

CHEMISTRY

Chemical Reactions
in Our World

**Why are oysters
dying, and how
can we use
chemistry to
protect them?**



HIGH SCHOOL SCIENCE



TEACHER EDITION

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

Chemical Reactions in Our World: Oysters

OpenSciEd Unit C.4





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TABLE OF CONTENTS

Unit C.4 Why are oysters dying, and how can we use chemistry to protect them?

Unit Overview	1
Unit Storyline	3
Teacher Background Knowledge	12
Home Communication	32
Lesson 1: What is happening to oysters?	35
Lesson 2: How can we break down the problem so we can solve it?	59
Lesson 3: Can carbon dioxide make the ocean more acidic?	71
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?	83
Lesson 5: How does carbon dioxide move between the atmosphere and ocean systems to cause the water to become more acidic?	101
Lesson 6: How can acidic water become less acidic again?	125
Lesson 7: How can we use what we have learned to help protect oysters?	147
Lesson 8: How can we figure out how much of a substance we need to neutralize acid?	161
Lesson 9: How much NaOH would we need to add to make ocean water safe for oysters?	189
Lesson 10: How does ocean acidification hurt oysters?	203
Lesson 11: How can we help oysters build shells quickly?	225
Lesson 12: What criteria and constraints do we need to consider when designing solutions to help protect oysters?	249
Lesson 13: How can we apply our science ideas to develop a solution to help protect oysters?	261
Lesson 14: How well do our different design solutions address our criteria and constraints?	275
Lesson 15: How can we apply our learning to other situations?	287
Unit C.4 Teacher Reference Materials	295
Unit C.4 Lesson-Specific Teacher Materials	311

UNIT OVERVIEW

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

This unit is anchored by the novel phenomenon of oyster larvae die-offs. These overnight events became widespread in the Pacific Northwest in the mid-2000s as ocean pH reached a new low in that area. In the first lesson set (Lessons 1-7), students learn that oyster die-offs occur in the Pacific Northwest due to ocean acidification. They decide they want to design solutions to help oysters and break the problem of oyster die-offs due to ocean acidification into smaller sub-problems. They investigate acids and bases, how carbon dioxide gets into the ocean, and how carbon moves through some of Earth's systems. They use a computational model to figure out how acidification and other processes can naturally reverse due to shifts in chemical equilibrium. Finally, they think about the interest different groups of people have in solving the problem of oyster die-offs and engage in a mid-unit transfer task. In the second lesson set (Lessons 8-10), students begin by developing a mathematical model (of stoichiometry) that will allow them to determine how much of a base is needed to neutralize an acid. They apply this model to adding bases to oyster tanks to restore a healthy pH. They model how increased acidity hinders shell-building this process as H^+ ions bond with carbonate ions. Finally, they investigate how adding higher concentrations of carbonate compounds or altering the surface area or temperature could impact the reaction rate of shell-building or other processes. In the third lesson set (Lessons 11-15), students work to establish more specific criteria and constraints for the problem of oyster larvae dying from increased ocean acidity. They quantify these criteria and constraints and develop the outlines of solutions. They give other groups feedback on their solutions and discuss how their solutions leveraged what they figured out about chemistry and Earth science in the unit. Finally, students close out the Driving Question Board and complete an assessment that engages them with the Haber-Bosch process for producing ammonia fertilizer.

Throughout the unit, students will do the following:

- Model ocean acidification at the particle level (with hand-drawn and computational models), as a chemical equation, in the context of the carbon cycle, using stoichiometric tools, and using chemically similar smaller-scale systems.
- Use mathematical and computational thinking to analyze the problem of oyster larvae die-offs.
- Break the problem of oyster larvae die-offs due to ocean acidification into manageable sub-problems.
- Define and quantify social, technical, and environmental constraints surrounding the problem of oyster larvae die-offs.

Building Toward NGSS Performance Expectations

HS-ESS2-6:

Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

HS-ESS3-4:

Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

HS-ETS1-1:

Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2:

Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-PS1-5:

Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

HS-PS1-6:

Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

HS-PS1-7:

Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.

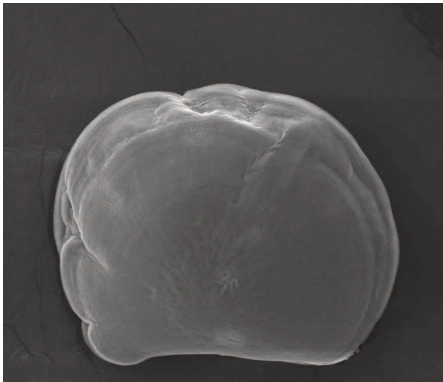
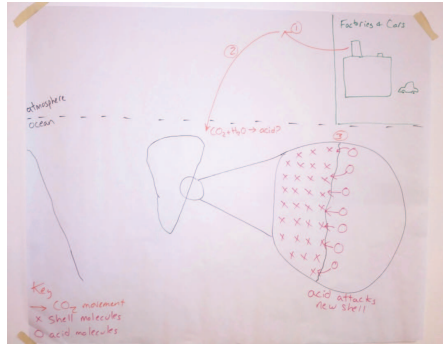
UNIT STORYLINE

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

How students will engage with each of the phenomena



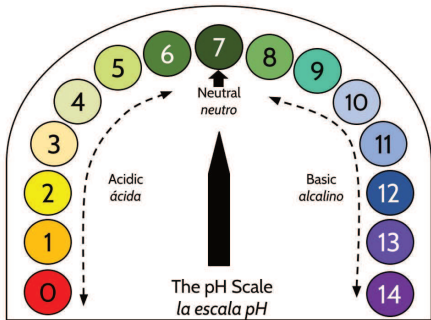
Lesson Set 1: What large and small-scale processes make water more or less acidic?

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 	 <i>Oysters are dying off in the United States. This is related to increased carbon dioxide levels in the atmosphere that causes ocean acidification.</i>	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.	

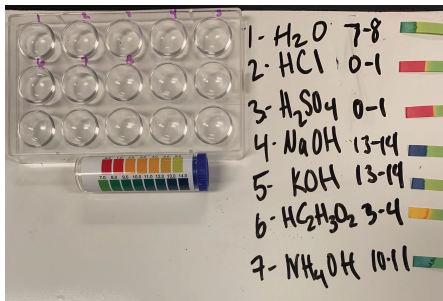
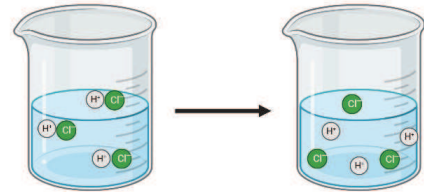
↓ **Navigation to Next Lesson:** We brainstorm ideas for investigations on our Driving Question Board. We have a variety of potential paths that we will narrow down in Lesson 2.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 2 Lesson Set 1 1 day How can we break down the problem so we can solve it? Anchoring Phenomenon 	 <i>People often break down complex problems into subproblems to solve them.</i>	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? - CO₂ gets into the atmosphere/ocean - CO₂ makes water more acidic - Acidity hurts oyster shells - Oyster death hurts ecosystems and people

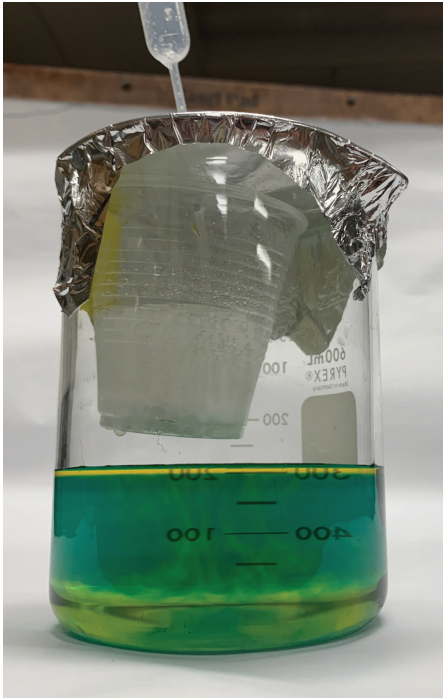
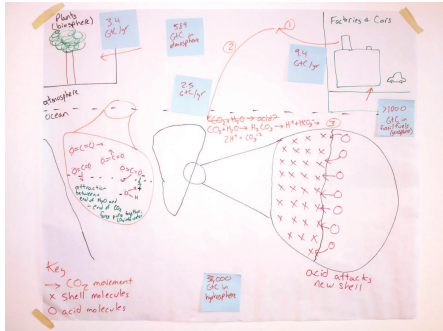
↓ **Navigation to Next Lesson:** We have multiple arguments on the table for which subproblems and categories of solutions to pursue. We want to decide on a shared direction for our work together during class time.

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 	 <i>The presence of carbon dioxide in water decreases the pH value of the water.</i>	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.	<table border="1"> <thead> <tr> <th colspan="4">Number of H⁺ and OH⁻ ions in 3mL of water at different pH levels (3mL of water contains 10²¹ water molecules)</th> </tr> <tr> <th>pH</th> <th>Number of H⁺ ions</th> <th></th> <th>Number of OH⁻ ions</th> </tr> </thead> <tbody> <tr><td>0</td><td>1,000,000,000,000,000,000,000</td><td>= 10²¹</td><td>10,000,000</td><td>= 10¹</td></tr> <tr><td>1</td><td>100,000,000,000,000,000,000</td><td>= 10²⁰</td><td>100,000,000</td><td>= 10²</td></tr> <tr><td>2</td><td>10,000,000,000,000,000,000</td><td>= 10¹⁹</td><td>1,000,000,000</td><td>= 10³</td></tr> <tr><td>3</td><td>1,000,000,000,000,000,000</td><td>= 10¹⁸</td><td>100,000,000</td><td>= 10⁴</td></tr> <tr><td>4</td><td>100,000,000,000,000,000</td><td>= 10¹⁷</td><td>10,000,000</td><td>= 10⁵</td></tr> <tr><td>5</td><td>10,000,000,000,000,000</td><td>= 10¹⁶</td><td>1,000,000</td><td>= 10⁶</td></tr> <tr><td>6</td><td>1,000,000,000,000,000</td><td>= 10¹⁵</td><td>100,000</td><td>= 10⁷</td></tr> <tr><td>7</td><td>100,000,000,000,000</td><td>= 10¹⁴</td><td>10,000</td><td>= 10⁸</td></tr> <tr><td>8</td><td>10,000,000,000,000</td><td>= 10¹³</td><td>1,000</td><td>= 10⁹</td></tr> <tr><td>9</td><td>1,000,000,000,000</td><td>= 10¹²</td><td>100</td><td>= 10¹⁰</td></tr> <tr><td>10</td><td>100,000,000,000</td><td>= 10¹¹</td><td>10</td><td>= 10¹¹</td></tr> <tr><td>11</td><td>10,000,000,000</td><td>= 10¹⁰</td><td>1</td><td>= 10¹²</td></tr> <tr><td>12</td><td>1,000,000,000</td><td>= 10⁹</td><td>0.1</td><td>= 10¹³</td></tr> <tr><td>13</td><td>100,000,000</td><td>= 10⁸</td><td>0.01</td><td>= 10¹⁴</td></tr> <tr><td>14</td><td>10,000,000</td><td>= 10⁷</td><td>0.001</td><td>= 10¹⁵</td></tr> </tbody> </table>	Number of H ⁺ and OH ⁻ ions in 3mL of water at different pH levels (3mL of water contains 10 ²¹ 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 ¹	1	100,000,000,000,000,000,000	= 10 ²⁰	100,000,000	= 10 ²	2	10,000,000,000,000,000,000	= 10 ¹⁹	1,000,000,000	= 10 ³	3	1,000,000,000,000,000,000	= 10 ¹⁸	100,000,000	= 10 ⁴	4	100,000,000,000,000,000	= 10 ¹⁷	10,000,000	= 10 ⁵	5	10,000,000,000,000,000	= 10 ¹⁶	1,000,000	= 10 ⁶	6	1,000,000,000,000,000	= 10 ¹⁵	100,000	= 10 ⁷	7	100,000,000,000,000	= 10 ¹⁴	10,000	= 10 ⁸	8	10,000,000,000,000	= 10 ¹³	1,000	= 10 ⁹	9	1,000,000,000,000	= 10 ¹²	100	= 10 ¹⁰	10	100,000,000,000	= 10 ¹¹	10	= 10 ¹¹	11	10,000,000,000	= 10 ¹⁰	1	= 10 ¹²	12	1,000,000,000	= 10 ⁹	0.1	= 10 ¹³	13	100,000,000	= 10 ⁸	0.01	= 10 ¹⁴	14	10,000,000	= 10 ⁷	0.001	= 10 ¹⁵
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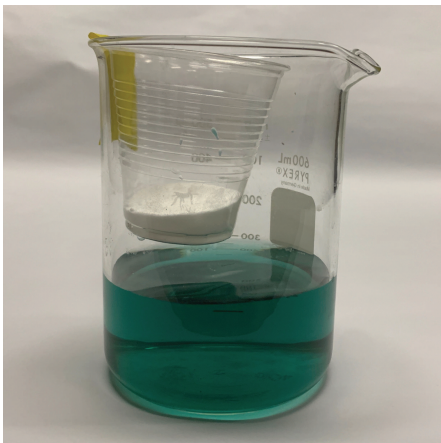
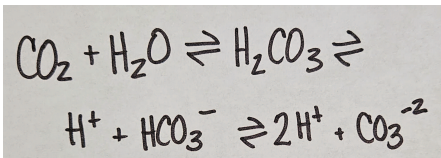
↓ **Navigation to Next Lesson:** Having seen that some substances are acidic, some are basic, and some are neutral, we are now wondering what it is about a substance that determines whether it forms an acid or a base when added to water.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
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 	 <i>Some acids or bases have different pHs, even when the molarities of the solutions are the same.</i>	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.	 <i>Illustrations created by OpenSciEd in BioRender</i>

↓ **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.

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, Problematising 	 <i>When carbon dioxide dissolves in a solution of water and bromothymol blue, a color change is observed.</i>	We investigate how CO₂ could naturally dissolve in water with an experimental setup in the lab, and examine amounts of CO₂ in the atmosphere and hydrosphere. We figure out: • CO₂ slowly gets into water through a natural process that does not “force” CO₂ into the water. • Atmospheric CO₂ has recently begun to dissolve into the ocean increasingly more, due to the buildup of atmospheric CO₂ 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 	 <i>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.</i>	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.	

↓ **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 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.

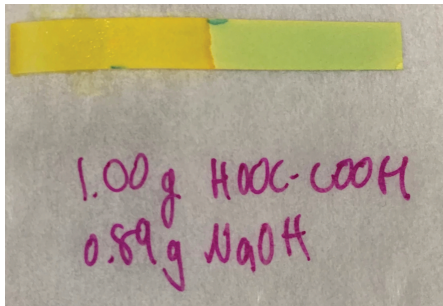
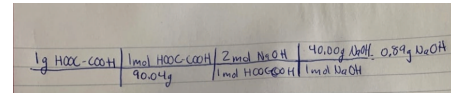
We discuss why it is important to learn from people who are directly affected by the oyster die-offs. We read about different interested parties and brainstorm additional criteria and constraints for our engineering design solutions. We complete an assessment investigating how pH changes as ion concentration 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.

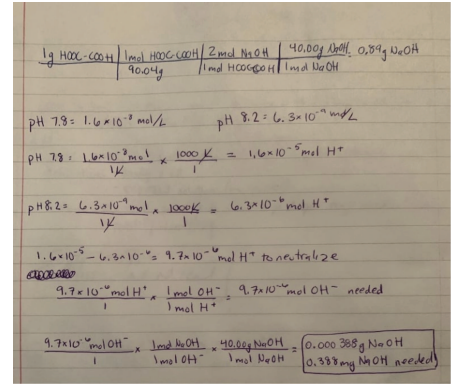
Criteria	Constraints
- produce lots of oysters - move back to old pH as much as possible - preserve as many wild oysters as possible - minimize cost - fast-working	- can't add anything toxic - can't reach pH unhealthy for other organisms - oysters must grow big enough to eat - affordable - shells have 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.

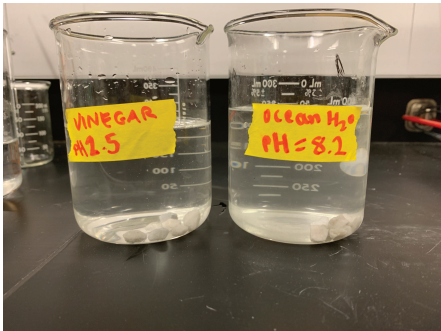
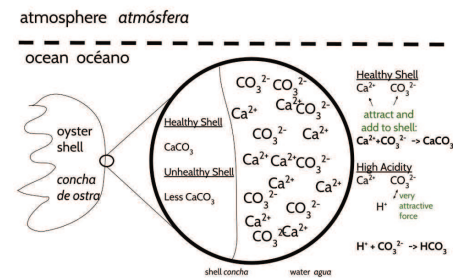
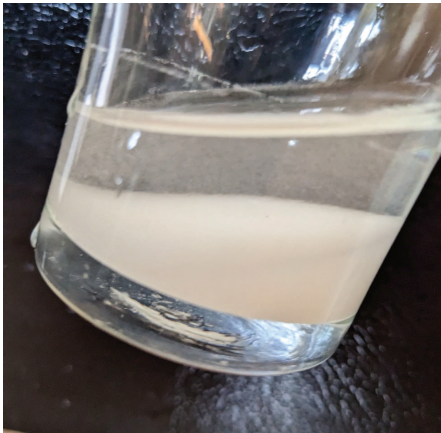
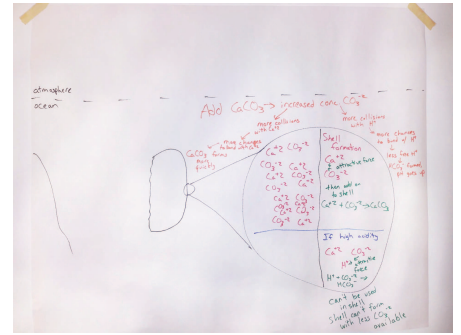
Lesson Set 2: What mathematical models can help us determine the scale of the reactions needed to save oysters?

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 	 <i>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.</i>	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.	

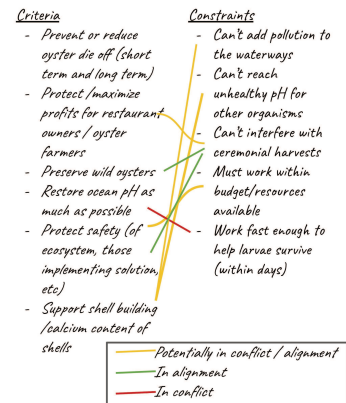
↓ **Navigation to Next Lesson:** Now that we know how to calculate the amount of base needed to neutralize an acid, we have some ideas about how we can apply this to helping oysters by adjusting the pH of water where oysters live.

LESSON 9 Lesson Set 2 2 days How much NaOH would we need to add to make ocean water safe for oysters? Investigation 	 <i>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.</i>	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.	
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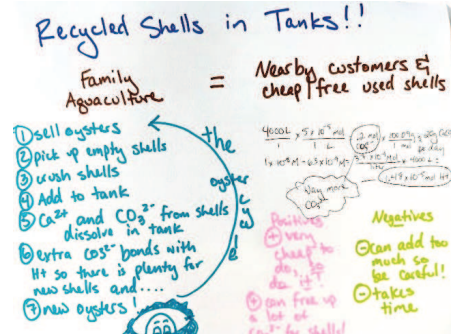
↓ **Navigation to Next Lesson:** We are not convinced that dumping NaOH in the ocean will solve the problem and we think it could be harmful to other living things, but there are other subproblems we identified earlier and have not investigated yet that could give us ideas for other possible solutions 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 	 <i>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.</i>	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.	 The diagram illustrates the process of oyster shell formation. In a 'Healthy Shell' environment, calcium ions (Ca^{2+}) and carbonate ions (CO_3^{2-}) combine to form calcium carbonate (CaCO_3). In a 'High Acidity' environment, hydrogen ions (H^+) from the atmosphere and ocean react with carbonate ions to form bicarbonate ions (HCO_3^-), which prevents the formation of calcium carbonate. The diagram also shows the chemical equation: $\text{H}^+ + \text{CO}_3^{2-} \rightarrow \text{HCO}_3^-$.
↓ 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 	 <i>Increasing temperature or concentration produces more calcium carbonate in a chemical reaction.</i>	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.	 The diagram shows a cross-section of an oyster shell. It illustrates the process of adding calcium carbonate (CaCO_3) to the water to help build the shell. The diagram includes labels for 'atmosphere', 'ocean', 'oyster shell', and 'concha de ostra'. It also shows the chemical equation: $\text{Ca}^{2+} + \text{CO}_3^{2-} \rightarrow \text{CaCO}_3$.
↓ 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 	 <i>Engineers must consider interrelated scientific, technical, and societal criteria and constraints, and develop solutions in context that meet community requirements.</i>	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.	

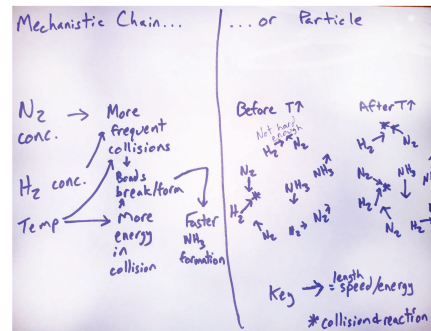
↓ **Navigation to Next Lesson:** We have a qualitative list of social, scientific, and technical criteria and constraints and have identified solutions that we are interested in developing. We wonder how to further clarify and quantify our list of criteria and constraints and need to figure out where 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 	 <i>Site data for different locations in the U.S. help students refine criteria and constraints and develop solutions to help oysters.</i>	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.	
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↓ **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.	<table><tr><th></th><th>Description of criterion</th><th>Reasoning for ranking</th></tr><tr><td>1</td><td>Needs to be low-cost</td><td>This is most important because if it is too expensive, we can't implement it.</td></tr><tr><td>2</td><td>The Indigenous groups in the area need to maintain access for their harvests</td><td>Indigenous people have rights to the land and we want to respect that.</td></tr><tr><td>3</td><td>Removes 0.53 miles of H₂ just twice per day</td><td>This has to happen for the pH to change enough for oyster larvae to form shells.</td></tr><tr><td>4</td><td>Work within the ecosystem</td><td>We don't want to damage other parts of the ecosystem with our solution.</td></tr><tr><td>5</td><td>Minimal time/labor required to implement</td><td>We want oyster farmers to have enough time and labor to do all the other parts of their job.</td></tr></table>		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 0.53 miles of H ₂ just 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 job.
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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 	 <i>The Haber-Bosch process is used to make ammonia fertilizer that can help provide nitrogen to crops.</i>	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 H₂ in the Haber-Bosch process releases large amounts of CO₂ 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.	
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Navigation to Next Lesson: This is the last lesson of this unit.

LESSONS 1-15

33 days total

TEACHER BACKGROUND KNOWLEDGE

Lab Safety Requirements For Science Investigations

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

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

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

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

Please follow these lab safety recommendations for any science investigation:

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



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

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

This unit is the fourth in the OpenSciEd High School Chemistry course sequence, and it is designed to build on previously developed understanding about kinetic molecular theory and patterns in how elements react to apply these ideas to oyster larvae die-offs due to ocean acidification. In the first unit of the course, *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, students developed ideas around kinetic molecular theory in the context of polar ice melt due to global climate change from increased atmospheric carbon dioxide causing sea level rise around the world. In the second unit of the course, *OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit)*, the differential damage caused by lightning in different countries motivated the need for students to build a detailed explanation of how charge (in the form of subatomic particles called electrons) moves between objects. In the third unit of the course, *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*, students used the search for another world for human habitation and the unique properties of water as a context to investigate subatomic structures and identify patterns in how different elements interact in different ways. This fourth unit pushes students to bring together different strains related to kinetic molecular theory and patterns in elements' interactions and apply them to the new situation of combatting the effects of another problem created by humans pumping carbon dioxide into the atmosphere - ocean acidification. This engineering context necessitates the use of stoichiometry to quantify and track matter, quantification of how much carbon is moving between Earth's systems, and careful consideration of how reversible reactions and differing reaction rates work at the particle level.

What is the anchoring phenomenon and why was it chosen?

For the anchoring phenomenon, students use the novel phenomenon of oyster larvae die-offs, overnight events that became widespread in the Pacific Northwest in the mid-2000s as ocean pH reached a new low in that area. Ocean acidification causing larvae die-offs provides the context in which to investigate acids and bases, reversible reactions and chemical equilibria, stoichiometry, reaction rates, carbon's movement through Earth's systems, and how people can apply ideas from chemistry and Earth science to decrease the effects of ocean acidification on oysters.

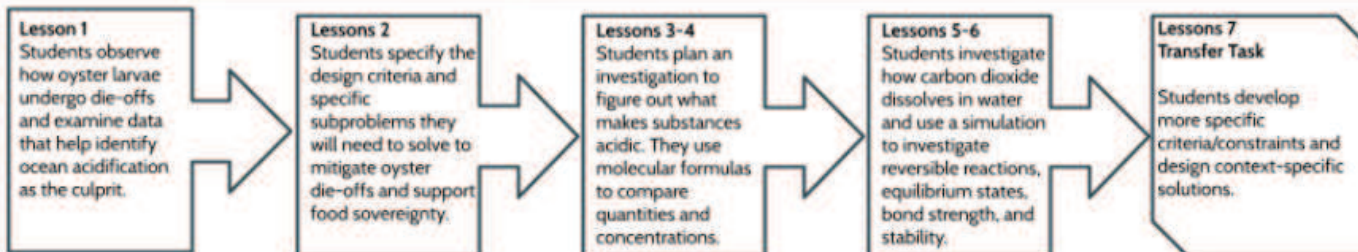
This anchoring phenomenon was chosen from a group of phenomena aligned with the target performance expectations based on the results of a survey administered to students from across the country and in consultation with external advisory panels that include teachers, subject matter experts, and state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

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

How is the unit structured?

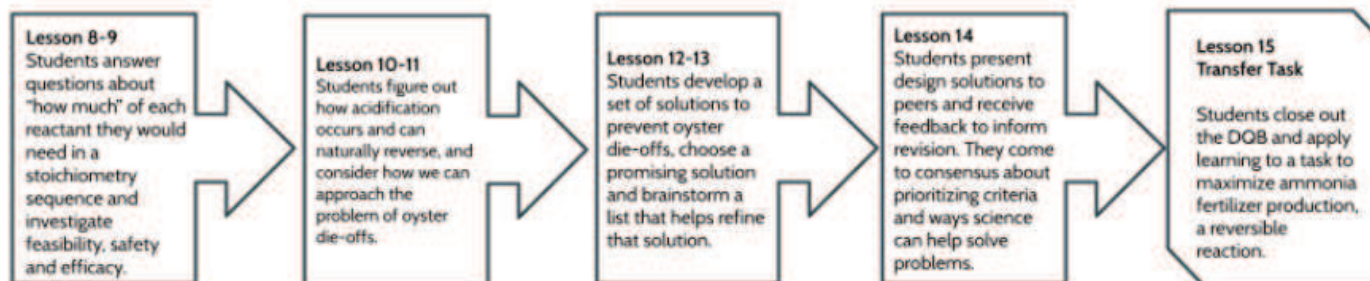
The unit is organized into three main lesson sets. Lesson Set 1 (Lessons 1-6) focus on developing science ideas about acids and bases, how ocean acidification occurs, and an introduction to reversible reactions. In this Lesson Set we begin using our progress tracker to organize our thinking and identify possible solutions to help protect oysters. Lesson Set 2 (Lessons 7-10) shifts the focus to determining how we can quantify substances using stoichiometry and how we specifically intervene to promote shell formation in oyster larvae. Lesson Set 3 (Lessons 11-14) shifts the focus to better clarifying criteria and constraints and applying our learning to develop solutions that will help oysters in specific situations. Students apply these ideas in a transfer task in Lesson 14.

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



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

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



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

This unit is designed to support students in developing an understanding of the **impacts of human activities altering the carbon cycle leading to changes in rates of chemical reactions** in a relevant context. **Asking questions and defining problems** is **intentionally developed** beginning in Lesson 1 as students generate questions about possible **causes** of oyster die-offs for the Driving Question Board. Later in the unit, students **define a design problem and identify social and environmental considerations** as they use concepts of **reversible reactions and reaction rates** to develop **possible solutions** to reduce ocean acidification. **Cause and effect** is intentionally developed as students investigate possible **causes** of ocean acidification and identify **effects of changes to the carbon cycle on chemical reactions** which impact ocean acidification and oyster shell development.

Students **intentionally develop Using mathematics and computational thinking** in the unit. Students **develop mathematical representations and use unit conversions to design solutions and make predictions** about the **outcomes of chemical reactions**. **Scale, proportion and quantity** is **intentionally developed** in this unit. Students consider **scale** when **addressing the problem** of ocean acidification and describe **changes** in pH values. Students examine **changes** to ocean pH values **over time** and **atmospheric carbon dioxide levels** establish a relationship between them. Students **intentionally develop Stability and change** as they investigate those relationships as well as explain **differences in stability** of **chemicals which do and do not undergo reversible reactions**.

This unit builds toward these performance expectations:

HS-PS1-5 Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs.

HS-PS1-6 Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium.

HS-PS1-7 Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.

HS-ESS2-6† Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

HS-ESS3-4* Evaluate or refine a technological solution that reduces impacts of human activities on natural systems.

HS-ETS1-1* Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2† Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

*This performance expectation is developed across multiple units.

†This performance expectation is developed across multiple courses.

This unit intentionally develops students' engagement in these practice elements: Asking Questions and Defining Problems - Ask questions that arise from examining models or a theory, to clarify and/or seek additional information and relationships. - Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations Using Mathematics and Computational Thinking - Create and/or revise a computational model or simulation of a phenomenon, designed device, process, or system. - Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. - Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m³, acre-feet, etc.). The following practices are also key to the sensemaking in this unit: - Developing and Using Models - Planning and Carrying Out Investigations - Constructing Explanations and Designing Solutions - Engaging in Argument from Evidence - Obtaining, Evaluating and Communicating Information	PS1.B: Chemical Reactions - Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. (HS-PS1-5) - In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. (HS-PS1-6) - The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-7) ESS2.D: Weather and Climate Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. (HS-ESS2-6, HS-ESS2-7) - Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. (HS-ESS2-6) ESS3.C: Earth and Human Activity - Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. (HS-ESS3-4) ETS1.A: Defining and Delimiting Engineering Problems - Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (HS-ETS1-1) - Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution; some of which can be addressed through engineering. These global challenges also may have manifestations in local communities. (HS-ETS1-1) ETS1.B: Developing Possible Solutions - When evaluating solutions, it is important to take into account a range of constraints,	This unit intentionally develops students' engagement in these practice elements: Cause and Effect - Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. - Cause and effect relationships can be suggested and predicted for complex natural and human designed systems by examining what is known about smaller scale mechanisms within the system. - Systems can be designed to cause a desired effect. Scale, Proportion, and Quantity - The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. - Patterns observable at one scale may not be observable or exist at other scales. - Using the concept of orders of magnitude allows one to understand how a model at one scale relates to a model at another scale. Stability and Change - Much of science deals with constructing explanations of how things change and how they remain stable. - Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. - Systems can be designed for greater or lesser stability. The following crosscutting concepts are also key to the sensemaking in this unit: - Systems and System Models - Energy and Matter - Structure and Function
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	including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (secondary to HS-ESS3-4) ETS1.C: Optimizing the Design Solution Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed. (secondary to HS-PS1-6)	
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*“Disciplinary Core Ideas” are reproduced verbatim from A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. DOI: <https://doi.org/10.17226/13165>. National Research Council; Division of Behavioral and Social Sciences and Education; Board on Science Education; Committee on a Conceptual Framework for New K-12 Science Education Standards. National Academies Press, Washington, DC. This material may be reproduced and used by other parties with this attribution. If the original material is altered in any way, the attribution must state that the material is adapted from the original.

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

Connections to the Nature of Science (NOS)	
Which elements of NOS are developed in the unit?	How are they developed?
Scientific Knowledge Assumes an Order and Consistency in Natural Systems. Science assumes the universe is a vast single system in which basic laws are consistent.	Students engage deeply with the idea that atoms and mass are conserved during a chemical reaction, especially using the mole for conversion from the atomic to the macroscopic scale. The unit emphasizes assessing students' use of mathematical thinking, especially in Lessons 8, 9, 10, and 15.

Connections to Engineering, Technology and Applications of Science (ETS)	
Which elements of ETS are developed in the unit?	How are they developed?
Influence of Science, Engineering, and Technology on a Society and the Natural World. New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.	Students analyze a number of chemical engineering technologies for mitigating oyster die-offs and they include how these solutions may cause other problems in the larger ocean systems. They analyze a number of costs and benefits to several interested groups.

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

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

This unit uses and builds upon **Disciplinary Core Ideas (DCIs)** and other science ideas that students should have previously developed in the OpenSciEd High School Biology and Chemistry courses.

- Gradual atmospheric changes were due to plants and other organisms that captured carbon dioxide and released oxygen. (*OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*)
- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. (*Fires Unit*)
- Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (tradeoffs) may be needed. (*Fires Unit*)

This unit reinforces and builds from the following science ideas from the OpenSciEd Middle School sequence.

- Particle motion in a substance changes as thermal energy is added or removed. (*OpenSciEd Unit 6.2: How can containers keep stuff from warming up or cooling down? (Cup Design Unit)* and *OpenSciEd Unit 6.3: Why does a lot of hail, rain, or snow fall at some times and not others? (Storms Unit)*)
- Atoms make up molecules. Atoms rearrange in chemical reactions. (*OpenSciEd Unit 7.1: How can we make something new that was not there before? (Bath Bombs Unit)*)

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

- Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation. (*OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*)
- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (*secondary*) (*Fuels Unit*)

- Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. (*Fuels Unit*)
- Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities. (*Fuels Unit*)

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

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

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

What are some common ideas that students might have?

Students will come into the unit with many ideas about acidity and related chemical processes derived from previous classroom experiences, intuitive understandings of the way the world works, everyday experiences with movement, and the conversations they have had with parents, friends, and family members.

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

1. Ocean acidification means that the ocean is becoming acidic, rather than increasing in acidity or decreasing in pH
2. Increased atmospheric carbon dioxide due to human activity primarily causes global climate change without other negative effects
3. Acids are always dangerous and corrosive
4. All corrosive substances are acids
5. A base is a part of an acid
6. A solution with a higher pH is more acidic
7. Only solids can dissolve in liquids
8. All acids or solutions of the same acid are the same in their “strength”
9. All reactions are irreversible
10. Irreversible processes are chemical while reversible processes are physical
11. Equilibrium means that no reaction is occurring
12. Neutralization breaks down an acid into something safe
13. The coefficients in a chemical equation can describe the mass ratios of the substances in the reaction
14. Moles, molar mass, and mass are all interchangeable
15. A reaction between substances either does or does not occur and there is little people or other organisms can do to alter a reaction rate

“Acid” is the common term applied to a solution which has a significant concentration of H^+ ions (or, more accurately, H_3O^+ ions), while a base is a solution that has a significant concentration of OH^- ions. There are other, more general definitions of an acid and base, but these Arrhenius definitions are used in this unit. A substance is acidic if it has a pH below 7 and basic if the pH is above 7; a substance with a pH of 7 is considered neutral. The acidity of the ocean is increasing (meaning the pH is still above 7 but decreasing) due to the reaction of atmospheric carbon dioxide with ocean water to form carbonic acid, H_2CO_3 . Although this is another consequence of increased atmospheric carbon dioxide, it is a separate phenomenon from global climate change. This process requires carbon dioxide to dissolve into the ocean, and acidification is in fact a reversible reaction - the reaction goes forward and backward at the same rate until more carbon dioxide is added.

Adding bases to ocean water to increase its pH (similar to how acids and bases neutralize) simply consists of adding OH^- ions that react with H^+ ions to decrease acidity. The amount of base needed can be calculated using stoichiometry, in which the coefficients in a balanced reaction can be used as ratios of the amount of the different substances. A mole is a number used to describe 6.02×10^{23} of any object (typically an atom, molecule, or ion), while the molar mass is the mass of one mole of an element or molecule (derived from the periodic table). Just as the amounts of substances present after a reaction have reached equilibrium if more of one substance is added, reaction rates can also be altered by changing the concentration, temperature, or surface area of reactants.

It is valuable to think of ideas like these not as misconceptions that need to be erased but as productive ideas that we can use to build understanding. Not only does this help some students feel more comfortable talking about science and build a scientific identity, it improves science learning across the board. For example, students may think from early in the unit that oyster larvae have trouble building shells because acid is “eating away” at the oysters or that acidity somehow prevents the oyster from accessing Ca^{2+} ions with which to form calcium carbonate shells. In fact, the dominant mechanism is that excess H^+ ions can bond with CO_3^{2-} ions to form HCO_3^- , leaving oysters with less available CO_3^{2-} with which to form shells. This is a complex process that students will understand better if, as in Lesson 9, they engage in an investigation that shows them that shells do not dissolve significantly in water with a similar pH to the ocean and model how the interactions of ions result in increased acidity making shell formation more difficult.

How will I need to modify the unit if taught out of sequence?

