UNIT STORYLINE

Unit Question: Why are oysters dying, and how can we use chemistry to protect them?

How students will engage with each of the phenomena

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

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

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

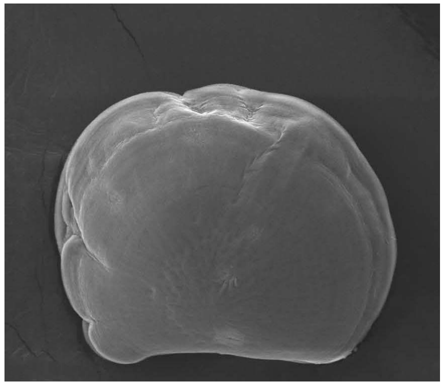
LESSON 1

Lesson Set 1

3 days

What is happening to oysters?

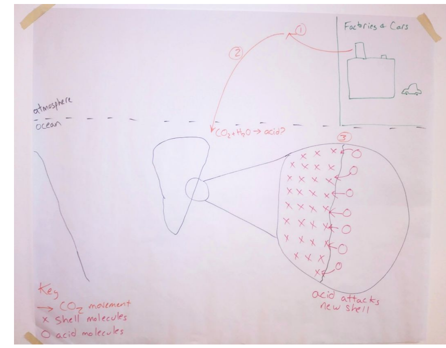
Anchoring Phenomenon



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

Lesson Set 1

1 day

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

Anchoring Phenomenon

People often break down complex problems into subproblems to solve them.

We decide to break down the big problem, and 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 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.

What **subproblems** did we decide to break our main problem into?

1. CO_2 gets into the atmosphere/ocean
2. CO_2 makes water more acidic
3. Acidity hurts oyster shells
4. Oyster death hurts ecosystems and people

⇓ **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.

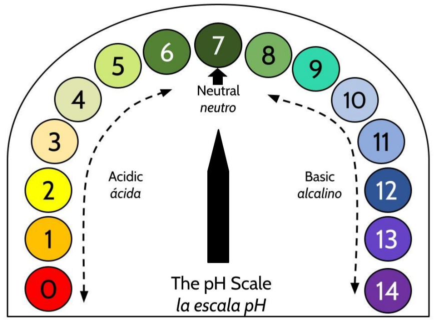
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it

LESSON 3
Lesson Set 1

2 days

Can carbon dioxide make the ocean more acidic?

Investigation



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

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.

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	$= 10^{21}$

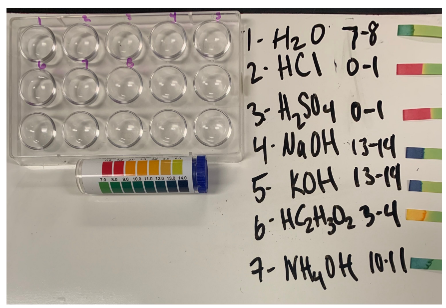
⇓ **Navigation to Next Lesson:** Having seen that some substances are acidic, some are basic, and some are neutral, we are now wondering what it is about a substance that determines whether it forms an acid or a base when added to water.

LESSON 4
Lesson Set 1

2 days

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

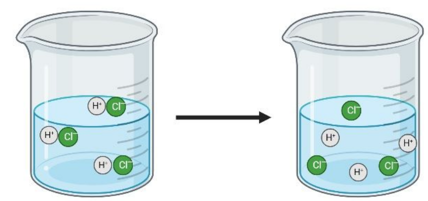
Investigation



Some acids or bases have different pHs, even when the molarities of the solutions are the same.

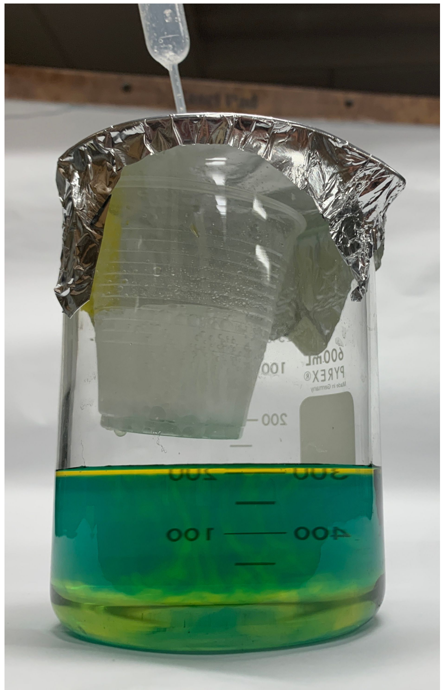
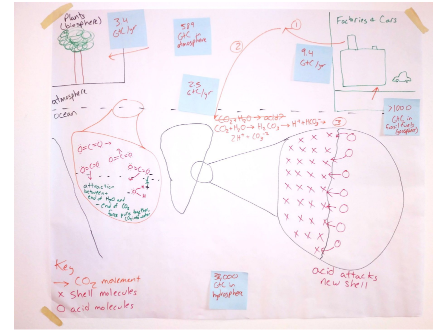
We use molecular formulas to predict which substances are acids, bases, or neither. We use mathematical thinking to compare quantities of particles and concentrations in different solutions and conduct an investigation. We develop a model to explain our results. We figure out:

- 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.

