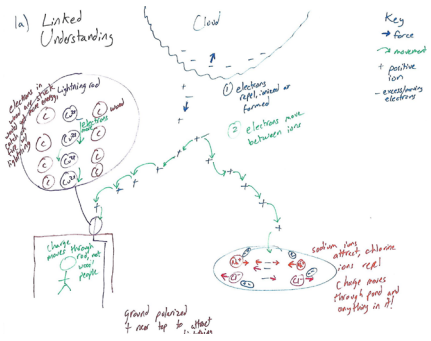
Navigation to Next Lesson: We are ready to try to answer all of our questions on the Driving Question Board and we have some ideas for how to lean on the Community Agreements we have developed so that we get the most out of the final learning and assessment experiences of the unit.

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LESSON 14

Why are some places safer than others when lightning strikes?

Putting Pieces Together **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
An airplane is struck by lightning and not damaged in any way.  Pxfuel	We create a consensus Gotta-Have-It Checklist and use it to build models to explain lightning safety. We take stock of our DQB questions and complete an assessment task. We figure out: • The model components/relationships/ mechanisms for why we should stay away from water when lightning strikes. • The model components/relationships/ mechanisms for why going inside buildings with lightning rods or indoor plumbing is safer when lightning strikes. • We have answered many of our questions on the DQB! • We can use our understanding to explain related phenomena about airplanes and conducting gels used to mimic brain tissue.	

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

Lessons 1–14 **29 Days Total**

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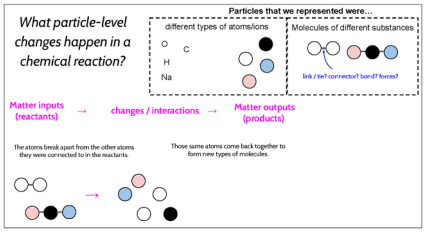
Unit Storyline

Lesson Set 1: How can we find water and other substances we need to survive on other objects in space?

LESSON 1

What substances would we need and how would we get them to live and work beyond Earth?

Anchoring Phenomenon **4 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Hundreds of crews have lived and worked in space for limited amounts of time. Future space travel would require us to remain there for longer amounts of time. 	We examine a video of NASA's plans in the near future. We identify criteria, constraints, and solutions for living and working beyond Earth for longer periods of time. We develop models of how new substances are made through chemical reactions. We add questions to a Driving Question Board and brainstorm ideas for data and investigations that could help answer them. We figure out: • People need certain substances to live and support the kinds of work they might want to do in places beyond Earth. • The scale of the solar system and the cost and speed of space travel mean that most of the substances that we need to live and work would have to be found, recycled, or made on-site. • New substances (products) can be created from one or more reactants through the rearrangement of matter in chemical reactions.	

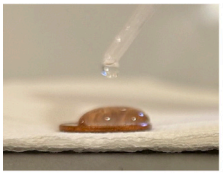
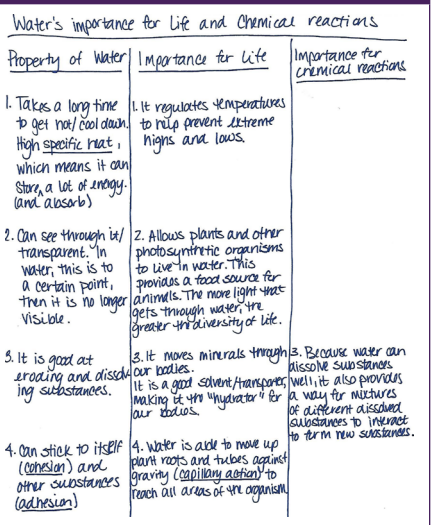
Navigation to Next Lesson: Though we have lots of ideas for investigations and data that we will need to answer our questions, we prioritized figuring out more about our water-related questions first.

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LESSON 2

How does water support life and chemical reactions?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Substances have different properties such as specific heat, ability to dissolve other substances, and transparency to light.   	We discuss other chemical reactions that include water, what is special about water, and properties of water we previously studied. We gather information on water's properties from two out of six investigation stations. We plan how to share this information. We integrate our information from across the six investigation stations. We figure out: • Water supports life and is used in chemical reactions because of its properties. • Some of those properties include surface tension, high specific heat capacity, transparency, and ability to dissolve most substances.	 Water's importance for life and chemical reactions Property of Water / Importance for Life / Importance for chemical reactions 1. Takes a long time to get hot/cool down. High specific heat, which means it can store a lot of energy. (and absorb) 1. It regulates temperatures to help prevent extreme highs and lows. 2. Can see through it/ transparent. In water, this is to a certain point, then it is no longer visible. 2. Allows plants and other photosynthetic organisms to live in water. This provides a food source for animals. The more light that gets through water, the greater the diversity of life. 3. It is good at eroding and dissolving substances. 3. It moves minerals through our bodies. It is a good solvent/transporter, making it the "hydrator" for our bodies. 3. Because water can dissolve substances well, it also provides a way for mixtures of different dissolved substances to interact to form new substances. 4. Can stick to itself (cohesion) and other substances (adhesion) 4. Water is able to move up plant roots and tubes against gravity (capillary action) to reach all areas of the organism.

Navigation to Next Lesson: We identify pictures as a source of evidence we could use to figure out whether there is water on other places beyond Earth.

LESSON 3

How can we find evidence of the water we need on the surfaces of other objects in space?

Investigation **1 day**

Phenomenon or design problem	What we do and figure out	How we represent it
Photos of the surfaces of Earth, the Moon, and Mars have been taken from satellites or uncrewed mission vehicles above them. 	We develop the "Surface Features and Causes" poster we use as evidence to support claims about which geologic processes caused the formation of surface features on Earth, the Moon, and Mars. We figure out: • Some surface features on Earth were produced primarily by water erosion, while others were produced primarily by tectonic processes or meteor impacts. • Mars's surface has some features that look similar to those produced by water erosion on Earth, while the Moon's does not.	Surface Features and Causes Water interacting with the surface: River beds - erosion; Sedimentary deposits - deposition by a river or glacier; Cracks - drought (lack of water); Avalanches - too much water (fast melting or a lot of rain); Canyons - erosion; Sea/ocean cliffs - erosion; Beaches - erosion Some other process interacting with the surface: Volcanoes - movement of magma (plate movement); Cracks - earthquakes (plate movement); Craters - asteroid or meteorite impact; Avalanches, rocks falling - gravity or wind; Trenches - earthquakes (plate movement); Mountains - plate movement

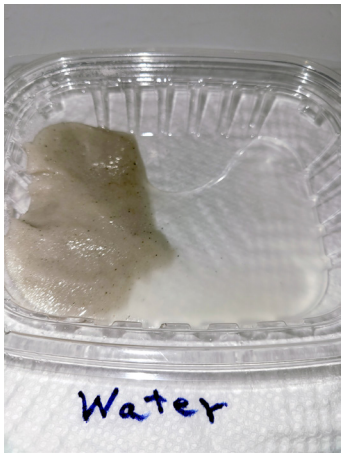
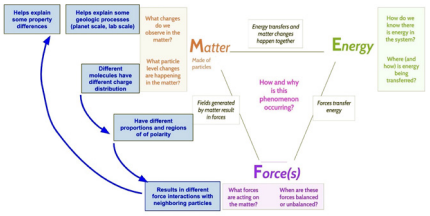
Navigation to Next Lesson: We conduct investigations into what other liquids, if any, interacting with materials could have produced the surface features we see on the Moon and Mars.

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LESSON 4

How and why do water and other liquids interact with materials to make surface features?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Different liquids behave differently on the erosion table. Water erodes surface materials and expands when it freezes because of its polarity.  	We investigate how liquids interact with surface materials to help us determine that surface features on Mars were likely made by water. We examine molecular models of them to compare polarities of different liquids. We figure out: • Polar regions on molecules are due to a greater amount of negative or positive charge in that region of the molecule. • Polar regions on molecules will produce force interactions with nearby polar regions on neighboring molecules, which can be used to explain some property differences between substances. • Polar molecules could more easily erode some materials in their surroundings than nonpolar molecules.	

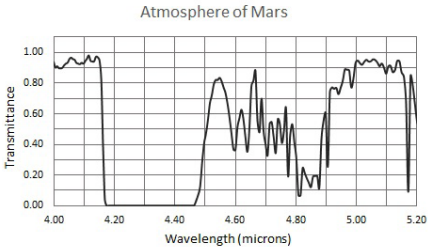
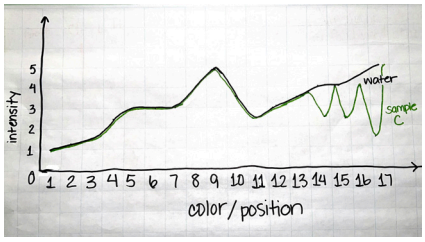
Navigation to Next Lesson: We wonder where we can look for or find water other than on the planetary surface.

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LESSON 5

How can we tell what is in the atmosphere (and just below the surface) of objects in space?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Substances in an object's atmosphere, surface, or subsurface can be identified based on the light they absorb and transmit (spectroscopy). 	We use a projector-based spectrometer to investigate the absorption and transmission of light by solutions of pure substances and construct a way to graphically display this phenomenon. We use reference spectra to identify gases in simple mixtures and in the atmospheres of objects in space. We figure out: • Different substances absorb and transmit different colors of visible light and different wavelengths of non-visible light (e.g., infrared). • Spectroscopy is the study of the light that is transmitted or emitted by different objects and is used to determine the presence of different gases. • Scientists can perform spectra analysis on the interactions of solids with sunlight to determine the presence of substances in the soil or ice.	