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

- If taught before OpenSciEd High School Biology, supplemental teaching of carbon cycling due to photosynthesis, respiration, and decomposition will be required.
- If taught earlier in the school year, supplemental teaching of the kinetic theory of matter, ionic bonding and balancing chemical equations may be required.

- If taught as part of an AP Chemistry course, be prepared to provide students with additional support around rate laws, reaction mechanisms, catalysis, equilibrium constants and solubility equilibria, calculation of pH/pOH/pK_a, and properties of buffers.

If this unit is taught before *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*, consider using lesson set 1 from C.1 Polar Ice before you begin this unit in order to establish anthropogenic climate change.

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

We recommend allocating time so that the entire course can be taught. Depending on your priorities for physical and earth and space science, you may condense and focus students on the following parts. If you condense the unit, you will lose important sensemaking for students.

- Lessons 1-8 focus on acid-base interactions (especially HS-PS1-5 and HS-PS1-6).
- Lessons 6-10 focus on stoichiometry and reversible reactions and equilibrium (especially HS-PS1-7). This is where key components of water chemical engineering occur when the “what is killing oysters” question gets answered.
- Lesson 11-15 focuses on balancing the needs of interested parties in solving a difficult chemical engineering problem (ETS1-1, ETS1-2, and ETS1-3).

To extend or enhance the unit, consider following all lesson extensions

- A number of lessons have extension opportunities and alternate activities. See lessons 4, 5, 10, 11, and 15 for built-in extensions.
- Spend more time on **carbon cycle thinking and sequestration**, building from storing carbon in rocks in Lesson 13. You could accomplish a number of DCI-related objectives related to PS and ESS and ETS thinking, especially in the context of an Earth Science course or focus. A carbon sequestration focus could lead into C.5 Fuels unit coherently.
- Investigate how pH levels fluctuate in the natural world, such as in aquariums, soil, or in other living things, beyond what is presented in Lesson 4 Home Learning.

Additional guidance for extensions are given within each teacher guide. There are several throughout the unit.

What mathematics concepts will students engage with in the unit?

This unit requires students to use unit conversions to reason about algebraic equations (mathematical models) that they collaboratively build from data. This unit does not assume students are fluent with the mathematical practices listed below, but that students develop these practices as part of the sensemaking. Thus these standards are not so much prerequisites, as co-requisites. If students are simultaneously developing the skills and vocabulary in math class, you can help by making explicit connections to the mathematical standards below.

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

Category	Code	Domain and Heading	Standard	Lesson
Number and Quantity	CCSS.MATH.CON TENT.HS.N-Q.1	Quantities: Reason quantitatively and use units to solve problems.	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays	8, 9, 11, 13, 15

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

OpenSciEd units are designed to promote equitable access to high-quality science learning experiences for all students. Each unit includes strategies which are integrated throughout the OpenSciEd routines and are intended to increase relevance and provide access to science learning for all students. OpenSciEd units support these equity goals through several specific strategies such as: 1) integrating Universal Design for Learning (UDL) Principles during the unit design process to reduce potential barriers and increase accessibility for

students to engage in learning experiences; 2) developing and supporting Community Agreements that encourage a safe learning culture; 3) supporting classroom discourse to promote students in developing, sharing, and revising their ideas; and 4) specific strategies for supporting emerging multilingual students in science classrooms.

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

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

The example callout below highlights how alternate activities are provided to support a wider variety of learners.

ALTERNATE ACTIVITY- You may also show the story of Koo-Kwal-Alwoot (kuh-KWAL-ah-wit) with <https://youtu.be/2ZkXdmWXHdE> with **slide D**. It will add additional context for how seafood is more than biologically sustaining for the Swinomish Tribal Community. Students in your class may also have traditional, cultural, or religious reasons for connecting with first foods in similar ways. You may also distribute *Koo-Kwal-Alwoot Transcript* to go with it.

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

The OpenSciEd instructional model focuses on the teacher being a member of the classroom community, supporting students to figure out scientific ideas motivated by their questions about phenomena. Students iteratively build their understanding of phenomena as the unit unfolds. To match the incremental build of a full scientific model across the unit, the science content background necessary for you to teach individual lessons incrementally builds too. Throughout the unit, we provide just-in-time science content background for you that is specific to the Disciplinary Core Ideas (DCIs) that will be figured out in a lesson. Places to look for this guidance include the “Where we are going” and “Where we are not going” sections for each lesson. Also, the expected student responses, keys, and rubrics illustrate important science ideas that should be developed in each lesson. The K-12 Science Framework is another great resource to learn more about the DCIs in this unit (**PS1.B: Chemical Reactions**, **ESS2.D: Weather and Climate**, **ESS3.C: Human Impacts on Earth Systems**, **ETS1.A: Defining and Delimiting Engineering Problems**, **ETS1.B: Developing Possible Solutions**, **ETS1.C: Optimizing the Design Solution**), including what students have learned previously and where they are headed in high school. In addition to the science content background information embedded in the lesson resources, below we provide recommended resources that can help build your understanding of phenomena and Performance Expectations bundle for this unit:

- to learn a model-based view of reversible reactions and dynamic equilibrium
 - Engage with the simulation that students use ahead of time to learn the mechanism of reversibility: <https://opensci-ed-static.s3.amazonaws.com/HTML+Files/Water+and+Carbon+Dioxide+Interactions.html>
 - An additional model for equilibrium leveraging the Haber Process (N_2 & H_2) is here: <https://www.netlogoweb.org/launch#https://www.netlogoweb.org/assets/modelslib/Curricular%20Models/Connected%20Chemistry/Connected%20Chemistry%20Reversible%20Reaction.nlogo>
- to learn more about the restoration of oysters, visit the
 - website of Imani Black, aquaculturist who contribute to this unit: <https://www.baltimoremagazine.com/section/gamechangers/gamechanger-imani-black-minorities-in-aquaculture/>
 - oyster life cycle reference in Lesson 10
- to learn more about oysters and indigenous food sovereignty:
 - <https://www.si.edu/newsdesk/releases/indigenous-peoples-have-shucked-billions-oysters-around-world-sustainably>
- to reach the Swinomish Shellfish Company to buy oysters or contribute to their efforts:
 - shellfishco@wsinomish.nsn.us
 - www.swinomishshellfishcompany.com
- to learn about climate change education:
 - Data and information about other aspects of climate change: <https://www.climate.gov/climatedashboard>
 - Common misconceptions about climate change: <https://theconversation.com/five-climate-change-science-misconceptions-debunked-122570>
 - Generation Dread and psychological responses to climate crisis: <https://www.britttray.com/gen-dread>

There are several additional factors at play in ecosystems that are outside the scope of the NGSS but may occur to the teacher. Do not pursue these ideas with students unless they have already suggested the concepts based on evidence.

1. Carbon dioxide, like many gasses, dissolves more easily in lower-temperature water, as the gas molecules do not escape as easily when the particles around them are moving relatively slowly.
2. This will not show up in students' investigations, but calcium carbonate formation from dissolved ions is actually favored in the long run at lower temperatures. This occurs because of the relative bond energy of the intermolecular forces that water forms with the dissolved ions compared to the bond energy of the calcium-carbonate bond. This will not show up in classroom level investigations, but it is a nuanced part of aquaculture chemistry.
3. Other compounds that do not contain carbonate may also support marine ecosystems. For more information, see <https://www.frontiersin.org/articles/10.3389/fclim.2019.00007/full>.

How do I support students' emotional needs?

This unit is anchored by the phenomenon of oyster larvae die-offs due to ocean acidification. Students figure out in the course of the unit ocean acidification, like climate change, is a consequence of the tremendous rate at which human beings have been transferring carbon from underground into the atmosphere in the form of carbon dioxide. Any hopes to protect wild and cultivated oysters rely on collective changes in human behavior as well as mitigation strategies that come from chemical engineering. For this reason, the unit was built to give students multiple opportunities to engage in Social Emotional Learning.

Social awareness. In Lesson 1 and Lesson 7, students have opportunities to engage with stories of people who have been or could be negatively impacted by ocean acidification. Give students space to think about what it would feel like to be in a position where they are affected. The site profiles in Lesson 13 also help give students a clearer picture of the experiences of stakeholders in the problem of oyster die-offs, and students are pushed to think deeply about this picture as they develop designs that would be appropriate for these stakeholders.

Self-awareness. At several points, students are explicitly directed in considering their own emotions and actions. In the Lesson 10 gallery walk, in which students are explicitly directed to identify similarities and differences between models without evaluating or judging them. You may also wish to promote self-awareness in Lessons 1 & 2. As students think about the problem of oyster larvae die-offs, they may become despondent. The Teacher Guide provides support to help cultivate critical hope. Teachers can also encourage students to sign up for the Generation Dread newsletter, which contains psychological research about the progression of climate change anxiety and how it can support action.

Climate Change Anxiety. Educate yourself on the phenomenon of climate anxiety. More than two-thirds of Americans, including 84% of those aged 16 to 25, are at least moderately worried about climate change. This brief piece from Harvard Medical School provides an excellent starting point: <https://www.health.harvard.edu/blog/is-climate-change-keeping-you-up-at-night-you-may-have-climate-anxiety-202206132761>. Other online resources, such as the *Emotional Resilience Toolkit for Climate Work (Version 1.5)* <https://static1.squarespace.com/static/5f74c9f17e186b15c051629e/t/5fad42316947a58febe7782/1605223460375/Copy+of+Copy+of+Emotional-Resilience-Toolkit-for-Climate-Work-v1.5-04Oct19-2.pdf>, also offer other tools to help students manage their emotions when studying climate change (Climate Therapy Alliance - Pacific Northwest, 2019). Be aware that students who are struggling may demonstrate a variety of behaviors including, but not limited to: fidgeting, withdrawal, disruption or distraction, rapid breathing, holding of breath, and change in body language or tonation. If you notice a student might be struggling, share what you are observing and ask if they need some help. Often in science classrooms, we are focused on evidence and data. When addressing a phenomenon or design solution that straddles the nature-culture divide, like this one, supporting students in using an empathy or socio-emotional lens will also be important. Make space for students to process, and validate their feelings and reactions. These opportunities were built in throughout the unit.

Furthermore, an important part of addressing climate anxiety is recognizing that there is hope. Lesson Set 3 focuses on how people can work together to address the problem that humanity created and considering the wider, interconnected effects of science and engineering on human and more-than-human relations.

Responsible decision making. Lesson Set 3 includes supports to push students to consider how they can make decisions about design solutions in a way that considers those who are affected (Lessons 12 and 13) as well as technical, environmental, and financial considerations (Lesson 13). In Lesson 14, students explore how differences in values result in different decisions and further consider unintended effects of decisions.

Relationship skills. Throughout the unit, structures support students' interactions with each other. Particular examples include the use of Scientists Circles to promote equitable discussion, the 3 Stray, 1 Stay protocol in Lesson 13 to support communication of ideas, and peer feedback guidance in Lesson 14 to help students provide useful and respectful feedback.

For more support around social-emotional learning, visit <https://casel.org/>.

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

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

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

In this unit, students confront the issue of oyster die-offs through the initial lens of indigenous leaders and aquaculturists. In Lesson 1, food sovereignty is established; oysters are a "first food" for many indigenous peoples of the Pacific Northwest and essential to the "nourishment of more than just bodies" (see Alana Quintasket Transcript). This places the issue of oysters and food access as central to the unit and provides a broader ethical reason to care about their survival. In Lesson 2, students identify the subproblems of oyster die-offs they can use chemistry and engineering to solve. In Lessons 4-7, students design and conduct investigations that help them investigate solutions that could help oysters inside the confines of the hatchery and then to think critically about whether they could add "that much" of a base to the ocean. They determine that while it might be possible, it would be ethically problematic. In Lesson 7 students re-encounter many voices that explain the stakes of the decision to help oysters and these rights holders or interested parties are revisited throughout Lessons 8-15 as students focus on engineering design and the delicate reversible balance of CO₂ and H⁺ ions in the water needed to support oysters.

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

Guidance for Developing Your Personal Glossaries

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

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

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

Lesson	Words we earn	Words we encounter
L1	ocean acidification	larvae
L2		
L3	pH, acid, base, concentration	molarity, neutralization
L4	carbon cycle	
L5	reversible reaction, equilibrium	weak and strong acids and bases
L6	interested parties	criteria, constraints
L7	mole, molar mass, mole ratio	neutralization, stoichiometry
L8	molarity	
L9		spat, seed oysters
L10	reaction rate	
L11		
L12		
L13	trade-offs	

L14		ammonia, Haber-Bosch process
L15		

HOME COMMUNICATION

Dear Guardian,

Your student's high school chemistry class is starting a unit called *Why are oysters dying, and how can we use chemistry to help them?*, as part of the OpenSciEd high school science curriculum. This unit develops science ideas about acid-base reactions and engineering with chemistry. Throughout the unit, students will draw on their own experiences and everyday understandings to help them figure out complex science ideas.

In the first few lessons of the unit, students will engage with important ideas about your family and community foods. They may ask you about your family's historical foods. Here are some things to consider:

- foods that your great-grandparents' generation may have eaten, even if they are lost to you today
- ways that your family's foods have changed over generations
- ways that your child can connect with food or agricultural traditions in your family or community

Food sovereignty, or access to a reliable, quality food supply chain, is an important part of healthy communities. Helping your child know where their food comes from is empowering. Throughout the unit, students investigate ways to help restore an important food and environmental protection agent for one US culture: the Olympia oyster.

The major cause of oyster decline is water's increased acidification caused by human burning of fossil fuels. This is related to global climate change. If your student is anxious about the future of the global climate, you can contact me at ___(contact information here)___ or the school counselor at ___(contact information here)___ . By knowing about your student's experiences and concerns in advance, we can be sensitive to their needs.

How to your student make sense of their learning:

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

Please get in touch if you have any additional questions or concerns. I am looking forward to working with your student.

Best,

(Your name or signature here)

Querido guardián,

La clase de química de la escuela secundaria de su estudiante está comenzando una unidad llamada *¿Por qué están muriendo las ostras y cómo podemos utilizar la química para ayudarlas?*, como parte del plan de estudios de ciencias de la escuela secundaria OpenSciEd. Esta unidad desarrolla ideas científicas sobre reacciones ácido-base y la ingeniería química. A lo largo de la unidad, los estudiantes aprovecharán sus propias experiencias y conocimientos cotidianos para ayudarlos a descubrir ideas científicas complejas.

En las primeras lecciones de la unidad, los estudiantes considerarán ideas importantes sobre los alimentos de su familia y comunidad. Es posible que le pregunten sobre las comidas históricas de su familia. Aquí hay algunas cosas a considerar:

- Alimentos que la generación de sus bisabuelos pudo haber comido, incluso si hoy los ha perdido.
- Formas en que los alimentos de su familia han cambiado a lo largo de generaciones.
- Maneras en las que su hijo puede conectarse con las tradiciones alimentarias o agrícolas de su familia o comunidad.

La **soberanía alimentaria**, o acceso a una cadena de suministro de alimentos confiable y de calidad, es una parte importante de las comunidades saludables. Ayudar a su hijo a saber de dónde viene su comida es empoderador. A lo largo de la unidad, los estudiantes investigan formas de ayudar a restaurar un importante agente de protección ambiental y alimentaria para una cultura estadounidense: la ostra Olympia.

La causa principal de la disminución de las ostras es la mayor acidificación del agua provocada por la quema de combustibles fósiles por parte de los seres humanos. Esto está relacionado con el cambio climático global. Si su estudiante está ansioso por el futuro del clima global, puede contactarme en [___\(información de contacto aquí\)___](#) o el consejero escolar en [___\(información de contacto aquí\)___](#). Al conocer de antemano las experiencias e inquietudes de su estudiante, podemos ser sensibles a sus necesidades.

Cómo hacer que su estudiante dé sentido a su aprendizaje:

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

Póngase en contacto si tiene alguna pregunta o inquietud adicional. Tengo muchas ganas de trabajar con su estudiante.

Sinceramente,

[\(Su nombre o firma aquí\)](#)

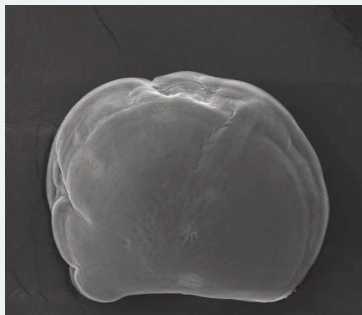
LESSON 1: What is happening to oysters?

PREVIOUS LESSON *There is no previous lesson.*

THIS LESSON

ANCHORING PHENOMENON

3 days



Oregon State University

We hear from primary sources about a “first food” restoration effort in the Pacific Northwest and learn about threats to the oyster populations. We see on a map that oyster populations are declining along US coastlines. We identify potential causes of oyster die-offs and analyze data that lead us to identify possible causes. We read about how carbon dioxide in the atmosphere is entering the ocean and making it more acidic, which harms oysters and the ecosystem that relies on them. We develop an initial model to explain how carbon dioxide causes increased acidity that hurts oysters. We ask questions and generate ideas for investigations that will guide our work.

NEXT LESSON *We will want to prevent oyster die-off. We will decide to break the problem into subproblems, then brainstorm initial ideas for big picture approaches to solving each subproblem. Ultimately we will develop an argument about which subproblem to pursue.*

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-1,
HS-ETS1-2



WHAT STUDENTS WILL DO

1.A Develop a model using evidence that compares large-scale carbon dioxide changes to explain small-scale oyster die-offs using particle-level interactions. (SEP: 2.3; DCI: ESS2.D.3; CCC: 3.4)

1.B Ask questions to clarify how oyster populations and changes in climate due to atmospheric carbon dioxide are connected. (SEP: 1.2; DCI: ESS2.D.3; CCC: 7.1)

WHAT STUDENTS WILL FIGURE OUT

- Oyster farms have experienced sudden die-offs of oyster larvae due to something in the water, and oysters have been declining due to changes in the water in the Pacific Northwest and elsewhere.
- Oysters are an important part of many Indigenous peoples' and others' livelihood and culture.
- 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 provide habitat and help hold coastal land in place, reducing impacts from storms and rising sea levels.

Lesson 1 • Learning Plan Snapshot

Part	Duration	Summary	Slide	Materials
1	7 min	ENGAGE CONNECTION WITH SPECIAL FOODS Elicit students' ideas of culturally important foods to their families/communities.	A-B	
2	8 min	SHARE VIDEO(S) OF ALANA QUINTASKET Share the video of Alana Quintasket's community effort to revitalize oysters and the (optional) video of oysters' significance.	C-E	Unknown material with identifier: cc.l1.rdg1, Unknown material with identifier: cc.l1.rdg2 (optional if alternate video is shown), https://youtu.be/zKyfbGbRz7c , https://youtu.be/2ZkXdmWXHdE (optional alternate video)
3	9 min	SHARE VIDEO OF STUART THOMAS Share a video of Stuart Thomas and guide students' concerns toward oyster die-offs and water quality.	F-G	Unknown material with identifier: cc.l1.rdg3, https://youtu.be/UlOSbJD92og
4	6 min	PREDICT THE CAUSE OF OYSTER DIE-OFFS Have students hypothesize the cause of die-off events.	H-J	
5	5 min	REVISIT COMMUNITY AGREEMENTS Lead the class in revisiting community agreements and individually identifying a focal agreement to work on during the unit.	K	Community Agreements
6	7 min	EXAMINE DATA ON POTENTIAL CAUSES OF OYSTER DIE-OFFS Distribute different data sets to different students that allow them to examine whether proposed potential causes of oyster die-offs could be contributing factors.	L	Die-Off Causes Analysis, Ocean Temperature Map, Carbon Dioxide Maps, Pollution Data, Ocean Acidity Maps
7	3 min	NAVIGATE Assign home learning in which students ask about special foods in their families and communities.	M	Traditional Foods
<i>End of day 1</i>				
8	3 min	NAVIGATE Discuss the home learning and focus on how to investigate oyster die-off events.	N	Traditional Foods
9	6 min	DISCUSS DATA ON POTENTIAL CAUSES OF OYSTER DIE-OFFS Organize students into groups based on which data set they analyzed. Build consensus about whether the causes we read about could be responsible for the effect of oyster die-offs.	O-Q	Die-Off Causes Analysis, Ocean Temperature Map, Carbon Dioxide Maps, Pollution Data, Ocean Acidity Maps

Part	Duration		Summary	Slide	Materials
10	5 min		READ ABOUT THE BILLION OYSTER PROJECT Distribute <i>Billion Oyster Project</i> and lead students in a discussion about acidification and oysters' role in water filtration.	R-U	<i>Billion Oyster Project</i> , https://youtu.be/RimJKVqvzUA (optional)
11	10 min		DEVELOP INITIAL MODELS Distribute <i>Initial Modeling</i> and direct students to model how atmospheric carbon dioxide causes problems for oysters' shells.	V	<i>Initial Modeling</i>
12	7 min		COMPARE SIMILARITIES AND DIFFERENCES IN INITIAL MODELS Have students meet with several partners to compare their initial models.	W	<i>Initial Modeling</i>
13	14 min		BUILD INITIAL CONSENSUS MODEL Organize the class into a Scientists Circle to hold a Consensus Discussion around what should be included in a model of how atmospheric carbon dioxide hurts oysters.	X-Y	chart paper, chart paper markers
<i>End of day 2</i>					
14	3 min		NAVIGATE Direct students' attention back to the consensus model so they can identify new, interesting, and confusing parts of it.	Z	class consensus model
15	7 min		IDENTIFY RELATED PHENOMENA Lead students in a discussion of phenomena similar to the strange effects on oysters' shells.	AA	
16	25 min		RECORD QUESTIONS AND BUILD THE DRIVING QUESTION BOARD Direct students to record new questions about the anchoring phenomenon on 3x3 sticky notes. Lead students in building a Driving Question Board for the unit.	BB-CC	3 3x3 sticky notes, permanent markers, class consensus model, Driving Question Board, chart paper markers
17	10 min		GENERATE IDEAS FOR FUTURE INVESTIGATIONS Lead students in generating ideas for future investigations that could be done in the unit.	DD	chart paper, class consensus model, chart paper markers
<i>End of day 3</i>					

Lesson 1 • Materials List

	per student	per group	per class
Lesson materials	- science notebook <i>Unknown material with identifier: cc.l1.rdg1</i> <i>Unknown material with identifier: cc.l1.rdg2</i> (optional if alternate video is shown) <i>Unknown material with identifier: cc.l1.rdg3</i> <i>Die-Off Causes Analysis</i> <i>Ocean Temperature Map</i> <i>Carbon Dioxide Maps</i> <i>Pollution Data</i> <i>Ocean Acidity Maps</i> <i>Traditional Foods</i> <i>Billion Oyster Project</i> <i>Initial Modeling</i> 3 3x3 sticky notes - permanent markers		https://youtu.be/zKyfbGbRz7c https://youtu.be/2ZkXdmWXHdE (optional alternate video) https://youtu.be/UlOSbJD92og - Community Agreements https://youtu.be/RimJKVqvzUA (optional) - chart paper - chart paper markers - class consensus model - Driving Question Board

Materials preparation (40 minutes)

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

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

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

Add images of traditional foods to **slide B**. This slide is currently blank for this purpose. Ask cultural experts in your community to weigh in on foods that are important to the students in your school, especially foods that are no longer eaten or for which recipes have been lost. Consider asking guidance counselors, translators/interpreters, office staff, or cultural liaisons. Try to include as many cultural groups as you can.

Test the videos to be sure they play correctly:

- <https://youtu.be/zKyfbGbRz7c>
- <https://youtu.be/2ZkXdmWXHdE> (optional)
- <https://youtu.be/UlOSbJD92og>
- <https://youtu.be/RimJKVqvzUA> (optional)

Make the video transcripts available to students to follow along:

- Unknown material with identifier: cc.l1.rdg1*
- Unknown material with identifier: cc.l1.rdg2* (optional)
- Unknown material with identifier: cc.l1.rdg3*

Print *Billion Oyster Project*.

Ensure access to a color version of each of the following so every student has one of the four:

- Ocean Temperature Map*
- Carbon Dioxide Maps*

- *Pollution Data*
- *Ocean Acidity Maps*

Have your Community Agreements visible on day 1. If your Community Agreements are posted on chart paper, students can reflect on them by marking them with green and yellow dot stickers or 3x3 sticky notes. Alternatively, you might create a virtual representation of the Community Agreement so your students can mark green and yellow “stickies” or dots on them for reflection. You can use Google Jamboard by setting an image of your community agreements as the background and having students add stickies, or use a shared slide of the Community Agreement with a green dot and a yellow dot for students to copy/paste and drag to where they want them.

Obtain four pieces of chart paper--two pieces for the initial consensus model, one for the Driving Question Board (DQB), and one for ideas for investigations. Prepare the chart paper for the class consensus model by making an approximation of the blank model on *Initial Modeling*. Be sure to leave some space at the top and bottom, as more information will be added to this model throughout the unit.

Make sure you have materials ready to add 3x3 sticky notes with student questions to the Driving Question Board. Include the unit question at the top of the DQB: *Why are oysters dying, and how can we use chemistry to protect them?*

Lesson 1 • Where We Are Going and NOT Going

Where We Are Going

The targeted disciplinary core idea that we are continuing to develop in this lesson is:

- **ESS2.D.3 Weather and Climate:** Changes in the atmosphere ~~due to human activity~~ have increased carbon dioxide concentrations ~~and thus affect climate~~.

Crossout explanation: This DCI was first developed in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*. This lesson includes chemistry (acidification) as part of the climate change model, expanding the energy-movement model in C.1: Polar Ice. The narrow term “climate” does not typically include ocean-atmosphere interactions, so it is crossed out, but global changes in water acidity are another direct result of anthropogenic climate change.

In addition, this lesson leverages a disciplinary core idea about chemical reactions that was first introduced in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*:

- **PS1.B.3 Chemical Reactions:** The fact that atoms are conserved, together with the knowledge of the chemical properties of the elements involved, can be used to ~~describe and~~ predict chemical reactions.

Students should have already developed [SEP: 2.3](#): Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system in *Polar Ice Unit*, *Electrostatics Unit*, and *Space Survival Unit*. In this lesson, students develop models to illustrate relationships between systems to explain ocean acidification. Students continue to develop portions of this SEP element throughout this unit. For example, in Lesson 7 students use models based on investigation evidence to predict relationships between components in a system as a result of adding a substance to neutralize an acid.

This lesson leverages everyday experiences to focus students on a problem of food traditions and food security, eventually settling on understanding recent changes that are causing oyster die-off events in the Pacific Northwest.

Students consider potential causes of oyster die-offs so that they can identify increased ocean acidity as the likely culprit. Beyond that point, students need to solidify ocean acidification due to increased atmospheric carbon dioxide as the cause of oyster die-offs and think about why this matters to people.

Next, students model Earth's interacting systems to discover what they do and do not understand as they explain acidification and oyster die-offs, including the carbon dioxide particles and their interactions in the atmosphere and hydrosphere, and how those systems and their components might be investigated in future lessons ([SEP: 2.3](#); [DCI: ESS2.D.3](#)).

This model-building presses students to the edges of their current knowledge about particle-level interactions occurring in the system causing large-scale die-offs, that they developed when thinking about lightning in *Electrostatics Unit* ([CCC: 3.4](#)). Incorporation of this thinking helps students generate questions that will be productive in later lessons. Students specifically develop orders of magnitude understanding as they explain changes in pH due to H⁺ ion concentration (Lesson 3), develop ways to quantify large numbers of molecules (Lesson 8), and evaluate design solutions using scale thinking (Lesson 14).

The investigation materials in days 2 and 3 of the unit focus on the central cause of ocean acidification: anthropogenic climate change and CO₂ emissions, and seek to explain how the changes in the air can change other systems, such as in aquatic life ([CCC: 7.1](#)). In the final steps of the unit, students ask investigable questions that arise after they examine their models as they build a Driving Question Board ([SEP: 1.2](#)). They focus on the chemical phenomenon of ocean acidification and atmospheric carbon dioxide's interaction with the water ([DCI: ESS2.D.3](#)).

Unit sequencing note: If students do not have the background knowledge of **anthropogenic climate change**, consider using materials from *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)* before this unit.

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

Where We Are NOT Going

Students will leave this lesson without a clear particle-level explanation for how carbon dioxide gets into the ocean from the atmosphere, how carbon dioxide causes ocean acidification, or why increased acidity makes it difficult for oysters to build shells. Students explore these ideas throughout the unit, starting in Lesson 3. Partial understandings are perfectly acceptable here. The term *pH* is also intentionally downplayed in this lesson so that students can leverage the more familiar-sounding and evocative *acidity*. Relevant chemical equations will also be discovered throughout the unit as students seek to answer questions asked in this lesson.

LEARNING PLAN for LESSON 1

1 · ENGAGE CONNECTION WITH SPECIAL FOODS

7 min

MATERIALS: None

Introduce the unit. Show **slide A**. Say, *Our next unit will focus on some special foods. What are some special foods in our families and community? Think about foods you share that are especially nourishing, foods you eat at special times, or any foods that your family has lost access to that you wish you could eat.* Ask students to share with a partner for 30 seconds and then ask students to share what they heard as a class. *

Encourage students to describe ingredients and share the histories of their foods. You may ask questions like:

- You have a really long history with that food. Did anyone else hear about a grandparent or great-grandparent's recipe?
- Did anyone hear a story from their partner about a food that was lost to their family or community?

Sum up. Say, *I had conversations with people in our school community before we started this unit. Do any of you recognize some of these foods?* Show **slide B** containing images you have added of locally important foods. Say, *A lot of us have lost our traditional foods over the last century or so for a variety of reasons, like moving, industrialization, and "big food" industries. We are going to hear from someone who almost lost a really important food for their family and community.*

* ATTENDING TO EQUITY

"Related experiences" and community connections are usually made after introducing the scientific phenomenon in an Anchoring Phenomenon Routine. However, this unit makes **related experiences salient first** to support students in engaging their background knowledge as they watch the videos. The related experiences portion of the anchoring phenomenon routine is important in helping students bridge home and school learning and leads to deeper engagement.

Connecting with students' ancestral or traditional resilience and knowledge is a strategy for trauma-informed teaching and for making students' family and community experiences relevant in schools..

2 · SHARE VIDEO(S) OF ALANA QUINTASKET

8 min

MATERIALS: science notebook, *Unknown material with identifier: cc.l1.rdg1*, *Unknown material with identifier: cc.l1.rdg2* (optional if alternate video is shown), <https://youtu.be/zKyfbGbRz7c>, <https://youtu.be/2ZkXdmWXHdE> (optional alternate video)

Show the Alana Quintasket video. Display **slide C**. Distribute *Unknown material with identifier: cc.l1.rdg1*. Show <https://youtu.be/zKyfbGbRz7c>. *

After the video, say, *This connection to food and being able to access your important foods is sometimes called "food sovereignty."*

ALTERNATE ACTIVITY

You may also show the story of Ko-Kwal-Alwoot (kuh-KWAL-ah-wit) with <https://youtu.be/2ZkXdmWXHdE> and **slide D**. It will add additional context for how seafood is more than biologically sustaining for the Swinomish Tribal Community. Students in your class may also have traditional, cultural, or religious reasons for connecting with first foods in similar ways. You may also distribute *Unknown material with identifier: cc.l1.rdg2* to go with the video.

Have students summarize key points. Display **slide E**. Ask them to turn and talk to a partner to identify three reasons oysters are special to Alana's community. * Student examples may include: *

- the timescale of the community's dependence on oysters ("since time immemorial")
- a sense of sacredness or connection ("more than just our bodies")

* ATTENDING TO EQUITY

Swinomish = SWIN-uh-mish

It's good to use the proper names for people and groups. The Swinomish Tribal Community is known as such because "tribe" and "nation" are inaccurate -- many tribes and nations make up the Swinomish Tribal Community.

* ATTENDING TO EQUITY

Focus on restoration efforts. Ask students to identify what Alana said about Indigenous efforts to restore oysters. Students should identify that the Swinomish Tribal Community has a “Swinomish Shellfish company” that is working to help with oysters. If students do not remember this from the video, ask them to consult the transcript or rewatch the video.

Translanguaging and Supporting EML Students. It is important to encourage students to represent their ideas in a way that is meaningful to them. This may include using any languages they can to best think through their ideas. As they continue to express their ideas and hear others' ideas, their linguistic repertoires in science will deepen. This practice of encouraging *translanguaging* should be encouraged in all OpenSciEd High School units.

*** SUPPORTING STUDENTS IN ENGAGING IN OBTAINING, EVALUATING, AND COMMUNICATING INFORMATION**

The NGSS, as well as Common Core State Standards in English/Language Arts, require students to thoughtfully *critique and leverage elements of the text to support a claim*. Students should refer to parts of the video or transcript as they share their thinking. Press for the use of text evidence using the talk move, “What in the video makes you say that?” (SEP: 8.4)

3 · SHARE VIDEO OF STUART THOMAS

9 min

MATERIALS: science notebook, *Unknown material with identifier: cc.l1.rdg3*, <https://youtu.be/UlOSbJD92og>

Show a video about oyster die-offs. Display slide F. Say, *A scientist working with Alana's community talked to us about oyster die-off events and how scientists are helping restore this special food to the Swinomish Tribal Community.* Distribute *Unknown material with identifier: cc.l1.rdg3*. Then play <https://youtu.be/UlOSbJD92og>.

Summarize oyster die-offs. Display slide G and have students collectively explain what a die-off is without interrupting them.

KEY IDEAS

Purpose of this discussion: Surface ideas about what a die-off event is to begin to think about the severity of them. This helps students to identify why this problem is an important one to try to solve.

Listen for these ideas:

Die-off events:

- are sudden;
- are due to something in the seawater pumped into the hatchery;
- cause baby oysters to die;
- cause oysters to fall to the bottom of the tank and smell bad.

4 • PREDICT THE CAUSE OF OYSTER DIE-OFFS

6 min

MATERIALS: science notebook

Outline the problem's location. Display and read **slide H**, showing that die-off events are rare outside of the Pacific Northwest.

Predict the problem's root cause. Show **slide I**. Have students take out their science notebooks. Ask them to write down a few things that might be causing these die-off events. Then have students share their list with a partner and circle the ideas they have in common.

SCIENCE NOTEBOOK



Keeping a science notebook allows students a space in which to reflect and communicate their developing understandings about science ideas and to track changes in their understandings. Each student should have a binder that will serve as their “science notebook” for the course. Students can use large dividers to indicate the start of a new unit. They can use additional smaller dividers or 3x3 sticky notes to create three sections within the unit, corresponding to the three lesson sets.

Display **slide J**. Have students share what their classmates said in the previous discussion. Students should share the ideas that they circled (those they had in common with their partner). *

KEY IDEAS

Purpose of this discussion: Surface ideas about what potential causes there are to explain oyster die-offs. This is used as a navigation move to help lead students to the next activity in the lesson.

Listen for these ideas:

- bacteria
- pollution
- temperature of the water
- CO₂ in the air

Suggested prompt

*Based on the videos, readings, map, and your background knowledge, what do you think might be causing oysters to die off? **

Sample student response

We know from Polar Ice Unit and middle school that Earth is getting warmer, so maybe the water is too hot for oyster larvae?

We know from Polar Ice Unit and middle school that there is more CO₂ in the air, so maybe that is getting in the ocean and hurting oysters?

Pollution seems like a bad thing that could hurt oysters, so maybe it is something like that?

Maybe there is a new predator or something that is hurting the oysters--but that does not seem like an overnight event.

In the video it said there was something in the water, so maybe there's something else we are not thinking about?

* SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

Initial questions about a phenomenon are intended to *clarify what information is known and not known* and, as is often the case, there are more questions than answers when scientists begin their investigations. Develop a safe and supportive space for students' uncertainty, and focus on the need to ask and answer questions to help address and resolve their uncertainty over the course of the unit. (SEP: 1.2)

* ATTENDING TO EQUITY

Building classroom culture and norms: Community building is emphasized throughout this unit. In this lesson, it will be important to encourage students to draw from their own ideas and not to worry about whether their ideas or questions are right or wrong. At this stage in an investigation, there are no “correct” ideas to think or questions to ask. All ideas and questions are welcome.

Suggested prompt	Sample student response
<i>If any of these things were actually hurting oysters, where and when would we expect the problem to be the worst?</i>	The problem should be worse in the Pacific Northwest than other parts of the coast. Something should have changed over time to make the problem more common in the last few decades than in the many years before.

If students do not have the background knowledge of anthropogenic climate change, consider using materials from *Polar Ice Unit* before this unit.

Follow up by saying, *Those are all interesting ideas, but we don't really know which of these is causing so many oyster larvae to die. I have some data here that might help us get a better picture of what is going on.*

5 • REVISIT COMMUNITY AGREEMENTS

5 min

MATERIALS: Community Agreements

Commit to a focal community agreement. Post the previous community agreements. Display **slide K**. Ask students to think about one community agreement they would like to work on during this unit. Have them share with a partner and invite their partner to remind them about their commitment.

ALTERNATE ACTIVITY

You may spend more time than allocated on community agreements, but do not skip it entirely.

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

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

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

Modify the instructions above to fit your students.