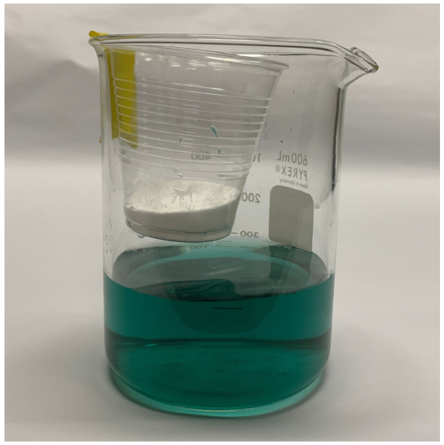


Illustrations created by OpenSciEd in BioRender

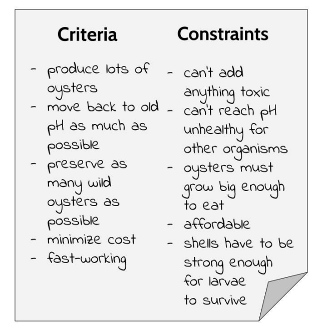
⇓ **Navigation to Next Lesson:** Because we are not sure whether each acid molecule formed from H2O molecules chemically reacting with CO2 dissociates into one or two H+ ions, and because we do not know whether CO2 gets into the water or interacts with water at the surface when this happens, we want to investigate these questions further next time.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 5 Lesson Set 1 3 days **How does carbon dioxide move between the atmosphere and ocean systems to cause the water to become more acidic?** Investigation, Problematizing	 *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 CO2 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.

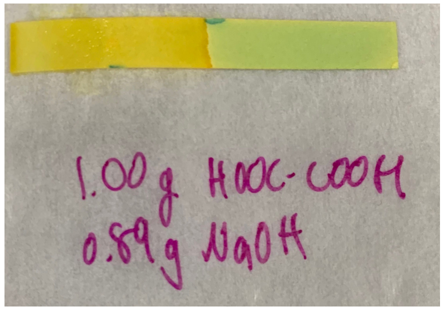
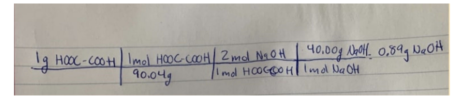
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 6 Lesson Set 1 3 days **How can acidic water become less acidic again?** Investigation	 *When a solution of water and bromothymol blue with dissolved carbon dioxide is left out overnight, the color of it 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 reaches 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.

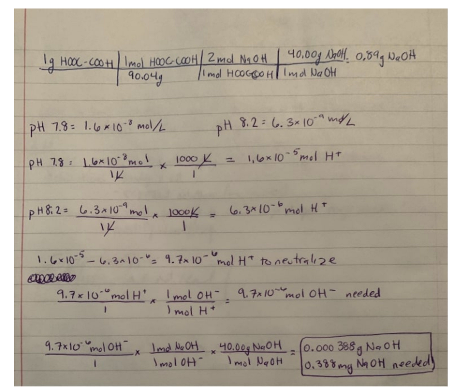
Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 7 Lesson Set 1 2 days **How can we use what we have learned to help protect oysters?** Putting Pieces Together	 *The people who are impacted by oyster die-offs are being affected in different ways.*	We discuss 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.	

⇓ **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.

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

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 8 Lesson Set 2 3 days **How can we figure out how much of a substance we need to neutralize acid?** Investigation	 *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.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 9 Lesson Set 2 2 days **How much NaOH would we need to add to make ocean water safe for oysters?** Investigation	 *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.*	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.

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

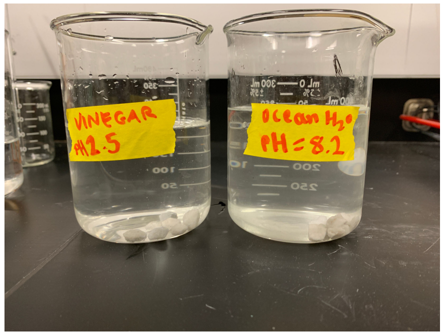
LESSON 10

Lesson Set 2

2 days

How does ocean acidification hurt oysters?