Navigation to Next Lesson: We figure out that water can be found in some atmospheres in the solar system, but we are still wondering about other elements we need for survival.

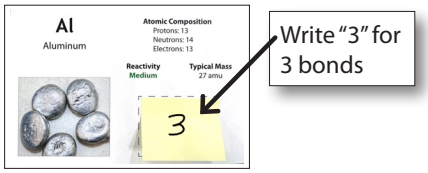
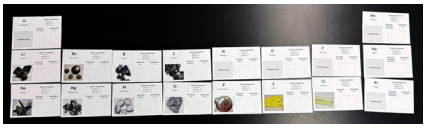
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Lesson Set 2: Why do we need certain types of atoms to create the substances we need?

LESSON 6

What patterns are there between the types of atoms and the number of bonds they form in the resources we need?

Investigation, Problematizing **2 days**

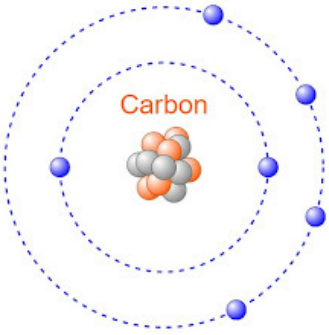
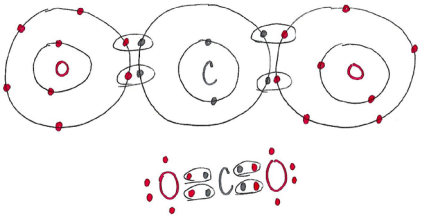
Phenomenon or design problem	What we do and figure out	How we represent it
Different elements have different numbers of subatomic particles and can be organized into patterns based on their atomic composition, numbers of bonds/charges formed, and chemical properties. 	We identify patterns in the numbers of subatomic particles (especially protons) and of bonds that different elements form and use these patterns to organize the elements. We figure out: • Elements have varying numbers of protons, electrons, and neutrons which correspond to changes in typical mass and atomic number. • Each element forms a specific number of bonds/ charges when it combines with other elements. • Elements are arranged on a table based on their repeating properties (numbers of bonds/charges formed, reactivity, composition, etc.). • Patterns in elements' bonds/charges repeat (periodicity), while atomic mass and number of protons increase across rows.	

Navigation to Next Lesson: We compare the number of electrons in carbon to the number of bonds it forms and notice that the numbers do not match. We wonder where the missing electrons went.

LESSON 7

Why is there a difference between the number of electrons an element has and the number of bonds an element forms?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
The electron shell model can account for differences in electron numbers in elements and connections formed by elements. 	We examine new models of atomic structure and evaluate the usefulness of different models to explain and make predictions about interactions between elements (bonds). We figure out: • Various models of atomic substructures can be used to try to account for differences in the numbers of electrons and connections formed by the element carbon. • A model of atomic structure illustrating valence electrons is best for determining the number of interactions (connections) each element will have with other elements.	

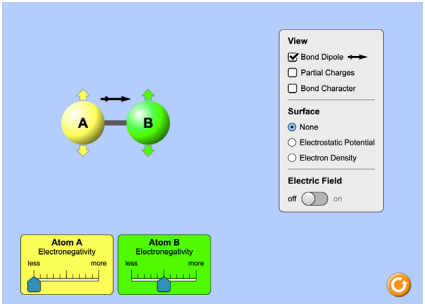
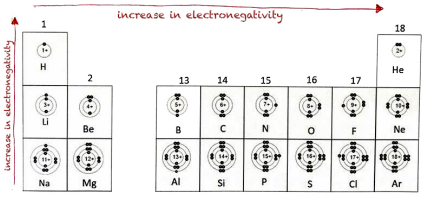
Navigation to Next Lesson: We wonder what is exactly happening between two elements when electrons bond to each other.

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LESSON 8

Could another substance serve as a substitute for water for some of the processes we need to use it for in space?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Many properties of water are different from the properties of hydrogen sulfide. 	We predict whether another substance could replace water for some processes and model the structures of H_2O and H_2S molecules. We explain why the electronegativities of O and S are different and use a simulation to explore how electronegativity differences affect where electrons are in a bond, the bond characteristic, and its polarity. We figure out: • Differences in the polarity of H_2O and H_2S molecules help explain some of their property differences. • Electronegativity is a measure of how strongly a nucleus is attracted to shared electrons. Greater electronegativity equals stronger attraction. • Atoms of elements with more electron shells are larger. The size of an atom is called the atomic radius. • Electronegativity is affected by an atom's atomic radius and amount of charge.	

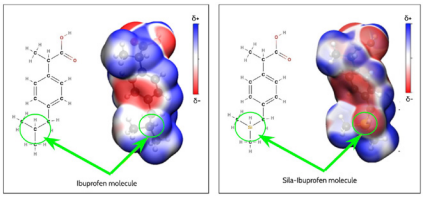
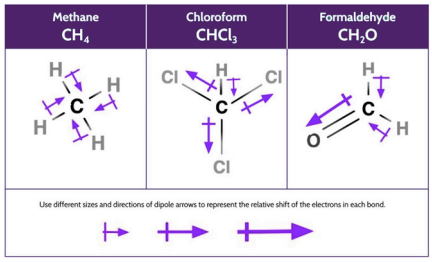
Navigation to Next Lesson: We brainstormed examples of substances with undesirable properties or side effects to begin to consider substitute substances that we can use in some of the processes needed for living and working in space and on Earth.

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LESSON 9

How can the ideas we developed be applied to making a possible substitute for another substance?

Putting Pieces Together **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Biochemists have developed a new medicine, sila-ibuprofen, by substituting a single silicon (Si) atom for a carbon (C) atom in the ibuprofen molecule. 	We describe bond characteristics in salt, wood, and metal and consider salt substitutes in our diets. We complete the Mid-Point Assessment. We figure out: • Some pairs of atoms can form double or triple bonds. • The polarity of a molecule can be determined by comparing the relative polarities of bonds within it, which can be determined from the difference in the electronegativities of the atoms that make up the bond. • Some biochemistry and environmental chemists work on designing new substances, like medicines, that have more desirable properties or fewer side effects than those we use now.	

Navigation to Next Lesson: We made progress on many of our DQB questions, but we have a lot of questions about the role of water in so many of these chemical reactions.

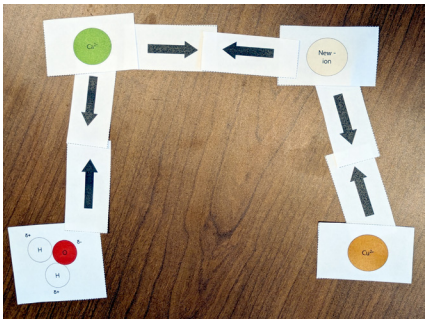
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Lesson Set 3: How can we make the substances we need to survive off of Earth using the existing matter in the solar system?

LESSON 10

Why do we need water in so many reactions?

Problematizing 1 day

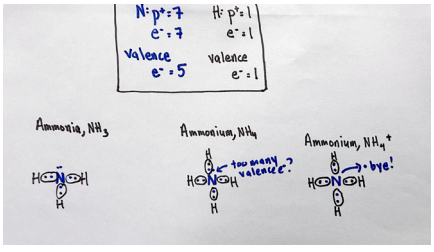
Phenomenon or design problem	What we do and figure out	How we represent it
Dissolved copper ions can be cleaned from water with certain types of reactions. 	We return to the different processes we encountered in Lesson 1, with more information about the reactions that are occurring. We read about how copper can be cleaned from water by forming a precipitate and model this reaction. We figure out: • Water is involved in many reactions and must be clean for them to work properly. • Ions come together so that the substance formed is neutral. • The intermolecular forces between water (a polar molecule) and certain ions allow for the observed cleaning reaction to occur. • Some substances cannot be easily dissolved because their bonds are too strong.	

Navigation to Next Lesson: We wonder what other substances we might need to remove from the water we find on Mars before we use it.

LESSON 11

How can we grow food in space?

Putting Pieces Together, Investigation 2 days

Phenomenon or design problem	What we do and figure out	How we represent it
Plants can be grown in space to give us many materials for survival, but we need to enrich the soil with fertilizer. 	We engage in a reading about growing plants in space and model the differences between ammonia (NH_3) and ammonium (NH_4^+). We read about perchlorate ions in Martian soil and model chemical reactions. We figure out: • To successfully grow plants off of Earth, nitrogen must be added to the soil. Two possible fertilizers, ammonia (NH_3) and ammonium (NH_4^+), could be added to the soil. • NH_3 and NH_4^+ have different structures and charges. Ammonium could be made successfully in space. • Polyatomic ions are substances that have many atoms but carry an overall net charge.	

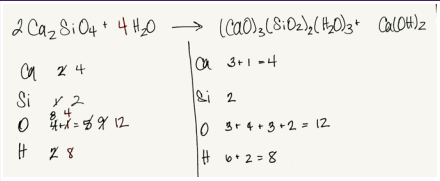
Navigation to Next Lesson: We look to outer space to find the other materials we need to survive beyond Earth.