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

6 · EXAMINE DATA ON POTENTIAL CAUSES OF OYSTER DIE-OFFS

7 min

MATERIALS: *Die-Off Causes Analysis, Ocean Temperature Map, Carbon Dioxide Maps, Pollution Data, Ocean Acidity Maps*

Prepare to analyze data on potential causes of die-offs. Display slide L. Say, *I have data on four different potential causes of oyster die-offs, some of which you mentioned: temperature, carbon dioxide, pollution, and ocean acidity. Assign approximately one-quarter of the class to individually examine one of the data sets.**

Distribute *Ocean Temperature Map, Carbon Dioxide Maps, Pollution Data, and Ocean Acidity Maps*, one to each student. Also distribute a copy of *Die-Off Causes Analysis*. Direct students to focus on how the patterns in the maps compare with what they would expect if their possible cause was in fact contributing to oyster die-offs. Give students approximately 6 minutes to work.*

In the handout, students will predict the pattern they would see if the potential cause was the culprit. Then they will analyze and record the actual pattern and compare it to the prediction.

ADDITIONAL GUIDANCE

The second prompt on the handout, which focuses on predicted patterns, is vital if students are going to make sense of the data. If students are struggling, bring the class together and present the example of an oyster predator as a possible cause. Ask students, *If a new predator were killing oysters, where would you expect that predator to be found?* Students should answer that the new predator would be in the Pacific Northwest, but not in other areas where the die-offs are less common.

* ATTENDING TO EQUITY

The four data sources differ in complexity. *Pollution Data* is easiest to analyze, followed by *Carbon Dioxide Maps*. *Ocean Temperature Map* and *Ocean Acidity Maps* have more challenging maps embedded in them. You may wish to distribute these materials to students so that each student can be successful with the data they are given.

* SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

In this activity students should be using *patterns to compare their noticings* to the prevalence of *potential causes of oyster die-offs* across space and time. Students should see enough *evidence to rule out possible causes, but not enough to establish causality in any case*. The second prompt on the handout is designed to help students make hypotheses about the patterns they expect to find if their potential cause was a cause so that they are looking to make direct comparisons between their new data and the original anchoring materials. (CCC: 1.1)

7 · NAVIGATE

3 min

MATERIALS: *Traditional Foods*

Set up home learning. Display slide M. Distribute *Traditional Foods*. Say, *We all have these kinds of “first foods” in our communities. What are some that are important to our community? For example, what would we do without corn? It’s in our candy, our syrups and sweeteners, tortillas, chips, and cereal. Your assignment is to ask two people over age 20 about foods that are important to them, and what they would do without those foods.*

Tell students the class will start the next day by discussing the home learning prompt.

HOME LEARNING OPPORTUNITY



Home learning is an important place to do cultural formative assessment (Penuel, Shepard, & Davidson, 2016), where students bring ideas generated in their home into school and vice versa. By encouraging students to get ideas from their communities, you are blurring the boundaries of home and school learning and making for a more meaningful and integrated science experience.

End of day 1

8 • NAVIGATE

3 min

MATERIALS: *Traditional Foods*

Discuss the home learning. Display slide N. Ask a few students to share responses to the home learning. * All students have their own traditional foods, whether they know about them or not, so if students forgot to interview anyone, they can speak from their own experiences.

Suggested prompt

What are some of the “first foods” or traditional foods you heard about?

What would life be like without those important foods?

Did anyone hear about a food that someone lost?

Sample student response

Accept all responses, and be especially open and accepting of non-mainstream foods. It is important for all students to hear about cultures other than their own.

We would have to come up with something else to eat.

It might not be so healthy.

Historically we might have moved.

Our cousins emigrated from Peru and they really miss their food so we try to find it nearby, but that’s really difficult.

Navigate. Say, *Yesterday we figured out that oysters are a “first food” for a large number of people in the United States. It sounds like first foods are important to our own families and communities, too. Let’s continue trying to figure out what’s hurting the Olympia oysters, an important first food in the Pacific Northwest.*

* ATTENDING TO EQUITY

This conversation is about food, and an estimated 30% of US students are food-insecure, meaning they experience hunger or they do not know where their next meal will come from. In this conversation, be sensitive to those who might be hungry. For example, some students might say that they have had their main sources of food taken away, and some students may rely on school lunch as a major source of their nutrition.

9 • DISCUSS DATA ON POTENTIAL CAUSES OF OYSTER DIE-OFFS

6 min

MATERIALS: *Die-Off Causes Analysis, Ocean Temperature Map, Carbon Dioxide Maps, Pollution Data, Ocean Acidity Maps, science notebook*

Discuss data in groups. Display slide O. Tell students they will meet briefly with a group of classmates who analyzed the same data as they did. They will need to come to a consensus as to whether the data support their possible cause for oyster die-offs. Explain that they should have a group representative ready to share their data and findings with the rest of the class. Break students into groups of three to six and

* SUPPORTING STUDENTS IN DEVELOPING AND USING CAUSE AND EFFECT

give them about two minutes to discuss.

Discuss data as a class. Display **slide P**. Bring the class back together and have each representative briefly explain their data and share whether or not they think their potential cause could be affecting oysters. It is not necessary to have multiple groups with the same data re-explaining their piece of data.

Come to consensus on causes as a class. Display **slide Q**. Use the questions on the slide to lead students in a brief discussion about which of the potential causes are actually likely. *

Suggested prompt	Sample student response
<i>What patterns were you looking for in your data?</i>	The data should have shown that things were different in the Pacific Northwest to make the situation worse for oysters. The cause should have been something that got worse over time.
<i>Which potential causes fit the geographical patterns we saw in the readings and maps?</i>	The ocean has gotten more acidic, including on the West Coast. pH seems to have gone down (acidity gone up) a lot in the Pacific Northwest and Alaska compared to the rest of the coast. Acidity is a possibility. CO₂ is going up in the atmosphere. It might be a possibility that some gets into the ocean, although there does not seem to be anything special about carbon dioxide in the Pacific Northwest.
<i>Which causes do not fit?</i>	Temperature should be eliminated from consideration because the die-offs are occurring in the Pacific Northwest, which has gotten warmer but no more than any other part of the country. Plus, water in the Pacific Northwest would not be that hot anyway. The West Coast has the least pollution, even though that is where oysters are being most affected by overnight die-offs. So, pollution is probably not the cause, even though we know it has been a problem in the past.
<i>What evidence do we have that these patterns could be the actual causes or mechanisms for die-offs?</i>	We don't have real evidence yet that CO₂ or increased acidity is the cause, but they might be.
<i>Could any of these potential causes be related to each other?</i>	We know CO₂ and temperature are connected. Maybe CO₂ is connected to acidity?
Once the discussion has concluded, collect all references.	

Students may be passionate about their potential cause or unsure if any of the *potential causes are actually affecting oysters*. If so, you may mention to students that all of these potential causes have been harmful to oysters at some place and time. However, it is important to emphasize that we want to keep the focus on what caused the die-offs that happened overnight and began in 2005 in the Pacific Northwest. Ask students to consider which *causes actually meet those space and time restrictions*. (CCC: 2.2)

10 · READ ABOUT THE BILLION OYSTER PROJECT

5 min

MATERIALS: *Billion Oyster Project*, science notebook, <https://youtu.be/RimJKVqyzUA> (optional)

Read about the Billion Oyster Project. Display slide R. Distribute *Billion Oyster Project*. Say, *I found out that oysters are really beneficial for other reasons, too. Let's check out a cool oyster project on the other side of the US.* Offer choice in how students read the passage. *

Give students time to read, then have them respond to questions on the slide in their notebook or with a partner before leading them in a whole-class discussion.

Suggested prompt	Sample student response
<i>What other benefits do oysters have that we did not know about?</i>	Oysters clean water. Oysters can provide physical barriers to help hold coastline in place and protect from rising sea levels.
<i>How does the article fit with the ideas we had yesterday about what might be causing oyster die-offs?</i>	Carbon dioxide makes the ocean more acidic (ocean acidification) which makes it harder for larvae to build shells, so our ideas yesterday were correct! We thought temperature was really important in the Pacific Northwest, which it might be, but temperature is not the cause of the die-offs.
<i>What are communities doing to restore oyster populations and habitats?</i>	Communities all along the United States coast are taking old shells and using them to grow baby oysters on.

Collect *Billion Oyster Project* when the discussion has concluded.

Optional: Show the cleaning abilities of oysters. Display slide S and say, *The article talked about oysters cleaning water as they feed. This video shows just how much of an impact they can have. Be sure to watch the clock in the video so you can see how quickly this occurs.* Play <https://youtu.be/RimJKVqyzUA> and allow students to share their reactions.

Show the effects of acidity on oyster larvae. Display slide T and say, *The images on top show magnified oyster larvae growing in "normal" ocean water at 1, 2, and 4 days of age. On the bottom are the same ages of larvae in more acidic water.* Listen for students to note the misshapeness and the "trouble forming shells". Students may say shells are being eaten away.

Update personal glossaries. Display slide U and say, *What new terms we have picked up that need to be added to our personal glossaries?* Students will likely identify "ocean acidification." Explain to the students that we do not know a lot about ocean acidification yet, so our definition may not be exact, but it can be revised over time. Give a minute for students to add this term to their personal glossaries, as well as any others they wish to add.

* ATTENDING TO EQUITY

Universal Design for Learning: Offering choice in how students read the passage supports *representation* by offering ways of customizing the information. Representing the text on paper while it is being read aloud can support comprehension and language learning for all students.

If reading aloud to the whole class is not preferred, form **choice reading groups** where students can choose to 1) listen to you read in a small group, 2) read with a partner, or 3) read silently. This reading structure can give students choice in *engagement*.

ADDITIONAL GUIDANCE

Not every vocabulary word should be added to personal glossaries. A helpful distinction for determining if a word should be added is to decide if it is a “word we co-construct” versus a “word we find out” or “encounter.” A “word we co-construct” is one we work together to understand through investigation and collaborative sensemaking, thus we should celebrate our growing understanding of the word by adding it to our personal glossaries. A “word we encounter” may be seen or defined in text or media. These words are less important to add to our personal glossaries, though they may become “words we co-construct” if our understanding of the word grows and changes. Words that students co-construct in the first four lessons of the unit include **ocean acidification**, **pH**, **acid**, and **neutralization**.

11 · DEVELOP INITIAL MODELS

10 min

MATERIALS: *Initial Modeling*



Develop initial models. Display **slide V**. Distribute *Initial Modeling* and say, *It sounds like we have a decent idea now of why oysters are dying, so let's try to put our ideas on paper. We will draw a model that answers the question, “How is more carbon dioxide in the atmosphere causing problems for oysters' shells?” We also want to make sure we can zoom in too, so we know what is actually happening to the oyster shell to harm it.* Give students time to work on their models individually.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' **models use evidence** to show how **large-scale ocean system changes result in ocean acidification at a particle level**. (SEP: 2.3; CCC: 3.4)
- Students' **models use evidence** to show how ocean acidification at a **particle level affects small-scale oyster structures (systems)**. (SEP: 2.3; CCC: 3.4)
- Students **trace the flow of carbon dioxide from human activities to the atmosphere, and from the atmosphere into the ocean**. (DCI: ESS2.D.3)

What to do: Students' models will be incomplete since this is the first lesson of the unit. It may be used as a pre-assessment opportunity to check in on students' modeling and use of patterns noted in the data analysis. If students do not agree on the idea that carbon dioxide somehow causes ocean acidification which in turn causes oyster die-off, use the crosscutting concept of scale, proportion, and quantity to push students to use the evidence they examined to consider what might be happening at a particle level.

Building toward 1.A.1 **Develop a model using evidence** that **compares large-scale carbon dioxide changes to explain small-scale oyster die-offs using particle-level interactions**. (SEP: 2.3; DCI: ESS2.D.3; CCC: 3.4)

12 · COMPARE SIMILARITIES AND DIFFERENCES IN INITIAL MODELS

7 min

MATERIALS: *Initial Modeling*, science notebook

Share models with partners. Display **slide W** and direct students to make a T-chart in their notebooks to record similarities and differences between their models. Briefly explain the instructions for “Stand Up, Hand Up, Pair Up” and give students about five minutes to mingle, comparing models with a few different partners. Students should record similarities and differences in their T-charts while they are talking with different partners. If other questions come up during their conversations, students should also record those questions in their science notebooks.

ALTERNATE ACTIVITY

If there is time, you may wish to give students a chance to update their models before building a class consensus model. This can help students articulate how their thinking changed as they learned from classmates' ideas, and can also help them more effectively advocate for their ideas during the consensus discussion.

13 · BUILD INITIAL CONSENSUS MODEL

14 min

MATERIALS: science notebook, chart paper, chart paper markers

SCIENTISTS CIRCLE



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

ADDITIONAL GUIDANCE

You will need 2 pieces of chart paper available for this activity.

Debrief similarities and differences of initial models. Arrange students in a Scientists Circle. Display **slide X** and put up a piece of chart paper. Invite students to briefly share the similarities and differences they wrote in their science notebooks. Begin with writing the similarities on the first piece of chart paper.

Represent areas of agreement and disagreement in a consensus model. Display **slide Y**. On the second piece of chart paper, build a class consensus model. An example is shown below. It is unlikely that you will have complete consensus about how increased atmospheric CO₂ is causing acidification that hurts oysters. Throughout the discussion, and again toward the end, remind students to record any questions they have in their science notebooks so that they do not lose those questions.

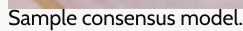
KEY IDEAS

Purpose of this discussion: There are two goals of this discussion: 1) to solidify the outlines of the story told throughout the materials students have analyzed as well as likely areas of agreement, namely that atmospheric CO₂ is released by people, somehow gets into the ocean, and somehow makes the ocean more acidic, and then this relative acidity hurts oysters (and therefore people); 2) to scope out the territory of what the class is uncertain about or has competing ideas about, in order to problematize what the group needs to figure out. As such, it is again important to accept all student responses and to encourage students to share their ideas. Furthermore, it is important to highlight areas of disagreement and help students clearly explain their thinking in these areas. Push students to keep explaining their thinking or providing evidence until they reach a point where they cannot explain any further. Be careful not to respond favorably to any one idea over others so as not to “give away” what the class will investigate as the unit progresses.

Listen for these ideas:

- Carbon dioxide has to be getting into the water somehow.
- Somehow, carbon dioxide makes the water more acidic.
- Something is happening to oyster shells at the molecular level, but we are not sure what--perhaps some sort of reaction?
- This reaction affects larvae in particular very quickly, even overnight.

Suggested prompts	Sample student responses	Follow-up questions
<i>How is more carbon dioxide in the atmosphere causing ocean acidification?</i>	Maybe it reacts with something in the water to make an acid? We are not really sure.	<i>What evidence do we have that a reaction is or is not occurring?</i>
<i>If we think there is some kind of reaction happening with carbon dioxide, then why is there carbon dioxide in the air?</i>	Maybe it has to get into the water to react. Maybe it reacts with something that runs out.	<i>Why does only some of the carbon dioxide in the air go into the water?</i> <i>What evidence do we have that this is happening?</i>
<i>What is happening to oyster shells at the molecular level that is making it hard for them to form?</i>	Acid molecules get in the way when the shell is coming together. The acid eats away at them?	<i>What evidence do we have that the specific molecular things we think are happening, are happening?</i>
<i>What is acid?</i>	Acid is a certain type of molecule.	<i>What type of molecule is acid?</i> <i>How exactly does carbon dioxide make acid?</i>
<i>What bigger issues help cause oyster die-offs?</i>	People pumping carbon dioxide into the atmosphere Ocean acidification	<i>What do people do that causes the carbon dioxide to appear?</i> <i>How is ocean acidification caused by human activity?</i>



- Does anyone disagree with the idea presented?
- Is there anything about the phenomenon that we have not explained yet? Are there any gaps that need filling?

3 min

Reflect back on the model. Display slide Z and make sure the class consensus model is displayed so that it is visible to the whole class. Say, *You all have built a consensus model based on the evidence we have to this point. We didn't have complete agreement on what went in, so in your notebooks briefly jot down something on the model that is new, interesting, or confusing to you. You will have a minute to think, then we will take a few responses.*

Page 53

- I never thought that the ocean could become acidic.
- I didn't know gasses could get into water.
- It is weird that the carbon dioxide is having such a strong effect on the water.
- Oyster shells are hard, right? How can something eat away at them, even when they are little?

15 · IDENTIFY RELATED PHENOMENA

7 min

MATERIALS: None

Turn and talk about related phenomena. Display **slide AA**. Direct students to talk with a neighbor about the questions on the slide.* Then after two minutes, discuss the questions as a class.*

Suggested prompt	Sample student response
<i>Describe how the image of the oyster on the right looks different from the oyster on the left.</i>	It is broken down or worn down. It is smaller. It did not fully develop. There seem to be dents or divots in it.
<i>Where else have we seen a substance or object look brittle or weak like the oyster shells?</i>	Worn-down stone or brick (sometimes from acid rain) Rusted metal Maybe it's like tooth decay? Older people and animals sometimes have bones that break easily. Some people and animals are born with bones that develop in unexpected ways.

ADDITIONAL GUIDANCE

Use questions to push students' thinking to new contexts and provide more opportunities for students to make connections to their experiences. For example, if students are only naming other shelled organisms with weakened or broken shells, say, *Those examples are great, but are really similar to oysters. Think about what you see at home, at school, at work, or in your neighborhood--where else do you see weak-looking objects and materials like the oyster in the picture?*

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Since models are used to explain a range of phenomena, students will refer back to this list of related phenomena throughout the unit to help them generalize the model(s) they are developing. As students suggest ideas, prompt them to explain how they are related. This will help students expand their thinking beyond the *individual components to the relationships and processes* that will be developed in the model. (SEP: 2.3)

* ATTENDING TO EQUITY

Use talk strategies to draw out a wide variety of related phenomena from a larger pool of students. If it seems like the students do not have any more ideas, resist moving on right away. Instead, count to 10 in your head to give students more time to consider. Have students jot down some ideas in their notebooks after the Turn and Talk and before sharing out. This can be particularly supportive for emergent multilingual students. See the **Additional Guidance** section for sample prompts.

16 · RECORD QUESTIONS AND BUILD THE DRIVING QUESTION BOARD

25 min

MATERIALS: 3 3x3 sticky notes, science notebook, permanent markers, class consensus model, Driving Question Board, chart paper markers



Generate questions. Display **slide BB**. Say, *It seems like we know of some things that are similar to oyster shells being "eaten away," but based on our models we are not 100% sure what's happening with oysters. Let's take this opportunity to record our questions so we can think about useful next steps.* Direct students to look back at their notebooks and the consensus model and think about discussions they had today

* SUPPORTING STUDENTS IN DEVELOPING AND USING STABILITY AND CHANGE

to identify relevant questions. Students should write down at least two new questions that they have now about the phenomenon of oyster die-off due to ocean acidification. Remind students to write big so their questions are easier to read. Give students a few minutes to record their questions on 3x3 sticky notes.

Gather around the Driving Question Board (DQB). Display slide CC. Direct students to bring their questions on 3x3 sticky notes and form a Scientists Circle. Remind students of the procedure for developing the Driving Question Board as shown on the slide.

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

Lead students in building the Driving Question Board. *

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' questions are related to changes occurring in the anchoring phenomenon, unresolved portions of the model, and/or related phenomena. (SEP: 1.2; CCC: 7.1)
- Students' questions are based on figuring out how increased levels of carbon dioxide in the atmosphere interact with the hydrosphere and/or biosphere. (SEP: 1.2; DCI: ESS2.D.3)

What to do: Accept all student questions, but if only a small number are related to the ideas listed above, wait until all students have posted a question. Then ask students to connect their question to a specific point of confusion on the class consensus model. Many students will not be able to make that connection, so ask them to generate a question related to the model that can be posted and then viewed by their classmates in a gallery-walk style.

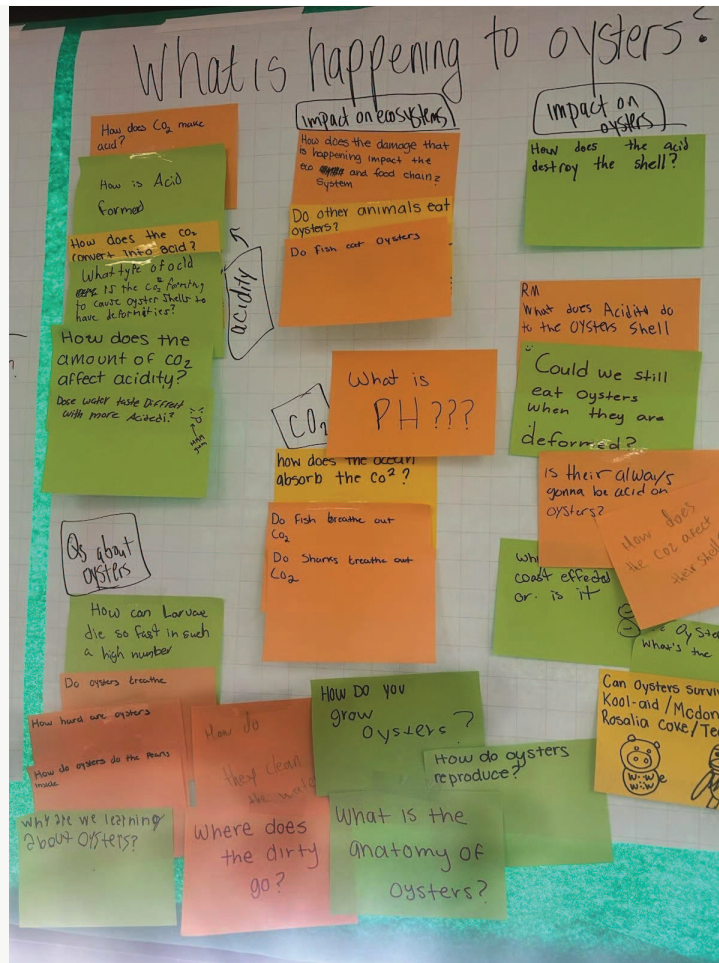
Building toward 1.B.1 Ask questions to clarify how oyster populations and changes in climate due to atmospheric carbon dioxide are connected. (SEP: 1.2; DCI: ESS2.D.3; CCC: 7.1)

Categorize the questions. After all students have shared their questions, you will have several different clusters of questions on the DQB. As a class, decide on "umbrella" questions or topics for the clusters of questions and then label them. Then, if you have not already done so, post the overarching unit question at the top of the DQB: *Why are oysters dying, and how can we use chemistry to protect them?*

Possible "umbrella" topics (and the lessons in which students will explore them) include:

- acidity (Lessons 3 & 4)
- CO₂ (Lesson 5)
- impact on oysters (Lesson 7)
- how to grow oysters (Lessons 9-12)
- impact on ecosystems (Lessons 12-15)

In this lesson, students are confronted with a phenomenon that reflects a *change over time*--relatively recent decreases in oyster populations and mysterious larvae die-offs. Student questions will ideally seek to explain this phenomenon or specific parts of their model and how they are tied to the climate change of ocean acidification. (CCC: 7.1)



Sample Driving Question Board

17 · GENERATE IDEAS FOR FUTURE INVESTIGATIONS

10 min

MATERIALS: science notebook, chart paper, class consensus model, chart paper markers

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

Accept all ideas and add them to the Ideas for Investigations chart paper. Student ideas may include the following:

- We should see if CO₂ actually makes water acidic so we can figure out how it works.
- We should research how people are approaching this problem now, since that might give us some clues about what to do.
- We could try dissolving oyster shells or something like them in water to see what happens.
- We can try figuring out how CO₂ is actually interacting with water to make an acid.
- We need to research how oysters build their shells so we can figure out how acidity is stopping it.

Thank students for sharing their ideas and tell them that the class will start the next lesson by thinking about how we might tackle this problem by breaking down the study of these large-scale system interactions into smaller-scale systems.

Additional Lesson 1 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.9: Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts.

Students are analyzing text and comparing and contrasting it with data they examined in the lesson. As students read about the Billion Oyster Project, they will see that “acidification” is a cause of die-offs, confirming or disconfirming what they found in the readings. Consistent with the CCSS standard, students will take note of how the article’s discussion of the problems affecting oysters compares to students’ conclusions from analyzing data about potential causes of the oyster die-offs.

LESSON 2: How can we break down the problem so we can solve it?

PREVIOUS LESSON *We analyzed data to figure out potential causes of oyster die-offs and read about how atmospheric carbon dioxide enters the ocean and makes it more acidic, harming oysters and the ecosystem. We developed initial models to explain how carbon dioxide causes increased acidity that hurts oysters. We asked questions and generated ideas for investigations that will guide our work.*

THIS LESSON

ANCHORING PHENOMENON

1 day



USDA

We want to prevent oyster die-off. We decide to break the problem into subproblems, then brainstorm initial ideas for big picture approaches to solving each subproblem. Ultimately, we develop an argument about which subproblem to pursue.

NEXT LESSON *We will brainstorm a list of substances that contain both water and carbon dioxide. We will plan an investigation with our group to test whether solutions of carbon dioxide and water are acidic. We will share our data. We will read an article and explore a website about pH.*

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-1, HS-ETS1-2



WHAT STUDENTS WILL DO

2.A Use **consideration of scale** and **patterns related to scale** to **evaluate proposals** of the most productive **design subproblem** to pursue to **counteract negative human impacts on oysters**. (SEP: 7.6; DCI: ETS1.A.2; CCC: 1.1, 3.1)

WHAT STUDENTS WILL 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.

Lesson 2 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	7 min		NAVIGATE Review takeaways from Lesson 1 and transition into thinking about oyster die-offs as a problem to solve.	A-B	Ideas for Investigations chart from Lesson 1
2	10 min		BREAK THE PROBLEM INTO SUBPROBLEMS Direct students to review classroom consensus models of the problem impacting oysters and generate group lists of subproblems. Lead the class in a brief discussion to build a consensus list of focal subproblems.	C-E	<i>Progress Tracker</i> , chart paper, chart paper markers
3	3 min		BRAINSTORM INITIAL IDEAS Direct students to jot down initial ideas for solutions to address each subproblem on 3x3 sticky notes.	F	4 3x3 sticky notes, <i>Progress Tracker</i> , permanent markers
4	10 min		LOOK FOR PATTERNS IN OUR INITIAL IDEAS Lead the group in a discussion of patterns in ideas for solutions.	G-H	4 3x3 sticky notes, chart paper, chart paper markers
5	15 min		DEVELOP AN ARGUMENT FOR WHAT TO FOCUS ON AND NAVIGATE Prompt students to consider solutions through the lens of scale to build and revise arguments for what to focus on moving forward.	I-L	

End of day 1

Lesson 2 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • <i>Progress Tracker</i> • 4 3x3 sticky notes • permanent markers		• Ideas for Investigations chart from Lesson 1 • chart paper • chart paper markers

Materials preparation (25 minutes)

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

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

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

Have the "Ideas for Investigations chart" from Lesson 1 visible at the start of the lesson.

You will need 3 pieces of chart paper. One will be used to record a list of four focal subproblems. This can be labeled, "Focal Subproblems." The second will be a place for students to post 3x3 sticky notes of initial ideas for solutions related to subproblems they identify. This can be labeled, "Initial Ideas for Solutions." The third will be to record categories of solutions related to scale. This can be labeled, "Categories of Solutions."

Lesson 2 • Where We Are Going and NOT Going

Where We Are Going

The targeted disciplinary core idea that we are beginning to develop is:

- **ETS1.A.2: Defining and Delimiting Engineering Problems.** Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution; some of which can be addressed through engineering. These global challenges also may have manifestations in local communities.

Crosscut Explanation: In *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*, students will examine strategies we are using to generate energy while reducing pollution (carbon dioxide emissions). Later in this unit, students will examine and read about interested parties and develop solutions for a particular community.

Students have previously developed **CCC: 3.1**: The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. in *Polar Ice Unit* and *Space Survival Unit*. This unit builds on students' use of scale and quantity in earlier units and incorporates proportion thinking. In later lessons, students use proportional thinking to try to use chemistry to solve the problem of ocean acidification by scaling up classroom investigations to address the larger problem (Lessons 4, 8, and 9). Finally, students apply this thinking in the unit transfer task to explain how much CO₂ is released by the Haber-Bosch process (Lesson 15).

Students break down engineering problems that are large and global, such as ocean acidification, into smaller problems that can be investigated in class (**SEP: 7.6**; **DCI: ETS1.A.2**). This relationship of large problems to smaller subproblems brings into play interrelated issues of scale and patterns (**CCC: 1.1, 3.1**).

Students brainstorm initial ideas about what is happening with oysters and look across each others' ideas to find patterns (**CCC: 1.1**).

Finally, students build an argument about the focus of their initial search for solutions to ocean acidification (**SEP: 7.6**). They evaluate proposals by comparing scale and patterns, and prioritize counteracting negative human impacts on oyster systems (**SEP: 7.6**; **DCI: ETS1.A.2**; **CCC: 1.1, 3.1**). One argument is that students are well positioned to design solutions for local mitigation in chemistry class (**SEP: 7.6**; **DCI: ETS1.A.2**). This motivates future investigations centered around chemical engineering.

Where We Are NOT Going

This lesson is NOT to be used to lead students into prioritizing local mitigation at the expense of addressing the root cause of ocean acidification, or to advocate for purely scientific and technical approaches in place of social and political solutions. Rather, the aim is to build rationales for why it is important to simultaneously address acute problems like oyster die-off and underlying causes like anthropogenic greenhouse gas emissions.

While **SEP** element **7.6** focuses on evaluating competing design solutions, we use this lesson to evaluate competing larger-scale solutions (meta-strategies) for large-scale earth system problems. These include breaking large problems into subproblems, prioritizing the subproblems that are investigatable in our context, and arguing for a dual science and engineering approach to such problems, rather than a science-only or engineering-only approach. This is an important connection to the nature of science as a human endeavor (subsumed within the crosscutting concepts).

LEARNING PLAN for LESSON 2

1 · NAVIGATE

7 min

MATERIALS: science notebook, Ideas for Investigations chart from Lesson 1

Navigate to today's work. Say, *We ended up with a lot of questions and ideas to investigate last class! But let's take a moment to think about the different scales at work in this phenomenon and problem.* Display **slide A**. Give students a couple of minutes to turn and talk with a partner.

Suggested prompt

Which aspects of the phenomenon and problem that we explored last time seem to be happening at relatively large scales?

Which aspects of the phenomenon and problem that we explored last time seem to be happening at relatively small scales?

Sample student response

Amount of carbon dioxide in the atmosphere.

The whole ocean is becoming acidic.

How ocean water pH affects oyster shell formation.

Consider approaches to solving big problems in students' everyday experiences. Display **slide B**. Say, *We have identified two different scales of problems we need to solve. Think about how you and your classmates have solved problems in the past. What are some ways we have approached solving a large-scale problem differently from a small-scale problem?* *

Allow students about 4 minutes to jot down ideas. Then call on a few students to share these ideas. Listen for the following responses, related to students' work from prior units:

- We evaluated different types of solutions individually for preventing polar ice melt (microbeads vs. a berm). *Polar Ice Unit*
- We looked at different boundaries/parts that were interacting within a single system (e.g., light/surface, light/air, water/water, water/ice, water/air). *Polar Ice Unit*
- We explored a smaller scale version of the interactions at work in a large system (e.g., with water in a cup, a water dropper to explore lightning, rubbing materials together to produce charges). *Electrostatics Unit*
- We looked at the possibility of using chemistry to make the things we need (large scale) by examining how individual elements combine with each other (atomic scale). *Space Survival Unit*

If students do not readily recall examples from prior units, consider using one or more of these prompts to elicit similar responses:

- When have we found it useful to evaluate possible design solutions one at a time rather than considering them all at the same time?
- When have we looked at the interactions between different subparts of a system rather than the entire system?
- When have we collected data by creating a smaller scale version of a part of a larger system?
- When have we tried to figure out what was happening at a particle level to help us understand a larger scale phenomenon?

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

It is important at this point in the lesson to have students think about solving problems at *different scales*. Later, students will break this unit's problem, oyster die-off due to ocean acidification, into smaller scale subproblems. Encourage students to explain the *different scales* at which we explored problems in prior units. (CCC: 3.3)

2 · BREAK THE PROBLEM INTO SUBPROBLEMS

10 min

MATERIALS: science notebook, *Progress Tracker*, chart paper, chart paper markers

Extend these everyday strategies to all science and engineering problems. Display **slide C**. Say, *All of these strategies are ones that scientists and engineers use to solve problems. In this unit, we are going to do our deepest dive into figuring out how to make those strategies as generalizable as possible so that we can reuse them to solve bigger and bigger problems in the future! We can use our oyster problem to do that, but another big*

mission is to develop a way to figure out how to approach solving any large-scale problem.

Introduce the idea of breaking a problem into subproblems. Continue to display **slide C**. Say, *Almost every approach we talked about involved a way to break a larger problem into a set of smaller subproblems. Where have you seen people take a big problem and break it into smaller subproblems in order to solve it? For example, an artist working on a wall mural will take the big picture and divide it into more manageable sections or layers that get created one at a time.*

Give students a couple of minutes to discuss with a partner before sharing ideas with the whole class. Sample student responses could include:

- Working on a hard math problem in class
- Construction workers building a house
- Activists organizing toward long-term goals
- Putting together a large jigsaw puzzle

Suggest that students review the class consensus model to name the subproblems. Display **slide D**. Say, *Your examples are great, and breaking a problem down is something that engineers often do. For example, engineers who are working on big, complicated problems typically break those problems down into smaller tasks, and they have to clearly state which specific part of the problem they are trying to address. Fortunately, we already have a class consensus model that might help us identify subproblems. Let's take a look at it.*

Direct students to work in small groups to review the class consensus model from Lesson 1 to generate a list of 3-5 subproblems to share with the class.

Say, *As you look back at the consensus model, look for different components of the model and how those components interact with each other as a starting point for identifying subproblems.*

Facilitate a brief discussion to agree on focal subproblems. Display **slide E**. Say, *Let's hear from each group and build a consensus list of subproblems. You can repeat subproblems that have already been mentioned, or propose new ones. In the end let's decide on a list of problems we want to focus on that feels manageable.*

As each group shares their list, record their ideas on a piece of chart paper, make note of any repeated ideas with a check mark, plus sign, or some other acceptable method. Ultimately, work toward a consensus list that is some variation of the four key ideas. After reaching consensus, label the piece of chart paper, "Focal Subproblems."

KEY IDEAS

Purpose of this discussion: Generate a list of subproblems that we will regularly use and revisit throughout the unit.

Listen for these ideas:

- CO₂ gets into the atmosphere/ocean.
- CO₂ makes water more acidic.
- Acidity hurts oyster shells.
- Oyster die-off hurts ecosystems and people.

If students propose a list of subproblems that differs significantly from the key ideas offered here, lead the class in a whole-group discussion referring back to the class consensus model from Lesson 1. Ask students to explain their thinking in terms of the class consensus model. Clarify ideas and press for reasoning using the following prompts:

- *Can you say more about that?*
- *Is that something you have heard, observed, or experienced before?*
- *What do you mean when you say the word “_____”?*
- *Who has a different way of thinking about this topic?*
- *How does this idea connect back to our class consensus model?*

Distribute *Progress Tracker*. Direct students to update the subproblem box on *Progress Tracker* with the four focal subproblems the class identifies. Make sure students number the subproblems so that they can be easily referenced in future lessons.

ADDITIONAL GUIDANCE

Progress Tracker is designed to guide students through the engineering design process. It focuses on the main subproblems identified in Lesson 2, and asks students to separately record the science ideas they figure out, how they might apply those ideas, and the criteria and constraints that impact how they apply those ideas. As students return to the *Progress Tracker*, prompt them to consider the interrelation of these columns, and how all subproblems are important to investigate in order to design solutions that address the large, complex problem identified in the Anchoring Phenomenon Routine. *Progress Tracker Key* offers some possible ideas that students will have added to their *Progress Trackers* by Lesson 12.

This also provides an opportunity to remind students that there are many ways to solve big problems, and that it is important to learn as much as we can about the problem, the people affected by it, and the people working on it, to make sure we can design solutions that do not further harm those who are already marginalized.

3 • BRAINSTORM INITIAL IDEAS

3 min

MATERIALS: 4 3x3 sticky notes, *Progress Tracker*, permanent markers

Invite students to individually jot down initial ideas for solutions to focal subproblems. Lead students in quickly generating ideas about possible solutions for each subproblem. In the next activity section, you will organize and guide students in how to go public with their ideas.

Display **slide F**. Say, *Consider our list of focal subproblems. Think about what you already know about how people are working to address these pieces of the larger problem, as well as possible new ideas for solutions to each subproblem. How might we address each subproblem?*

Ask students to jot down each idea they have on a new sticky note and then put them into different stacks, one for each subproblem. Emphasize that many decisions and approaches to solutions are not made using science alone but also rely on social and cultural contexts to resolve issues.

Ask, Which science or engineering solutions might work? Which social or political solutions might work?

Allow students about two minutes to generate ideas.

Suggest we look for patterns to help decide where to go next. Continue to display slide F. Say, Wow. Look at the many different subproblems and solutions we came up with! Where do we start? It is not always easy to know where to start. We can try to organize our solutions somehow and look for patterns that might help focus us.