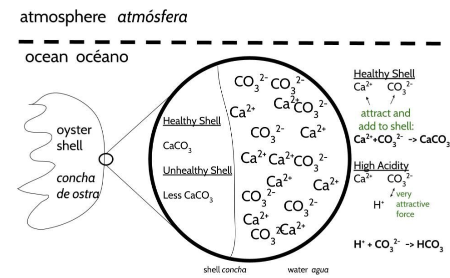
Investigation



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.

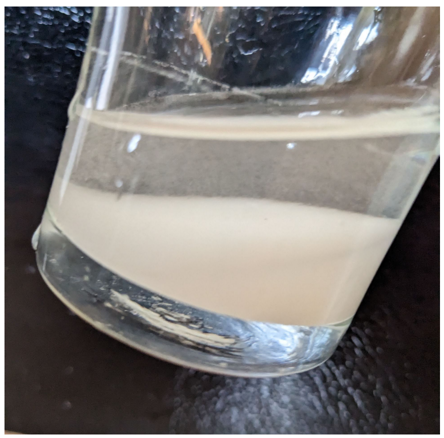
LESSON 11

Lesson Set 2

3 days

How can we help oysters build shells quickly?

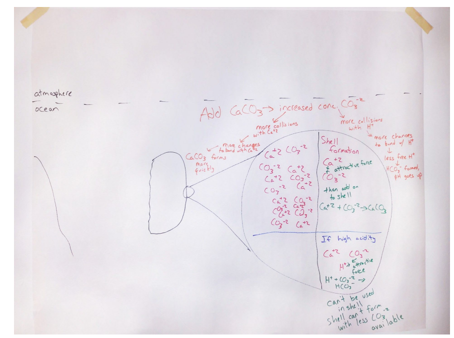
Investigation



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.

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

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

LESSON 12

Lesson Set 3

1 day

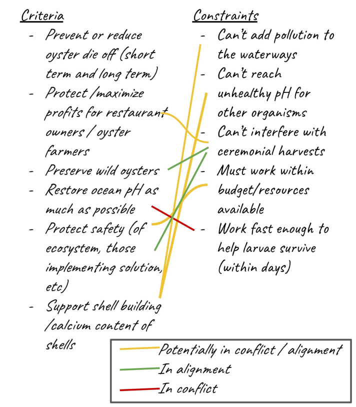
What criteria and constraints do we need to consider when designing solutions to help protect oysters?

Putting Pieces Together, Problematizing

Engineers must consider interrelated scientific, technical, and societal criteria and constraints, and develop solutions in context that meet community requirements.

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.

LESSON 13

Lesson Set 3

2 days

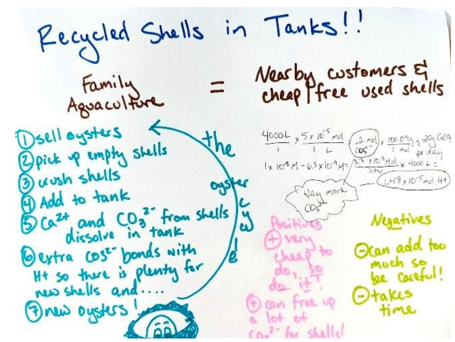
How can we apply our science ideas to develop a solution to help protect oysters?

Putting Pieces Together, Investigation

Site data for different locations in the U.S. help students refine criteria and constraints and develop solutions to help oysters.

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

LESSON 14

Lesson Set 3

2 days

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

Putting Pieces Together

Engineers prioritize criteria and make trade-offs in order to design solutions for a specific context and community.

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	Reasoning for ranking
1	Needs to be low-cost	This is most important because if it is too expensive, we can't implement it
2	The Indigenous groups in the area need to maintain access for their harvests	Indigenous people have rights to the land and we want to respect that
3	Removes 0.57 moles 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	eWe want oyster farmers to have enough time and labor to do all the other parts of their job

⇓ **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.

LESSON 15

Lesson Set 3

2 days

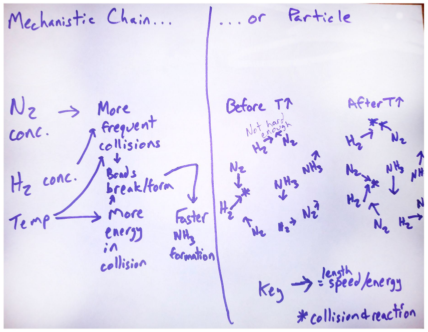
How can we apply our learning to other situations?

Putting Pieces Together

The Haber-Bosch process is used to make ammonia fertilizer that can help provide nitrogen to crops.

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 this unit.

LESSONS 1-15

33 days total