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LESSON 12

Which location(s) in the solar system has the elements we need and what relative amount is required to make any substance?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Three Mars rovers have sampled the chemical composition of surface material at three different locations. Experimental studies of sulfur-based concrete have been carried out on Earth.	We break down the chemical equation for photosynthesis and figure out that we need to add more molecules of some reactants and products to ensure there are equal numbers of elements on both sides of the equation. We obtain information about cement production using substances on Mars. We figure out: • Since matter cannot be created or destroyed, balanced chemical equations must have equal numbers of each element in the reactants and products. This is done by adding coefficients to reactants and products in the chemical reaction. • Mars has more of the elements needed to make the substances to live and work in space than any other location in the solar system. • It is possible to develop processes to make the substances we need that utilize in situ resources if we know what elements are present on an object in space and their amounts.	

Process	Reactants				Products	
Photo-synthesis	Carbon dioxide CO_2		Water H_2O		Glucose $C_6H_{12}O_6$	Oxygen O_2
Making steel	Iron Fe	Carbon C	Manganese Mn		Steel* $Fe_{99}CMn$	
Making glass	Silica SiO_2	Sodium carbonate Na_2CO_3	Calcium carbonate $CaCO_3$		Glass* $(Na_2O)(CaO)(SiO_2)_6$	Carbon dioxide $CaCO_3$
Making hardened cement	Tricalcium silicate Ca_3SiO_5	Dicalcium silicate Ca_2SiO_4	Tricalcium aluminate $Ca_3Al_2O_6$	Water H_2O	Hardened cement* $(CaO)_{10}(Al_2O_3)(SiO_2)_{10}(H_2O)_{39}$	
Making plastic	Terephthalic acid $C_8H_6O_4$		Ethylene glycol $C_2H_6O_2$		Polyethylene terephthalate* $-[C_{10}H_8O_4]_n-$	Water H_2O

Navigation to Next Lesson: We wonder about recycling sulfur concrete and other materials on Mars and here on Earth.

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Lesson Set 4: How can we be more sustainable in what we use and produce?

LESSON 13

Why can we recycle some of the substances we need and not others?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Different people and communities are able to recycle some substances but not others. 	We synthesize information from various sources to answer questions about why we recycle some of the substances we need but not others, and how this could apply to our long-term plans for living and working beyond and/or on Earth. We figure out: • We can recycle some substances by melting, freezing, and reshaping • Polymers are molecules with chains of repeating subunits (monomers). • There are a variety of naturally and synthetically produced polymers that have different characteristic properties that make them well suited to specific uses. • The structure of the polymer affects its properties.	

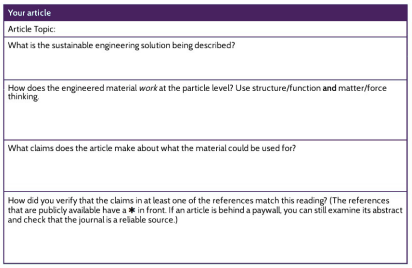
Navigation to Next Lesson: We identified some candidate substances that we hope to see scientists and engineers develop more sustainable substitutes for, and wonder what new research is happening along those lines.

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LESSON 14

What are some more sustainable approaches we are developing to help us make the things we need off of Earth and on it?

Investigation 1 day

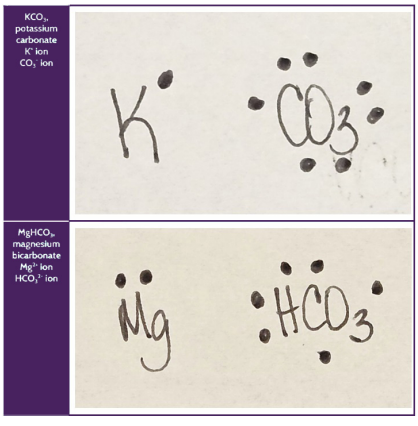
Phenomenon or design problem	What we do and figure out	How we represent it
Innovative materials technologies could be more sustainable, both off of and on Earth. 	We read articles about different innovative materials technologies. We share with a partner and evaluate the arguments made in the articles. Then we share our evaluations with a pair that investigated a different set of materials technologies. We figure out: • New technologies may allow for common materials (or replacement materials) to be more sustainable. • A given material must have the right microscopic structures and resulting forces in order to produce the desired bulk-scale interactions. • Technologies that could aid living off of Earth could make life on Earth more sustainable, but in general using less of a given material is best.	

Navigation to Next Lesson: We figure out that different materials technologies could support living off of Earth as well as sustainable living on Earth. We think that human survival beyond Earth could be possible one day, but are unsure whether it is a good idea.

LESSON 15

What is the full impact of going to space?

Putting Pieces Together 3 days

Phenomenon or design problem	What we do and figure out	How we represent it
Soap scum forms on surfaces due to interactions between dissolved ions. 	Students read about perspectives on space travel, balance a final equation, close out the DQB, and then demonstrate their understanding on a transfer task about the formation of soap scum. We figure out: • There are competing science and ethics arguments about human survival in space. • The elements available to us in outer space limit what we can build on another planet. Matter cannot be gained or lost in a chemical reaction. • Soap scum is formed as a result of interactions between polyatomic ions and other ions that are dissolved in water.	

Navigation to Next Lesson: This is the final lesson of the unit.

Lessons 1–15 **31 Days Total**

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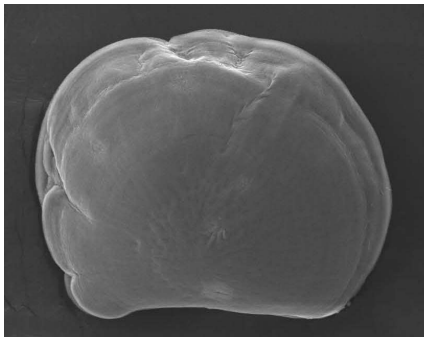
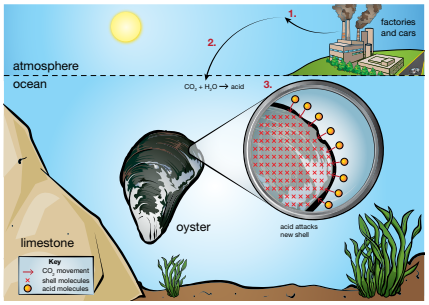
Unit Storyline

Lesson Set 1: What large- and small-scale processes make water more or less acidic?

LESSON 1

What is happening to oysters?

Anchoring Phenomenon 3 days

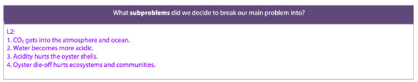
Phenomenon or design problem	What we do and figure out	How we represent it
Oysters are dying off in the United States. This is related to increased carbon dioxide levels in the atmosphere that causes ocean acidification. 	We explore cases, analyze data, and read about how carbon dioxide in the atmosphere is entering the ocean and making it more acidic, which hurts oysters and the ecosystem that relies on them. We develop an initial model and build a Driving Question Board. We figure out: • Increased carbon dioxide in the atmosphere interacts with the ocean in some way, making it more acidic. This is called ocean acidification and can prevent oysters from building shells. • Oysters are valuable to the ecosystem and people for their ability to filter and clean the water and build reefs that help hold coastal land in place.	

Navigation to Next Lesson: We brainstorm ideas for investigations on our Driving Question Board. We have a variety of potential paths that we will narrow down in Lesson 2.

LESSON 2

How can we break down the problem so we can solve it?

Anchoring Phenomenon, 1 day

Phenomenon or design problem	What we do and figure out	How we represent it
People often break down complex problems into subproblems to solve them.  USDA	We decide to break down the big problem. We look back at our classroom consensus model from Lesson 1 and realize that the big problem of oyster die-off is made up of a few key subproblems. We spend some time thinking about how action is required on multiple scales, and we develop some initial arguments about which subproblems and solutions we are best positioned to pursue in our chemistry class. We figure out: Solving the problem of oyster die-off in the United States will require breaking the problem into subproblems, and developing solutions that address both root cause and mitigating local impacts.	

Navigation to Next Lesson: We have multiple arguments on the table for which subproblems and categories of solutions to pursue. We want to decide on a shared direction for our work together during class time.

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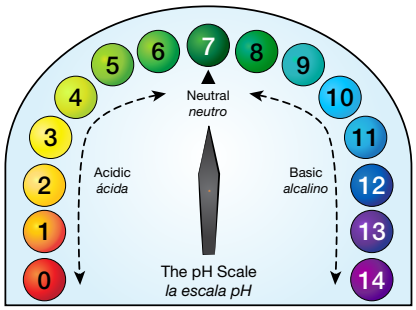
LESSON 3

Can carbon dioxide make the ocean more acidic?

Investigation **2 days**

Phenomenon or design problem

The presence of carbon dioxide in water decreases the pH value of the water.



What we do and figure out

We brainstorm a list of substances that contain both water and carbon dioxide. We plan an investigation with our group to test whether solutions of carbon dioxide and water are acidic. We read an article and explore a website about pH. We figure out:

- We can test the pH of a substance using pH indicator strips or indicator solutions.
- Water that is carbonated has a lower pH value than water that is not carbonated.
- Acidic substances have a pH below 7, basic substances have a pH above 7, and neutral substances have a pH of 7. This is determined by the ratios of H^+ and OH^- ions in the solution.
- A tenfold change in the H^+ ion concentration changes the pH value by 1 on the pH scale.