4 · LOOK FOR PATTERNS IN OUR INITIAL IDEAS

10 min

MATERIALS: 4 3x3 sticky notes, chart paper, chart paper markers

ADDITIONAL GUIDANCE	Have a piece of chart paper available for students to add their 3x3 sticky notes. You can label this piece of chart paper, “Initial Ideas for Solutions.” At this point, students will group their sticky notes based on related ideas. Later, they will identify patterns and consolidate ideas.
Give students directions for going public with initial ideas and finding patterns. Display slide G. Say, Gather your stacks of 3x3 sticky notes. Then come to the front to add your notes to our public record. As you add each sticky note, read the ideas that are already posted, and either put your idea next to a related idea, or start a new group of ideas. Once you have posted all of your 3x3 sticky notes, head back to your spot.	
ADDITIONAL GUIDANCE	Students will not yet have fleshed out ideas for solutions, but will have initial ideas for possible approaches. Below are some examples of the grain size of solutions that will be useful to surface in this step. This list does not include all possible student ideas. • Build something (or plant something) that takes CO₂ out of the atmosphere. • Stop putting CO₂ in the atmosphere or put less in the atmosphere. • Create laws that people can only drive electric cars that are powered from renewable sources (so not drawing power from coal-based power plants). • Genetically engineer oysters to resist acidity. • Come up with a reaction that removes the acid. • Put something around where the oysters live to protect them. • Coat oysters with something to protect them from acid (antacid?). • Find oyster replacement meats for people who eat them. • Create other structures to protect shorelines or filter water.
Focus on patterns in ideas for solutions. Display slide H. Lead the class in a discussion of patterns in ideas for solutions. Read aloud some of the individual 3x3 sticky notes in each cluster, then invite the class to consider if the clusters can be merged or consolidated any further. Look for ways to consolidate approaches across multiple subproblems.	
Suggested prompt	Sample student response
What are our initial ideas for solutions? Do we notice any patterns across clusters?	Many groups have a category about doing something about the CO₂ and a category about doing something directly where the oysters are located. Lots of groups have both science-based solutions and social solutions.

Suggested prompt	Sample student response
Can we name these categories?	Addressing the problem at its source would eventually help solve all the subproblems. It seems like we have some solutions we could implement at a local scale that would address the more immediate subproblems like acidity hurting both the oysters and the local people who depend on them. Some solutions are bigger picture and more focused on the subproblems of CO₂ getting into the ocean and air and making it acidic to begin with. In all of the solutions, it is important to think about impacts to local ecosystems and communities.
Look at our solutions through a lens of proportion and scale. Do any of these require us to think about scale?	Local scale solutions and global scale solutions Addressing root cause and mitigating acute impacts Preventing the problem at its source and reacting to the problem Treating “symptoms” and treating the “disease”
Add the broad categories of solutions to a piece of chart paper. You can label this chart paper “Categories of Solutions” to reference later in the unit. Summarize broad categories of solutions. Say, <i>We came up with some broad categories of solutions</i>, then describe those categories using the language the class decided upon (e.g., mitigating local impacts, addressing root cause).	
ADDITIONAL GUIDANCE	Your class should have some version of the subproblem “Oyster die-off hurts ecosystems and people.” Though this is not an explicitly chemistry related problem, we will brainstorm possible solutions to this subproblem in this lesson. In Lesson Set 3 we will integrate this subproblem with the other subproblems, as all of our solutions should consider impacts to local communities and ecosystems. In this discussion of patterns in ideas about solutions, underscore ideas about how social and ecological considerations cut across various approaches.

5 · DEVELOP AN ARGUMENT FOR WHAT TO FOCUS ON AND NAVIGATE

15 min

MATERIALS: science notebook

Prompt students to consider the categories of solutions through the lens of scale. Display slide I and instruct students to take out their notebooks. Say, *Let’s sit with these broad categories of solutions for a little bit longer as we work to decide on a direction. Which of these is most important to focus on? Is it enough to act on just one or the other? Why? On what timescales would we see results related to these different approaches to solutions? Where is chemical engineering going to be most useful? Where is engineering or science alone not enough to solve the problem? Jot down your thinking individually first.*

Ask students to discuss what they wrote with a partner. Display slide J.

* ATTENDING TO EQUITY

To cultivate critical hope (Duncan-Andrade, 2009) in the face of eco-anxiety, highlight forms of social and political action already underway to address the root causes of anthropogenic climate change. For example,

 **Debrief partner discussions.** Present slide K. Invite students to share important ideas that came up in their partner discussions with the class. Encourage students to respond to and build on each others' ideas. Affirm that **both** addressing the root cause and mitigating local impacts are important and urgent, and that science and engineering as well as social and political action are important to help save the oysters, the ecosystems, and the communities connected to oysters. *

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students reason about the **interrelated nature of different approaches to solutions**. (SEP: 7.6) *For example, that mitigation might be an immediate priority, but will become increasingly more difficult to achieve without addressing the root cause.*
- Students share reasonable ideas about **timescales on which we would see results** from various **approaches to solutions** tied back to evidence from Lesson 1. (SEP: 7.6; CCC: 1.1, 3.1) *For example, you might see results from treating water within hatchery tanks within days, whereas it might take years to see ocean acidification reverse.*
- Students identify initial ideas about which **types of solutions** would most **benefit from a chemical engineering perspective**. (SEP: 7.6; DCI: ETS1.A.2) *For example, a chemical engineering perspective might be more beneficial when working on scientific solutions that reduce greenhouse gases caused by human emissions as opposed to providing policy, economic, or political solutions.*

What to do: If students are not yet thinking about the interrelated nature of different approaches to solutions and subproblems, or have not yet thought through ideas related to scale, ask questions like, *How do ____ and ____ affect each other over time? On the basis of the data you have, what do you predict would be the effect of a change in ____ on ____?*

If students are struggling to think about which problems might benefit most from a chemical engineering perspective, briefly explain what chemical engineers do. For example, *Chemical engineers apply ideas to manipulate the chemistry of systems to achieve the desired results*. Then ask students which ideas for solutions seem to have more explicit chemistry connections and why they think so.

Building toward 2.A.1 Use **consideration of scale** and **patterns related to scale** to **evaluate proposals** of the most productive **design subproblem** to pursue to **counteract negative human impacts on oysters**. (SEP: 7.6; DCI: ETS1.A.2; CCC: 1.1, 3.1)

you might say, *Engineering and science alone will not be enough to fix the problem. There are already social and political actions that people, and in particular young people, are taking to address the root causes of increased CO₂ in the atmosphere and oceans.*

Consider inviting students to share local actions that youth are taking to address climate change in your community. This may include joining collective actions like climate strikes or walkouts, testifying for local legislatures, working with family members on sustainable farming approaches, supporting tribal stewardship of local resources, etc.

Suggested prompt

Which of these (addressing root cause or mitigating local impacts) is most important to focus on? Is it enough to act on just one or the other? Why?

Sample student response

Mitigating local impacts can only do so much. Root cause is really important and it will take time for climate systems to get back in balance, and oysters need help now.

Both are important and it is not enough to just focus on one because they are related.

Suggested prompt	Sample student response
<i>On what timescales would we see results related to these different approaches to solutions?</i>	Climate changes are on longer timescales. It would take some time for CO₂ levels in the atmosphere and ocean to be restored. You could see results more quickly with local mitigation efforts, but if the root cause is still a problem, you will have to keep doing it and eventually it might not work.
<i>Where is engineering, and chemical engineering specifically, going to be most useful? Where is engineering or science alone not enough to solve the problem?</i>	Chemical engineering seems useful for both root cause and local mitigation, but maybe especially for local mitigation if we can use chemistry to protect oysters. We already have technological solutions that would reduce CO₂ but for social reasons we have not used them as much as we could.



Invite students to build initial arguments for which subproblem to focus on next. Display slide L. Say, *Given everything we have discussed, let's think back to our list of focal subproblems and decide which one we should pursue next to help us build out a full design for a solution.*

Tell students to discuss first with their group, then share their thinking with the whole class.

Debrief small group discussions as a class. Affirm each idea the groups propose and push for rationale.

Suggested prompt	Sample student response
<i>Which subproblems do we know the least about how to solve, at this point?</i>	We know less about how CO₂ is causing ocean acidification, and how this is harming oysters, ecosystems, and communities.
<i>What does this mean for which subproblem(s) we should focus on next? Which subproblem(s) are we uniquely positioned to learn about in this class so we can take more informed action?</i>	We should figure out what is happening when CO₂ goes into the ocean that makes it more acidic. There is chemistry going on here that we do not understand yet and it seems like something we could use chemistry to solve. We can figure out the chemistry of the subproblem of acidification next while still looking for opportunities to act to address CO₂ emissions.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students reason about the **interrelated nature of different approaches to solutions**. (SEP: 7.6) *For example, that mitigation might be an immediate priority, but will become increasingly more difficult to achieve without addressing the root cause.*
- Students evaluate **competing arguments based on evidence** about which **subproblems we are best positioned to pursue** in the context of our chemistry class. (SEP: 7.6; DCI: ETS1.A.2)

What to do: If the class is leaning in one direction and there are few competing ideas about which subproblems to pursue, ask, *Who has a different way of thinking about this topic? Who wants to add on to what _____ is saying?*

If students argue that addressing the root cause above all else is most important and is worthy of time in our chemistry class, affirm this idea. For example, you might say something like, *The science is clear that we must do something to reduce anthropogenic greenhouse gas emissions at their source. Science alone cannot fix this problem. To be good science communicators and effective engineers we have to hold onto social and political dimensions of the problems we face as well.*

Building toward 2.A.2 Use **consideration of scale** and **patterns related to scale** to **evaluate proposals** of the most productive **design subproblem** to pursue to **counteract negative human impacts on oysters**. (SEP: 7.6; DCI: ETS1.A.2; CCC: 1.1, 3.1)

Navigate. Say, *You did such a great job building arguments. There are multiple valid arguments for which subproblems and categories of solutions to pursue. That is usually the case with complex problems. Let's pick this up at the beginning of next class and decide on a shared direction.*

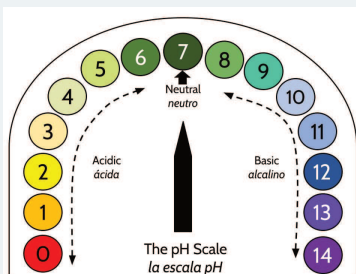
LESSON 3: Can carbon dioxide make the ocean more acidic?

PREVIOUS LESSON We wanted to prevent oyster die-off. We decided to break the problem into subproblems, then brainstormed initial ideas for big picture approaches to solving each subproblem. Ultimately, we developed an argument about which subproblem to pursue.

THIS LESSON

INVESTIGATION

2 days



We identify different data we need in order to address subproblems. 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 share our data and wonder about what pH is. We read an article and explore a website about pH. We share what we figure out, add to our personal glossaries, and add new questions to the DQB.

NEXT LESSON We will use molecular formulas to predict which substances are acids, bases, or neither. We will compare quantities of particles and concentrations in different solutions. We will collect and analyze the pH of these solutions. We will develop a model to explain our results. We will use our model to predict how increases in atmospheric carbon dioxide make the ocean more acidic.

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-1,
HS-ETS1-2



WHAT STUDENTS WILL DO

3.A Plan and conduct an investigation to produce empirical evidence that supports the claim that increased atmospheric carbon dioxide levels causes ocean water to become more acidic. (SEP: 3.1; DCI: PS1.B.2, ESS2.D.3; CCC: 2.1)

3.B Integrate sources of information to answer scientific questions about pH values and how a change in magnitude of hydrogen ions in solution affects pH values. (SEP: 8.2; DCI: PS1.B.2; CCC: 3.4)

WHAT STUDENTS WILL 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.

Lesson 3 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	6 min		NAVIGATE Lead students in a discussion to revisit subproblems using <i>Progress Tracker</i> .	A	<i>Progress Tracker</i>
2	10 min		BRAINSTORM EXAMPLES OF CARBON DIOXIDE IN WATER Problematize the class consensus model around the $\text{CO}_2 + \text{H}_2\text{O} = \text{acid}$ question. Have students work with a partner to brainstorm a list of examples of CO_2 mixed in water. Develop a class list of substances.	B-C	class consensus model, chart paper, chart paper markers
3	17 min		PLAN INVESTIGATIONS TO TEST WATER ACIDITY Organize students into groups of 5 to develop investigation plans.	D-F	<i>Safety Instructions</i> , salt-water solution, carbonated water, “flat” carbonated water, distilled water, citric acid solution, bromothymol blue indicator, universal pH strips, disposable plastic pipette, 250 mL beakers, Community Agreements (optional)
4	12 min		CONDUCT WATER ACIDITY INVESTIGATION Have students work in their small groups to carry out their investigation plans.	G	Measuring Acidity of Water
End of day 1					
5	12 min		DISCUSS INVESTIGATION RESULTS Lead a whole-class discussion to make sense of the investigation data.	H-I	group investigation data posters
6	19 min		READ ABOUT pH SCALE Distribute a reading about the pH scale and indicators. Have students look back at Lesson 1 data with their new understanding.	J-K	<i>Connect, Extend, Question, Measuring pH</i> , computer with internet access to https://www.openscienced.org/general/noaaglobaldataexplorer/
7	12 min		BUILD UNDERSTANDING ABOUT pH Lead a class discussion to share what new understandings students have about pH. Add additional questions to the DQB.	L-N	2 3x3 sticky notes, permanent markers, <i>Connect, Extend, Question, Measuring pH</i> , chart paper, chart paper markers, Driving Question Board
8	2 min		NAVIGATE Have students complete an Exit Ticket.	O	loose-leaf paper
End of day 2					

Lesson 3 • Materials List

	per student	per group	per class
Measuring Acidity of Water materials	• <i>Safety Instructions</i> • safety goggles • disposable gloves (optional) • chemical apron (optional)	• chart paper • chart paper markers • 6 universal pH strips • 10 mL bromothymol blue indicator • disposable plastic pipette • 100 mL salt-water solution • 100 mL carbonated water • 100 mL “flat” carbonated water • 100 mL distilled water • 100 mL citric acid solution • 6 250 mL beakers	
Lesson materials	• <i>Progress Tracker</i> • science notebook • <i>Safety Instructions</i> • <i>Connect, Extend, Question</i> • <i>Measuring pH</i> • 2 3x3 sticky notes • permanent markers • loose-leaf paper	• computer with internet access to https://www.openscienced.org/general/noaa/globaldataexplorer/	• class consensus model • chart paper • chart paper markers • salt-water solution • carbonated water • “flat” carbonated water • distilled water • citric acid solution • bromothymol blue indicator • universal pH strips • disposable plastic pipette • 250 mL beakers • Community Agreements (optional) • group investigation data posters • Driving Question Board

Materials preparation (40 minutes)

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

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

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

Have the class consensus model visible on day 1.

Have the Community Agreements visible on day 1.

Prepare two sheets of chart paper for day 2, when the class shares the information they were able to connect and extend to their prior knowledge about pH. Label one chart paper “Connect” and the other “Extend.”

Have the Driving Question Board visible on day 2.

Day 1: Measuring Acidity of Water

- **Group size:** 5 students
- **Setup:** See *Preparing Water Solutions* for preparation instructions.
- **Notes for during the lab:** If the same disposable plastic pipette is being used to add bromothymol blue indicator to all the 250 mL beakers, instruct students not to touch the surface of the liquid so as to avoid cross-contamination. Otherwise, have students use a separate disposable plastic pipette for each 250 mL beaker.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*.
- **Disposal:** All liquids can be safely disposed of in the sink. Used universal pH strips can be put in the trash.
- **Storage:** Store unused bromothymol blue indicator and universal pH strips in lockable storage cabinets.

Lesson 3 • Where We Are Going and NOT Going

Where We Are Going

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

- **ESS2.D.3 Weather and Climate:** Changes in the atmosphere due to human activity have increased carbon dioxide concentrations ~~and thus affect climate.~~
- **PS1.B.2 Chemical Reactions:** In many situations, a dynamic and condition-dependent balance between a reaction ~~and the reverse reaction~~ determines the numbers of all types of molecules present.

Crossout explanation: ESS2.D.3 Weather and Climate was first developed in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*. This lesson includes chemistry (acidification) as part of the climate change model, expanding the energy-movement model in C.1: Polar Ice. The narrow term “climate” does not typically include ocean-atmosphere interactions, so it is crossed out, but global changes in water acidity are another direct result of anthropogenic climate change. PS1.B.2 Chemical Reactions is fully developed in Lesson 6 when students build understanding around reversible reactions.

At this point, students know that the ocean is becoming more acidic, which is causing problems for oysters. This lesson addresses how carbon dioxide lowers the pH of water through a series of chemical reactions, which builds on the data students saw in **Lesson 1** and prepares students to investigate the particle model of the process in **Lesson 4**.

Students identify data needed to make progress on addressing subproblems they identified in **Lesson 2** (SEP: 3.1). They work with a partner to brainstorm examples of substances that contain both carbon dioxide and water. Students use some of the substances on the list, as well as additional substances, to design investigation plans in small groups to test whether substances that contain carbon dioxide and water are acidic (SEP: 3.1; DCI: PS1.B.2). After completing their investigations, students discuss the evidence they gathered to come to the conclusion that carbon dioxide in water causes water to become acidic (SEP: 3.1; DCI: PS1.B.2, ESS2.D.3; CCC: 2.1). Students evaluate the usefulness of the types of evidence gathered and determine what tools are best to use moving forward (SEP: 3.1).

Students wonder about what pH measures. They are given a reading and website to gather information to help them answer questions about pH values (SEP: 8.2; DCI: PS1.B.2). They are able to integrate information from their investigation data, the reading, and the website to determine how a slight change in pH represents a larger magnitude change in the concentration of hydrogen (H⁺) ions in the solution (SEP: 8.2; DCI: PS1.B.2; CCC: 3.4).

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

Where We Are NOT Going

Ideas around the logarithmic scale of pH measurements are not discussed in this lesson or unit. The mathematical reasoning required to make sense of the logarithmic pH scale is typically developed in grade 11 of CCSS Mathematics. The OpenSciEd High School Chemistry course is designed for students in grade 10, so such reasoning is beyond the scope of CCSS High School Mathematics at this point in the course sequence. In this lesson, students develop ideas around pH in terms of ratios and magnitudes of 10. They continue to build on and expand this understanding in **Lesson 4**, when students are introduced to *molarity*.

LEARNING PLAN for LESSON 3

1 · NAVIGATE

6 min

MATERIALS: *Progress Tracker*

Revisit the subproblems identified in Lesson 2. Refer students to the list of subproblems at the top of *Progress Tracker*. Display slide A and say, *In the last lesson, we figured out that the big problem of oyster die-off can be broken into more manageable subproblems.* Ask students to do an individual quick write to answer the prompts on slide A. After a few minutes, lead a discussion to share student responses.

Suggested prompt	Sample student response
What subproblems did we identify?	CO ₂ gets into the atmosphere/ocean. CO ₂ makes water more acidic. Acidity hurts oyster shells. Oyster die-off hurts ecosystems and people.
What types of data do we need in order to address these subproblems? *	We need to learn more about acids to understand how they can change ocean water and hurt oyster shells. CO ₂ seems to be important, so we need to learn more about where it comes from and how it reacts.

* SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

It is important for students to identify types of data that we need to collect to address some of the subproblems the class identified in Lesson 2. This supports students' use of Planning and Carrying Out Investigations so that later in this lesson, there is a need to collect specific types of data as students work in small groups to develop investigation plans (SEP: 3.1).

2 · BRAINSTORM EXAMPLES OF CARBON DIOXIDE IN WATER

10 min

MATERIALS: science notebook, class consensus model, chart paper, chart paper markers

Problemalyze a portion of the class consensus model. Display slide B and have the class consensus model visible. Point to the section that shows the interaction between carbon dioxide and water. Ask, *We think that carbon dioxide is interacting with water in some way to form an acid. But, we are not sure. What could we do to figure out if our idea is accurate?* Look for students to say that we should test it somehow.

Brainstorm other mixtures of carbon dioxide and water. Display slide C. Have students work with a partner to brainstorm a list of substances that contain both carbon dioxide and water. * Give groups about four minutes before leading a discussion to develop a class list on a sheet of chart paper.

Work with the class to develop a list of substances that contain both carbon dioxide and water, on a sheet of chart paper. Students' suggestions may include:

- soda (pop, soda pop)
- carbonated water (fizzy water, seltzer)

If students suggest substances that contain only carbon dioxide (e.g., candy or dry ice), encourage them to go back to the prompt or remind them that the substances should contain both carbon dioxide and water.

* ATTENDING TO EQUITY

Supporting Emergent Multilinguals: Before students engage in whole-class discussions, it can be helpful to first provide them with the opportunity to work in pairs, triads, or small groups on ideas related to their reasoning. Smaller groups can be especially helpful to emerging multilingual students because they offer a chance to engage in sensemaking with their peers. They also offer students a comfortable space to use their linguistic and nonlinguistic resources to express their ideas, as well as learn from other students.

3 • PLAN INVESTIGATIONS TO TEST WATER ACIDITY

17 min

MATERIALS: *Safety Instructions*, science notebook, salt-water solution, carbonated water, “flat” carbonated water, distilled water, citric acid solution, bromothymol blue indicator, universal pH strips, disposable plastic pipette, 250 mL beakers, Community Agreements (optional)

Share investigation materials with students. Say, *I have some materials we can use to test whether substances that contain carbon dioxide and water are acidic.* Display **slide D** and organize students into groups of 5. Have the following materials displayed:

- 100 mL salt-water solution
- 100 mL carbonated water
- 100 mL “flat” carbonated water
- 100 mL distilled water
- 100 mL citric acid solution
- 10 mL bromothymol blue indicator
- 6 universal pH strips
- disposable plastic pipette
- 6 250 mL beakers

Explain to students that these are the materials available to them when they develop their investigation plans. Point out that groups will be limited to testing six different solutions. You should also explain that bromothymol blue indicator and universal pH strips are used by scientists to test whether substances are acidic and/or basic.

ADDITIONAL GUIDANCE

Students may benefit from seeing how bromothymol blue indicator and universal pH strips work before developing their investigation plans. Quickly demonstrate this using **tap water**. The purpose of using tap water is to avoid giving away any data that students might collect later during their investigation.

Discuss safety precautions students should follow. Display **slide E** and distribute *Safety Instructions*. Go over the safety instructions with students and ask if there are any clarifying questions. ✱ Be sure to point out that the investigation plans cannot include mixing the citric acid solution with any of the other types of water solutions.



Plan investigations in small groups. Display **slide F**. Continue to have the investigation materials available to groups as they develop their investigation plans. As groups work, walk around the room and assist as needed. Give groups about 10 minutes to develop their investigation plans and then spend the next two minutes checking them before allowing groups to carry out their investigations.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **collaboratively plan an investigation to produce data to support a scientific claim.** (SEP: 3.1)
- Students' **investigation plan ensures that variables are controlled** so that the **empirical evidence collected** can be **used to evaluate a claim.** (SEP: 3.1; CCC: 2.1)

What to do: Sample investigation plans are provided in *Sample Investigation Plans*. If groups' investigation plans differ from those examples, that is okay. It is important that investigation plans are specific, will provide data, and will collect empirical evidence. If plans are not, use probing questions to guide group designs to increase specificity, identify data to collect, and consider how that data can be used as evidence to evaluate a claim. It may be helpful to demonstrate the types of data students can collect when using bromothymol blue and pH strip indicators.

Building toward 3.A.1 Plan and conduct an investigation to produce empirical evidence that supports the claim that increased atmospheric carbon dioxide levels causes ocean water to become more acidic. (SEP: 3.1; DCI: PS1.B.2, ESS2.D.3; CCC: 2.1)

✱ ATTENDING TO EQUITY

Building Classroom Culture: This may be an opportunity to revisit the Community Agreements before having small groups work independently to develop investigation plans. Have groups choose a focal community agreement to help ensure equitable contributions of group members during the planning portion of this lesson activity step. If you notice that specific groups are struggling to follow any one of the community agreements during their work time, revisit the agreements and strategize ways to help the group follow them.

4 · CONDUCT WATER ACIDITY INVESTIGATION

12 min

MATERIALS: Measuring Acidity of Water

Carry out investigation plans. Display **slide G** and give groups the remaining class time to carry out their investigation plans. As groups work, circulate around the room, assist as needed, and ensure groups are following the safety instructions on *Safety Instructions*.

End of day 1

5 · DISCUSS INVESTIGATION RESULTS

12 min

MATERIALS: science notebook, group investigation data posters

 **Discuss investigation results.** Make sure that each group's investigation data poster is visible to everyone in the class. Display **slide H**.

KEY IDEAS

Purpose of this discussion: Identify patterns in group investigation data that can be used to support a claim. Determine which tools for recording data and which substances the class should use in future investigations.

Listen for these ideas:

- Carbonated water has a lower pH value than “flat” carbonated water.
- Distilled water has a pH of 7, or is neutral.
- We should use pH strip indicators in future investigations.
- Distilled water should also be used as a control in future investigations.

Suggested prompt

Sample student response

What patterns are you noticing in the class data?

Citric acid solution has the lowest pH value.

Carbonated water has a lower pH value than “flat” carbonated water.

Distilled water has a pH of 7.

How do the data either support or refute the claim that increasing atmospheric CO₂ levels cause ocean water to become more acidic?

The data support the claim because the carbonated water had lower pH values than both the salt-water solution and the “flat” carbonated water.

Which indicator, the pH strip or bromothymol blue, provided more useful data? Why?

The pH strip because you got an actual pH value. The bromothymol blue could tell you only if it was acidic, but not how acidic.

Suggested prompt	Sample student response
<i>Based on your group's measurements and/or the class data, what other water that was tested could be considered a control? Why?</i> <i>What implications does using distilled water as a control and pH strip indicators have on future investigations?</i>	The distilled water because it had a pH of 7. We should make sure to use those whenever we do pH tests. We need to make sure we have distilled water to check that our pH strips are accurate.
ADDITIONAL GUIDANCE	Students may benefit from taking a few minutes to look through each group's data and form responses to the prompts on slide H prior to participating in the whole-class discussion.
ASSESSMENT OPPORTUNITY	What to look/listen for in the moment: - Students identify empirical evidence that supports the claim that increased atmospheric carbon dioxide levels have caused ocean water to become more acidic. (DCI: PS1.B.2, ESS2.D.3; CCC: 2.1) - Students consider which pH indicator and water should be used to gather data in future investigations. (SEP: 3.1) What to do: Have students look back at the evidence from the group investigations to find supporting empirical evidence for the claim. Students may benefit from a brief discussion around the difference between the qualitative BTB and quantitative pH strip indicator measurements (prompt 3) if they are struggling to identify which indicator should be used in future investigations. Use the additional guidance suggestion if students need more time to evaluate the data. Building toward 3.A.2 Plan and conduct an investigation to produce empirical evidence that supports the claim that increased atmospheric carbon dioxide levels causes ocean water to become more acidic. (SEP: 3.1; DCI: PS1.B.2, ESS2.D.3; CCC: 2.1) Develop initial ideas about pH. Display slide I. Give students a few minutes to stop and jot a response to the prompt on the slide . After a few minutes, ask for a few students to share their responses. Ask, <i>Based on what you know about acids and bases, what do you think pH is?</i> Accept all student ideas. Summarize student responses and point out that they have many different ideas.

6 • READ ABOUT pH SCALE

19 min

MATERIALS: *Connect, Extend, Question, Measuring pH*, science notebook, computer with internet access to <https://www.openscienced.org/general/noaaglobaldataexplorer/>



Read about measuring pH. Say, *I have a reading about pH that may help us.* Display **slide J** and distribute *Measuring pH* and *Connect, Extend, Question*. Ask students to read *Measuring pH* and complete the protocol on *Connect, Extend, Question*. This protocol asks students to relate what they are reading to what they already know and what they are trying to figure out. Prompt students to consider the question they want to test and how what they read might help their investigation. After they have completed the organizer, ask students to compare their responses with a partner and update their responses with any new ideas from their partner.

Revisit Lesson 1 ocean pH data. Display slide K. Have students continue to work with their partner. After completing *Measuring pH*, ask students to explore <https://www.openscienced.org/general/hoaaglobaldataexplorer/>. Have them add to *Connect, Extend, Question* with this new information. This simulation allows students to visualize how pH of the oceans has changed over time and how it is predicted to change through the year 2100.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **integrate information from a reading and website to answer questions about pH values.** (SEP: 8.2; DCI: PS1.B.2)
- Students explain that **pH values indicate the concentration of hydrogen (H^+) ions in a solution.** (DCI: PS1.B.2)
- Students identify that an **increase by a factor of 10 in the concentration of hydrogen (H^+) ions in a solution** leads to a **decrease by 1 in the pH value of the solution.** (DCI: PS1.B.2; CCC: 3.4)

What to do: As students work, look at the types of information they record on *Connect, Extend, Question*. Ask students to show you where in the reading or website they have found the information they used to help answer the question.

Building toward 3.B.1 Integrate sources of information to answer scientific questions about pH values and how a change in magnitude of hydrogen ions in solution affects pH values. (SEP: 8.2; DCI: PS1.B.2; CCC: 3.4)

7 • BUILD UNDERSTANDING ABOUT pH

12 min

MATERIALS: 2 3x3 sticky notes, permanent markers, *Connect, Extend, Question, Measuring pH*, science notebook, chart paper, chart paper markers, Driving Question Board



Develop class connect and extend posters. Display slide L. Ask, *How do the ideas and information connect to what you already know?* As students share their ideas, record them on one piece of chart paper labeled “Connect.” If other students show agreement, have them indicate non-verbally by adding check marks next to those ideas or pieces of information.

Ask, *What new ideas did you get that extended or broadened your thinking?* As students share their ideas, record them on a second piece of chart paper labeled “Extend.” Again, if other students show agreement, have them add check marks next to those ideas. Two sample posters are shown.

<i>Connect</i>	<i>Extend</i>
• Acids have a lower pH than bases. • Pure water has a neutral pH (?). • Different indicators can give us different levels of information - pH value or is it acidic or basic. • Ocean pH was stable for a long time and recently has changed faster.	• pH measures the concentration of hydrogen (H^+) or hydroxide (OH^-) ions in a substance. • Acids have a high concentration of H^+ ions • Bases have a high concentration of OH^- ions • A 1 number change in pH is a 10x change in H^+ ion concentration. • Smaller bodies of water change pH faster than the ocean.

Ask, *How do these ideas connect back to our investigation data? What new ideas from the reading or website can help us make sense of some of the differences in pH we measured?* Look for students to suggest:

- Because there was a change in the pH of the carbonated water, that means something happened to release a lot of hydrogen ions into the solution.

- There are fewer hydrogen ions in the “flat” carbonated water, so something is happening such that as carbon dioxide leaves the solution, the hydrogen ions that were present are no longer there.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **integrate information from a reading and website to answer questions about pH values.** (SEP: 8.2; DCI: PS1.B.2)
- Students explain that **pH values indicate the concentration of hydrogen (H⁺) ions in a solution.** (DCI: PS1.B.2)
- Students identify that an **increase by a factor of 10 in the concentration of hydrogen (H⁺) ions in a solution leads to a decrease by 1 in the pH value of the solution.** (DCI: PS1.B.2; CCC: 3.4)

What to do: If students do not suggest some of the examples found on the Connect and Extend posters, prompt them to think about what we already knew about pH, acids, or bases. Leverage student prior knowledge by making this visible. Ask students to show you where in the reading or website they have found the information they used to help answer the question. Encourage students to think about how a small change in pH indicates a large change in the hydrogen ions in the solution. It is not important that students mathematically determine this, rather qualitatively thinking about it is appropriate.

Building toward 3.B.2 **Integrate sources of information to answer scientific questions about pH values and how a change in magnitude of hydrogen ions in solution affects pH values.** (SEP: 8.2; DCI: PS1.B.2; CCC: 3.4)

Update personal glossaries. Display slide M. Say, *We have developed some understandings around what pH, acid, and base means. Let's take a moment to reflect on that and update our personal glossaries.* Have students turn and talk with a partner to discuss the prompt on the slide. Give students a few minutes to add definitions for *pH*, *acid*, and *base* to their personal glossaries.

Add new questions to the DQB. Display slide N and have the DQB visible. Say, *You also recorded some new questions that came up for you after reading about pH and examining the website. Take a moment to record these on sticky notes so we can add them to our DQB.* Distribute 2 3x3 sticky notes and permanent markers to students as needed. After students have recorded their new questions, add them to the DQB.

Questions may include:

- How can adding something to water change its pH?
- How can adding carbon dioxide to water cause H⁺ ions to form?
- Can water split into H⁺ and OH⁻ ions?

8 • NAVIGATE

2 min

MATERIALS: loose-leaf paper

Navigate with an Exit Ticket. Display slide O. Have students answer the prompt on a piece of loose-leaf paper. Collect the exit tickets and choose some student responses to highlight on slides A-B of Lesson 4. Ensure that the responses you choose represent ideas about different types of acids and bases.

Additional Lesson 3 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

As students read about pH and examine a website, they connect ideas in the two resources to their current knowledge as well as extend their knowledge. Students use their understandings to develop definitions for acid, base, and pH in their personal glossaries.

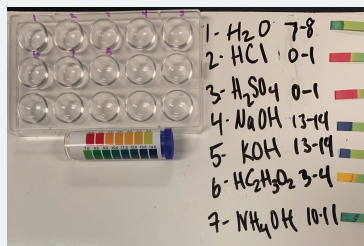
LESSON 4: What is it about a substance that determines whether it produces more or fewer H^+ or OH^- ions when it is added to water?

PREVIOUS LESSON We brainstormed a list of substances that contain both water and carbon dioxide. We planned an investigation with our group to test whether solutions of carbon dioxide and water are acidic. We shared our data. We read an article and explored a website about pH. We shared what we figured out, added to our personal glossaries, and added new questions to the DQB.

THIS LESSON

INVESTIGATION

2 days



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. We collect and analyze the pH of these solutions. We develop a model to explain our results. We use our model to predict how increases in atmospheric carbon dioxide make the ocean more acidic.

NEXT LESSON We will investigate how carbon dioxide could naturally dissolve in water and use the data to help explain large-scale system interactions. We will examine additional data about carbon's movement among Earth's spheres. We will use the data to revise the class consensus model. We will examine our investigation from day 1 and wonder what could explain the color change.

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-1,
HS-ETS1-2



WHAT STUDENTS WILL DO

4.A Apply ratio thinking in the context of complicated measurement problems involving quantities with compound units (moles/L) to predict how the concentration of an acid or base dissolved in water will affect the pH of the solution. (SEP: 5.5; DCI: PS1.B.2; CCC: 3.1)

4.B Develop a particle-level model that connects the structure of different acids to the measured pH values that explains why those values vary for each acid. (SEP: 2.3; DCI: PS1.B.3; CCC: 6.2)

WHAT STUDENTS WILL 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.

Lesson 4 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Have students identify themes in their ideas in the Lesson 3 exit ticket responses and discuss how we can investigate them.	A-B	Images of student ideas from the Lesson 3 exit tickets inserted into slides A and B.
2	14 min		MAKE PREDICTIONS AND CONSIDER RELATED PHENOMENA Have students individually predict if substances are acids, bases, or neither then compare with a partner. Carry out the Solution Preparation Demonstration.	C-F	Solution Preparation Demonstration
3	8 min		COMPARE SOLUTIONS USING MATHEMATICAL THINKING Walk students through how to use mathematical thinking to compare quantities of particles and concentrations in different solutions.	G-K	
4	18 min		CONDUCT pH CONCENTRATION INVESTIGATION Organize students into groups of 5 and assign them a group of substances to investigate. Review safety precautions and have students carry out the investigation.	L-N	pH Concentration Investigation
<i>End of day 1</i>					
5	6 min		ANALYZE AND INTERPRET DATA Have students pair up with a classmate that investigated a different set of solutions and compare results.	O	<i>Investigating pH Concentration</i>
6	12 min		DEVELOP AN INITIAL MODEL Have students individually develop initial models to explain differences in pH values for two acids of the same concentration. Organize students into groups of five to use manipulatives to model differences in rates of acid dissociation.	P-Q	<i>Modeling H⁺ Concentrations</i> , prepared <i>Molecule Deck</i> , scissors (optional)
7	12 min		DEVELOP UNDERSTANDING OF DISSOCIATION Organize the class into a Scientists Circle to discuss acid and water interactions to develop understanding around dissociation and degrees of dissociation.	R-T	<i>Modeling H⁺ Concentrations</i> , prepared <i>Molecule Deck</i> , M-E-F triangle, chart paper, chart paper markers
8	8 min		COMPLETE AN ELECTRONIC EXIT TICKET Have students individually complete the Electronic Exit Ticket.	U	Link to class copy of the Electronic Exit Ticket, computer with internet access
9	6 min		NAVIGATE Have students discuss ideas relating changing CO ₂ levels in the atmosphere to ocean acidity.	V	
10	1 min		OPTIONAL: INTRODUCE HOME LEARNING Introduce the Home Learning: <i>pH and Organisms</i> .	W	<i>pH and Organisms</i>
<i>End of day 2</i>					

Lesson 4 • Materials List

	per student	per group	per class
Solution Preparation Demonstration materials	- science notebook - indirectly vented chemical splash goggles		2 1000 mL beakers labeled A and B 2000 mL distilled water - weighing paper containing 60g citric acid - weighing paper containing 6g citric acid 2 glass stir rods - safety shield
pH Concentration Investigation materials	- goggles - nitrile gloves - chemical apron (optional) <i>Investigating pH Concentration</i>	8 universal pH strips 1 well plate 1 sheet copy paper	18 250 mL beakers containing 100 mL of each of the following: 1 M HCl - 1 M H₂SO₄ - 1 M HC₂H₃O₂ - 1 M NaOH - 1 M KOH - 1 M NH₄OH - 1 M NaCl - 0.1 M HCl - 0.1 M H₂SO₄ - 0.1 M HC₂H₃O₂ - 0.1 M NaOH - 0.1 M KOH - 0.1 M NH₄OH - 0.1 M NaCl - distilled water 32 disposable plastic pipettes
Lesson materials	<i>Investigating pH Concentration</i> <i>Modeling H⁺ Concentrations</i> - Link to class copy of the Electronic Exit Ticket - computer with internet access <i>pH and Organisms</i>	- prepared <i>Molecule Deck</i> - scissors (optional)	- Images of student ideas from the Lesson 3 exit tickets inserted into slides A and B. - prepared <i>Molecule Deck</i> - M-E-F triangle - chart paper - chart paper markers

Materials preparation (60 minutes)

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

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

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

Insert 4 images of students' **Lesson 3** exit ticket responses at the bottom of slides A and B that are related to different amounts/concentrations and/or different molecular structures of acids and bases. Use this opportunity to create different versions of these slides that show student responses from each class period you teach.