How we represent it

Number of H+ and OH- ions in 3mL of water at different pH levels
(3mL of water contains 10^{23} water molecules)

pH	Number of H^+ ions		Number of OH^- ions	
0	1,000,000,000,000,000,000,000	$= 10^{21}$	10,000,000	$= 10^{7}$
1	100,000,000,000,000,000,000	$= 10^{20}$	100,000,000	$= 10^{8}$
2	10,000,000,000,000,000,000	$= 10^{19}$	1,000,000,000	$= 10^{9}$
3	1,000,000,000,000,000,000	$= 10^{18}$	10,000,000,000	$= 10^{10}$
4	100,000,000,000,000,000	$= 10^{17}$	100,000,000,000	$= 10^{11}$
5	10,000,000,000,000,000	$= 10^{16}$	1,000,000,000,000	$= 10^{12}$
6	1,000,000,000,000,000	$= 10^{15}$	10,000,000,000,000	$= 10^{13}$
7	100,000,000,000,000	$= 10^{14}$	100,000,000,000,000	$= 10^{14}$
8	10,000,000,000,000	$= 10^{13}$	1,000,000,000,000,000	$= 10^{15}$
9	1,000,000,000,000	$= 10^{12}$	10,000,000,000,000,000	$= 10^{16}$
10	100,000,000,000	$= 10^{11}$	100,000,000,000,000,000	$= 10^{17}$
11	10,000,000,000	$= 10^{10}$	1,000,000,000,000,000,000	$= 10^{18}$
12	1,000,000,000	$= 10^{9}$	10,000,000,000,000,000,000	$= 10^{19}$
13	100,000,000	$= 10^{8}$	100,000,000,000,000,000,000	$= 10^{20}$
14	10,000,000	$= 10^{7}$	1,000,000,000,000,000,000,000	$= 10^{21}$

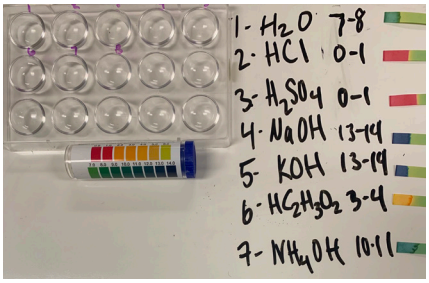
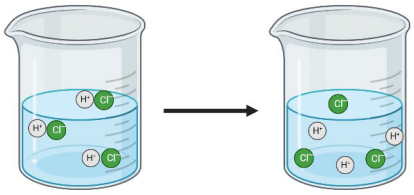
Navigation to Next Lesson: Having seen that some substances are acidic, some are basic, and some are neutral, we are now wondering what it is about a substance that determines whether it forms an acid or a base when added to water.

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LESSON 4

What is it about a substance that determines whether it produces more or fewer H^+ or OH^- ions when it is added to water?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Some acids or bases have different pHs, even when the molarities of the solutions are the same. 	We use molecular formulas to predict which substances are acids, bases, or neither. We use mathematical thinking to compare quantities of particles and concentrations in different solutions and conduct an investigation. We develop a model to explain our results. We figure out: • All acids contain hydrogen in their chemical formula and produce hydrogen ions (H^+) in aqueous solutions. • All bases contain hydroxide in their chemical formula and produce hydroxide ions (OH^-) in aqueous solutions. • The degree to which different acids or bases dissociate into ions in water varies. This, along with the initial concentration of the acid or base in the solution (molarity), affects the pH. • Force interactions (due to charges) between the molecules and atoms of water and the acid or base can help explain why some acids and bases dissociate more completely than others in water. • Although carbon dioxide is not an acid, it must react with water to form a product that contains hydrogen in it.	 Illustrations created by OpenSciEd in BioRender

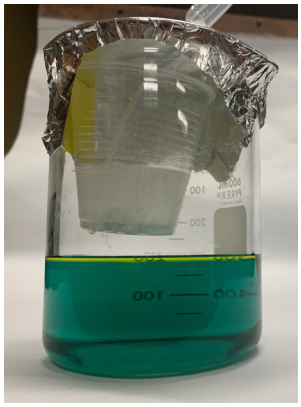
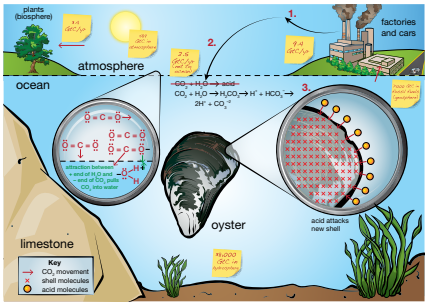
Navigation to Next Lesson: Because we are not sure whether each acid molecule formed from H_2O molecules chemically reacting with CO_2 dissociates into one or two H^+ ions, and because we do not know whether CO_2 gets into the water or interacts with water at the surface when this happens, we want to investigate these questions further next time.

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LESSON 5

How does carbon dioxide move between the atmosphere and ocean systems to cause the water to become more acidic?

Investigation, Problematizing **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
When carbon dioxide dissolves in a solution of water and bromothymol blue, a color change is observed. 	We investigate how CO_2 could naturally dissolve in water with an experimental setup in the lab and examine amounts of CO_2 in the atmosphere and hydrosphere. We figure out: • CO_2 slowly gets into water through a natural process that does not "force" CO_2 into the water. • Atmospheric CO_2 has recently begun to dissolve into the ocean increasingly more, due to the buildup of atmospheric CO_2 caused by human activity. • There are different amounts of carbon within the atmosphere, hydrosphere, biosphere, and geosphere. The carbon moves through these spheres at very different rates.	

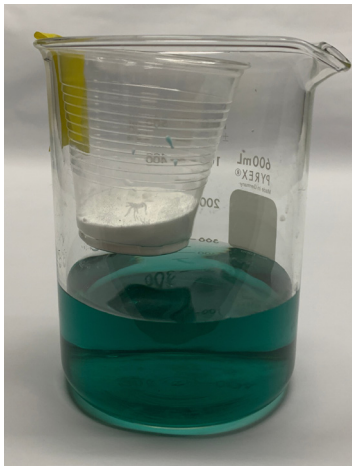
Navigation to Next Lesson: Because the acidic solution we made from adding CO_2 into a closed system shifted back toward its original pH when left out in an open system in our classroom overnight, we are now wondering what exactly is happening that would have caused that change.

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LESSON 6

How can acidic water become less acidic again?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
When a solution of water and bromothymol blue with dissolved carbon dioxide is left out overnight, the color of it changes back to the color of water and bromothymol blue. 	We use a simulation to investigate how acidic water could become less acidic again. We use the results to argue that a reversible reaction was taking place that reached an equilibrium state. We use data to determine a relationship between bond strength, stability, and reversibility of reactions. We figure out: • Carbon dioxide leaves the solution when this happens. • Reversible reactions occur when the products of a reaction react to form the original reactants. • The concentrations of different substances in a reversible reaction will eventually stabilize at an equilibrium level. • Some reactions are irreversible because their reactants have fairly weak bonds, so they break apart easily. • Strong acids and strong bases dissociate completely because the products are more stable than the reactants, while weak acids and weak bases only partly dissociate and undergo reversible reactions with water, resulting in less extreme pHs.	$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons$ $H^+ + HCO_3^- \rightleftharpoons 2H^+ + CO_3^{-2}$

Navigation to Next Lesson: Since we figured out that some reactions are reversible, like the one that is causing acidification of ocean water, we start considering how we might apply these ideas to help oysters.

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LESSON 7

How can we use what we have learned to help protect oysters?

Putting Pieces Together **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
The people who are impacted by oyster die-offs are being affected in different ways.  NOAA	We discuss why it is important to learn from people who are directly affected by the oyster die-offs. We read about different interested parties and brainstorm additional criteria and constraints for our engineering design solutions. We complete an assessment investigating how pH changes as ion concentration changes. We figure out: • Many groups of people are impacted by what happens to the oysters. • Interested parties have important knowledge that can help us plan effective engineering design solutions. • Criteria and constraints guide engineering design solutions. • Each interested party has specific needs that require targeted criteria and constraints. • Adding a product ion to a reversible reaction causes the reaction to move in the reverse direction.	**Criteria** - produce lots of oysters - move back to old pH as much as possible - preserve as many wild oysters as possible - minimize cost - fast-working **Constraints** - can't add anything toxic - can't reach pH unhealthy for other organisms - oysters must grow big enough to eat - affordable - shells have to be strong enough for larvae to survive

Navigation to Next Lesson: We saw that adding a certain type of ion to an acidic solution caused it to become more neutral, so we started to consider whether this phenomenon could be applied to helping oysters and the people who depend on them.

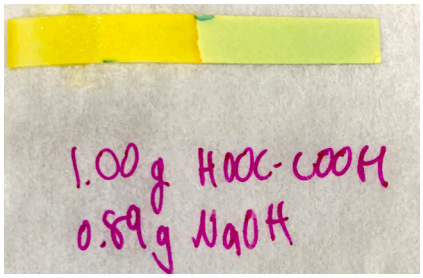
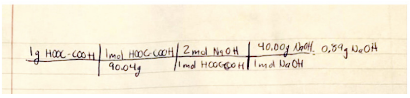
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Lesson Set 2: What mathematical models can help us determine the scale of the reactions needed to save oysters?

LESSON 8

How can we figure out how much of a substance we need to neutralize acid?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
When we add double the mass of base to a sample of acid, the solution is very basic, but when we determine the amount needed using a balanced chemical equation and molecular masses from the periodic table, the resulting pH is neutral. 	We model acid–base neutralization and argue that the ratios in balanced chemical equations are mass ratios. We test this model and figure out that these ratios are particle-number ratios rather than mass ratios. We apply a mathematical model using these ratios and molar masses to predict the amount of base needed to neutralize an acid and carry out a second neutralization investigation to test this. We figure out: • Balancing chemical equations with coefficients is a way to model conservation of mass and to determine mole ratios of products and reactants. • Molar mass can be calculated using the atomic masses on the periodic table. • Molar masses and mole ratios are both needed to convert between mass and moles of any two substances involved in a chemical reaction.	

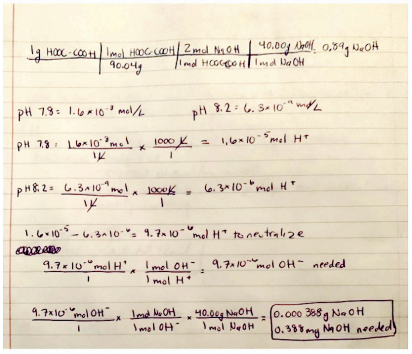
Navigation to Next Lesson: Now that we know how to calculate the amount of base needed to neutralize an acid, we have some ideas about how we can apply this to helping oysters by adjusting the pH of water where oysters live.

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LESSON 9

How much NaOH would we need to add to make ocean water safe for oysters?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
The pH of ocean water has changed over time and is projected to change in the future. The correct amount of base added to that water should be able bring the pH back to historical levels.  Louisiana Sea Grant College Program, Louisiana State University, CC BY 2.0	We use mathematical thinking to determine how many grams of a base would need to be added to return ocean pH levels to one that is safe for baby oysters. We wonder whether this solution would be feasible, effective, or safe for other organisms. We figure out: • The pH indicates a specific concentration of hydrogen ions, and we can use this concentration and volume to calculate moles of H^+ present. • If we know how many moles of H^+ we need to remove, we know how many moles of OH^- are needed to neutralize it, since they combine in a one-to-one ratio to form the same number of moles of water molecules. • 5.0×10^{11} kg of NaOH would be needed to shift the pH of the ocean from 8.2 back to its historical level.	

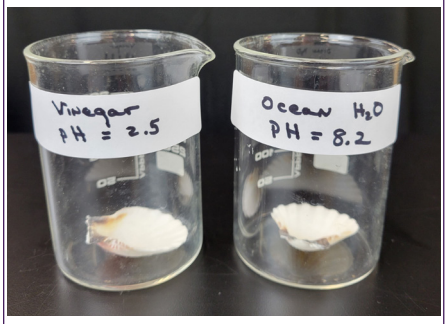
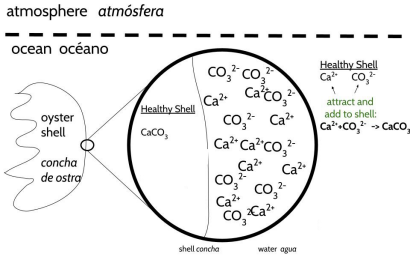
Navigation to Next Lesson: We are not convinced that dumping NaOH in the ocean will solve the problem and we think it could be harmful to other living things, but there are other subproblems we identified earlier and have not investigated yet that could give us ideas for other possible solutions for protecting oysters.

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LESSON 10

How does ocean acidification hurt oysters?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Calcium carbonate, which makes up oyster shells, does not dissolve in water with the same pH as the ocean and only slowly reacts with vinegar. 	We investigate how different pH levels affect oyster shells and read about the oyster's life cycle. We figure out: • Although decreasing pH of ocean water affects oyster shells somehow, it does not dissolve existing oyster shells. • Oysters build their shells by filtering out calcium and carbonate ions from the water. • As acidity increases, hydrogen ions bond with carbonate, preventing calcium from bonding with carbonate during shell formation. • Carbonate takes a long time to end up in the ocean because the erosion of limestone is a process that occurs on a geological timescale.	

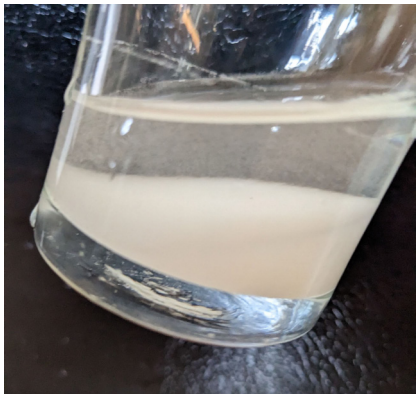
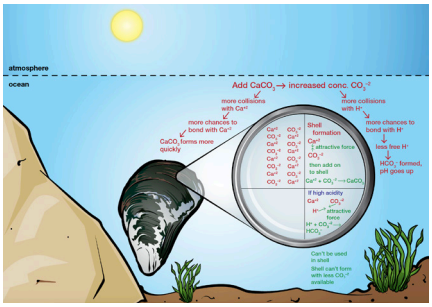
Navigation to Next Lesson: We think that increasing the amount of carbonate in the ocean might help oysters but realize that carbonate takes a long time to end up in the ocean. We decide to find ways to speed up the process.

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LESSON 11

How can we help oysters build shells quickly?

Investigation **3 day**

Phenomenon or design problem	What we do and figure out	How we represent it
Increasing temperature or concentration produces more calcium carbonate in a chemical reaction. 	We design an investigation to test how temperature and concentration might influence how much product a reaction makes in a given time. We build a particle model of reaction rate and use this model to identify the effects of adding calcium carbonate slightly reverses acidification. We figure out: • More product can be made in a short amount of time if the concentration of reactants or temperature is increased. • These interventions speed reactions because they cause molecules to hit harder or more frequently, making it more likely that bonds will break and form. • Adding crushed-up calcium carbonate in significant amounts could help oysters build shells and push equilibrium toward the reactants in ocean acidification, slightly decreasing the water pH as well.	

Navigation to Next Lesson: Though adding calcium carbonate to water is a possible solution, it is only one of many we have considered. To determine if any solution(s) is one that we would recommend, we will need to evaluate it against different criteria and constraints that we must keep in mind.

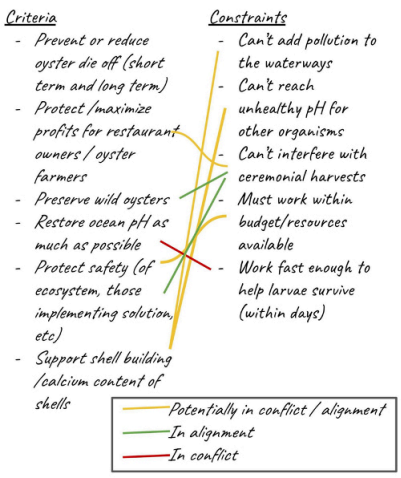
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Lesson Set 3: How can engineering design help us determine the best process to save oysters?

LESSON 12

What criteria and constraints do we need to consider when designing solutions to help protect oysters?

Putting Pieces Together, Problematizing **1 day**

Phenomenon or design problem	What we do and figure out	How we represent it
Engineers must consider interrelated scientific, technical, and societal criteria and constraints, and develop solutions in context that meet community requirements.  Virginia State Parks, CC BY 2.0	We develop and narrow down a class list of possible solutions to prevent oyster die-off based on the criteria and constraints for our design, the information gathered about the priorities of impacted communities, and our own knowledge and experience. We choose a promising solution to develop in groups. We figure out: • In addition to scientific and technical criteria and constraints, engineering solutions must meet requirements set by society. • Criteria and constraints can be interrelated, and at times contradictory. • Specific, quantifiable criteria and constraints are based on context. We first need to know where and with whom we plan to develop a particular solution.	

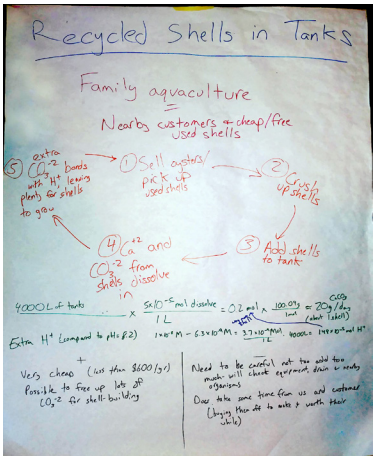
Navigation to Next Lesson: We have a qualitative list of social, scientific, and technical criteria and constraints and have identified solutions that we are interested in developing. We wonder how to further clarify and quantify our list of criteria and constraints and need to figure out where and with whom we will design our solutions in order to do so.

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LESSON 13

How can we apply our science ideas to develop a solution to help protect oysters?

Putting Pieces Together, Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Site data for different locations in the US help students refine criteria and constraints and develop solutions to help oysters.  NOAA, New Hampshire Sea Grant	We brainstorm a list of information that helps us refine our solutions, criteria, and constraints. We work in groups and choose a site profile to design a solution for. We share our plan with another group, then complete our solution design by quantifying data. We figure out: • Specific desired outcomes require specific inputs or changes to a system. • Criteria and constraints can be quantified to help develop specific solutions. • We can quantitatively model the impacts that proposed changes will have on a system.	

Navigation to Next Lesson: Now that we have developed some specific solutions and modeled their impacts, we want to share ideas with each other and evaluate our solutions.

LESSON 14

How well do our different design solutions address our criteria and constraints?

Putting Pieces Together **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Engineers prioritize criteria and make trade-offs in order to design solutions for a specific context and community.  Jstuby	We identify the main points of and the criteria that guided our design solution. We present our design solution to a group of our peers and receive feedback, then use the peer feedback to refine our solution. We engage in a discussion to come to a consensus on the chemistry and Earth science ideas that we used in our design solutions. We figure out that: • When deciding to prioritize specific criteria to guide a design solution, engineers need to consider the trade-offs of different priorities. • There are multiple ways to use chemistry and Earth science ideas to help prevent oyster die-off, but they all target a process on our class consensus model.	