Create 2 stations for groups to carry out the pH Concentration Investigation using the directions found on *Solution Preparation*. If you have the space in your classroom, consider making 4 stations, 2 of each solution set.

Print 7 **single-sided** copies of *Molecule Deck*. Cut out the cards for each molecule and clip the same types of molecules together (4 clips per group). These 4 clipped sets form a molecule deck. Place each deck in a small plastic bag or bin for easier distribution.

- The assumption is that students will find manipulating the molecular cards with their groups insightful after completing *Modeling H⁺ Concentrations*. If you anticipate that some groups might have trouble visualizing or articulating how H⁺ ions would be produced by different force interactions between these molecules, consider preparing additional copies of *Molecule Deck* as consumables and allowing those groups to cut out some of the cards themselves.

Have the M-E-F Triangle chart visible on day 2.

Create Electronic Exit Tickets for this lesson using the directions found on *Electronic Exit Ticket*.

Day 1: Solution Preparation Demonstration

- **Group size:** Whole class.
- **Setup:**
 - Fill 2 1000 mL beakers with 1000 mL of distilled water for each class.
 - Label one container "A."
 - Label the second container "B."
 - Prepare two pieces of weighing paper for each class:
 - One weighing paper with 60g of citric acid.
 - The second weighing paper with 6g of citric acid.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*. These include:
 - When working with hazardous chemicals, wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and takedown segments of the activity.
 - When diluting acids or bases, the acid or base should be added to water and not water to the acid or base.
 - Observers of activities involving hazardous chemicals must have appropriate PPE eye protection (indirectly vented chemical splash goggles) and non-latex aprons in addition to being positioned approximately 15 feet in front of a demonstration safety shield or closed fume hood sash.
 - Secure loose clothing, wear closed-toe shoes, and tie back long hair.
 - Never eat any food items used in a lab activity.
 - Never taste any substance or chemical in the lab.
 - Only combine substances and amounts as instructed by your teacher.
 - Follow your teacher's instructions for disposing of waste materials.
 - Use caution when working with glassware, which can shatter if dropped and cut skin.
 - Immediately clean up any liquid spilled on the floor so it does not become a slip/fall hazard.
 - Never pour chemicals, either used or unused, back into their original container.
 - If you get a hazardous chemical on your clothing or have a clothing fire, use the emergency shower.
 - If you get a chemical in your eye, use an eyewash station immediately.
 - Point the test tubes, beakers, or other vessels away from yourself and other people when the vessels contain reactants or other substances.
 - Never use mouth suction to fill pipets.
 - Wash your hands with soap and water immediately after completing this activity.
- **Disposal:** All liquids can be safely disposed of in the sink.
- **Storage:** None.

Day 2: pH Concentration Investigation

- **Group size:** 5 students
- **Setup:** Review *Solution Preparation* for detailed instructions for making the 1 M and 0.1 M solutions and set up for stations. Review *Sample pH Data* for sample results.
- **Notes for during the lab:** 100 mL of each solution is more than needed, but will provide extra in case of spills or if a group needs to repeat a trial. It is important that students not move pipettes from one solution to another, as this will lead to mixing of solutions and errors in data.
- **Safety:** Follow safety precautions on **slide M**.
- **Disposal:** Throw universal pH strips directly into the trash. Rinse out well plates into the sink. Unused solutions can be poured down the drain and followed with cold water, or stored for one year.

- **Storage:** Place unused solids and solutions in lockable cabinets used specifically for storing corrosive substances.

Lesson 4 • Where We Are Going and NOT Going

Where We Are Going

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

- **PS1.B.2 Chemical Reactions:** In many situations, a dynamic and condition dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.
- **PS1.B.3 Chemical Reactions:** The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.

Crosscut Explanation: PS1.B.2 Chemical Reactions is fully developed in Lesson 6 when students build understanding around reversible reactions.

In this lesson, students begin to leverage [SEP: 5.5](#) they previously developed this element in *Polar Ice Unit* as they use ratio thinking to explain molarity (mol/L). The complexity of unit conversions increases in Lessons 8 and 9 as students move between grams, mols, and molecules to determine how much of a substance is needed to neutralize a sample of an acidic solution.

Students make predictions about which substances are acids, bases, or neither based on the chemical formulas of the substances. They use mathematical thinking to ensure that fair comparisons are made when testing each of the substances to check their predictions ([SEP: 5.5](#)). Students think about how concentrations of the substances when dissolved in water could affect the amount of H^+ or OH^- ions found in the solution ([DCI: PS1.B.2](#); [CCC: 3.1](#)). Students are introduced to how scientists use moles as a standard unit of measure to describe the number of particles (or molecules) of a substance ([SEP: 5.5](#)). They also are introduced to molarity, or moles/L, to describe the concentration of a substance ([SEP: 5.5](#)). Students conduct and analyze data from testing the pH values of the substances they made predictions about. They determine which substances are acids, bases, or neither and identify relative amounts of H^+ or OH^- ions of each in the solution ([DCI: PS1.B.2](#); [CCC: 3.1](#)). Students use this information to develop initial models to explain the differences in pH values of two acids ([SEP: 2.3, 5.5](#); [DCI: PS1.B.2, PS1.B.3](#); [CCC: 3.1](#)).

Students use manipulatives to refine their ideas and develop a list of interactions to explain the differences in recorded pH values ([DCI: PS1.B.2](#); [CCC: 3.1](#)). Students develop a definition for dissociation and degree of dissociation. They use these definitions to revise their initial models ([SEP: 2.3](#); [DCI: PS1.B.3](#); [CCC: 6.2](#)). Students complete an Electronic Exit Ticket ([SEP: 2.3](#); [DCI: PS1.B.3](#); [CCC: 6.2](#)).

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

Where We Are NOT Going

Though students will see evidence of different levels of dissociation for different acids, they will not define strong and weak acids/bases in this lesson. They will not yet discuss the reverse reaction of carbonate reacting with hydrogen ions to form carbonic acid. Equilibrium and reversible reactions will be addressed in future lessons, and at that point students will be able to model the reaction in both directions.

LEARNING PLAN for LESSON 4

1 · NAVIGATE

5 min

MATERIALS: Images of student ideas from the Lesson 3 exit tickets inserted into slides A and B.

Navigate by looking at Lesson 3 exit ticket responses. Display **slide A**. Recall that we started considering this question at the end of our last class:

- When a substance is added to water, what do you think determines whether the solution will become acidic or basic?

Emphasize that you had a chance to look through everyone's exit tickets and ask students to consider the theme(s) they see in their ideas. * Cue students to think for a few seconds on their own and then share their responses as a class.

Ask, *What themes do you see across these ideas?* Look for students to suggest:

- There are differences in the amount of a substance.
- There are differences in the atoms that make up the substance.

Display **slide B**. Give students a few seconds to consider the question on the slide on their own before sharing their responses as a class. Ask, *How could comparing the molecules of these different types of acids and bases AND testing their pH help us support or refute these ideas?* Accept all student responses.

ALTERNATE ACTIVITY

If you want to strengthen connections back to Lesson 3, ask students to summarize why we decided to use universal pH strips rather than BTB in future investigations.

* ATTENDING TO EQUITY

Universal Design for Learning: Use this opportunity to use different instances of slides A and B for each class period you teach, so that the ideas you display to a particular class came from students in that class. This class period-based customization can increase student *engagement* by highlighting students' ideas in their own words and handwriting. This can help students recognize that their own work is critical to refining the trajectory of their entire learning community.

2 · MAKE PREDICTIONS AND CONSIDER RELATED PHENOMENA

14 min

MATERIALS: Solution Preparation Demonstration

Make predictions about substances. Display **slide C**. Emphasize that we have the listed substances available for us to test later today in the lab and that we have different amounts of them dissolved in water that we can test as well. Read the two prompts on the slide and give students two minutes to write their ideas in their notebooks.

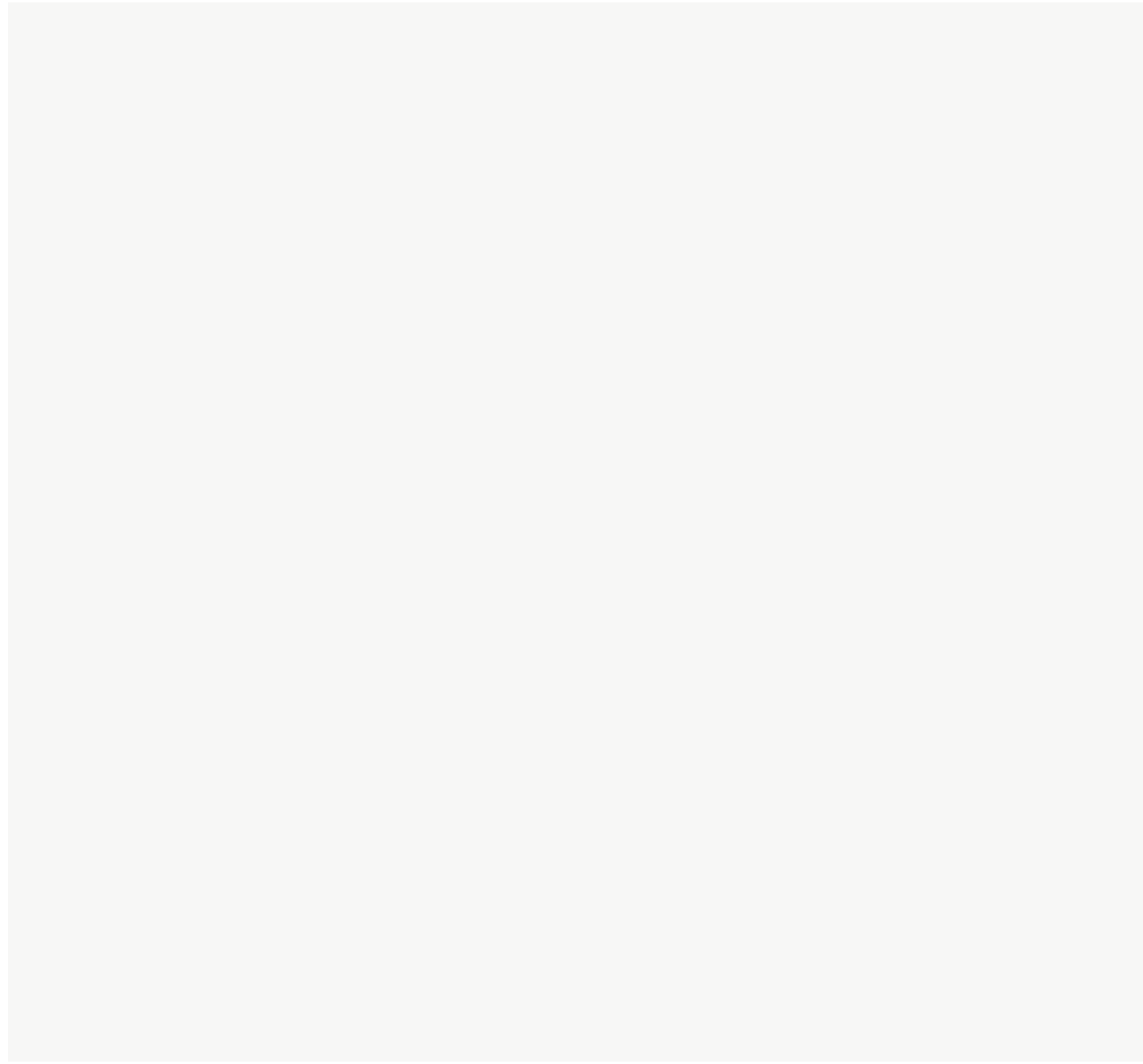
- What patterns do you notice in the atoms that make up these substances?
- Which do you predict are acids, which are bases, and which one of these is neither?

ADDITIONAL GUIDANCE

Though students encountered the word *concentration* in a reading in the prior lesson, avoid referring to anything about the concentration of these solutions at this point. You will reintroduce the idea of concentration right before slide .

Keep in mind that students may have some uncertainty around whether a few of the substances (those with both H and O in their chemical formulas) are acids or bases.

Compare predictions. Display **slide D**. Prompt students now to compare their predictions with a partner's and then discuss the two questions on the slide for two minutes. Then have students share their responses as a class. Follow up with the two additional questions below.



Suggested prompt	Sample student response
Will every one of the acids produce the same amount of H^+ ions when added to water?	Maybe not, since some of the substances that have hydrogen atoms in them have more H's than others.
Will every base produce the same amount of OH^- ions when added to water?	If the ones that have OH at the end are bases, then maybe they will, since they all have only one O atom in them. If the molecules of other substances that have O's in them are bases, then maybe not, since they have more than one O and H in them.
Which substance are we pretty sure is neither an acid nor a base, and why?	NaCl, because it has no H atoms or O atoms in it, and so it shouldn't be able to produce any H^+ or OH^- ions from it. We tested NaCl in water last time and found its pH was 7, which wasn't any different than distilled water. That means it is not an acid or a base.
How would testing these different substances with pH paper help confirm or refute our predictions?	The colors on the pH paper will be different if they produce different amounts of these particles. The color on the pH paper will be the same for the acids if they produce the same amounts of H^+ ions. The pH value we determine from the paper will be the same for bases if they produce the same amounts of OH^- particles.

Highlight the need to consider the initial number of particles in the system, in order to make more accurate predictions. Say something like, *If we want to compare which substances produce more or fewer of these types of particles, it might also be important to think about how we can ensure a fair comparison to start with in terms of the numbers of molecules of these substances we are adding to water when we prepare each solution.*

Make predictions about different solutions. Suggest that we prepare two different solutions of acids and use some mathematical thinking to consider how to ensure fair comparisons between different acids or bases.

SAFETY PRECAUTIONS

Make sure your goggles are on for this demonstration.



Display **slide E**. Hold up the two different containers labeled "A" and "B" and point out that each contains 1 L of distilled water. Point to the two weighboats and share that one contains 10 times as much acid as the other. Do not tell students what the substance is during this demonstration.

Ask students to think about the question on the bottom of the slide as you demonstrate adding these different amounts of solid acetic acid to each container (A vs. B). Pour the weighing paper containing 60 g of citric acid into container “A” and stir it for a few seconds. Then pour the weighing paper containing 6 g of citric acid into container “B” and stir it for a few seconds.

Repeat the question on the slide and ask students to share their ideas. Listen for an argument for there being an unfair comparison because there is more matter (particles) being added to the same amount of water in one solution vs. the other.

Suggest that in this example, some of what we are identifying as a difference in starting conditions can be described as one solution being more concentrated than another.

Consider related phenomena. Say, *Let's talk about related experiences where we adjusted the concentration of a drink to make it sweeter or less sweet. This will help us think about how we can prepare our solutions in the lab to make fairer comparisons.* Display **slide F**.

Ask, *What are examples where you or someone else adjusted how concentrated or how diluted a drink was? What was done to accomplish that?*

Look for students to suggest:

- Adding water to juice
- Adding ice to soda
- Adding more powdered drink mix to water
- Adding more pumps of chocolate, or flavoring, to a drink or an extra shot of espresso to a coffee

Consider an example of lemonade, where a certain amount of sugar and lemon juice is added to a certain amount of water to make a batch. Ask students to consider how the recipe for the lemonade would need to change if we wanted to keep the concentration or taste of the lemonade the same. Say, *If we triple the amount of water, what else do we need to do to ensure the same outcome?* Students will say that we need to triple the amount of lemon juice and sugar too.

Emphasize that this mathematical thinking involves scaling up or down the amounts of ingredients used to ensure that the ratios of those ingredients stay the same, and for the examples we considered, that the concentration of molecules in the liquid is the same no matter how much of the mixture is made.

Say something like, *Scientists have ways of measuring, describing, and keeping track of the concentration of different solutions to ensure fairer comparisons between them, by referring to the number of molecules of a substance they are adding to water when they make a solution. Let's consider the sorts of scales and ratios we will be using when we talk about the numbers of particles in a system, like solutions (a) and (b) that we just made.*

3 · COMPARE SOLUTIONS USING MATHEMATICAL THINKING

8 min

MATERIALS: None

Consider quantities in the system. Display **slide G**. Hold up the container with **solution (A)** in it. Remind students that you added 60 g of solid citric acid to the water to make this solution. Read the question on the slide for the poll and the four possible responses. Take the poll. Most students will select option 4) many, many billions.

Suggest that we compare the number of molecules of the substance that we added to solution A, to the number of molecules of the same substance that we added to solution B, which had only 6 g of citric acid added to it.



Use mathematical thinking. Display **slide H**. Prompt students to take a half minute to think on their own about how the quantities compare.*

Tell students that two new solutions (c and d) have been added to the table along with additional information about the amounts of water used to make them. Display **slide I**. Prompt students to discuss the two questions on the slide for two minutes with a partner.

Display **slide J**. Introduce moles as a standard unit that is often used in science to simplify comparisons of large numbers of particles.

- 1 mole = $\sim 6 \times 10^{23}$ particles (e.g., molecules)

Ask students how the word *mole* compares to *molecule*. Students will say that it is the first four letters of the latter. Suggest that we can think of the word *mole* as a sort of shorthand way to refer to a huge number of particles – in this case, about 6×10^{23} molecules.

Ask students how the differences in the numbers in the new row in the table compare to the differences in the first row. Students will say that the values in both rows represent differences in terms of factors of ten.

Emphasize that using moles as a unit to represent a fixed number of molecules allows us to make the comparisons without needing to use scientific notation to keep track of exactly how many molecules are in the system.

Have students add the term *mole* to their personal glossaries.

Display **slide K**. Introduce another standard unit used for simplifying comparisons of large numbers of molecules.

- 1 M = 1 mole per L of water

Explain that *M* is a unit of measure that describes the concentration of a solution. It is shorthand for the number of moles of a substance dissolved in 1 liter of water, or moles per L, and is also called the *molarity* of the solution. Ask students how the molarities that we see in the fourth row of the table help us determine which solutions have lower concentrations of acetic acid molecules and which solutions have the same concentration.

Have students add the term *molarity* to their personal glossaries.

* SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

There are multiple experiences that students have had in the course up to this point that will help them make a reasonable estimate of the quantity of molecules being in the many billions:

- Students have seen standard notation used to represent the number of H^+ and OH^- ions in 3mL of water at different pH values and likely will have noted numbers of particles that exceed a billion for many pH values.
- Students calculated the number of charges (e.g., electrons) they accumulated on a surface in *Electrostatics Unit* and determined that it was in the billions.

And students have worked with scientific notation to represent numbers much larger than a billion in two prior units of study: *Polar Ice Unit* and *Electrostatics Unit*.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students explain that the concentrations of solutions are equal because the ratios of moles/L are equal, even though the quantities of moles (molecules) and water are different. (SEP: 5.5; CCC: 3.1)

What to do: Have students calculate the ratio of moles or molecules to liters, as a unit rate, using a calculator.

Building toward 4.A.1 Apply ratio thinking in the context of complicated measurement problems involving quantities with compound units (moles/L) to predict how the concentration of an acid or base dissolved in water will affect the pH of the solution. (SEP: 5.5; DCI: PS1.B.2; CCC: 3.1)

4 • CONDUCT pH CONCENTRATION INVESTIGATION

18 min

MATERIALS: pH Concentration Investigation

Choose which substances to investigate. Display slide L. Ask students to decide which set(s) of solutions would ensure a fair comparison between acids or bases. Students should say that either set would allow us to make fair comparisons as long as we compare the solutions within that set, because the concentrations (molarities) are the same.

Assign half the lab groups to work with set A and half the groups to work with set B, and then say that you will briefly orient students to the materials and data sheet they will be using so they can get started.

Review safety precautions. Distribute *Investigating pH Concentration*. Give students a minute to read the investigation procedure. Display slide M. Then review the safety precautions on the slide as a class.

Carry out investigations. Display slide N. Monitor students to ensure safe lab use of these solutions. Students should see a range of pH results, including approximately neutral for distilled water and salt solution (NaCl). *Sample pH Data* provides sample results. They may also start to notice some patterns in the substances they test, including which ones are acids and which ones are bases, and which are stronger vs. weaker acids and bases.

End of day 1

5 • ANALYZE AND INTERPRET DATA

6 min

MATERIALS: *Investigating pH Concentration*

Analyze and interpret the investigation data. Display slide O. Instruct students to compare their results with a classmate who tested a different set of solutions and complete the questions on *Investigating pH Concentration*.

ADDITIONAL GUIDANCE

Students are asked to think about evidence that allows them to determine if there are the same amounts of H^+ or OH^- ions in the acids and bases. During the discussion, it is okay if students share this information, but not necessary. The prompt was provided on *Investigating pH Concentration* to begin to get students thinking about evidence when they develop a model in the next activity.

After four minutes, share and discuss results as a class. Listen for these findings:

- These 3 substances were acids: HCl , $\text{HC}_2\text{H}_3\text{O}_2$, H_2SO_4 .
- HCl and H_2SO_4 produced a higher concentration of H^+ ions than $\text{HC}_2\text{H}_3\text{O}_2$.
- These 3 substances were bases: NaOH , KOH , NH_4OH .
- NaOH and KOH produced a higher concentration of OH^- ions than NH_4OH .

6 • DEVELOP AN INITIAL MODEL

12 min

MATERIALS: *Modeling H^+ Concentrations*, prepared *Molecule Deck*, scissors (optional)

ADDITIONAL GUIDANCE

At this point in the lesson, the term *dissolve* is appropriate for students to hear and use to describe acids and bases forming ions in water. In the next activity, students are introduced to the term *dissociate*. Note that assessment guidance uses dissociation before students have been exposed to the term and that is okay as they are developing a mechanistic understanding of it.



Develop an initial explanation. Display **slide P**. Problematize something we cannot yet explain about the results by reading the top of the slide. Say, *Even when we made solutions with the same concentration of substances added to them, different substances produced a different concentration of H^+ or OH^- ions when they dissolved in the water.*

Suggest that we try to make sense of this outcome by developing a model. Distribute *Modeling H^+ Concentrations*. Direct students to use the prompts on the handout to help them model what could be happening to the molecules of two different acids to account for our results. Give students five minutes for this. Collect the handout before the end of the period.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students explain that the **concentrations of solutions are equal** because the **ratios of moles/L are equal**, even though the **quantities** of moles (molecules) and water are **different**. (SEP: 5.5; CCC: 3.1)
- Students explain that **different acids dissociate unequally to account for differences in the amounts of H^+ ions in solution** as **measured by pH values**. (DCI: PS1.B.2; CCC: 3.1)

What to do: Ask students to think about prior experiences where substances somewhat dissolve/ dissociate in water but not completely. Prompt them to think if this could account for the differences in measured pH values. See *Modeling H^+ Concentrations* for additional information.

Building toward 4.A.2 Apply **ratio thinking in the context of complicated measurement problems involving quantities with compound units (moles/L)** to predict how the concentration of an acid or base dissolved in water will affect the **pH of the solution**. (SEP: 5.5; DCI: PS1.B.2; CCC: 3.1)

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Student models use pH values as evidence to predict rates of dissociation of different acids. (SEP: 2.3; DCI: PS1.B.3)

What to do: Have students indicate which acid they chose had the highest pH and then review *Measuring pH* from Lesson 3 to determine whether this corresponds to a higher or lower concentration of H^+ ions than the acid they chose with a lower pH.

Building toward 4.B.1 Develop a particle-level model that connects the structure of different acids to the measured pH values that explains why those values vary for each acid. (SEP: 2.3; DCI: PS1.B.3; CCC: 6.2)

Use manipulatives to refine ideas. Organize students into groups of five. Motivate how using manipulatives to try to explain this kind of phenomenon might help further refine our ideas. Say something like, *It is sometimes hard to picture the results of different force interactions that might be going on between particles without being able to move them around in the system. Let's get ready to use some manipulatives to make our thinking visible. This will help us further refine our ideas with other members of our group.* Display slide Q. Distribute the prepared card decks along with an additional copy of *Molecule Deck* to each group. Give students six more minutes to work with these manipulatives in their group.

ALTERNATE ACTIVITY

The assumption is that students will find manipulating the molecular cards with their groups insightful after completing *Modeling H^+ Concentrations*. If you anticipate that some groups might have trouble visualizing or articulating how H^+ ions would be produced by different force interactions between these molecules, consider preparing additional copies of *Molecule Deck* as consumables and allowing those groups to cut out some of the cards themselves.

7 • DEVELOP UNDERSTANDING OF DISSOCIATION

12 min

MATERIALS: *Modeling H^+ Concentrations*, prepared *Molecule Deck*, M-E-F triangle, chart paper, chart paper markers



Develop a list of possible interactions. Have students meet in a Scientists Circle with a table in the middle and bring *Modeling H^+ Concentrations*. Display slide R. Work with students to develop a list of interactions that might be happening between different acid and water molecules to explain the differences in recorded pH values. Record these ideas on a piece of chart paper.

Possible interactions could include:

- When molecules of an acid dissolve, some of them must break into a H^+ ion and a negative ion containing the remaining atoms in the original substance.
- Some acids dissolve better than others, or a different proportion (or percentage) ionize when added to water.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students explain that different acids dissociate unequally to account for differences in the amounts of H^+ ions in solution as measured by pH values. (DCI: PS1.B.2; CCC: 3.1)

What to do: If students struggle to identify that not all acids dissolve the same in water, ask them to consider their experiences of different substances not completely dissolving in water. You could suggest differences in sugar or salt dissolving compared to baking soda or flour. See *Modeling H^+ Concentrations* for additional information.

Building toward 4.A.3 Apply ratio thinking in the context of complicated measurement problems involving quantities with compound units (moles/L) to predict how the concentration of an acid or base dissolved in water will affect the pH of the solution. (SEP: 5.5; DCI: PS1.B.2; CCC: 3.1)

Build understanding around dissociation. After identifying the interactions, explain that scientists sometimes refer to these differences in the ways substances break into ions as differences in their *dissociation*.

Display **slide S**. Point out that the general meaning of the word *dissociation* is the separation of something from something else, whereas the word *association* means a connection or a link.

Suggested prompt	Sample student response
How does the word <i>dissociation</i> compare to the word <i>dissolve</i> ?	They both refer to substances breaking apart into particles.
What is similar about the two words?	Both words start with “dis.”

Emphasize that we refer to the general process of substances breaking apart into smaller pieces as dissolving, but when the smaller pieces we are talking about are ions, we refer to the *degree of dissociation* or how well the substance dissociates. For example, we could now say that all the solutions we used were prepared by dissolving equal concentrations of different substances in water, but each of the substances underwent a different degree of dissociation in the water.



Use a forces perspective to explain degree of dissociation. Suggest that we switch to a forces perspective to try to explain these differences in the degree to which each acid or base dissociates in water. Refer to the M-E-F triangle.

Display **slide T**. Ask students how force interactions between atoms or molecules in solution might help explain these outcomes. * Encourage students to show how they understand the ideas their peers are communicating by demonstrating these interactions using the manipulatives from *Molecule Deck* on the table in the middle of the Scientists Circle. At this point you may wish to have students stand up to have a better view of what others are showing on the table.

Have students add the term *degree of dissociation* to their personal glossaries.

KEY IDEAS

Purpose of this discussion: Recall ideas about polarization and differences in bonds strengths from *Electrostatics Unit* and *Space Survival Unit*. Try to use these ideas to 1) describe different possible force interactions between particles in a solution, and 2) explain differences in the degree of dissociation (differences in H^+ concentrations) for different acids.

Key ideas:

- Water molecules are permanently polarized. This means that one end has a positive charge and the other has a negative charge.
- The molecules of acids also are also polarized.
- Both of these would produce force interactions that either push or pull on other charged parts in other matter around them.
- The bonds between atoms (elements) in substances vary in strength.
- Differences in the strength of attractive forces (bonds) between the atoms in a substance, and/or between these atoms and the water molecules, and differences in how they interact with each other, result in a greater concentration of H^+ ions breaking away from some substances more than from others.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Student **models use pH values as evidence to predict rates of dissociation of different acids.** (SEP: 2.3; DCI: PS1.B.3)
- Students explain that the **structure of the acid (strength of bonds between atoms)** allows for some to have a **higher degree of dissociation** than others. (DCI: PS1.B.3; CCC: 6.2)

What to do: Have students share their models from question 2 of *Modeling H^+ Concentrations* with a partner to identify how these key ideas are represented in each other's models.

Building toward 4.B.2 Develop a particle-level model that connects the **structure of different acids** to the **measured pH values** that explains why those **values vary** for each acid. (SEP: 2.3; DCI: PS1.B.3; CCC: 6.2)

If you have time, allow students to revise their chosen acids on *Modeling H^+ Concentrations* before collecting them.

8 · COMPLETE AN ELECTRONIC EXIT TICKET

8 min

MATERIALS: Link to class copy of the Electronic Exit Ticket, computer with internet access

ADDITIONAL GUIDANCE

See *Electronic Exit Ticket* for instructions on how to make the Electronic Exit Ticket.



Complete the electronic exit ticket. Display slide U. Share the related link with students and have them individually complete the electronic exit ticket. Some of the questions require self-assessment on classroom community norms in addition to science ideas.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Exit Ticket Key*.

What to do: See *Exit Ticket Key*. Provide students with feedback in a timely manner. One way to do this is by using the “show results” feature of the Form in order to show with graphs how the class is thinking as you begin the next portion of the lesson. Do not skip the self-assessment questions; they are important for continuing to build community.

Building toward 4.B.3 Develop a particle-level model that connects the structure of different acids to the measured pH values that explains why those values vary for each acid. (SEP: 2.3; DCI: PS1.B.3; CCC: 6.2)

9 • NAVIGATE

6 min

MATERIALS: None

Summarize what we figured out in this lesson. Display slide V. Have students turn and talk with a partner about the prompt on the slide. Then briefly share a few of these as a class and follow-up with the related question below.

Suggested prompt	Sample student response
<i>What new ideas do you and your partner have now for how increases in the concentration of CO₂ in the atmosphere cause the ocean to become more acidic?</i>	Higher concentrations of CO ₂ would lead to more particle-level interactions (e.g., collisions) with molecules that make up the ocean water. CO ₂ makes the ocean more acidic by chemically reacting with water molecules to form an acid (some product that contains H atoms, like H ₂ CO ₃). This product would then dissociate, which releases H ⁺ ions.
<i>What questions about this interaction do we still have?</i>	We don't know whether CO ₂ gets into the water or interacts with water at the surface. Can a gas really just go into a liquid? We aren't 100% sure where the increase in H ⁺ ions is coming from when H ₂ CO ₃ molecules dissociate. Is it HCO ₃ ⁻ or CO ₃ ⁻² ?

Say, *Let's plan to investigate these ideas and questions further next class.*

10 • OPTIONAL: INTRODUCE HOME LEARNING

1 min

MATERIALS: pH and Organisms

Assign optional Home Learning. Remind students that on the Electronic Exit Ticket they considered some new phenomena related to pH ranges in human blood, fish tanks, and soils and were asked to consider what new questions this raised for them. Explain that you have a short reading available as an extension opportunity for home learning that may help answer those questions. Display slide W. Distribute *pH and Organisms* to students. Review the directions on the slide and ask if students have any clarifying questions.

ALTERNATE ACTIVITY

Extension Opportunity: The Electronic Exit Ticket introduced three types of living things that need certain pH ranges to survive. This reading, *pH and Organisms*, will explore these phenomena in greater detail. Because the reading will not be discussed in the next lesson, the recommendation is to provide it as an optional extension opportunity for interested students.

If many of your students did not see the anchor as directly relevant to their lives or communities, consider using this reading to support an increased sense of relevance for them. It may help motivate the need to continue to figure out how acids and bases interact with living things. If you do this, also consider allocating additional time at the start of the next lesson to have students select a new question the reading raised for them, share it with others, and add it to the Driving Question Board.

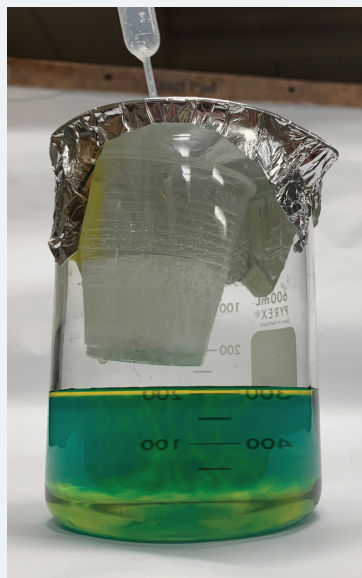
LESSON 5: How does carbon dioxide move between the atmosphere and ocean systems to cause the water to become more acidic?

PREVIOUS LESSON We used molecular formulas to predict which substances are acids, bases, or neither. We compared quantities of particles and concentrations in different solutions. We collected and analyzed the pH of these solutions. We developed a model to explain our results. We used our model to predict how increases in atmospheric carbon dioxide make the ocean more acidic.

THIS LESSON

INVESTIGATION, PROBLEMATIZING

3 days



We investigate how carbon dioxide could naturally dissolve in water. We annotate the investigation to include additional measurements to let us know exactly where the water and CO₂ react to form carbonic acid. We use the data from our small-scale investigation to begin to think about how it helps explain large-scale system interactions. Individually, we update our Progress Trackers and examine additional data about carbon's movement among Earth's spheres. We use the data to annotate and revise the class consensus model. We apply the revised carbon cycle model to oysters. We examine our investigation from day 1 and wonder what could explain the color change.

NEXT LESSON We will use a simulation to investigate how acidic water could become less acidic again. We will use the results to argue that a reversible reaction was taking place. We will use data to determine a relationship between bond strength, stability, and reversibility of reactions.

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-
1, HS-ETS1-2



WHAT STUDENTS WILL DO

5.A Revise a model to explain how the increased movement of carbon dioxide from the atmosphere to the ocean results in the decrease of oceanic pH, using data from examining a small-scale system gathered with appropriate investigative tools. (SEP: 2.3, 3.4; DCI: ESS2.C.1, ESS2.D.3; CCC: 2.2)

WHAT STUDENTS WILL FIGURE OUT

- CO₂ slowly gets into water through a natural process that does not “force” CO₂ into the water.
- Atmospheric CO₂ has recently begun to dissolve into the ocean increasingly more, due to the buildup of atmospheric CO₂ 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.

Lesson 5 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	10 min		NAVIGATE Have students work with a partner to develop initial models tracing carbon flow and interactions between systems.	A-B	individual whiteboard, dry erase markers, class consensus model
2	7 min		EXAMINE A SMALL-SCALE SYSTEM Display an investigation setup and have students map the small-scale system back to the large-scale system.	C-D	individual whiteboard, prepared Dissolving Carbon Dioxide in Water Investigation setup, class consensus model
3	20 min		CONDUCT AN INVESTIGATION Organize students into groups of five and have them annotate, develop a data table, and conduct an investigation.	E-I	Dissolving Carbon Dioxide in Water Investigation
4	8 min		MAKE SENSE OF OUR FINDINGS Distribute <i>Evaluate Investigation Data</i> and have students individually answer the questions to evaluate their investigation data.	J	<i>Evaluate Investigation Data, Investigation Procedure</i>
<i>End of day 1</i>					
5	8 min		DISCUSS INVESTIGATION FINDINGS Have students turn and talk with a partner to share their data findings. Lead a Building Understandings Discussion.	K-L	<i>Investigation Procedure, Evaluate Investigation Data, Ocean Acidity Maps</i> (optional), class consensus model
6	7 min		UPDATE PROGRESS TRACKERS Have students update <i>Progress Tracker</i> .	M	<i>Progress Tracker</i>
7	23 min		CONSIDER MOVEMENT OF CARBON ON EARTH Have students examine graphical data about CO ₂ changes and sources individually and with a partner.	N-Q	<i>Carbon Data</i> , 4 3x3 sticky notes in two colors, permanent markers, class consensus model
8	7 min		DISCUSS THE MOVEMENT OF CARBON Lead a Building Understandings Discussion.	R	<i>Carbon Data</i> , 4 3x3 sticky notes in two colors, permanent markers, class consensus model
<i>End of day 2</i>					
9	15 min		ANNOTATE OUR CLASS CONSENSUS MODEL Organize the class into a Scientists Circle to annotate and discuss the class consensus model.	S-T	4 3x3 sticky notes in two colors, permanent markers, class consensus model
10	10 min		REVISE CLASS CONSENSUS MODEL TO CARBON CYCLE MODEL Lead a discussion to “rebrand” the class consensus model to the carbon cycle model by identifying prior knowledge.	U	class consensus model, chart paper markers

Part	Duration		Summary	Slide	Materials
11	10 min		APPLY THE CARBON CYCLE MODEL TO OYSTERS Have students apply the carbon cycle model to the oysters phenomenon.	V-X	individual whiteboard, dry erase markers, <i>Progress Tracker</i> , carbon cycle model
12	10 min		NAVIGATE Have students predict what they would expect to see in the saved investigation setups.	Y-AA	Examining Water Changes Demonstration

End of day 3

Lesson 5 • Materials List

	per student	per group	per class
Dissolving Carbon Dioxide in Water Investigation materials	• <i>Investigation Procedure</i> • science notebook • safety goggles	• 20-oz clear cup • 9-oz paper cup • 6" by 6" square of aluminum foil • 6 disposable plastic pipettes • 100-mL graduated cylinder • sheet of plain white paper • invisible tape • 4 universal pH strips	• digital scale • 100 mL bromothymol blue indicator • 200 g baking soda • 2.0 L distilled water • 500 mL vinegar • scoopula
Examining Water Changes Demonstration materials	• science notebook • sheet of loose-leaf paper		• 3 saved investigation setups from day 1 • 3 sheets of plain white paper (optional)
Lesson materials	• science notebook • individual whiteboard • dry erase markers • <i>Evaluate Investigation Data</i> • <i>Investigation Procedure</i> • <i>Ocean Acidity Maps</i> (optional) • <i>Progress Tracker</i> • <i>Carbon Data</i> • 4 3x3 sticky notes in two colors • permanent markers		• class consensus model • prepared Dissolving Carbon Dioxide in Water Investigation setup • chart paper markers • carbon cycle model

Materials preparation (60 minutes)

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

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

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

Have the class consensus model from Lesson 1 displayed at the start of the lesson and again on day 3.