	Description of Criterion	Reason for Ranking
1	The indigenous groups in the area need to maintain access to their harvests.	Indigenous people have the rights to the land and need to eat.
2	Needs to be low-cost.	This is most important because if it is too expensive, we can't implement it.
3	Removes 0.57 mol of H^+ ions twice per day.	This has to happen for the pH to change enough for oyster larvae to form shells.
4	Work within the ecosystem.	We don't want to damage other parts of the ecosystem with our solution.
5	Minimal time/labor required to implement.	We want oyster farmers to have enough time and labor to do all the other parts of their jobs.

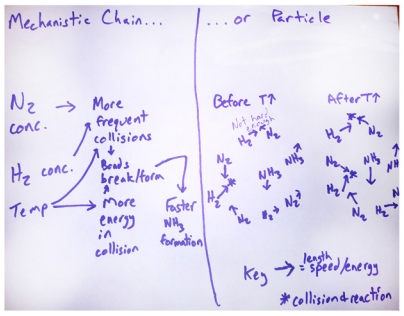
Navigation to Next Lesson: Now that we have shown how we can use chemistry to help the problem of oyster die-off, we wonder if there are other engineering problems that we could use chemistry to solve.

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LESSON 15

How can we apply our learning to other situations?

Putting Pieces Together **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
The Haber–Bosch process is used to make ammonia fertilizer that can help provide nitrogen to crops.  Thirteen Of Clubs, CC BY-SA 2.5	Having had a chance to refine solutions, we take stock of the Driving Question Board for the final time in the unit. We complete a transfer task assessment. We figure out: • The Haber–Bosch process produces ammonia fertilizer and is another example of a reversible reaction. • The reaction rate of the Haber–Bosch process can be increased by constantly adding reactants into the system or by carrying out the reaction at high temperature. • Production of H_2 in the Haber–Bosch process releases large amounts of CO_2 as a byproduct. We can use stoichiometry to figure out how much is released. • The Haber–Bosch process allows us to consider different criteria for a design solution, which can be prioritized based on resource availability and other factors.	

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

Lessons 1–15 **33 Days Total**

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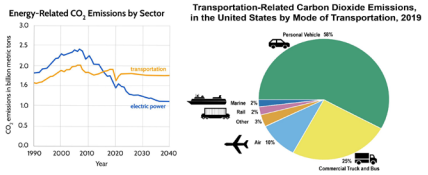
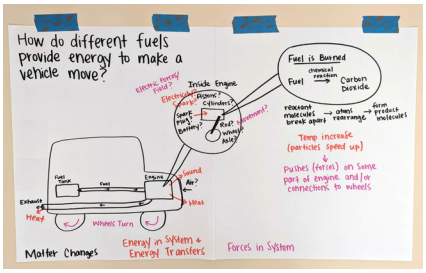
Unit Storyline

Lesson Set 1: How do carbon-based fuels release energy?

LESSON 1

What different fuels have we used, and do we currently use, for transportation?

Anchoring Phenomenon **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Transportation is one of the leading sources of CO_2 emissions. Different fuel sources are used to provide energy to make our vehicles move. 	We analyze data on sources of carbon emissions to think about which fuels we should consider for future vehicles. We figure out: • Most of the CO_2 emissions in the world come from transportation and electric power, and in transportation, cars and trucks are responsible for most of the emissions. • Different fuels are used to provide energy in the vehicles we use for transportation. • Different fuels contain different types of atoms, have different amounts of (or no) CO_2 emissions, have different energy released values, and come from different sources. • If we want to design a new generation of fuels or vehicles that do not contribute as much to climate change, there are other criteria we must consider as well.	

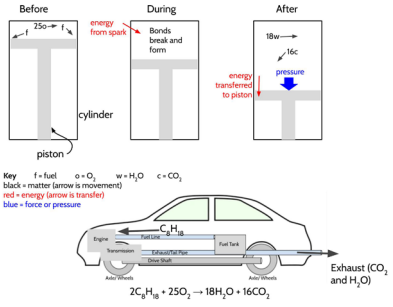
Navigation to Next Lesson: We have some gaps in our initial models related to what is happening inside the engine of a vehicle. We should inspect parts of the system more closely to see what is happening during combustion to clarify our models.

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LESSON 2

What is happening to the fuels inside the engine to make the vehicle move?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Vehicles have structures that allow them to transfer energy from burning fuel in the engine to the wheels. 	We watch several demonstrations, examine different models, and revise models based on new information. We figure out: • The inputs of a combustion reaction are fuel and oxygen, and the outputs are carbon dioxide and water vapor. • The release of energy when fuel combusts in a vehicle engine results in forces applied to various parts of the vehicle, which cause the wheels to turn. • Diesel and biodiesel fuels provide more energy and less CO_2 emissions, but are not consumed as much as gasoline. • Engines that operate on diesel rather than gasoline work slightly differently.	

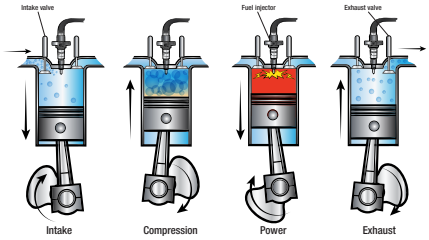
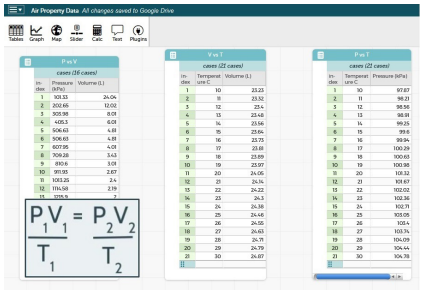
Navigation to Next Lesson: We have figured out that combustion reactions using either gasoline or diesel require some energy input to start, but the sources of this energy are different. We want to figure out where the energy input in diesel systems comes from.

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LESSON 3

How can diesel engines be working so differently from gasoline engines?

Investigation **1 day**

Phenomenon or design problem	What we do and figure out	How we represent it
For air-related phenomena from Lesson 2, there is a relationship between volume, temperature, and pressure.  	We examine relationships between the pressure, volume, and temperature of air in a closed system and use the Combined Gas Law to quantify those relationships. We figure out: • In a diesel engine, compressing air increases the air temperature above the ignition temperature of the fuel, causing the fuel to combust when it is injected. • We can determine how much pressure must be applied to the piston for the gas inside the diesel cylinder to reach the ignition temperature of a fuel using the Combined Gas Law. • As the air in the cylinder is compressed, its temperature increases because energy is transferred from the moving piston to the air molecules.	 Images generated using CODAP (https://codap.concord.org/), developed at the Concord Consortium.

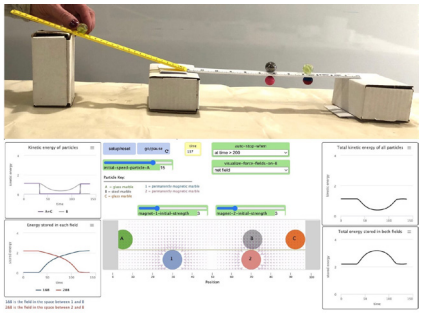
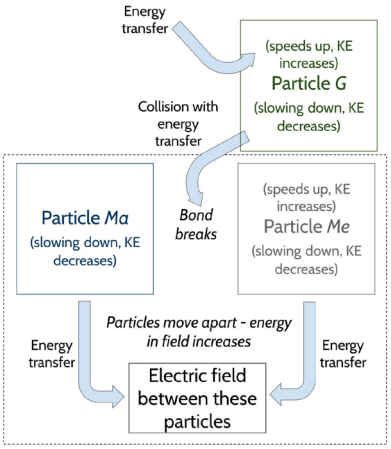
Navigation to Next Lesson: We have figured out that there is a relationship between the pressure, volume, and temperature of a gas. When air in a diesel cylinder is compressed, it gets hot because energy is transferred to it from the moving piston. We want to figure out why an initial energy input is needed to start the combustion reactions in gasoline or diesel engines.

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LESSON 4

Why do we need to put energy into the system to start the reaction?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Marbles and computer models can be used to illustrate interactions of molecules inside the cylinder system to explain why an energy input is required to break bonds in the reactants of combustion reactions.  Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.	We use marbles and a computer model to examine what is happening as bonds break in a combustion reaction. We figure out: • Energy has to be transferred into the field between bonded atoms in order to overcome attractive forces and break them apart. • If too little energy is added to the system to break the bonds, they will wobble. This wobble is caused by energy moving into and out of the fields of the atoms in the reactant.	

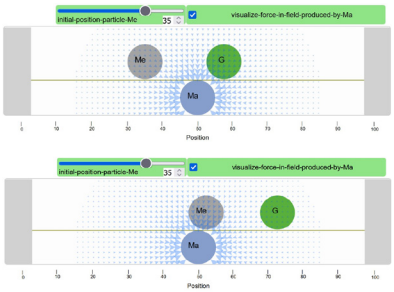
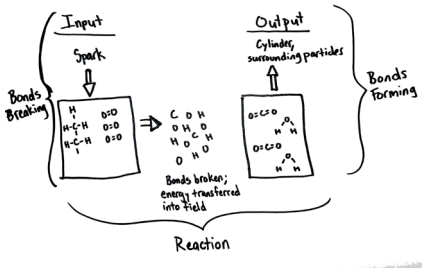
Navigation to Next Lesson: We have figured out why energy is needed to start combustion, but are unsure where the energy comes from in the reaction or why we continue to use carbon-based fuels even though they release carbon dioxide.