Day 1: Dissolving Carbon Dioxide in Water Investigation

- Group size: 5 students

- **Setup:** See *Investigation Procedure* for a list of the materials each group will need. Create several “stations” for students to collect the various chemicals necessary for the investigation:
 - baking soda station with digital scales, scoopulas and baking soda;
 - bromothymol blue indicator station;
 - distilled water station; and
 - vinegar station with beakers to transport the vinegar.
- **Notes for during the lab:** Ensure that groups place the sheet of plain white paper behind their investigation setup so they can observe the bromothymol blue indicator color change more easily. Save **two** investigation setups for day 3. Seal the hole in one of them where the pipette with vinegar was, and remove the foil seal from the other.
- **Safety:** Ensure that students follow the safety precautions outlined on **slide H**.
- **Disposal:** Students should dilute any liquid waste with twice as much water as waste before disposing down the drain. Unused solutions can also be poured down the drain and followed with twice as much water, or stored for one year.
- **Storage:** Store unused solids and solutions according to the OSHA Safety Data Sheets. Clean and dry the clear plastic cups and store for reuse. Dispose of the pipettes.

Day 3: Examining Water Changes Demonstration

- **Group size:** Whole class
- **Setup:** Prepare a solution of water and bromothymol blue indicator as students did for the investigation on day 1, but do nothing else with it and leave uncovered. Have the two investigation setups you saved from day 1 ready to show students.
- **Notes for during the lab:** Consider placing sheets of plain white paper behind each of the three investigation setups so students can see color differences more easily.
- **Safety:** Ensure that students follow the safety precautions outlined on **slide H**.
- **Disposal:** Follow disposal directions for the **Dissolving Carbon Dioxide in Water Investigation**.
- **Storage:** Follow storage directions for the Dissolving Carbon Dioxide in Water Investigation.

Lesson 5 • Where We Are Going and NOT Going

Where We Are Going

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

- **ESS2.C.1: The Roles of Water in Earth's Surface Processes.** The abundance of liquid water on Earth's surface and its unique combination of physical and chemical properties are central to the planet's dynamics. These properties include water's exceptional capacity to absorb, store, and release large amounts of energy, transmit sunlight, expand upon freezing, dissolve and transport materials, and lower the viscosities and melting points of rocks.
- **ESS2.D.3: Weather and Climate.** Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.

Crosscut Explanations: The struck through portions of each DCI element are developed in other units as follows:

- **ESS2.C.1:** Students develop understanding of the crossed-out portions in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)* and *OpenSciEd Unit P.2: How forces in Earth's interior determine what will happen to its surface? (Earth's Interior Unit)*.
- **ESS2.D.3:** Students develop understanding of the crossed-out portion in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*.

This lesson asks students to apply a disciplinary core idea at the middle school level, which supports the sensemaking in the lesson.

- **PS1.B: Chemical Reactions.** Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants.

Students previously used [SEP: 3.4](#): Select appropriate tools to collect, record, analyze, and evaluate data. in *Polar Ice Unit*. Students build new understandings of this SEP element as they evaluate an investigation plan to include additional tools to collect data.

Students build on [CCC: 2.2](#) developed in *Electrostatics Unit*. In this lesson they connect small scale systems back to a large scale system. Later in the unit students develop a new use of the CCC as they predict relationships of human designed, small-scale systems and scale those up to natural large-scale systems (Lessons 6, 7, 10, and 15).

Students use a small-scale system to investigate the movement of carbon dioxide between two Earth systems, the atmosphere and hydrosphere ([SEP: 3.4](#); [DCI: ESS2.D.3](#); [CCC: 2.2](#)). They consider what other tools to gather additional data would be helpful and annotate the investigation plan ([SEP: 3.4](#)). After conducting the investigation, students discuss how carbon dioxide dissolves in water, reacts to form carbonic acid, and is transported from one area to another ([DCI: ESS2.C.1](#)).

Students examine a data set showing historic and current movement of carbon throughout Earth's spheres ([DCI: ESS2.D.3](#)). They use specific pieces of the data set to develop annotations for revising the class consensus model ([SEP: 2.3](#)). After revising the class consensus model, students rebrand it to the carbon cycle model, noting interactions among the large-scale Earth systems ([SEP: 2.3](#); [DCI: ESS2.D.3](#); [CCC: 2.2](#)). They apply the carbon cycle model to explain how the impacts of changes to it can help us determine what is happening to oysters. Finally, students look back at their small-scale investigations and notice that the color of the bromothymol blue indicator has changed back to its original color. They wonder what happened to cause the bromothymol blue indicator to change color.

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

Students will encounter the term (*carbon*) *sink* on *Carbon Data*. If students also want to add this term to their personal glossaries, encourage them to do so. Some students who experienced *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)* in OpenSciEd High School Biology may already have an idea about the meaning of *carbon sink* and its importance to the carbon cycle.

Where We Are NOT Going

Because students are mainly invested in explaining how the molecules are regrouped into different molecules with new properties and do not discuss rates and energy changes as a result of chemical processes, they do not engage with the high school disciplinary core idea:

- **PS1.B.1: Chemical Reactions.** Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.

Students will not develop the idea that CO_2 can leave the water until Lesson 6. Much of the carbon cycle will also remain unbuilt for now. In Lesson 10, students will flesh out additional arrows in the carbon cycle, such as dissolved ions in the ocean coming from erosion, ions helping build shells, and shells forming limestone over many years after oysters die.

LEARNING PLAN for LESSON 5

1 · NAVIGATE

10 min

MATERIALS: science notebook, individual whiteboard, dry erase markers, class consensus model

Model initial ideas for how CO₂ interacts with water to make it acidic. Display the class consensus model from Lesson 1 for students to examine. Remind students that we were wondering about how carbon dioxide moves from the atmosphere into the ocean and what interactions between carbon dioxide and water result in an increase in H⁺ ions in the water.

Display **slide A**. Have students meet with a partner and give each student an individual whiteboard and dry erase markers. Tell students they should develop an initial model that shows how carbon dioxide in the atmosphere interacts with water in the ocean to make it acidic. Explain that their models should show the movement of carbon dioxide between the atmosphere and ocean systems, and where in the ocean the interaction between carbon dioxide and water occurs. Give partners 5 minutes to develop their initial models.

After 5 minutes, have pairs share their models and identify areas of agreement and disagreement. Some possible areas of agreement could include: dissociation of carbonic acid, H₂CO₃, into 2 H⁺ ions and CO₃⁻ ions, and movement of carbon dioxide into the ocean at the surface. Some possible areas of disagreement could include: the location in the water column where carbon dioxide reacts with water to form carbonic acid, and how often the reaction occurs.

ADDITIONAL GUIDANCE	Have students keep these initial whiteboard models available for the next lesson step. They will need to reference them as they map the small-scale (investigation) system to the large-scale (initial model) system.
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Problematize the need to move to a smaller-scale system as a way to understand the large-scale systems in the models. Point out that we have several different ideas about what is happening as carbon dioxide moves between the atmosphere and ocean systems. Present **slide B**. Say, *In previous units, we sometimes investigated a smaller-scale system to help us identify relationships or mechanisms that might explain what is happening in a large-scale system.* *

Suggested prompt	Sample student response
What are some examples of where we have used a small-scale system to study a large-scale system?	Melting ice in OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit). Testing liquids of different densities in OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit). Using the water dropper system in OpenSciEd Unit C.2: What causes lightning and why are some places safer than others when it strikes? (Electrostatics Unit).
What are some limitations we have encountered with this approach?	Accept all responses.
What are some advantages to using this approach?	Accept all responses.

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

While this crosscutting concept is not assessed in this lesson, using scale thinking is important to support student sensemaking when moving to the investigation step. Because the scale of the two systems that interact is *too large to observe directly*, using a smaller-scale system allows students to *study* those interactions *indirectly*. In the next lesson step, students transition to using an investigation to model those *large-scale interactions* at a *small-scale*. (CCC: 3.2)

2 · EXAMINE A SMALL-SCALE SYSTEM

7 min

MATERIALS: individual whiteboard, prepared Dissolving Carbon Dioxide in Water Investigation setup, class consensus model

Examine and map a small-scale system to a large-scale system. Present **slide C** along with the investigation setup on display. Say, *I have gathered equipment we can use to investigate a smaller-scale system of the large-scale system we are trying to model. The small cup contains baking soda, NaHCO_3 , and the large cup contains distilled water and bromothymol blue. Additionally, we have a pipette filled with vinegar, $\text{HC}_2\text{H}_3\text{O}_2$, and a piece of aluminum foil.*

Make sure the class consensus model is visible. Ask, *How does this small-scale system map to the large-scale system?* Look for students to suggest the following:

- The large cup with water and bromothymol blue indicator maps to the ocean.
- The area above the water in the large cup maps to the atmosphere.
- The chemical reaction in the small cup maps to people producing CO_2 emissions.

Make investigation predictions using our initial models. Display **slide D**. Say, *Look back at your initial models on the whiteboards. What would we expect to see happen in the small-scale system if our initial models are accurate?* Look for students to suggest that we should see a color change with the bromothymol blue indicator.

3 · CONDUCT AN INVESTIGATION

20 min

MATERIALS: Dissolving Carbon Dioxide in Water Investigation

Discuss types of measurements to gather during the investigation. Display **slide E**. Say, *In Lesson 3 we used another type of pH indicator, the universal pH strips. Let's take a moment to think about how we could use them in our investigation, and what other measurements we should take that might help us understand what is happening in the large-scale system we modeled. **

* SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

Suggested prompt	Sample student response
Which of the pH indicators would give you a sense of where the greatest H^+ ion concentration is in the water?	I think they both might. The pH strips, because you could get a water sample at a specific level.
What are the advantages and disadvantages of using either?	The pH strips would give us a specific measurement. The bromothymol blue indicator only lets us know if the solution has become acidic. It might be hard to get accurate samples using the pH strips because we can't stick them directly in the water.

Providing students with the opportunity to select additional *investigative tools* emphasizes the essential element of design when planning an investigation. While students are being given the investigation procedure, the discussion questions are designed to help students think about what types of additional *data* are needed and how to *record that data* in a data table. (SEP: 3.4)

 Annotate the investigation procedure. Display slide F. Organize students into groups of five and distribute *Investigation Procedure*.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students annotate *Investigation Procedure* to include **additional investigative tools** (e.g., pH indicator strips and a timer). (SEP: 3.4)
- Students provide reasoning for where they **chose to annotate** *Investigation Procedure* to support the **appropriateness** of their choice. (SEP: 3.4)

What to do: If groups struggle to identify areas to annotate *Investigation Procedure*, ask them to consider at what point and where in the sample would it make sense to record pH values of the water.

Building toward 5.A.1: Revise a model to explain how the **increased movement of carbon dioxide from the atmosphere to the ocean results in the decrease of oceanic pH, using data from examining a small-scale system gathered with appropriate investigative tools.** (SEP: 2.3, 3.4; DCI: ESS2.C.1, ESS2.D.3; CCC: 2.2)

 **Draft a data table for the investigation.** Show slide G. Explain to students that before we conduct the investigation, it is necessary to clarify how we will collect and evaluate our observations. Say, *We want to have a data table that outlines the changes we think we will see and gives us a way to record these changes over the course of the investigation.* Give groups 4 minutes to draft a data table in their science notebooks. See examples of student data tables.

Time (min)	Color of BTB in water

Pipette squeezes of vinegar	Color of BTB in water

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students draft a **data table to record qualitative and quantitative data of pH changes caused by increased CO₂ levels.** (SEP: 3.4; CCC: 2.2)

What to do: As students consider the different ways to structure the empty data table, emphasize the importance of specifying what types of measurements to collect beyond just “observations.” Ask questions such as:

- What is being observed?*
- What might we need to measure?*
- Are we recording qualitative or quantitative data?*

Building toward 5.A.2: **Revise a model to explain** how the **increased movement of carbon dioxide from the atmosphere to the ocean results in the decrease of oceanic pH, using data from examining a small-scale system gathered with appropriate investigative tools.** (SEP: 2.3, 3.4; DCI: ESS2.C.1, ESS2.D.3; CCC: 2.2)

Review safety precautions. Show slide H. Review important safety precautions as listed, and add any relevant precautions for your particular lab area.

Conduct the investigation. Show slide I. Give students 10 minutes to conduct the investigation in their groups. As they conduct the investigation, circulate around the room and assist as needed.

Time (min)	Color of BTB in water
0	dark blue
2	dark blue
4	yellow on top 1mm, dark blue everywhere else
6	yellow on top 5mm, teal swirled w/yellow everywhere else
8	yellow top half, teal swirled w/yellow bottom half

Sample of completed student data table

ADDITIONAL GUIDANCE

Ask two groups to retain their investigation setups for use during the **Examining Water Changes Demonstration** on day 3. Additionally, take a picture of the results of one of the investigation setups immediately after the investigation to add to **slide Z**.

4 • MAKE SENSE OF OUR FINDINGS

8 min

MATERIALS: *Evaluate Investigation Data, Investigation Procedure*, science notebook

Evaluate investigation data. Display slide J and distribute *Evaluate Investigation Data*. Give students the remaining class time to answer the questions on the handout on their own. Tell them that if they do not finish, they should complete the handout as home learning.

End of day 1

5 · DISCUSS INVESTIGATION FINDINGS

8 min

MATERIALS: *Investigation Procedure*, *Evaluate Investigation Data*, science notebook, *Ocean Acidity Maps* (optional), class consensus model

 Share *Evaluate Investigation Data* responses with a peer. Display slide K. Give students 3 minutes to turn and talk with a partner to share their responses to *Evaluate Investigation Data*. Tell students that as they share, they should add to their responses based on new ideas their partner may have.

Build understanding around large-scale system interactions. * Present slide L. Have the class consensus model visible. It may also be helpful to have students reference *Ocean Acidity Maps* from Lesson 1 to support discussion around the third prompt.

Suggested prompts	Sample student responses	Follow-up questions
<i>In what part of our small-scale system did we see evidence of increased H⁺ ion concentration?</i>	The bottom part of the water changed color, showing that it became acidic because of increased H ⁺ ions.	<i>How can we explain all of the water in the small-scale system becoming acidic, not just the water in a certain area?</i>
<i>What mechanisms might cause these ions to be transferred to other parts of an ocean?</i>	There are currents in the ocean, meaning the water moves around.	<i>What are the implications of the movement of hydrogen ions from one part of an ocean to another?</i>
<i>Could these ions be transferred from one ocean to another? Why or why not?</i>	I think so because the oceans are all connected together.	<i>What could this mean for Earth's oceans? Are they just one ocean?</i>

* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

During this Building Understandings Discussion, listen for students to make connections between the small-scale system interactions in the investigation and the large-scale system interactions in the class consensus model. Remind students of how they mapped the parts of the investigation setup to the systems in the class consensus model. It is also important for students to understand that while we name several oceans, they are all part of one ocean. Because of this interconnectedness, changes in one part of the ocean have the potential to cause changes in all areas of the ocean system. Students should know from *Polar Ice Unit* that polar ice melt causes all oceans to rise, but they have not yet identified that ultimately, all of the world's oceans are a single ocean.

Collect *Evaluate Investigation Data* and use that, along with students' participation in the Building Understandings Discussion, as a formative assessment opportunity.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use **data from their investigation** to **describe the movement of carbon dioxide**. (SEP: 3.4; DCI: ESS2.D.3)
- Students **use a small-scale system to determine a cause-and-effect relationship to explain changes to the pH of ocean water because of water's ability to dissolve and transport materials**. (DCI: ESS2.C.1; CCC: 2.2)

What to do: If students struggle to connect specific investigation data at a small scale to explain large-scale changes, have them look at both *Investigation Procedure* and *Ocean Acidity Maps* from Lesson 1. Remind them of how we mapped the small-scale systems back to the large-scale atmosphere and ocean systems. Students may benefit from developing visual representations of the data. Point back to the class consensus model and mapping of the small-scale systems to support students in making connections with the movement of carbon dioxide between the atmosphere and ocean systems.

Building toward 5.A.3: **Revise a model to explain** how the **increased movement of carbon dioxide** from the **atmosphere to the ocean results in the decrease of oceanic pH, using data from examining a small-scale system gathered with appropriate investigative tools**. (SEP: 2.3, 3.4; DCI: ESS2.C.1, ESS2.D.3; CCC: 2.2)

6 • UPDATE PROGRESS TRACKERS

7 min

MATERIALS: *Progress Tracker*, science notebook

Update progress trackers. Show **slide M**. Celebrate all of the progress we have made over the last three lessons. Say, *We have figured out so many new science ideas that could help us address the problem happening to the oysters! Let's take a moment to update our Progress Trackers with these new ideas.* Give students the remaining time to update *Progress Tracker* with information from Lessons 3, 4, and 5. You can allow students to work independently, with a partner, or in a small group.

See *Progress Tracker Key* for a sample *Progress Tracker* entry.

* ATTENDING TO EQUITY

Universal Design for Learning. Engagement and sustained effort and persistence are intentionally developed here as we connect oysters back to issues of food sovereignty. Oysters are not compelling to all students on their own, but reminding students that oysters are an important food source to many people, as they heard about in the videos from Lesson 1 can increase engagement. If needed, reconnect students to the locally-sourced foods they rely on.

7 · CONSIDER MOVEMENT OF CARBON ON EARTH

23 min

MATERIALS: *Carbon Data*, science notebook, 4 3x3 sticky notes in two colors, permanent markers, class consensus model

Transition students to consider historic movement of carbon between Earth's spheres. Say, *We have spent a lot of time during chemistry thinking about interactions between Earth's different spheres. In this lesson we have focused on the movement of carbon dioxide between the atmosphere and the ocean, or hydrosphere. Can someone remind us of the other Earth spheres we have not yet considered?* Look for students to suggest the biosphere and geosphere. Show **slide N**. Explain that while we have focused on carbon dioxide so far, now we will think about the movement of carbon in general. Give students some individual think time about the prompts on the slide before leading a brief class discussion. *

Suggested prompts	Sample student responses	Follow-up questions
<i>Has the movement of carbon from the atmosphere to the hydrosphere always happened at the rate we see today?</i>	Accept all responses.	<i>Why do you think that way? What evidence have you seen that supports your thinking?</i>
<i>What about the movement of carbon between other spheres? From the biosphere to...</i>	I think humans are moving more CO ₂ to the atmosphere because of things we do, like cutting down trees.	<i>Besides moving carbon from the biosphere to the atmosphere, what other spheres can human activity affect?</i>
<i>What about the movement of carbon between other spheres? From the geosphere to...</i>	I'm not sure. Maybe when we mine and burn fossil fuels, we move carbon from the geosphere to the atmosphere.	<i>Besides moving carbon from the geosphere to the atmosphere, what other spheres can human activity affect?</i>

Summarize student ideas and point out that we have many areas of uncertainty. Suggest that we should spend some time examining data that can help us.

Individually examine carbon data. Display **slide O**. Tell students that they will be looking at four data displays and one table, all pertaining to the movement of carbon between Earth's spheres. Give students a few minutes to set up the Notice and Wonder chart shown on the slide. Distribute *Carbon Data*. Give students about 10 minutes to individually examine *Carbon Data* and add to their Notice and Wonder chart in their science notebook.

* ATTENDING TO EQUITY

Universal Design for Learning Providing students individual think time before engaging in a whole-class discussion supports students' use of *representation*. Individual think time is used here to provide additional opportunities for comprehension, which could activate prior knowledge and help to maximize students' ability to transfer information to and from each other during the discussion.

ADDITIONAL GUIDANCE

Purpose of this data handout: To identify how carbon has moved throughout Earth's systems and how human activity in different parts of the world may have impacted the amount of carbon that moves among Earth's systems.

Look/listen for these ideas:

- Although there have been fluctuations of CO₂ in the atmosphere and hydrosphere during Earth's geological history, there has not been anything like what we are seeing now.
- The amount of CO₂ in the ocean is not growing as rapidly as the amount of CO₂ in the atmosphere.
- The rate at which plants take CO₂ out of the atmosphere is far lower than the rate at which CO₂ is added to the atmosphere.
- Almost all of the atmospheric CO₂ came from coal, oil, or natural gas that was mined or extracted from the earth.
- Most of the CO₂ comes from North America, Eurasia, and Australia, and not so much from Africa and South America.

Present **slide P** during the last minute of students' independent time tracking their noticings and wonderings. Share with students that they will be writing important or relevant noticings and wonderings on 3x3 sticky notes to annotate the existing class consensus model. Distribute the 3x3 sticky notes and permanent markers throughout the class as students wrap up with independent time.

Share noticings and wonderings with a partner. Display **slide Q**. Have students meet with a partner to share their interpretations of the data from *Carbon Data*. Give pairs 4 minutes to compare their Notice and Wonder charts and make any additions.

8 • DISCUSS THE MOVEMENT OF CARBON

7 min

MATERIALS: *Carbon Data*, science notebook, 4 3x3 sticky notes in two colors, permanent markers, class consensus model



Make sense of data found in *Carbon Data*. Display **slide R**. Use the prompts to lead a Building Understandings Discussion. Accept all student responses, but use the Key Ideas below to listen for specific ideas that students should mention.

- *How do these data support or refute the measurements we took during our investigation?*
- *What additional information do the data provide that could help us revise our class consensus model?*

KEY IDEAS

Purpose of this discussion: Build understanding around what the data represent in terms of the movement of carbon among Earth's spheres.

Listen for these ideas:

- Figure 1 and Figure 2 support our investigation data because they show that an increased concentration of CO₂ in the atmosphere can lead to an increased concentration in water.
- Table 1 shows that CO₂ has moved from the atmosphere to the ocean.
- Figure 1: Atmospheric CO₂ levels have always varied throughout Earth's geologic history but never went above 300 ppm until recent history (1960s).
- Figure 2: Amounts of dissolved CO₂ in water off of Hawaii have increased at a similar rate to atmospheric CO₂ levels shown in Figure 1.
- Figure 3: Most of the global greenhouse gas emissions are due to energy production, which includes transportation, industry, and use in buildings.
- Figure 4: Some countries emit more CO₂ than others, and these tend to be the more developed countries.
- Table 1: CO₂ has moved from the atmosphere to the hydrosphere and biosphere. CO₂ has also moved from the geosphere to the atmosphere.

Have 3x3 sticky notes and permanent markers available for students to use to annotate the class consensus model. Let students know that they will need to hold onto these in their science notebooks for the next day of class.

ALTERNATE ACTIVITY

Extension Opportunity: If you have time, consider having students share some of their wonderings.

- This may include a discussion about what a (carbon) sink is as described in Table 1 on *Carbon Data*. One way to do this is to have students consider whether the values presented in the table show a gain (+) or loss (-). Provide time for students who need it to add *carbon sink* to their personal glossaries. Students who have experienced the OpenSciEd High School Biology unit *Fires Unit* may have an idea already of what a carbon sink is.
- You may also have students take a moment to add their wonderings to the DQB and/or answer some questions using the information from *Carbon Data*.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use **data from their investigation** to **describe the movement of carbon dioxide**. (SEP: 3.4; DCI: ESS2.D.3)
- Students connect how the **movement of CO₂ between Earth's spheres has been altered due to human activity**. (DCI: ESS2.D.3)
- Students record possible ideas about **movement of CO₂ through Earth's spheres** to inform **revisions to the class consensus model**. (SEP: 2.3; DCI: ESS2.D.3)

What to do: During the discussion, encourage students to share which piece of data presented on *Carbon Data* supports their ideas. This will provide more opportunities for others to build onto those ideas. Spend time talking through each piece of data to help students build an understanding of what they are examining.

Building toward 5.A.4: **Revise a model to explain** how the **increased movement of carbon dioxide from the atmosphere to the ocean results in the decrease of oceanic pH, using data from examining a small-scale system gathered with appropriate investigative tools**. (SEP: 2.3, 3.4; DCI: ESS2.C.1, ESS2.D.3; CCC: 2.2)

End of day 2

9 • ANNOTATE OUR CLASS CONSENSUS MODEL

15 min

MATERIALS: 4 3x3 sticky notes in two colors, permanent markers, science notebook, class consensus model

ADDITIONAL GUIDANCE

Have students take their science notebooks with them as they assemble in a Scientists Circle. Students will remain in the Scientists Circle for the rest of the lesson.

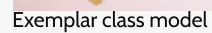


Annotate our class consensus model with findings from the data handouts. Show slide S. Display the class consensus model and ask students to use their 3x3 sticky notes to annotate it with the quantitative data they gathered. Students should post their notes where they think the data addresses or relates to the model. Emphasize that the model becomes a better representation of the phenomena at hand with more specific and quantifiable data.

Then have students repeat the process with the sticky notes that contain other types of data.

ADDITIONAL GUIDANCE

It may be helpful to add the 3x3 sticky notes to the class consensus model using a similar protocol to how students add questions to the DQB. Encourage students to show agreement with each other's annotations by stacking 3x3 sticky notes with the same data on top of each other.



Suggest that we use arrows to show these movements. Then, add an arrow between the earth (geosphere) and the air (atmosphere), next to where students place their annotations related to the source of atmospheric CO₂ or to plants removing CO₂ (carbon sink). Highlight the arrow previously drawn between the air (atmosphere) and ocean (hydrosphere) and link it to annotations where students draw a connection between amounts of CO₂ in those two spheres.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students record possible ideas about **movement of CO₂ through Earth's spheres** to inform revisions to the class consensus model. (SEP: 2.3; DCI: ESS2.D.3)
- Students should **show the relationship between the amounts of carbon stored in the atmosphere, the hydrosphere, and the geosphere, and the amounts released through human activity.** (SEP: 2.3; DCI: ESS2.D.3)

What to do: Allow students to rise from their seats as needed to place their annotations on the class consensus model where they believe the annotations fit best. Also take note of students' noticings and wonderings on the 3x3 sticky notes they add to the model. Identify which 3x3 sticky notes are placed between existing components of the model or are placed with arrows to show a clear connection between two components. If students are unsure of where to place their annotations, guide them toward anything on the existing model that is similar or related to their idea.

Building toward 5.A.5: **Revise a model to explain** how the **increased movement of carbon dioxide from the atmosphere to the ocean results in the decrease of oceanic pH, using data from examining a small-scale system gathered with appropriate investigative tools.** (SEP: 2.3, 3.4; DCI: ESS2.C.1, ESS2.D.3; CCC: 2.2)

10 · REVISE CLASS CONSENSUS MODEL TO CARBON CYCLE MODEL

10 min

MATERIALS: class consensus model, chart paper markers

Prepare to revise the class consensus model to focus on the carbon cycle. Say, *These annotations seem to be tracking the movement of CO₂ and things that produce or use CO₂. All of these things contain carbon because we know the carbon in CO₂ does not just disappear when it is produced or used in different processes. So to put it simply, we are actually tracking the movement of carbon.*

Show **slide U**. Ask, *What else do we remember from previous classes or units that would fit into this model?* Accept all student responses.

If plants are already part of the consensus model, point out how they tie into the tracking of carbon. If plants are not yet part of the model, prompt students to recall what they learned in biology about plants' use of carbon dioxide. Then say, *We have seen this cycle before! We know from biology that carbon moves between plants, animals, and the atmosphere.*

Use the prompts below to have students consider additional components and labels they should add to the carbon cycle model given their prior knowledge.

Suggested prompt	Sample student response
<i>What parts of the biosphere do we know have carbon, use carbon, or produce carbon?</i>	Plants undergoing photosynthesis, taking CO ₂ from the atmosphere Animals eating plants and undergoing respiration, releasing CO ₂ to the atmosphere

Suggested prompt	Sample student response
<i>What non-living things do we know have carbon, use carbon, or produce carbon?</i>	The ocean has carbon, so maybe other water sources do too. Fossil fuels come from underground in the geosphere.

Once you have added all the shared ideas to the model, have students rename the class consensus model based on what we have been tracking throughout the lesson, such as the movement (or cycling) of carbon.

ADDITIONAL GUIDANCE	Remind students to revisit <i>Polar Ice Unit</i> , where they first encountered Earth's systems. If students have not yet encountered these terms because they did not engage with <i>Polar Ice Unit</i> or a similar unit, offer an analogous example. Say, <i>If we use the term atmosphere to describe the air around us and the term hydrosphere to describe bodies of water, what term would make sense for plants or for rocks?</i>
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11 · APPLY THE CARBON CYCLE MODEL TO OYSTERS

10 min

MATERIALS: individual whiteboard, dry erase markers, science notebook, *Progress Tracker*, carbon cycle model

Apply the carbon cycle model to oysters. While students are in the Scientists Circle, show **slide V**. Distribute an individual whiteboard and dry erase marker to each student. Give students 2 minutes to stop and jot a response to the prompt on the slide. Then have students show their individual whiteboards. Give students a minute or two to compare their answers with their classmates. Then ask, *Where do we see similarities in our ideas?* Accept all responses. Summarize areas of agreement, such as:

- Humans have put more CO₂ in the atmosphere than used to be there. We are getting it from the ground where it was not hurting anybody.
- More CO₂ gets into the ocean than used to in the past.
- CO₂ reacts to make the water acidic, which hurts oysters.

Consider possible solutions to help oysters. Display **slide W**. Have students turn and talk about the prompt on the slide for 2 minutes. They will not share out their discussions, but students will use them as they update their Progress Trackers in the next step.

Update Progress Trackers. Present **slide X**. Say, *Let's take a moment to record our ideas about how the carbon cycle model helps us understand oyster die-offs and improve access to them as an important food source.*

Say, *Update your Progress Trackers for a second time this lesson.* Give students enough time to update their Progress Trackers while ensuring that you have 10 minutes to complete the next lesson activity.

See *Progress Tracker Key* for a sample Progress Tracker entry.

12 · NAVIGATE

10 min

MATERIALS: Examining Water Changes Demonstration

Discover that the dissolved CO_2 from day 1 is no longer in the water. Say, *We saved some of the water from our investigation a few periods ago and left it sitting out in the room since then.* Display slide Y. Give students a minute to stop and jot their prediction and explanation in their science notebooks.

Present slide Z. Display the two saved investigation setups and additional control setup. Remind students of each of the setups:

- Sealed investigation setup
- Unsealed investigation setup
- Control setup containing distilled water and bromothymol blue indicator

Suggested prompt	Sample student response
<i>What do you notice?</i>	Whoa! The colors changed again! The water turned yellow after the CO ₂ got in, but now it is greenish-blue again.
<i>How does this compare to your prediction?</i>	Accept all answers.

Problematicize color change. Show slide AA. Say, *So something must be happening at a particle level between the systems to explain the color change we observe.* Give students the remaining class time to record their responses to the prompts on the slide. Tell students to space out their responses and save them in their science notebooks for next class. Students will need to leave enough space between the responses to tear the sheet of loose-leaf paper in half.

Additional Lesson 5 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

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

Students perform a complex investigation using a multistep procedure that they have modified to fit their specifications.

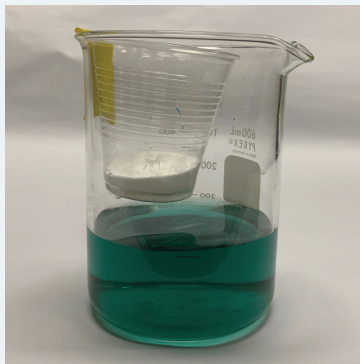
LESSON 6: How can acidic water become less acidic again?

PREVIOUS LESSON We investigated how carbon dioxide could naturally dissolve in water. We used the data from our small-scale investigation to think about how it helps explain large-scale system interactions. We examined additional data about carbon's movement among Earth's spheres. We used the data to annotate and revise the class consensus model. We examined our investigation from day 1 and wondered what could explain the color change.

THIS LESSON

INVESTIGATION

3 days



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.

NEXT LESSON We will discuss why it is important to learn from people who are directly affected by the problem of oyster die-offs. We will read about different interested parties and will use what we learn to brainstorm additional criteria and constraints for our engineering design solutions. We will complete an assessment investigating pH and ion concentration.

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-
1, HS-ETS1-2



WHAT STUDENTS WILL DO

6.A Make an argument about and use a computational model to generate data about small-scale mechanisms underlying the natural system of the reversible reaction that occurs in weak acid dissociation. (SEP: 2.6, 7.4; DCI: PS1.B.2; CCC: 2.2)

6.B Use multiple types of models to make predictions about the relative stability of substances in reversible reactions. (SEP: 2.4; DCI: PS1.B.2; CCC: 7.1)

WHAT STUDENTS WILL 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.

Lesson 6 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	7 min		NAVIGATE Organize students in a Scientists Circle. Use a snowball protocol to share responses to the Lesson 5 prompts.	A	invisible tape, 2 3x3 sticky notes (optional), permanent markers (optional), DQB
2	18 min		USE GRAFFITI BOARDS TO DEVELOP ARGUMENTS Distribute eight graffiti boards throughout the classroom. Divide the class into eight groups to complete the graffiti board activity.	B-D	permanent markers, 4 4x6 sticky notes (optional), graffiti boards
3	5 min		DISCUSS ARGUMENTS IN GROUPS Have students meet with their groups to discuss their arguments.	E	
4	15 min		LEAD INITIAL IDEAS DISCUSSION Lead a whole-class initial ideas discussion about what might be causing the color change.	F-H	"Ideas and Evidence" poster, chart paper markers, chart paper
End of day 1					
5	17 min		EXPLORE THE SIMULATION Remind students of the simulation needs they identified. Have students work with a partner to complete <i>Explore NetLogo Simulation</i> .	I-K	<i>Explore NetLogo Simulation</i> , computer with internet access, https://www.openscienced.org/general/waterco2interactions/ , "Simulation Needs" poster, chart paper markers
6	20 min		PLAN AND CARRY OUT INVESTIGATION USING THE SIMULATION Have students work with a partner to use <i>NetLogo Investigation</i> to plan an investigation using the simulation. Approve investigation plans and have groups carry out the investigation.	L-M	<i>NetLogo Investigation</i> , computer with internet access, https://www.openscienced.org/general/waterco2interactions/
7	8 min		DISCUSS INVESTIGATION IN GROUPS Have one pair meet with a second pair to discuss their investigation results.	N	<i>NetLogo Investigation</i> , "Ideas and Evidence" poster
End of day 2					
8	20 min		BUILDING UNDERSTANDINGS DISCUSSION Gather the class in a Scientists Circle to build understanding around the investigation results. Revise the carbon cycle model to include reversible reactions. Have students add terms to their personal glossaries.	O-W	<i>NetLogo Investigation</i> , "Evidence after Investigation" poster, carbon cycle model, chart paper markers, https://www.openscienced.org/general/waterco2interactions/
9	21 min		ANALYZE DATA ON ACIDS AND BASES Have students work with a partner to complete <i>Bond Data</i> . Lead a Consensus Discussion around the data.	X-AA	<i>Bond Data</i> , <i>Acid-Base Bonding Patterns</i> , chart paper, chart paper markers
10	4 min		NAVIGATE Lead the class in updating their Progress Trackers.	BB	<i>Progress Tracker</i>

Part	Duration		Summary	Slide	Materials
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End of day 3

Lesson 6 • Materials List

	per student	per group	per class
Lesson materials	- invisible tape 2 3x3 sticky notes (optional) - permanent markers (optional) - science notebook <i>NetLogo Investigation</i> <i>Bond Data</i> <i>Acid-Base Bonding Patterns</i> <i>Progress Tracker</i>	- permanent markers 4 4x6 sticky notes (optional) <i>Explore NetLogo Simulation</i> - computer with internet access https://www.openscienced.org/general/waterco2interactions/	- DQB - graffiti boards "Ideas and Evidence" poster - chart paper markers - chart paper "Simulation Needs" poster https://www.openscienced.org/general/waterco2interactions/ "Evidence after Investigation" poster - carbon cycle model

Materials preparation (45 minutes)

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

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

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

Have the DQB visible at the start of class.

See *Graffiti Board Preparation* for instructions on preparing the chart paper for the graffiti boards.

On another piece of chart paper, make a two-column data table with 4-5 rows. Label one column "Ideas" and the second column "Evidence." This will be called the "Ideas and Evidence" poster.

On a final piece of chart paper, make a third column with rows in line with the previous paper's table. Label this column "Evidence after Investigation." This will be called the "Evidence after Investigation" poster.

Familiarize yourself with the simulation <https://www.openscienced.org/general/waterco2interactions/>. This intro video will help walk you through key features: <https://youtu.be/pRkWQfcYKnI>, you can follow along with *Transcript: NetLogo Video*.

You will also need to have the carbon cycle model (class consensus model) visible on day 3.

Lesson 6 • Where We Are Going and NOT Going

Where We Are Going

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

- **PS1.B.2: Chemical Reactions.** In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.

This lesson is intended to fully build the concepts of chemical equilibrium and reversible reactions (DCI: PS1.B.2). Students should realize that when molecules collide, weak bonds can be broken and new ones form, making reactants with stronger bonds more likely to engage in reversible reactions.

Students begin this lesson by building an argument on graffiti boards about the cause of the color change in Lesson 5 (SEP: 7.4). They work together to propose that the color change might be happening because some of the particles are not fully breaking apart, but students need to see this on a smaller, simulated scale to be sure (CCC: 2.2).

Students use a computational model to expand that understanding to realize that carbon dioxide can return to the atmosphere through random motion and that the dissociation of carbonic acid (H_2CO_3) is not complete, as the process can happen in reverse (SEP: 2.6). If students struggle to identify the role of dissociation to explain the reverse reaction, refer them back to explanations of dissociation they previously developed in *Electrostatics Unit*. Students account for the numbers of all types of molecules present as the matter combines and recombines via the small-scale mechanisms of equilibrium (DCI: PS1.B.2; CCC: 2.2).

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

In *Polar Ice Unit* Lesson 10, students co-constructed a definition for *equilibrium* in their personal glossaries. Students will update their definition for this term in their personal glossaries based on new information.

Where We Are NOT Going

Chemical equilibrium is also influenced by temperature. This idea is not directly addressed in the NGSS. It is not addressed in this unit, either, as the mechanism requires a more complete understanding of bond energies that will be developed in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities?* (*Fuels Unit*).

Chemical equilibrium also plays an important role in one of the identified solutions to oyster die-offs. This involves adding carbonate compounds to water to alter carbonate equilibria and aid shell-building. This idea is hinted at in the Lesson 7 assessment and explored further in Lessons 11 and 12. In those lessons, students figure out how oysters build shells from calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions and how hydrogen (H^+) ions interfere with that process by out-competing calcium to bond with carbonate.

LEARNING PLAN for LESSON 6

1 · NAVIGATE

7 min

MATERIALS: invisible tape, 2 3x3 sticky notes (optional), permanent markers (optional), DQB

Use the snowball protocol to share ideas and questions. Say, *When we left off in the last lesson, we noticed that our water sample with carbon dioxide was no longer acidic. It had changed back in color! At the end of the lesson, you recorded responses to two prompts on a sheet of paper.*

Display **slide A**. Read through the directions for the snowball protocol on the slide. Ask if students have any clarifying questions, then carry out the snowball protocol to share student ideas and questions from Lesson 5. As students share questions, tape them to the DQB or have students copy them onto 3x3 sticky notes with a marker and then add them.

Students' explanations for the color change might include:

- CO₂ was released from the water back into the atmosphere (air).
- There wasn't enough CO₂ dissolved in the water to keep it acidic.
- Maybe there was another chemical reaction that changed the water back to normal.

After completing the snowball protocol, point out that there are many different ideas we have about what could be causing the color change. Say, *There are a lot of different possibilities here for substances that could be involved, but we are not sure. Let's think about how these different substances could have been involved in the color change.*

2 · USE GRAFFITI BOARDS TO DEVELOP ARGUMENTS

18 min

MATERIALS: science notebook, permanent markers, 4 4x6 sticky notes (optional), graffiti boards

ADDITIONAL GUIDANCE

See *Graffiti Board Preparation* for instructions on preparing the chart paper for the graffiti boards. To help manage the amount of chart paper needed for multiple class sections, consider having groups add to the graffiti boards using 4x6 sticky notes.



Prepare students for the graffiti boards. Distribute the prepared graffiti boards around the room, with one board for each substance on each side of the room. Display **slide B**. Divide the class into eight groups and show students that there are four boards in their half of the room. Tell them they will have two minutes at each of the four boards and that you will tell them when it is time to move to the next one. Students should work with their group to answer the questions on each board. It is okay if they do not get to all of the questions. Explain to the students that when they move to a new board, they should answer any unanswered questions and add to or comment on the previous group's work. It is fine if they have comments that build on their classmates' previous statements rather than the original question.

If you did not write the prompts on the chart paper, display **slide C**. As students work, circulate to ensure that they are focused on the task at hand and that all students are participating.* Likely student responses are shown in the table.

* ATTENDING TO EQUITY

You may wish to use a variety of techniques to ensure equitable participation and that all students are engaged in sensemaking. Depending on group size, this may include asking students to take turns writing between boards, providing different color markers for all members of a group, or assigning roles within the group.

Likely Student Responses			
Substance / Board	How did the substance get into the system?	What effect, if any, did the substance have on the blue to yellow color change?	What could the substance have done in the small-scale system to cause the color change back to blue? What evidence do you have?
Water	<i>We put it there.</i>	<i>The water changed color, but mostly because of other stuff.</i>	<i>Maybe it reacted with something else in the air, but we do not know what that would be. Our evidence is it would be possible since the sample was uncovered.</i>
Bromothymol blue indicator	<i>We put it there.</i>	<i>The bromothymol blue indicator actually changed color--it made the water blue, then turned to yellow.</i>	<i>It changed color because of CO_2 and H^+ ions, so maybe it could have turned back if those went away. This was possible since the sample was uncovered. Or maybe it went bad overnight somehow.</i>
CO_2	<i>It dissolved into the water as it was pumped into the air by the baking soda-vinegar reaction.</i>	<i>The color change happened when CO_2 came into the water.</i>	<i>If the color change happened when the CO_2 came in, maybe it would go back if the CO_2 left? We do not know if that happened or is possible.</i>
H_2CO_3 , HCO_3^- , CO_3^{2-} , and H^+	<i>They formed from the reaction of CO_2 and water and the dissociation of H_2CO_3.</i>	<i>The color change happened because CO_2 reacted with H_2CO_3, which produced H^+ ions. The bromothymol blue indicator shows when there are H^+ ions present.</i>	<i>If the color change happened when H^+ was formed, then maybe it would go back if H^+ was eliminated somehow, like if the reaction went backward. We do not know if that happened or is possible.</i>

Review the graffiti boards and record thinking in science notebooks. Thank the students for all of the interesting ideas they recorded on their graffiti boards. Display **slide D**. Say, *You have generated a lot of great ideas, but you have not had a chance to look at what other people said about your first board.* Direct students to individually view the first two boards they had written on with their groups. Then instruct students to write an answer to the prompt on the slide in their notebook.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Student ideas use **particle-level interactions** to try to **explain the macroscopic color change**. (CCC: 2.2)
- Students **develop arguments** about how **chemical reactions between water, CO₂, and carbonic acid led to the reversible** bromothymol blue indicator color change. (SEP: 7.4; DCI: PS1.B.2)

What to do: Encourage students to think about how particle-level interactions led to a macroscopic color change. Students have not uncovered a great deal of evidence to this point, but they should write arguments for the evidence they do have. If students are stuck on thinking about evidence, ask them to focus on the observable aspects of the phenomenon (uncovered top, color change, and so on) and/or ask them what they would need to investigate to better support their ideas.

Building toward 6.A.1 Make an argument about and use a computational model to generate data about **small-scale mechanisms underlying the natural system** of the **reversible reaction that occurs in weak acid dissociation**. (SEP: 2.6, 7.4; DCI: PS1.B.2; CCC: 2.2)

3 · DISCUSS ARGUMENTS IN GROUPS

5 min

MATERIALS: science notebook

Discuss individual ideas in groups. Display **slide E**. Direct the students back into their groups and share their arguments with each other as to what they think caused the color change. Make it clear that the group does not need to reach consensus and that the emphasis should be on listening to each others' differing evidence for their ideas.

ADDITIONAL GUIDANCE

The purpose of this group discussion is to provide a place for students to give each other feedback on the evidence they use to support their arguments. Visit groups during these discussions and prompt students to think about how they used the evidence provided on the graffiti boards to support their arguments. If there is time, consider giving students a few minutes to refine their arguments.

4 · LEAD INITIAL IDEAS DISCUSSION

15 min

MATERIALS: science notebook, “Ideas and Evidence” poster, chart paper markers, chart paper

Share arguments and evidence. Display **slide F**. Explain to students that while they develop arguments, you will record them under the “Ideas” column of the “Ideas and Evidence” poster. Use the prompts on the slide to help students share their ideas and evidence separately. As students share, record responses in the “Ideas” and “Evidence” columns of the chart paper. *

KEY IDEAS

Purpose of this discussion: This discussion should be a moment for students to share their arguments and supporting evidence. Use the discussion to help students identify areas of uncertainty which require additional evidence.

Listen for these ideas:

- The bromothymol blue indicator went bad, or lost the ability to be an indicator.
- The color change could be due to CO₂ escaping or the reaction somehow going backward to eliminate H⁺ ions.
- Some other unknown substance reacted with the H⁺ ions in the water.

Listen for these pieces of evidence:

- The bromothymol blue indicator changed back to its original color.
- Since CO₂ can easily dissolve into the water, maybe it can easily dissolve out of the water.
- Something had to remove H⁺ ions from the water to cause the color to change back.

ADDITIONAL GUIDANCE

It is okay if students feel they do not need the covered lab setup or uncovered bromothymol blue indicator to eliminate possibilities (e.g., the bromothymol blue indicator “going bad”). If students do ask for such investigations, explain that you have already conducted those experiments for them. Ask students which ideas, if any, can be eliminated based on these investigations.

If students ask for other investigations that would be easy to run, offer to set them up overnight.

* SUPPORTING STUDENTS IN ENGAGING IN ARGUMENT FROM EVIDENCE

Push students to provide evidence for their ideas using prompts like, *What makes you think that?* and *What can we observe that supports your idea?* Encourage students to offer counter-arguments by asking questions like, *How does your idea explain the evidence better than the other ideas that have been shared?* This should help narrow down the ideas on the table to only those that are supported by what students can see at the visible scale. (SEP: 7.4)

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

It is important for students to think about how the *patterns in the observable data may not provide us enough information to help us develop ideas about what is happening at the particle scale*. Using this line of questioning will help students think about the importance of gathering evidence at the *particle scale*. (CCC: 3.3)

Evaluate evidence that was shared. Display **slide G**. Say, *Let’s take a moment to evaluate the evidence we have shared.*

Suggested prompts	Sample student responses	Follow-up questions
<i>What size scale does most of our evidence come from? *</i>	It’s all stuff we can see with our own eyes.	<i>Why might this scale of evidence be problematic?</i>
<i>What size scale of evidence will allow us to evaluate our arguments, or ideas?</i>	We need to see what’s happening at the particle scale.	<i>Why would having evidence from that scale be better?</i>
<i>What have we used in the past to allow us to make measurements at a scale too small to see?</i>	Simulations!	<i>Great! Let’s think about what we would need to measure in a simulation.</i>

Determine simulation needs. Display **slide H**. Use the prompts on the slide to have students identify the visualizations, measurements, parts, and interactions they want to see in the simulation. Record these on a sheet of chart paper and title it “Simulation Needs.”

Look for students to suggest:

- We want particles to move around like they actually do in the water.
- We want to be able to control the amount of CO_2 leaving or staying in the water.
- We want to see all the particles that we know are in the solution (CO_2 , H_2O , H_2CO_3 , HCO_3^- , CO_3^{2-} , H^+).
- We want realistic reactions to happen when particles collide, like we saw in Lesson 3 (formation and dissociation of H_2CO_3).

Thank the students for their ideas. Say, *I think I have a simulation that might meet a lot of your requirements. We can explore it in the next class.*

End of day 1

5 • EXPLORE THE SIMULATION

17 min

MATERIALS: science notebook, *Explore NetLogo Simulation*, computer with internet access, <https://www.openscienced.org/general/waterco2interactions/>, “Simulation Needs” poster, chart paper markers

Introduce the simulation. Display the “Simulations Needs” poster and remind students of the needs they identified in the last class. Display **slide I**. As you demonstrate the simulation, have students compare its features to their “Simulation Needs.” Add checkmarks next to the needs that are included. It is fine if some are missing, but students should feel that the simulation will provide them with additional evidence they can use to support or refute their ideas.

Get to know the simulation with a partner. Display **slide J** and distribute *Explore NetLogo Simulation*. Say, *You will have 10 minutes to work through the prompts with a partner and make notes in your science notebook about what happened when you tried different things in the simulation. Then we will talk about ways we could use this tool to investigate what the particles were doing when the solution became less acidic overnight.*

Discuss the simulation as a class. After about 10 minutes, gather the class together. It is okay if all students have not had a chance to engage with every part of the simulation. Display **slide K**.

Suggested prompt	Sample student response
<i>What did you notice about the simulation?</i>	You can change the starting concentrations of CO_2 and H_2CO_3. You can turn H_2CO_3 dissociation on and off. The particles react when they collide. You can see the pH and the bromothymol blue indicator color. You can look at molecules or circles. The graph shows how the concentration changes over time.

Suggested prompt	Sample student response
<i>How could we make use of having multiple containers in the simulation?</i>	We could compare a container that we make changes to over time to one that we leave as it was originally set up. We could start the two containers with different concentrations and see what impact that has over time.
<i>How could we modify different variables in the simulation to test our ideas about how the color change occurred?</i>	We could start with a lot of H_2CO_3 and not much CO_2 and see if anything happens to the H_2CO_3 over time. We could start with a lot of CO_2 and no H_2CO_3, then take away CO_2 to simulate CO_2 leaving the container.
<i>How could it be helpful to turn dissociation on and off?</i>	We might want dissociation on so we can see a more realistic simulation. Turning dissociation off makes it easier to keep track of particles and read the graph.

6 • PLAN AND CARRY OUT INVESTIGATION USING THE SIMULATION

20 min

MATERIALS: *NetLogo Investigation*, science notebook, computer with internet access, <https://www.openscienced.org/general/waterco2interactions/>



Plan investigations with a partner. * Show slide L. Distribute *NetLogo Investigation*. Give students eight minutes to work with a partner to plan their investigation using prompts #1-4 on *NetLogo Investigation*. As students plan, ask them what they expect to happen when they make a change in the simulation. Students who think the CO_2 is coming out of the water should say that they will lower the CO_2 concentration and see that there is less H^+ . Students who think the reaction is going backward should say that if they start with no or very little CO_2 (because it all reacted), then the reaction will actually go backward and form CO_2 again. Once students have a hypothesis and ideas about what will occur, give them permission to begin their investigation.*

Investigate using the simulation. Show slide M. Give groups 10 minutes to investigate using the simulation. Remind students to record observations and data using prompts #5-7 on *NetLogo Investigation*. Students may also choose to record data in their science notebooks.

Tell students to answer the analysis and interpretation questions (#8-9) when they are finished.

* ATTENDING TO EQUITY

Universal Design for Learning: Working with a partner to design the investigation supports student *engagement*. Not only does planning the investigation help to recruit interest from the students, working with a partner helps to foster collaboration and community in the classroom.

* SUPPORTING STUDENTS IN DEVELOPING AND USING CAUSE AND EFFECT

Students are first trying to identify potential *cause-and-effect relationships between the microscopic and macroscopic worlds* so that they can then test them using the simulation in the next step. Remind students that we spend time on argumentation and

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Student ideas use **particle-level interactions** to try to **explain the macroscopic color change**. (CCC: 2.2)
- Students **develop arguments** about how **chemical reactions between water, CO₂, and carbonic acid led to the reversible** bromothymol blue indicator color change. (SEP: 7.4; DCI: PS1.B.2)
- Students **use a computational model to generate particle scale data which explains changes at the macroscopic scale**. (SEP: 2.6; CCC: 2.2)

What to do: It is important that students think about how changes at the particle scale cause changes at the macroscopic scale. At all stages of this investigation, if students are stuck or are unsure how to proceed, refer them to the “Ideas and Evidence” poster. This tool, along with the preceding graffiti board activity, is intended to help tie microscopic and macroscopic events together.

Building toward 6.A.2 Make an argument about and use a computational model to generate data about **small-scale mechanisms underlying the natural system** of the **reversible reaction that occurs in weak acid dissociation**. (SEP: 2.6, 7.4; DCI: PS1.B.2; CCC: 2.2)

developing a hypothesis to clarify our ideas so that we can obtain evidence for or against their accuracy. (CCC: 2.2)

7 · DISCUSS INVESTIGATION IN GROUPS

8 min

MATERIALS: *NetLogo Investigation*, science notebook, “Ideas and Evidence” poster

Break into groups to discuss the investigation. Have the “Ideas and Evidence” poster visible. Display **slide N**. Tell students that they will work with another pair to review how each pair’s evidence fits with the ideas the class had about what was happening in the solution as it changed color.*

Tell each partner group to share their responses to prompts #5–9 on *NetLogo Investigation* with each other and be ready to share how their new evidence fits with the class’s ideas and evidence from day 1. This is an opportunity for students to practice with a smaller group before sharing their conclusions during the next class period.

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

The key idea here is that students are using *evidence from the simulation (computational model) to explain how the color change occurred*. Push students to share this part of their thinking with their peers. (SEP: 2.6)

End of day 2

8 • BUILDING UNDERSTANDINGS DISCUSSION

20 min

MATERIALS: *NetLogo Investigation*, science notebook, “Evidence after Investigation” poster, carbon cycle model, chart paper markers, <https://www.openscienced.org/general/waterco2interaction/>

Discuss the investigation as a class. Gather students in a Scientists Circle. Have students bring *NetLogo Investigation* and their science notebooks with them. Display **slide O**. Then, ask each pair to share their conclusions to kick off a Building Understandings Discussion.* Add new pieces of evidence to the “Evidence after Investigation” poster.

KEY IDEAS

Purpose of this discussion: To help students establish what happened in the simulation. For example, the simulation showed amounts of CO_2 decreasing if it starts at a high concentration, or CO_2 forming if it starts at a low concentration. Students need to relate the simulation evidence to the ideas that 1) dissolved CO_2 can leave water, and 2) reactions can go in reverse or backward. They should be able to describe the reactions that can go backward as “reversible reactions” and explain that these reactions will eventually reach a relatively stable state or “equilibrium.”

Listen for these ideas:

- In the simulation, CO_2 could escape from the water and CO_2 could form from H_2CO_3 .
- In real life, CO_2 was leaking out and because there was not “enough” CO_2 left in the solution, it somehow formed from H_2CO_3 .
- All steps of ocean acidification can go backward (are reversible).*
- The forward and reverse reactions happen at about the same rate, creating a balance.

These ideas are complex. If students are struggling with the provided prompts, you may wish to allow them to return to the computer simulation while engaging in whole-class discussion so that students can test ideas in real time if they are unsure.

* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

A Building Understandings Discussion is a useful type of discussion following an investigation because the purpose is to focus students on drawing conclusions based on evidence. Your role during the discussion is to invite students to share conclusions and claims and to push them to support these with evidence. Students can disagree with each other and the class does not need to reach consensus on all ideas shared. Areas of disagreement can motivate future investigations.

General, helpful prompts during these types of discussion include:

What can we conclude?

How did you arrive at that conclusion?

What’s your evidence?

Does any group have evidence to support Group A’s claim?

What data do we have that challenges Group B’s claim?

* SUPPORTING STUDENTS IN DEVELOPING AND USING STABILITY AND CHANGE

Reversible reactions are one of many examples in chemistry where a *reaction reaches a stable state over time*. In this unit, students figure out that reactions can *reverse* and reach a *state of equilibrium*. Later, students will figure out mechanistically why some reactions are more likely to reverse than others due to relative bond energies. (CCC: 7.1)

Suggested prompt

Sample student response

What types of things did we try in our investigations in the simulation?

We tried starting a container with no CO_2 , then we added it as in the real-life reaction, then we took it away like overnight.

We started a container with just H_2CO_3 like we thought the real-life sample had.

What did we observe?

When we started with no CO_2 and added it over time before taking it away, H_2CO_3 formed and the pH went down. Then when we took CO_2 away, the pH went up a bit.

Some CO_2 formed in the water over time when we started with just H_2CO_3 . The pH goes down.

What does the evidence from our investigations tell us is happening in the color change?

CO_2 is coming out of the water.

Somehow CO_2 forms when there is only H_2CO_3 in the solution. This makes the solution less acidic.

Suggested prompt	Sample student response
<i>How does CO₂ form when there is only H₂CO₃ and water in the solution?</i>	It could be some sort of reaction. That idea is weird though, because that would be like the reaction going backward.

ADDITIONAL GUIDANCE

If students are unsure whether the simulation showed these ideas, demonstrate it for the whole class at once. What is happening in the reaction can best be viewed by slowing the simulation down, with dissociation off, and pausing the model after a CO₂ molecule is formed where there previously was no CO₂. This should be accompanied by the disappearance of H₂CO₃, visible both in the container and on the graph.

Discuss the implications of our results. Say, *This is the first time we have seen a reaction go backward, or gas leaving a liquid once it is dissolved. What is actually happening to cause CO₂ to leave the water or the reaction to go backward?* Display slide P. Have students turn and talk with a partner, then share their ideas as a class.

Suggested prompts	Sample student responses	Follow-up questions
<i>What is actually happening to cause CO₂ to leave the water?</i>	CO ₂ goes into water as it bounces around randomly, so it apparently can also randomly bounce out of the water.	<i>Does all of the CO₂ bounce out?</i>
<i>What is actually happening to cause the reaction to go “backward”?</i>	Maybe CO ₂ can form if H ₂ CO ₃ reacts or breaks apart?	<i>Is this something we can see in the simulation?</i>

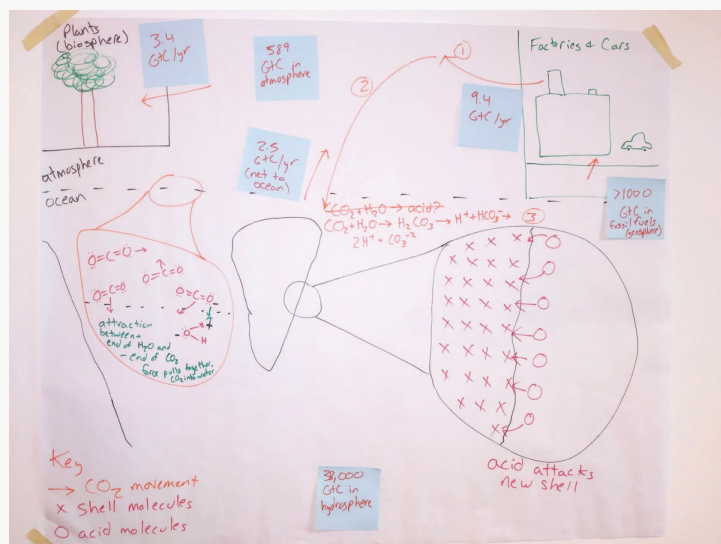
Revise the carbon cycle model. Display slide Q. Have the carbon cycle model visible. Direct students to turn and talk with a partner about the questions on the slide. Then discuss the questions as a class. Students should turn and talk about both questions, but the class will pursue implications of the first prompt before discussing the second.

Ask, *If CO₂ can leave water and return to the air, how can we show that in our carbon cycle model?* Look for students to say: We can add an arrow going from the hydrosphere and back to the atmosphere, showing the carbon moving out of the ocean.

Display slide R. Read the text at the top of the slide.

Suggested prompt	Sample student response
<i>What does this mean?</i>	The carbon is moving into and out of the ocean.
<i>If CO₂ can leave water and return to the air, how can we show that in our carbon cycle model?</i>	Accept all responses.

Add an arrow on the carbon cycle model going from the atmosphere to the ocean and alter the 2.5 GtC/year addition of carbon from the atmosphere to note that this is a net change in the ocean.



Build understanding about reversible reactions. Display slide S. Ask, *If the reaction can go backward, how do we show that in our model?* Look for students to suggest:

- We could draw the same reaction happening backward.
- We could add arrows to the reaction showing how it can go both forward and backward.

Ask, *Which of these approaches is easier?* Students should answer that the second approach is easier.

Say, *Chemists use this notation ($\rightleftharpoons$) to indicate reversible reactions--that is, reactions that go both forward and backward.* Use slide T to lead students in a brief discussion about which reaction steps are reversible.

ADDITIONAL GUIDANCE

Do not add the symbolic notation for reversible reactions yet to the carbon cycle model. This will be added after students view the simulation a second time.

Suggested prompt

Do you think each step of the acidification reaction goes backward?

How can we tell from the simulation where this is happening?

Sample student response

Maybe? It is hard to tell. We should look at the model.

We might be able to see changes while watching the container.

We can see if substances that were “reactants” go up on the graph when “products” go down.

Use the simulation to show the reversible reactions. Display slide U. Open the simulation using <https://www.openscienced.org/general/waterco2interactions/>. Turn dissociation on and point out places where the H^+ and CO_3^{2-} concentrations go down at the same time the HCO_3^- concentration goes up. Verify that the class is in agreement that this is evidence that each step of the acidification reaction is going backward.

Say, Now that we know that each step of the reaction moves in both directions, let's update our carbon cycle model. Change the arrows in the acidification reaction on the carbon cycle model to double arrows ($\rightleftharpoons$).

Display slide U again. Lead a discussion using the prompts below.

Suggested prompt	Sample student response
Does the reaction go backward completely, so that there is no "product" left? Why or why not?	No, because there is product AND reactant left. It is hard to tell why.
What do we see in the simulation that is preventing the reaction from going backward completely?	The forward and reverse reactions are both happening at the same time.
What makes this system have a roughly stable concentration if both forward and reverse reactions are happening?	The forward and reverse reactions must be happening at about the same level or rate.
What changes could we make that would impact how much of any of the substances are present?	Adding CO_2 (increasing the concentration) makes the concentration of everything else increase before leveling out. Taking CO_2 away makes the concentration of everything else decrease before leveling out.

ADDITIONAL GUIDANCE

If students are having trouble getting to the idea that the forward and reverse reactions must be happening at the same rate, walk the class through this using the simulation. Run it slowly and point out places where "products" are forming and where "reactants" are forming. Say, *Both of these events happen, but the overall concentrations stay about the same. Let's think about this in terms of the population in a town. If the town's population has been exactly the same for 50 years, what could that mean?* Students will say that either nothing is happening or that every time a person dies or leaves town, a baby is born or someone new comes into town. Then return to the prompt about keeping a stable concentration.

Develop definitions for reversible reaction and equilibrium. Say, *Scientists have names for some of these ideas we have been talking about. They call a reaction that can go backward and forward a reversible reaction. When the concentrations of substances reach a steady or stable level over time, scientists call that equilibrium.* * Show slide V. Have students add reversible reactions to their personal glossaries and revise equilibrium.

Discuss why some reactions are reversible. Say, *This is the first time we have ever seen reactions that are reversible--many reactions are not. Why is that?* Take all responses, then continue.

Say, *Let's break this problem down and think about what happens in reactions.* Display slide W. Give students a minute to turn and talk about the prompt on the slide before leading them in a discussion.

Suggested prompt	Sample student response
<i>What happens to the molecules to turn reactants into products?</i>	Bonds break and form.
<i>How do bonds break and form?</i>	Particles hit hard and often enough so that bonds are broken.
<i>What happens when substances on the right side react to make substances on the left side (the reverse or backward reaction)?</i>	The same thing happens--bonds break and form.
<i>So if bonds are breaking and forming in both forward and reverse reactions, why do some reactions reverse and others do not?</i>	Maybe the bonds are different somehow?
<i>How can bonds be different from each other?</i>	Some bonds are stronger than others.
<i>How could bond strengths determine whether a reaction reverses?</i>	If something in the reaction has strong bonds, that substance will not break apart and form another substance as easily.
ADDITIONAL GUIDANCE	If students are stuck on other aspects of reactions besides bonds breaking and forming, try to have them make relevant connections. For example, if students emphasize different elements involved in reactions rather than bonds, ask them to tell you or demonstrate how to draw a particle model of the reaction on the whiteboard. Have students highlight in their model where atoms are breaking apart and coming together. Make sure students connect that to bonds breaking and reforming. If students are focused on “types” of bonding (covalent, ionic, metallic) rather than strengths, ask them how the differences between bonds show themselves in real life--for example, <i>How do covalent and ionic compounds behave differently in water?</i> Follow up on the bond strength idea. Say, <i>It might be useful to get some information on both reversible and irreversible (meaning not reversible) reactions, along with their bond strengths. I have some data about acids and bases. Some of these acids and bases dissociate in water in a reversible reaction, while some do not. We can try using this data to figure out if bond strengths really have anything to do with reversibility.</i>

9 • ANALYZE DATA ON ACIDS AND BASES

21 min

MATERIALS: *Bond Data*, *Acid-Base Bonding Patterns*, chart paper, chart paper markers

ADDITIONAL GUIDANCE	If students need to move out of the Scientists Circle to better analyze the data and complete <i>Bond Data</i> with a partner, allow them to do so. Students should return to the Scientists Circle at the next lesson step.	* STRATEGIES FOR THIS CONSENSUS DISCUSSION A Consensus Discussion is designed to help students bring together, and come to agreement on, ideas that have been building
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 **Prepare students to analyze the data.** Display *slide X*. Distribute *Bond Data* and give students a minute to look over the data table. Ask, *What questions do you have about this data?* Answer all student questions. If students do not ask about the difference between the “actual” and “simplified” dissociation columns, be sure to remind them that water plays an important role in dissociation. When we write H^+ , it is really just short for H_3O^+ which forms as water bonds with H^+ ions. Allow students to complete *Bond Data* in pairs as needed.

ADDITIONAL GUIDANCE

It is important that students leverage their understanding of dissociation when looking at the data. If students do not mention dissociation, take a moment to have students think about whether the substances that have dissociated in water will remain separate or come back together at some point.

Lead a Consensus Discussion of the data. Display *slide Y*. Ask students to bring their completed *Bond Data* back to the Scientists Circle. Record the class's conclusions on a sheet of chart paper. *

KEY IDEAS

Purpose of this discussion: To help students come to consensus that a reaction (or process like dissociation) is reversible when the reactants have relatively strong bonds and are therefore relatively stable, while substances that dissociate completely tend to have weaker bonds. Acids and bases that dissociate completely have more extreme pH levels.

Listen for these ideas:

- Some substances underwent reversible dissociation and had strong reactant bonds and pH values closer to neutral.
- Other substances underwent irreversible dissociation and had weak reactant bonds and more extreme pH values.
- A moderate pH goes with strong bonds and reversibility because something with strong bonds will not dissociate easily, creating fewer ions and therefore a less extreme pH.
- Stability can be defined in different ways in reactions.

The goal is to help students figure out a piece of the puzzle of why reversible reactions might occur.* The picture they build here is incomplete, as it does not account for the bond strength (or strength of intermolecular forces) in the products, but these pieces may be added as students explore bond strength and energy more deeply in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities?* (Fuels Unit).

throughout a lesson.

- It is important that, as you record student ideas on chart paper or a whiteboard, you ask everyone to weigh in on each proposed idea. For example, students should consider if they had a similar idea.
- It is also important for students to work on restating and rephrasing the ideas that you write down. Ensure each idea captures what everyone thinks is essential and revise the ideas as students make suggestions.
- Do not have students write down ideas at this time. Have them work on listening and connecting to the ideas that other people share.

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

The idea of *using multiple mental models to make predictions about the same reaction* may be new to students. Remind them that the more independent ways we can arrive at the same prediction, the more confident we can be that our prediction is accurate. (SEP: 2.4)

Suggested prompt	Sample student response
Based on the data, what did acids undergoing reversible dissociation have in common?	Their bond strengths were high and their pHs were relatively high (or less acidic).
How were the reversible bases similar to and different from the reversible acids?	They also had high bond strengths, but they had relatively low pHs (less basic).
What were the bond strength and pH like when the dissociation was irreversible?	Bond strength was low and pH was more extreme.

Suggested prompt	Sample student response
<i>If an acid or base had a low bond strength, what would that mean for how completely it dissociates?</i> <i>What impact would it have on the pH if the acid or base dissociates more easily?</i> <i>Which substances would you say are most stable? Why?</i>	It would dissociate more easily because it is easier for water to break a weak bond. It would be lower if it was an acid because there would be more H^+ ions. It would be higher if it was a base because there would be more OH^- ions. The substances where dissociation is reversible are more stable because they have stronger bonds. The substances where dissociation is reversible are more stable because once they break up they will reach equilibrium where there is a bit of everything, like we saw in the simulation. The substances where dissociation is not reversible are the most stable because they dissociate more completely.
Summarize student thinking. Say, <i>It sounds like we think that the bonds in the reactant are stronger in reversible reactions than in irreversible ones. So if the bond is strong, there is less dissociation and a less extreme pH. It sounds, though, like we had more trouble agreeing on a definition of stability. Some talked more about the reactant, but others talked about the result--what we saw when the reaction was finished or at equilibrium. When looking at acids and bases, chemists tend to use certain words to talk about stability--strong and weak acids and bases.</i> Display slide Z and provide students with <i>Acid-Base Bonding Patterns</i>. Say, <i>This reference summarizes strong and weak acids and bases. You do not have to memorize all of these different terms, but hopefully the information will help you connect back to our discussion today. The key is that you are able to think about the connection between bond strength, reversibility, and stability. The sheet can help you connect these ideas to the terms.</i> Give students a couple of minutes to process and ask questions about the reference before continuing.	
Suggested prompt	Sample student response
<i>In what different ways can we define "stability" when looking at reactions?</i> <i>What makes us call a substance stable?</i> <i>What makes us call a system stable?</i>	We can focus on a particular substance (like the reactant or product). We can look at the whole system. Strong bonds It does not react easily. It looks the same overall.

Apply to other acids and bases. Display **slide AA**. Tell students to work with a partner to review the table on the slide and predict the direction of the reaction arrows on portions with a question mark.

Key to the table presented on the slide.

Reaction	Reactant bond strength	pH (0.1M)	Substance type	What is stable?
$\text{HCl} + \text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{Cl}^-$	low	1.08	strong acid	product
$\text{NaOH} \rightarrow \text{Na}^+ + \text{OH}^-$	low	12.88	strong base	product
$\text{HF} \rightleftharpoons \text{H}_3\text{O}^+ + \text{F}^-$	high	2.12	weak acid	reactant / system
$\text{NH}_4\text{OH} \rightleftharpoons \text{NH}_4^+ + \text{OH}^-$	high	11.12	weak base	reactant/ system

Suggested prompts	Sample student responses	Follow-up questions
What direction did you predict for the first reaction?	It should not be reversible.	How did you arrive at your prediction?
What direction did you predict for the second reaction?	It should be reversible.	How did you arrive at your prediction?

Use a similar set of suggested prompts and follow-up questions to go through the Reactant bond strength, Substance type, and What is stable? columns.

Collect *Bond Data* as a formative assessment.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- See *Bond Data Key* for additional guidance.
- Students correctly predict unknown information about **reversibility**, **bond strength**, **substance type**, and **stability**. (DCI: PS1.B.2; CCC: 7.1)
- Students cite **other model types as evidence**. (SEP: 2.4)

What to do: Be sure to engage multiple students in sharing their predictions. Also push students to provide as many pieces of evidence as possible, since that can reveal whether they are relying on one mental model or have started to build connections between the different concepts of reversibility, bond strength, pH, weak or strong nomenclature, and stability.

Building toward 6.B.1 Use multiple types of models to make predictions about the **relative stability** of **substances in reversible reactions**. (SEP: 2.4; DCI: PS1.B.2; CCC: 7.1)

10 · NAVIGATE

4 min

MATERIALS: *Progress Tracker*

Direct students to their Progress Trackers. Show **slide BB**. Ask students to add their new thinking from the day and note what subproblem(s) their science ideas might connect to. Close the lesson by thanking students for their deep thinking.

See *Progress Tracker Key* for a sample Progress Tracker entry.

LESSON 7: How can we use what we have learned to help protect oysters?

PREVIOUS LESSON We used a simulation to investigate how acidic water could become less acidic again. We used the results to argue that a reversible reaction was taking place that reaches an equilibrium state. We used data to determine a relationship between bond strength, stability, and reversibility of reactions.

THIS LESSON

PUTTING PIECES TOGETHER

2 days



NOAA

We discuss why it is important to learn from people who are directly affected by the problem. We break into groups and read about different interested parties who are impacted by oyster die-offs. We use what we learn to brainstorm additional criteria and constraints for our engineering design solutions. We return to the Driving Question Board to resolve some questions and add new questions. We complete an assessment in which we investigate how pH changes as ion concentration changes.