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LESSON 5

How and why is energy released when we burn carbon-based fuels?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Marbles and a simulation help students model changes in matter and energy transfers as a result of force interactions when bonds form.  Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.	We investigate bond formation using the magnet marbles and a simulation similar to the one from the prior lesson. We use the magnet marbles and simulation to observe the forces involved and energy changes that occur when a bond forms. We update our class consensus model to include energy transfers during bond breaking and formation, and read about the source of energy in carbon-based fuels. We complete an electronic Exit Ticket to assess our understanding of changes in matter and energy when bonds form. We figure out: • As attracted particles move closer together, there is a decrease in the energy stored in the field and an increase in kinetic energy. • Forming a chemical bond results in an increase in particle-level kinetic energy. • Energy in all fuels can be traced back to the sun. These resources are important because they allow for the development of society and affect where and how people live. • There are arguments for and against fossil fuels and biofuels.	

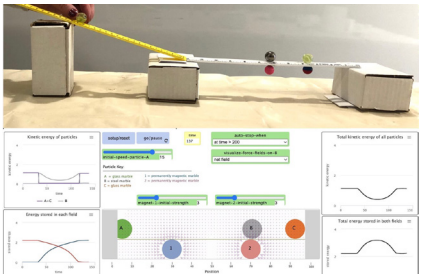
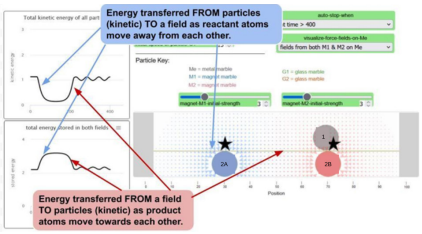
Navigation to Next Lesson: We have a possible idea about both breaking and forming bonds together and have thought about energy production at a larger scale, but we are not certain that our model is complete or final and we have not tested it with many real fuels.

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LESSON 6

How does the amount of energy we put into the reaction system compare to the energy we get out?

Investigation **1 day**

Phenomenon or design problem	What we do and figure out	How we represent it
A computer model allows students to examine changes in matter, total kinetic energy, and total energy stored in fields over time as bonds of different strengths break and form.  Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.	We use a physical model and a simulation to examine changes in kinetic energy as bonds break and form. We figure out: • The total energy (energy stored in electric fields and kinetic energy of particles) is conserved in a chemical reaction. • In our simulation, net energy is transferred from the field if the bonds formed are stronger than the bonds broken. • In our simulation, net energy is transferred to the field if the bonds broken are stronger than the bonds formed. • A minimum amount of energy must be transferred to the field to break a bond and start the reaction. This is called the activation energy.	 Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.

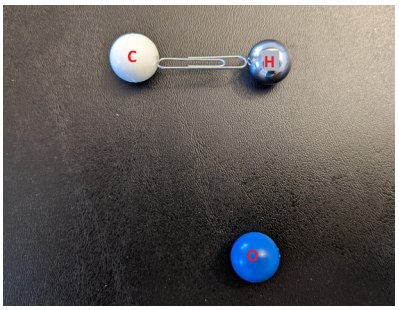
Navigation to Next Lesson: Now that we can explain why we get energy out of the system from combusting fuels, we want to see if we can apply these ideas to figure out why fuels are different.

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LESSON 7

How can fuels release different amounts of energy when they all have bonds breaking and forming?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Electronegativity differences and magnet marbles can be used to predict and model different bond strengths.  	We revisit everything we have figured out about how energy is involved in bond breaking and formation to make sense of how the types of atoms being bonded affect the bond energy. We then use these different bond energies to create a visual and mathematical representation of the energy transferred into fields to break the reactant bonds in methane combustion and the energy released when forming its products. We end our class revisiting the DQB to see what questions we can answer. We figure out: • The number of bonds broken and formed cannot fully explain the energy transferred out of a combustion reaction. • High-electronegativity elements tend to form stronger bonds than low-electronegativity elements. • More energy must be transferred to the field to break a strong bond compared to a weaker bond and more energy is transferred from the field when a strong bond is formed.	**Strongest** **C=O** **O=O** **O–H** **C–O** **C–C** **Weakest**

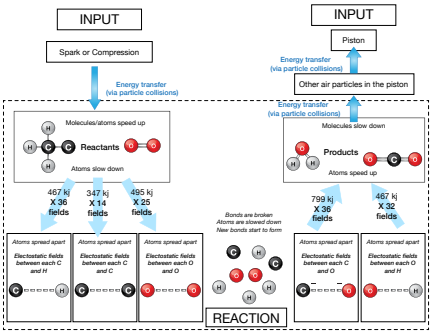
Navigation to Next Lesson: We figured out that different bond strengths result in different amounts of energy being transferred into and out of the field and used this to predict energy transfer. We are ready to put all the pieces from the unit together.

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LESSON 8

How does our understanding of carbon-based fuels inform our decision-making?

Putting Pieces Together **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
A chemical reaction between potassium chloride and water decreases in temperature, and a chemical reaction between calcium chloride and water increases in temperature. 	We explain and model why carbon-based fuels provide energy. We think about the impacts of carbon dioxide emissions and return to our Progress Trackers. We check in on our DQB and complete a mid-unit assessment on hot and cold packs. We figure out: • All fuels release energy when they are burned because the total bond energy of the products is greater than the total bond energy of the reactants. We can use this to explain the behavior of different fuels. • The amount of carbon dioxide produced by fuel combustion is related to the number of carbon atoms in the fuel. All carbon-based fuels emit large amounts of carbon dioxide when burned. • In cold packs, energy transfers in and out of fields result in a temperature decrease. In hot packs, energy transfers in and out of fields result in a temperature increase. This applies even when dissolution is the main process.	

Navigation to Next Lesson: We still have a lot of fuels that we have not investigated, and we are interested in whether they would be viable alternatives to carbon-based fuels.

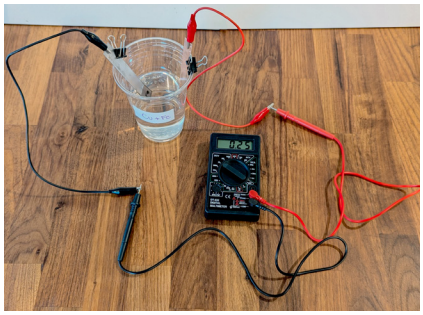
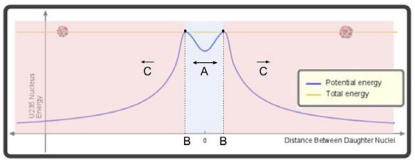
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Lesson Set 2: How do fuels that are not carbon based release energy?

LESSON 9

Where is the energy coming from (and what are some trade-offs) when we use batteries to power vehicles?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Electric vehicles have some significant advantages, as well as disadvantages, compared to gasoline-powered vehicles. Some of these issues can be addressed by improving battery technology, so we investigate how batteries work. 	We learn about the benefits and drawbacks of using electric vehicles powered by batteries. We analyze images of batteries and conduct investigations using different metal electrodes. We analyze data on the current produced by different electrolytes. We develop a battery design proposal that would provide the highest energy output rate. We figure out: • Batteries and EVs have a lot of benefits but also some drawbacks in the short-term relating to the environment and accessibility. • Differences in the types of solutions and metals used in batteries can affect the energy they can provide. • Combining metals with a larger difference in electronegativity in a battery can transfer more energy. • Batteries provide a vehicle energy as electrons move through wires and ions move through solution, transferring energy from fields to particles.	 PhET Interactive Simulations, University of Colorado Boulder

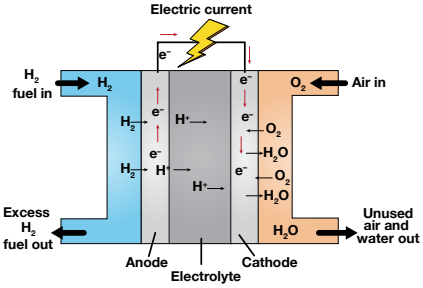
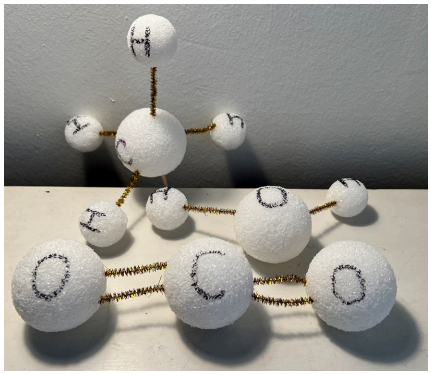
Navigation to Next Lesson: We still need to explain how hydrogen would be able to power a vehicle.

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LESSON 10

How can we use hydrogen as a fuel and what are the impacts?

Investigation **1 day**

Phenomenon or design problem	What we do and figure out	How we represent it
Hydrogen fuel cells have similar components to batteries and generate electricity by reacting hydrogen fuel with oxygen.  Data Source: OpenStax	We learn about how fuel cells generate electricity from hydrogen fuel. We determine that most hydrogen is produced from methane with the emission of carbon dioxide. We identify the locations of hydrogen refueling and battery recharging stations. We figure out: • Hydrogen fuel cells are similar to batteries in that they directly produce electricity and similar to engines in that they have inputs (hydrogen and oxygen) and outputs (water). • Most hydrogen is produced from fossil fuels in a process that also emits carbon dioxide. • Greenhouse gases persist in the atmosphere and wobble (vibrate) a lot when they absorb infrared radiation emitted by Earth. • Some special criteria and constraints must be considered with hydrogen fuel cells for transportation (not enough refueling stations, greenhouse gas emissions during hydrogen production).	

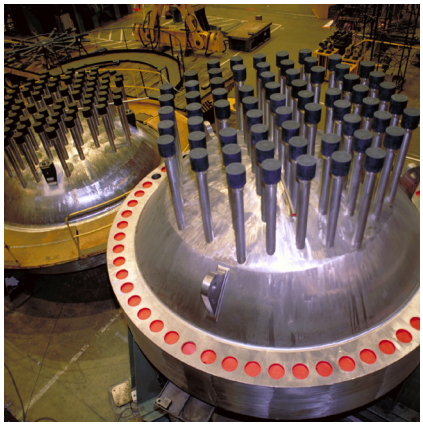
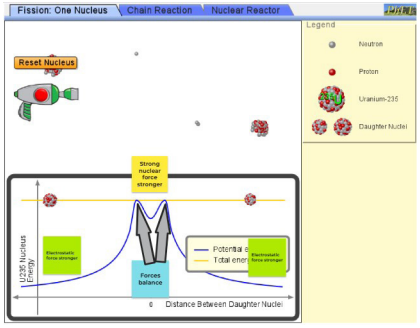
Navigation to Next Lesson: We still need to explain how energy could be output from a single atom, uranium.

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LESSON 11

Where is the energy coming from when we use uranium as a fuel?

Investigation, Problematizing **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Uranium provides much more energy than the chemical reactions we have examined so far even though there is nothing to react, as it just consists of one type of atom.  U.S. Nuclear Regulatory Commission	We examine how nuclear processes are similar and different from chemical reactions using M–E–F thinking. We jigsaw readings that describe different concerns with using uranium as fuel and added to our Progress Trackers. We figure out: • In nuclear fission, neutrons and protons are conserved, but atoms can change into different elements as large nuclei split. • We would expect protons to repel due to electrostatic forces, but when there are the right ratios of protons and neutrons in a nucleus, the strong nuclear force is able to hold them together. This force only works on short ranges. • When protons and neutrons get just too far apart for the strong nuclear force to take hold, protons repel strongly due to the electrostatic force and energy transfers from electric fields to the particles, causing a drastic increase in temperature. • Various constraints around size, safety, cost, and environmental concerns have limited the use of uranium as a fuel, particularly in transportation.	 PhET Interactive Simulations, University of Colorado Boulder

Navigation to Next Lesson: We have figured out how different fuels provide energy. We can start to think more systematically about their application to transportation problems.

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LESSON 12

How can our knowledge of fuel trade-offs support our evaluation of future rocket fuels?

Putting Pieces Together **1 day**

Phenomenon or design problem

The increased abundance of space missions is leading to a greater environmental impact.



NASA

What we do and figure out

We observe a video showing the process of how astronauts will reach Mars. We develop a list of criteria and constraints that engineers and scientists need to explore when choosing a rocket fuel. We read an article comparing the differences between chemical and nuclear rockets. We then work in groups to rank our criteria and constraints and compare each type of rocket against them. Finally, we individually argue for which, or neither, fuel should be used in future space missions. We figure out:

- More space flights using carbon-based fuels is harming the atmosphere.
- Uranium has a much higher energy released than hydrogen fuels.
- Hydrogen-fueled rockets release no harmful products, while nuclear rockets' exhaust is radioactive.
- Nuclear-powered rockets will lead to less travel time, which means astronauts will be exposed to less cosmic radiation than if traveling in chemical-fueled rockets.

How we represent it

Categories	Hydrogen-Based Rocket	Nuclear-Based Rocket
Weight		
Energy Released		
Timing		
Safety		
Environmental Impact		

Navigation to Next Lesson: We have examined an engineering problem around a specific type of transportation and have what we need to think about the whole transportation system.

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Lesson Set 3: How can we use what we have learned to improve our transportation system?

LESSON 13

Why do we use some fuels rather than others?

Problematizing, Investigation **2 days**

Phenomenon or design problem

It is difficult to evaluate new transportation solutions based only on environmental impacts because the effects are complex and there are both benefits and costs for each solution.



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What we do and figure out

We create a draft decision matrix and use it to evaluate two transportation solutions on the basis of environmental impact. We realize that our initial criteria and constraints are too complex and should be broken into subcategories. We update our consensus decision matrix to include subcategories for other criteria and constraints. We figure out:

- Evaluating the benefits of different transportation solutions requires comparison against clear criteria and constraints. Each transportation solution has trade-offs that must be considered before implementation.
- It is helpful to break large, broad criteria into smaller, more specific parts to better evaluate possible solutions.

How we represent it

Criteria/Constraints		
Safety / Health		
Will it explode?		
Does it cause cancer? other health issues?		
Can you transport or store it safely?		
Cost		
Cost per gram of fuel to purchase		
Cost for new engine or power plant		
Lifespan for engine or power plant		
Maintenance or storage costs		
Environmental Impact		
Direct or indirect carbon emissions		
Consequence of disposal		
Can it be recycled?		
Do byproducts of use or extraction/production affect air, soil, or water?		
Who lives in the areas most impacted?		
Energy Released		
Infrastructure / Availability		

Navigation to Next Lesson: We want to test our consensus decision matrix by using it to evaluate competing transportation alternatives.

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LESSON 14

How do we decide on the best transportation options for our future?

Investigation **3 days**

Phenomenon or design problem

There is a lot to consider when designing for future transportation systems. Using quantitative tools can help us organize and interpret the data to support our decision-making process.

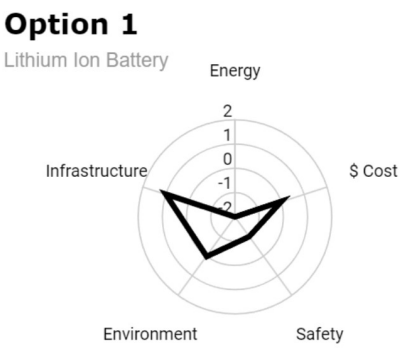
GASOLINE (C_8H_{18})	
Criteria/ Constraints Category	INFORMATION
ENERGY RELEASED	6,140 kJ / mol
FINANCIAL COST	Affordable but fluctuating due to uneven geographic availability and international political decisions. Artificially cheap in the United States compared to other countries because of subsidies. Gasoline is projected to run out completely by 2060. As a result, prices are expected to increase dramatically in the next few decades.
SAFETY	Can start grass fires while running, some risk of fire in an accident. It is also toxic and can contain carcinogens. Exhaust is a known carcinogen and can be deadly if a car is run in an enclosed space due to carbon monoxide exposure.
ENVIRONMENTAL IMPACT	Contributes 3.3 kg CO_2 for each 1.0 kg burned with no carbon capture; requires burning of additional fossil fuels to refine it. If all stores are used, it will significantly warm the planet, causing polar ice melt, sea-level rise, and other related effects. EPA regulations could decrease damage from gasoline. Its toxicity can affect nonhuman life.
INFRASTRUCTURE	Existing widespread, functional infrastructure. Gasoline shortages are expected as it is projected to run out, so the infrastructure of distribution will be greatly strained in the next few decades.

What we do and figure out

We use data from various sources to evaluate transportation options and develop arguments for which ones are best to use in the future. We figure out:

- Radar charts can be used to help visualize complex data sets. This allows for better comparison and ability to find patterns in data.
- Quantifying data into positive and negative values can help us to clearly compare the costs and benefits of using certain transportation options over others.
- Making decisions is a multistep process and is influenced by our individual priorities.

How we represent it



Navigation to Next Lesson: We are wondering how to wrap up all we have learned and include the helpful critiques we have received. We decide to finalize our arguments using feedback we received from our peers.

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LESSON 15

How can we make transportation decisions to benefit our communities and Earth?

Putting Pieces Together **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it

There are many ways that we could improve our transportation systems; what we ultimately decide to do is the result of prioritized criteria, our values, social contexts, environmental impacts, and available engineering solutions.

Sky 269, CC BY-SA 4.0
	We use our prioritized criteria, arguments from Lesson 14, and feedback on our arguments to propose a final transportation design solution. We reflect on our progress in this unit and throughout the chemistry course. We figure out:
	• We can combine our chemistry knowledge, engineering decisions, and prioritized criteria to create a final transportation design proposal.
	• We can use chemistry and engineering to design transportation solutions that provide the needed energy for transportation while reducing negative environmental impacts.
		Name: _____ Date: _____
		Final Design Proposal
		Over the course of this unit we have examined many different fuel options, as well as several potential future changes to our relationship with transportation. What is your final proposal for how we can improve our transportation system? In your proposal:
		• State the transportation goal you chose to focus on.
		• Describe the transportation option(s) you chose to meet this goal.
		• Explain how your chosen option(s) transfers energy to a vehicle to allow it to move. Discuss how this is different from the current system.
		  • In other words: How does your vehicle avoid energy use, shift to more desirable fuels to transfer energy to vehicles, or improve the energy transfer from existing fuels?
		  • You may wish to include energy transfer models to help visualize this connection between scientific ideas and engineering thinking.
		• Evaluate how well your chosen option(s) meets the current and growing need for energy for transportation while improving CO_2 emissions.
		• Discuss the other criteria you prioritized when making your decision. How did they impact it? What trade-offs did you consider?
		• Explain the impact you believe your proposal will have on your community and society at large, in terms of both the environmental impact and what life looks like for people. Use evidence from *Transportation Options* and your decision matrix as needed.

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

Lessons 1–15 **31 Days Total**

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