NEXT LESSON We will test our model of acid-base neutralization and figure out that balanced chemical equations show particle-number ratios rather than mass ratios. We will 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 investigation to test this.

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-1, HS-ETS1-2



WHAT STUDENTS WILL DO

7.A Define criteria and constraints that consider the needs of communities in order to design a solution that supports the stability of the complex system of oyster production.

(SEP: 1.8; DCI: ETS1.A.1; CCC: 7.4)

7.B Develop a predictive and explanatory model based on the particle-level interactions found in solutions at equilibrium.

(SEP: 2.3; DCI: PS1.B.2; CCC: 2.2)

WHAT STUDENTS WILL 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.

Lesson 7 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	6 min		NAVIGATE Have students turn and talk with a partner to summarize what they have recorded on their Progress Trackers.	A	<i>Progress Tracker</i>
2	9 min		DISCUSS THE ROLE OF INTERESTED PARTIES Facilitate a whole-group discussion about what engineers can learn from interested parties' perspectives.	B-E	chart paper, chart paper markers
3	15 min		LEARN ABOUT INTERESTED PARTIES Arrange students into groups of four and facilitate a jigsaw reading activity.	F-H	<i>Discuss Interested Parties, Poultry Farmers, Northwest Indian Fisheries, Oyster Farmers, Restaurant Personnel</i> , chart paper, chart paper markers
4	10 min		BRAINSTORM CRITERIA, CONSTRAINTS, AND NEW SOLUTIONS AS A CLASS Facilitate a whole-class discussion about criteria, constraints, and potential solutions.	I-J	<i>Discuss Interested Parties, Progress Tracker</i> , chart paper, chart paper markers
5	5 min		PREPARE TO RETURN TO THE DRIVING QUESTION BOARD Have students take stock of questions on the DQB using <i>Our DQB Questions</i> .	K	<i>Our DQB Questions</i>
<i>End of day 1</i>					
6	15 min		REVISIT THE DRIVING QUESTION BOARD Organize students into a Scientists Circle to take stock of the DQB.	L	<i>Our DQB Questions</i> , Driving Question Board, 3x3 sticky notes, permanent markers
7	5 min		PREPARE FOR ASSESSMENT Explain the expectations for the assessment to the class.	M-N	<i>Acid Behavior Assessment, Safety Instructions</i> from Lesson 3
8	25 min		COMPLETE INDIVIDUAL ASSESSMENT Have students work in small groups to conduct the Acid Behavior Investigation. Have students individually complete <i>Acid Behavior Assessment</i> .	O	Acid Behavior Investigation
<i>End of day 2</i>					

Lesson 7 • Materials List

	per student	per group	per class
Acid Behavior Investigation materials	• <i>Acid Behavior Assessment</i> • science notebook • safety goggles • disposable gloves • chemical apron	• 2 250-mL beakers • 50 mL 0.05M hydrochloric acid (HCl) solution • 50 mL 0.05M citric acid (H₃C₆H₅O₇) solution • 2 pieces weighing paper • 0.4 g sodium citrate (Na₃C₆H₅O₇) • 1 scoopula • 4 universal pH indicator strips • 1 glass stir rod	• digital scale
Lesson materials	• <i>Progress Tracker</i> • science notebook • <i>Discuss Interested Parties</i> • <i>Our DQB Questions</i> • <i>Acid Behavior Assessment</i> • <i>Safety Instructions</i> from Lesson 3	• <i>Poultry Farmers</i> • <i>Northwest Indian Fisheries</i> • <i>Oyster Farmers</i> • <i>Restaurant Personnel</i> • chart paper • chart paper markers	• chart paper • chart paper markers • Driving Question Board • 3x3 sticky notes • permanent markers

Materials preparation (45 minutes)

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

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

Create the handout *Our DQB Questions* for your class. Use a digital copy of *Our DQB Questions* as a template. List all of the questions that students developed on the Driving Question Board on the bottom of the handout. For ease of reference you can number each of the questions on the DQB and make sure the handout has the corresponding number next to that question. Then print sufficient copies for each student.

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

Day 2: Acid Behavior Investigation

- **Group size:** 5 students
- **Setup:** Review *Preparing Assessment Solutions* for detailed instructions for making the solutions. Make space for several weighing stations so groups can measure out sodium citrate (Na₃C₆H₅O₇) onto pieces of weighing paper.
- **Notes for during the lab:** Excess solutions can be used in case of spills, or if a group needs to repeat a trial. Tell students not to move stirring rods from one solution to the other, as this will lead to mixing of solutions and errors in data.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*. These include:
 - When working with hazardous chemicals, wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and takedown segments of the activity.
 - When diluting acids or bases, the acid or base should be added to water and not water to the acid or base.
 - Observers of activities involving hazardous chemicals must have appropriate PPE eye protection (indirectly vented chemical splash goggles) and non-latex aprons in addition to being positioned approximately 15 feet in front of a demonstration safety shield or closed fume hood sash.
 - Secure loose clothing, wear closed-toe shoes, and tie back long hair.
 - Never eat any food items used in a lab activity.

- Never taste any substance or chemical in the lab.
- Only combine substances and amounts as instructed by your teacher.
- Follow your teacher's instructions for disposing of waste materials.
- Use caution when working with glassware, which can shatter if dropped and cut skin.
- Immediately clean up any liquid spilled on the floor, so it does not become a slip/fall hazard.
- Never pour chemicals, either used or unused, back into their original container.
- If you get a hazardous chemical on your clothing or have a clothing fire, use the emergency shower.
- If you get a chemical in your eye, use an eyewash station immediately.
- Point the test tubes, beakers, or other vessels away from yourself and other people when the vessels contain reactants or other substances.
- Never use mouth suction to fill pipets.
- Wash your hands with soap and water immediately after completing this activity.
- **Disposal:** Unused solutions can also be poured down the drain and followed with cold water, or stored for one year. Used universal pH strips can be put in the trash.
- **Storage:** Store unused solids and solutions in lockable corrosives cabinets. Store unused universal pH strips in lockable storage cabinets.

Lesson 7 • Where We Are Going and NOT Going

Where We Are Going

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

- **PS1.B.2: Chemical Reactions.** In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.
- **ETS1.A.1: Defining and Delimiting Engineering Problems.** Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, ~~and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.~~

Crosscut Explanation: Students do not quantify criteria and constraints at this point in the unit. In Lesson Sets 2 and 3, students will quantify criteria and constraints so that they can evaluate possible design solutions. In this lesson, students identify additional criteria and constraints to consider as a result of reading about interested parties. (DCI: ETS1.A.1).

Students return to their Progress Trackers and summarize what they have figured out so far—namely, the reaction of carbon dioxide and water, and reversible reactions—that might help them solve the problem of oyster die-off (DCI: PS1.B.2). But science and engineering are not pursued in a vacuum; rather, we rely on interested parties to guide decision making on how ideas and solutions are developed and applied. Thus, students consider the perspectives of multiple interested parties who are affected by the die-off events (DCI: ETS1.A.1).

Students discuss what we can learn from the interested parties, and why it is important to listen to multiple perspectives when designing an engineering solution. They account for multiple social aspects of the oysters' system and how the system can be designed for lesser or greater stability (CCC: 7.4). Students learn about and identify initial ideas for criteria and constraints, which they will develop further in Lesson Set 3 (SEP: 1.8).

Students take an assessment at the end of this lesson. Use the *Discuss Interested Parties Key* to provide meaningful, three-dimensional feedback on students' understanding of the dimensions. On the *Acid Behavior Assessment*, students should observe and explain the pH changes of acids in water as they dissociate (DCI: PS1.B.2). During the assessment, students develop and use a model to predict the behavior of two acids by identifying cause and effect relationships of smaller scale mechanisms within the system (SEP: 2.3; CCC: 2.2).

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

Students will encounter the terms *criteria* and *constraints*. Both of these should have been developed during middle school as they are included as part of the Engineering Design DCIs. Provide an opportunity for students to come to consensus on what those terms mean.

Where We Are NOT Going

While students briefly brainstorm possible ideas for how we can use chemistry to protect the oysters, that activity is for navigation purposes only. We will not be doing a deeper dive into evaluating, quantifying, or designing engineering solutions in this lesson. We are intentionally taking time to learn from interested parties first in order to acknowledge the importance of listening to those who are most impacted by an ecological disruption before designing solutions to address it. Students will return to *Progress Tracker* throughout Lesson Sets 2 and 3 to further develop ideas that inform their design solutions.

LEARNING PLAN for LESSON 7

1 · NAVIGATE

6 min

MATERIALS: *Progress Tracker*

Summarize *Progress Tracker* ideas. Display **slide A**. Give students three minutes to turn and talk with a partner. Then ask for students to volunteer what they shared. Look for students to suggest:

- We learned that acids have hydrogen ions that are removed from the molecule and lower the pH of water. (Lesson 3)
- We learned that CO₂ is not an acid, but it reacts with water to form carbonic acid. (Lessons 3 and 4)
- We learned that carbon dioxide can enter the hydrosphere from the atmosphere. (Lesson 5)
- We learned that carbon cycles through the geosphere, atmosphere, hydrosphere, and biosphere in different forms. (Lesson 5)
- We learned that carbon moves from the geosphere to the atmosphere when we burn fossil fuels, and we measured how much carbon dioxide is produced. (Lesson 5)
- We learned that the reaction of carbon dioxide and water is reversible, which means that the reaction can go forward and backward. (Lesson 6)

ADDITIONAL GUIDANCE

If students do not share all of the ideas listed above, that is okay. You can use the lesson numbers provided to use to prompt students on where to look for key ideas that have not been suggested yet.

2 · DISCUSS THE ROLE OF INTERESTED PARTIES

9 min

MATERIALS: science notebook, chart paper, chart paper markers

Return to our unit question. Display **slide B**. Remind students of the overarching question we are trying to figure out: Why are oysters dying, and how can we use chemistry to protect them? Say, *We want to think about how we can use chemistry to protect the oysters. Based on what we have figured out so far, what are some ideas that we have for how we can do that?* Call on several students for responses. Say, *Let's think about our own experiences for a minute.*

Discuss why we learn from interested parties. Display **slide C**. Have students turn and talk with a partner about the prompts on the slide. Invite a few students to share their responses. Accept all responses.

Display **slide D**. Explain to students that they will first think about their responses to the prompts on the slide individually before pairing up with a new partner to share their responses. Remind students that in Lesson 1 we learned that there are many other people who are trying to help the oysters. After three minutes, ask for student responses. Record them on a sheet of chart paper. *

* ATTENDING TO EQUITY

This introductory discussion is important in order to reinforce the understanding that expertise about oysters and other technical issues exists in many places, and that knowledge is important to making decisions about engineering designs. It also addresses the nature of science by reminding students that science knowledge can help us understand what is going on in natural systems, but making decisions about how to use that knowledge requires us to think about ethics and values. This is also a good place to encourage students to think about how the solutions we design would affect the people who are most impacted by the problem. Rather than coming in to solve a

Suggested prompt	Sample student response	problem for them, science can be used together with the knowledge of impacted people to develop a more effective solution.
What can we learn from other people who also care about oysters?	We can learn how long this has been happening and who is most affected. We can learn what they have already tried that did not work. We can learn if they have made progress toward helping the oysters. We can learn about other plants and animals in those places so that we do not accidentally harm them. We can learn about different ways that oysters are used by people.	
Why is it important to listen to people who are already working on this problem?	When other people made a decision for me without including me, it made me angry and I stopped caring about the result. If we do not pay attention to what has already been tried, we might waste time and money. Scientists work together to solve problems, not all alone. In complex problems, having multiple people working on it is often needed to make progress.	
Update our personal glossaries. Introduce <i>interested parties</i> as a term we can use to refer to people who “have an interest” in the solution, meaning they also care about or are working on the problem. Display slide E and have students add this term to their personal glossaries.		

3 · LEARN ABOUT INTERESTED PARTIES

MATERIALS: Discuss Interested Parties, Poultry Farmers, Northwest Indian Fisheries, Oyster Farmers, Restaurant Personnel, chart paper, chart paper markers

15 min

Redefine the problem. Say, *We have been recording how our science ideas could help us create a design solution to address subproblems. What is our subproblem? Can we define that again?*

Introduce criteria and constraints. *We will want to know whether the design solution we come up with is a good one. How do we decide whether an engineering design solution is effective or not?* Look for students to mention:

- It needs to work without causing additional problems.
- It shouldn't be too expensive.

If students do not mention *criteria* and *constraints*, take a moment to introduce the terms. Ask students what each of the terms mean.

* ATTENDING TO EQUITY

Universal Design for Learning: For some students, this group activity may take longer than the time allotted because of the reading component. In order to support representation, consider allowing students to break up the reading passage among their group, providing an overview of each vignette, or taking a few minutes to review reading comprehension strategies before beginning the Jigsaw.

ADDITIONAL GUIDANCE

Students should be familiar with these terms from middle school. If they are not, explain the definition for each term.

Criteria are the guidelines that are used to judge the success of a solution.

Constraints are the limits on a solution.

Display **slide F**. Say, *If we are going to try to develop solutions to the oyster problem, we should probably also consult with people who have already been working on this issue and who are affected by the problem—the interested parties. How might thinking about perspectives and ideas from various interested parties help us develop criteria and constraints?* Look for students to mention:

- If we consult with various interested parties we will have criteria and constraints that cover a wider range of concerns.
- If our criteria and constraints are more fleshed out by seeing what multiple interested parties have to say, our solutions are more likely to be effective for multiple interested parties, rather than just considering one perspective.

ADDITIONAL GUIDANCE

This unit uses the term *interested parties* instead of *stakeholders*. Many governments, businesses, non-profits, and other organizations are making this switch for a variety of reasons related to the term's historical associations with power and even oppression.

1. The term *stakeholder* implies that all parties have equal interests or rights in a decision, which is rarely the case.
2. The term is considered offensive for some Indigenous peoples because it was historically used to divide up and take land that they did not consider anyone's to own. The "stake" part of the word originally referred to a literal stake in the ground used to indicate ownership.
3. The term is narrow, having historically been used to refer to only some people's interests, particularly those who have financial ownership, rather than everyone affected by the decision.
4. The term implies differentials in who has knowledge and power in a situation.

Feel free to use terminology that you and your students are comfortable with. Examples include *rights holders* or *interest holders*. Pause to give students a moment to enter these terms in their personal glossaries as words or definitions we encounter.

Read about interested parties in expert groups. Arrange students into "home" groups of four. Display **slide G**. Read through the directions on the slide to have students form and move into expert groups.

Ask students to gather in these expert groups. Depending on the number of students in the class, you may choose to divide those expert groups into smaller groups of three to four students. In expert groups, students will read one of four vignettes about interested parties who are connected to the oyster problem. ✱ After they read the vignettes, students discuss Questions 1–4 on *Discuss Interested Parties*. Students should record their responses in the space provided so that they can share those ideas with their home groups.

ADDITIONAL GUIDANCE

The readings in this Jigsaw are strategically written to emphasize varying scale and location, and to motivate the quantification questions that begin Lesson Set 2. Since the readings emphasize different interested parties, it is expected that students will have different initial criteria. Then when they come together in their home groups, students will have an opportunity to discuss the challenges of trade-offs and prioritizing the needs of multiple interested parties.

Sample student responses to Questions 3 and 4 on *Discuss Interested Parties* are included in *Discuss Interested Parties Key*.

 **Discuss criteria and constraints in home groups.** Have students return to their home groups. Display **slide H**. Distribute a sheet of chart paper and chart paper markers to each group. Read through the directions on the slide and ask if there are any clarifying questions.

Students should post their lists around the room so they are visible during the next activity. As you walk between groups, prompt students to consider why learning from the interested parties is an important step in designing an engineering solution.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students link the **criteria and constraints** they **name** to specific **considerations from the vignettes** or the **science ideas** figured out in Lesson Set 1. (SEP: 1.8; DCI: ETS1.A.1)

What to do: At this point, criteria and constraints will likely consist of loosely defined design goals, limits, and considerations based upon interested parties' needs. These loosely defined criteria and constraints can be used to motivate the need to learn more about the problem. This leads to more clearly defined criteria and constraints that can define a useful solution. A more detailed exploration of these criteria and constraints, including quantification, will happen in Lessons 12 and 13. By that point, students will know more about the chemical reactions involved in building oyster shells and will have developed the stoichiometric skills to calculate amounts and articulate specific, measurable constraints.

Building toward 7.A.1 Define criteria and constraints that **consider the needs of communities** in order to **design a solution** that **supports the stability of the complex system** of oyster production. (SEP: 1.8; DCI: ETS1.A.1; CCC: 7.4)

4 • BRAINSTORM CRITERIA, CONSTRAINTS, AND NEW SOLUTIONS AS A CLASS

10 min

MATERIALS: *Discuss Interested Parties, Progress Tracker*, science notebook, chart paper, chart paper markers

Brainstorm criteria, constraints, and solutions. Make sure groups have posted their criteria and constraints posters around the room. Display **slide I**. Give students a couple of minutes to complete a gallery walk using the prompts on the slide.

 Display **slide J**. As students share, record their responses on a piece of chart paper. Create two columns, one titled Criteria and the other Constraints. Label this chart paper "Class Consensus Criteria and Constraints."

Suggested prompts	Sample student responses	Follow-up questions
<i>What criteria did you come up with that were similar to each other?</i>	We need to produce a lot of oysters. We need to keep the pH of the ocean consistent or move it back to what it used to be. We need to help oysters build strong shells so that they can be used for feed. We need to make sure oysters are able to grow big enough to be sold for food. All of the ecosystems are interconnected, so we need to think about what will happen to other species in the same place. Maybe we need to find out what is a healthy pH for other plants and animals too. We want to preserve both wild oysters and farmed oysters.	<i>Which vignette prompted that idea? Why?</i> <i>What systems are involved in that criterion or constraint?</i>
<i>What constraints did you come up with that were similar to each other?</i>	We need to make sure it is affordable so that people are able to implement it. We need to make sure we are not adding anything toxic to the oysters so that people can still eat them. Our solution needs to work quickly enough that more oyster reefs are not permanently damaged.	
<i>What new solutions can we propose using what we have figured out so far?</i>	We could plant more kelp or other sea plants. Maybe we can find replacements for some of the ways that oysters are used, then we can leave the ones that are there in the ocean to clean it through filtration. In aquaculture, scientists monitor the water that their oysters are in. Maybe we can add something to the ocean water to reverse the reaction or change the pH.	<i>What will be the impact of this solution?</i> <i>How do you think this will change the ocean over time?</i>

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students link the **criteria and constraints** they **name** to specific **considerations from the vignettes** or the **science ideas** figured out in Lesson Set 1. (SEP: 1.8; DCI: ETS1.A.1)
- Students discuss the **interrelated systems** involved in **designing a solution**, including but not limited to **carbon cycling, social and economic systems** that are impacted by oysters, and the **process of ocean acidification**. (SEP: 1.8; DCI: ETS1.A.1)
- Students explain how those **systems have changed over time**, and how a **solution** might help them **gain stability**. (CCC: 7.4)

What to do: As students suggest criteria and constraints, encourage them to use the vignettes and their science ideas on *Progress Tracker* to justify why those criteria and/or constraints are important. Suggest that they have *Discuss Interested Parties* and *Progress Tracker* available to refer back to during the discussion. When students suggest potential solutions, ask them to clarify what they think the impact of each solution might be. This provides an opportunity to assess students' thinking about how making changes impacts the long-term stability of the system.

Building toward 7.A.2 Define criteria and constraints that **consider the needs of communities** in order to **design a solution** that **supports the stability of the complex system** of oyster production. (SEP: 1.8; DCI: ETS1.A.1; CCC: 7.4)

5 • PREPARE TO RETURN TO THE DRIVING QUESTION BOARD

5 min

MATERIALS: *Our DQB Questions*

ADDITIONAL GUIDANCE

Ensure that you have created *Our DQB Questions* using the instructions in the **Materials Preparation** section of the Teacher Edition.

Take stock of DQB. Display slide K. Say, *We have figured out so many ways to restore oysters to help food access issues with the Swinomish Tribal Community. * Let's take stock of all we have figured out.*

Distribute *Our DQB Questions* with the list of questions developed on the Driving Question Board. Have students work individually to mark questions they think the class has answered using the key on the handout, replicated here:

- We did not answer this question or any parts of it yet: ○
- Our class answered some parts of this question, or I think I could answer some parts of this question: ✓
- Our class answered this question, or Using the ideas we developed, I could now answer this question: ✓+

Say, *Next class we will revisit the Driving Question Board together to take stock of what we have figured out so far.*

ADDITIONAL GUIDANCE

If students do not complete *Our DQB Questions* during class, instruct them to complete it as home learning.

* ATTENDING TO EQUITY

Universal Design for Learning. Engagement and sustained effort and persistence are intentionally developed here as we connect oysters back to issues of food sovereignty. Oysters are not compelling to all students on their own, but reminding students that oysters are an important food source to many people, as they heard about in Lesson 1 videos, can increase engagement.

If needed, reconnect students to the locally-sourced foods they rely on.

End of day 1

6 · REVISIT THE DRIVING QUESTION BOARD

15 min

MATERIALS: *Our DQB Questions*, Driving Question Board, 3x3 sticky notes, permanent markers

Mark questions on the Driving Question Board. Ask students to take out their annotated *Our DQB Questions*. Gather students in a Scientists Circle by the Driving Question Board and display **slide L**. Direct the students to the DQB, one by one, and mark questions that the class has answered in whole or in part through our investigations. Have as many students as possible participate until all questions that the class has answered have been marked. If time permits, ask students to share evidence that we have answered the questions as they check them off.

Add questions to the Driving Question Board. Have 3x3 sticky notes available for any students who suggest adding questions to the DQB. Ask, *Do we have any new questions to add?* Provide students with a few minutes to write down questions if they have them. Call on students to share their questions and add them to the DQB. Some new questions that may arise at this point include:

- *How can we reverse ocean acidification?*
- *Who gets to decide what criteria we use to evaluate an engineering solution?*
- *How could we use plants to help prevent ocean acidification?*
- *Is there any way we could use reversible reactions to help prevent oysters from being harmed?*

The next lesson set will take on questions about “how much” base would need to be added to help the ocean and tanks be more habitable for oyster larvae. The final lesson set focuses on all wider engineering choices. You can group students’ ideas this way to increase coherence during these two lesson sets.

7 · PREPARE FOR ASSESSMENT

5 min

MATERIALS: *Acid Behavior Assessment*, *Safety Instructions* from Lesson 3

Explain the expectations for the assessment. Display **slide M**. Distribute *Acid Behavior Assessment* and say something like, *Today you will have a chance to show what you have figured out so far in this unit.* Show students where the measurement stations are located.

Display **slide N** and distribute *Safety Instructions* from Lesson 3. Review the safety instructions with students.

ADDITIONAL GUIDANCE

This assessment asks students to take pH measurements of solutions and make predictions about the solutions. In order to take the measurements, students can work in small groups to test the pH of each solution. You can strategically pre-assign groups and begin the assessment in those groups so that students can take the initial pH measurements. Once all students in the group reach Question 5, the group can reconvene to add the sodium citrate and measure pH again.

In this unit, citric acid is written as $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$ to help students identify the hydrogens that dissociate.

MATERIALS: Acid Behavior Investigation



Complete the mid-point assessment. Present slide O. Say, *You have the rest of the period, if needed, to complete your assessment.* Give students instructions about what you would like them to do if they finish early, in line with the community agreements.

**ASSESSMENT
OPPORTUNITY**

What to look/listen for in the moment: See *Acid Behavior Key* for guidance.

What to do: While the answers in *Acid Behavior Key* show the expected responses and calculations, keep in mind that student thinking may be valuable even if their answers are conventionally incorrect. Use the “Ideas to look for” in the key to help provide positive feedback and partial credit to students based on their responses. The key is designed to help you keep track of students’ use of all three dimensions of the NGSS, rather than just whether or not their statement of science ideas is correct.

Building toward 7.B.1 Develop a predictive and explanatory model based on the particle-level interactions found in solutions at equilibrium. (SEP: 2.3; DCI: PS1.B.2; CCC: 2.2)

Additional Lesson 7 Teacher Guidance

**SUPPORTING
STUDENTS IN
MAKING
CONNECTIONS IN
ELA**

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

As students read the interested parties’ vignettes, they summarize the information presented in the texts to convey the central ideas of the processes to their jigsaw groups.

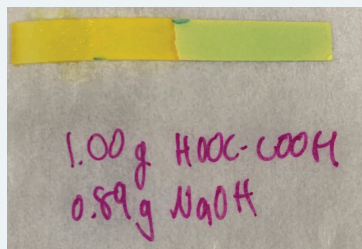
LESSON 8: How can we figure out how much of a substance we need to neutralize acid?

PREVIOUS LESSON We discussed why it is important to learn from people who are directly affected by the oyster die-offs. We read about different interested parties and used what we learned to brainstorm additional criteria and constraints for our engineering design solutions. We completed an assessment investigating how pH changes as ion concentration changes.

THIS LESSON

INVESTIGATION

3 days



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 the ratios in a balanced chemical equation are particle-number ratios rather than mass ratios. We use the periodic table to calculate the masses of the different particles. We apply a mathematical model using molar masses and particle-number ratios to predict the amount of base needed to neutralize an acid and carry out a second neutralization investigation to test our model.

NEXT LESSON We will use H^+ concentrations at an oyster hatchery to calculate the mass of NaOH needed to bring pH to safe levels. We will scale up those calculations to determine the amount of NaOH that would be needed for the whole ocean. We will wonder whether this solution is feasible, effective, or safe for other organisms.

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-1,
HS-ETS1-2



WHAT STUDENTS WILL DO

- 8.A** Plan and carry out an investigation of a neutralization reaction by predicting and manipulating the amounts of reactants using mass and mole proportions and collecting data to identify failure points to improve the reaction outcome. (SEP: 2.2, 3.6; DCI: PS1.B.3; CCC: 3.1)
- 8.B** Use a mathematical model of molecules in a chemical reaction and macro-scale evidence to determine what is happening at the particle level. (SEP: 5.2; DCI: PS1.B.3; CCC: 3.4)
- 8.C** Use proportions of different scales (ratios) to move between masses and numbers of particles that represent conservation of matter in a chemical reaction. (SEP: 5.5; DCI: PS1.B.3; CCC: 3.1)

WHAT STUDENTS WILL 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.

Lesson 8 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	8 min		NAVIGATE Lead a class discussion to revisit what students have figured out about acids, bases, and pH.	A-C	<i>Measuring pH</i> from Lesson 3
2	3 min		USE A MODEL TO VISUALIZE ION CHANGES DURING NEUTRALIZATION Talk through a model using the slides to help students visualize what happens to the ions in an acid or base and why water molecules form during neutralization. Discuss what else we need to know to try to neutralize the acid in the ocean.	D-I	
3	9 min		BALANCE A CHEMICAL EQUATION FOR A NEUTRALIZATION REACTION Have students work with a partner to balance an equation of a neutralization reaction using paper manipulatives.	J-L	<i>Balancing Equations Cards</i>
4	7 min		BALANCE ANOTHER CHEMICAL EQUATION Organize students into pairs to balance a second chemical equation representing a neutralization reaction.	M-N	<i>Balancing Equations Cards</i>
5	18 min		INVESTIGATE NEUTRALIZATION Organize students into groups of 5 to develop an investigation plan to neutralize an acid.	N-R	Neutralization Investigations
<i>End of day 1</i>					
6	5 min		NAVIGATE Have students turn and talk with a partner to recall what they did last class and what they figured out.	S	
7	5 min		THINK ABOUT RATIOS IN WATER Lead students through a simple equation of water decomposition to think about particle ratios versus mass ratios.	T-U	<i>Periodic Table</i>
8	10 min		INVESTIGATE HOW TO “COUNT” SMALL THINGS Work with students to develop a mathematical method to determine the number of small objects in a system by weighing the system and weighing one single object.	V-W	calculator, ~225 g paper clips, digital scale, plastic bag (sealable)
9	5 min		DETERMINE MASS OF OTHER SMALL OBJECTS Have students consider how to determine the mass of another small object.	X	staples, digital scale, plastic bag (sealable)
10	10 min		APPLY THIS IDEA TO ATOMS Have students apply the idea of counting objects by weighing them back to atoms and molecules.	Y	<i>Periodic Table</i>
11	10 min		REINTRODUCE THE MOLE Relate atomic mass to molar mass and reintroduce students to the mole and how to use it to quantify atoms and molecules.	Z-EE	<i>Periodic Table</i> , calculator
<i>End of day 2</i>					

Part	Duration		Summary	Slide	Materials
12	5 min		NAVIGATE Have students turn and talk with a partner to recall the ideas they learned last class and think about how to use them to neutralize an acid.	FF	
13	15 min		CALCULATE MOLAR MASS Have students individually calculate the molar masses of NaOH and H ₂ C ₂ O ₄ and determine what mass of NaOH is needed to neutralize an acid.	GG-HH	<i>Neutralization Investigation #2, Periodic Table, calculator</i>
14	15 min		RETRY THE NEUTRALIZATION REACTION Organize students into groups of 5 to develop and carry out a second neutralization investigation.	II-KK	Neutralization Investigations
15	5 min		UPDATE PROGRESS TRACKERS Have students add new science ideas they have figured out to their Progress Tracker.	LL	<i>Progress Tracker</i>
16	5 min		NAVIGATE Have students turn and talk with a partner to think about how to use this new information to adjust the pH of ocean water for oysters.	MM	

End of day 3

Lesson 8 • Materials List

	per student	per group	per class
Neutralization Investigations materials	• safety goggles • nitrile gloves • non-latex chemical apron • <i>Neutralization Investigation #1</i> • science notebook • <i>Neutralization Investigation #2</i>	• 1 250-mL beaker • 1 glass stir rod • 2 universal pH strips • 2 g NaOH • 1 g H₂C₂O₄ • 100 mL distilled water • 2 pieces weighing paper • another 2 universal pH strips • 0.89 g NaOH • another 1 g H₂C₂O₄ • another 100 mL distilled water • another 2 pieces weighing paper	• 2 digital scales • 2 scoopulas
Lesson materials	• <i>Measuring pH</i> from Lesson 3 • science notebook • <i>Periodic Table</i> • calculator • <i>Neutralization Investigation #2</i> • <i>Progress Tracker</i>	• <i>Balancing Equations Cards</i>	• ~225 g paper clips • digital scale • plastic bag (sealable) • staples

Materials preparation (45 minutes)

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

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

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

Provide written feedback to students based on the *Unknown material with identifier: cc.I7.ru* and prepare to return their assessments.

Students will be referring to the table found in *Measuring pH* from Lesson 3, on **slide C**.

For balancing equations on day 1, you will need **single-sided** copies of *Balancing Equations Cards* that you will cut to create cards. Prepare enough sets of cards for groups of 5 students in your largest class. There is a set of complete chemical formulas for the reactants and products, as well as a set of ions. You can use this as a choice opportunity in class by giving students both sets and letting them decide which to use, or give students one set or the other as a differentiation opportunity.

For day 2, you need a clear plastic bag of paper clips and another bag of staples.

Days 1 and 3: Neutralization Investigations

- **Group size:** 5 students

- **Setup:** Gather materials for the lab, so that each group will have 1 250-mL beakers, 2 universal pH strips, 1 glass stir rod, 2 pieces of weighing paper for each investigation. Additionally, create two weighing stations with enough NaOH and $\text{H}_2\text{C}_2\text{O}_4$ so that each group can measure 1 g of each for investigation 1 and 1g $\text{H}_2\text{C}_2\text{O}_4$ and 0.89 g NaOH for investigation 2.
- **Notes for during the lab:**
 - To prevent cross-contamination of substances, create 1 weighing station for NaOH and a second for $\text{H}_2\text{C}_2\text{O}_4$. Students should also make sure scales are tared or zeroed before measuring out substances. Weighing paper should be thrown away after use.
 - This lesson assumes the use of anhydrous sodium hydroxide and oxalic acid. If a hydrate is used, give students the formula on the bottle instead of the standard chemical formula, and explain the need for it on a basic level (sometimes chemicals are sold with some water already in the crystals). Help students adjust the mass calculations according to the new molar mass.
 - If oxalic acid is unavailable, another solid polyprotic acid may be substituted, such as citric acid. Because most polyprotic acids are weak acids, you may find that students' estimates are not quite as accurate and do not represent a perfect 3:1 mole ratio between citric acid and sodium hydroxide. Because so little sodium hydroxide is needed to neutralize citric acid, 2 or more grams of citric acid should be used in each trial.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*. These include:
 - When working with hazardous chemicals, wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and takedown segments of the activity.
 - When diluting acids or bases, the acid or base should be added to water and not water to the acid or base.
 - Observers of activities involving hazardous chemicals must have appropriate PPE eye protection (indirectly vented chemical splash goggles) and non-latex aprons in addition to being positioned approximately 15 feet in front of a demonstration safety shield or closed fume hood sash.
 - Secure loose clothing, wear closed-toe shoes, and tie back long hair.
 - Never eat any food items used in a lab activity.
 - Never taste any substance or chemical in the lab.
 - Only combine substances and amounts as instructed by your teacher.
 - Follow your teacher's instructions for disposing of waste materials.
 - Use caution when working with glassware, which can shatter if dropped and cut skin.
 - Immediately clean up any liquid spilled on the floor, so it does not become a slip/fall hazard.
 - Never pour chemicals, either used or unused, back into their original container.
 - If you get a hazardous chemical on your clothing or have a clothing fire, use the emergency shower.
 - If you get a chemical in your eye, use an eyewash station immediately.
 - Point the test tubes, beakers, or other vessels away from yourself and other people when the vessels contain reactants or other substances.
 - Never use mouth suction to fill pipets.
 - Wash your hands with soap and water immediately after completing this activity.
- **Disposal:** Universal pH strips can be thrown in the trash. Solutions can be emptied into sinks and followed with ample water. Rinse beakers thoroughly and ensure that solutions do not splash out of the sink.
- **Storage:** NaOH and $\text{H}_2\text{C}_2\text{O}_4$ should be stored in locked cabinets; do not store them together.

Lesson 8 • Where We Are Going and NOT Going

Where We Are Going

The targeted disciplinary core idea that we are developing is:

- **PS1.B.3: Chemical Reactions.** The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.

Crosscut Explanation: The salient chemical properties of the atoms involved in dissociation and equilibrium reactions include the strength of their bonds, their sizes, their electron counts, and other periodic trends (DCI: PS1.B.3). These are modeled extensively in the previous unit, *Space Survival Unit*. In this lesson, the focus is on accounting for matter within chemical reactions.

Students previously developed SEP: 5.2 in *Polar Ice Unit* and *Electrostatics Unit*. In this unit, students continue to use mathematical representations to support development of design solutions. Later, students apply this to quantify criteria and constraints used to evaluate design solutions (Lesson 13) and develop an explanation of how much CO₂ is released during the Haber-Bosch process (Lesson 15).

This lesson focuses on how we can “count” atoms and molecules, which are far too small in scale and numerous to actually count (proportion) (CCC: 3.2, 3.3). This is a stoichiometry-based lesson, but it is not rote or out of context. Students do not remember the procedures of stoichiometry as well if the practice is decontextualized, so this lesson roots stoichiometry practice in the issue of helping oysters.

Students will first attempt to neutralize an acid by combining proportional masses of acid and base in an experimental design that investigates and manipulates the variables of a reaction, leading students to identify a failure point (SEP: 3.5). This approach will not work because students are using grams instead of moles as the basis of the experiment (DCI: PS1.B.3). This failure causes students to reevaluate their variables and determine that they should count the molecules using Avogadro's number (SEP: 3.5).

When that does not work, students will realize they need to combine proportional numbers of molecules and that mass may not reflect that ratio. Students will complete a representative activity with visible-scale items (office supplies, such as paper clips) to help them think through how it is possible to “count” things by measuring their mass and will apply those ideas to a mathematical representation of atoms and molecules (SEP: 5.2; CCC: 3.2, 3.3).

Then students evaluate this mathematical representation for how to scale down to moles as a unit for converting between mass and molecule numbers (SEP: 2.2; CCC: 3.3). Students reason that this is necessary to ensure the conservation of matter and calculate the outcome of a chemical reaction (DCI: PS1.B.3).

When students test the neutralization reaction, it works much better because they have accounted for the molecules of each of the substances.

In this lesson, students will co-construct a definition for the following terms, which they should add to their Personal Glossary: *molar mass* and *mole ratio*; and they refine their definition of *mole*. **Do not** ask students to define or keep track of any words until after your class has developed a shared understanding of their meaning.

Additionally, students will encounter the terms *neutralization* and *stoichiometry*, which they may wish to add to their glossaries as well.

Where We Are NOT Going

While it is important for students to understand that one mole of any substance contains the same number of particles, knowing the exact number or calculating numbers of particles is not the goal of this lesson. Students also will not yet calculate the amount of substance needed to adjust the pH of water to ideal levels for oysters; they will do that in Lesson 9.

LEARNING PLAN for LESSON 8

1 · NAVIGATE

8 min

MATERIALS: *Measuring pH* from Lesson 3

Discuss what we figured out last class and where we decided to go next. Display **slide A**. Have students turn and talk about the questions on the slide and then share their ideas as a class. Students should recall from the previous lesson that adding salt to an acidic solution changed the pH, making it less acidic, so maybe adding a similar substance to acidic ocean water could be a solution. However, at this point students do not know how much substance would be needed or how exactly to figure that out.

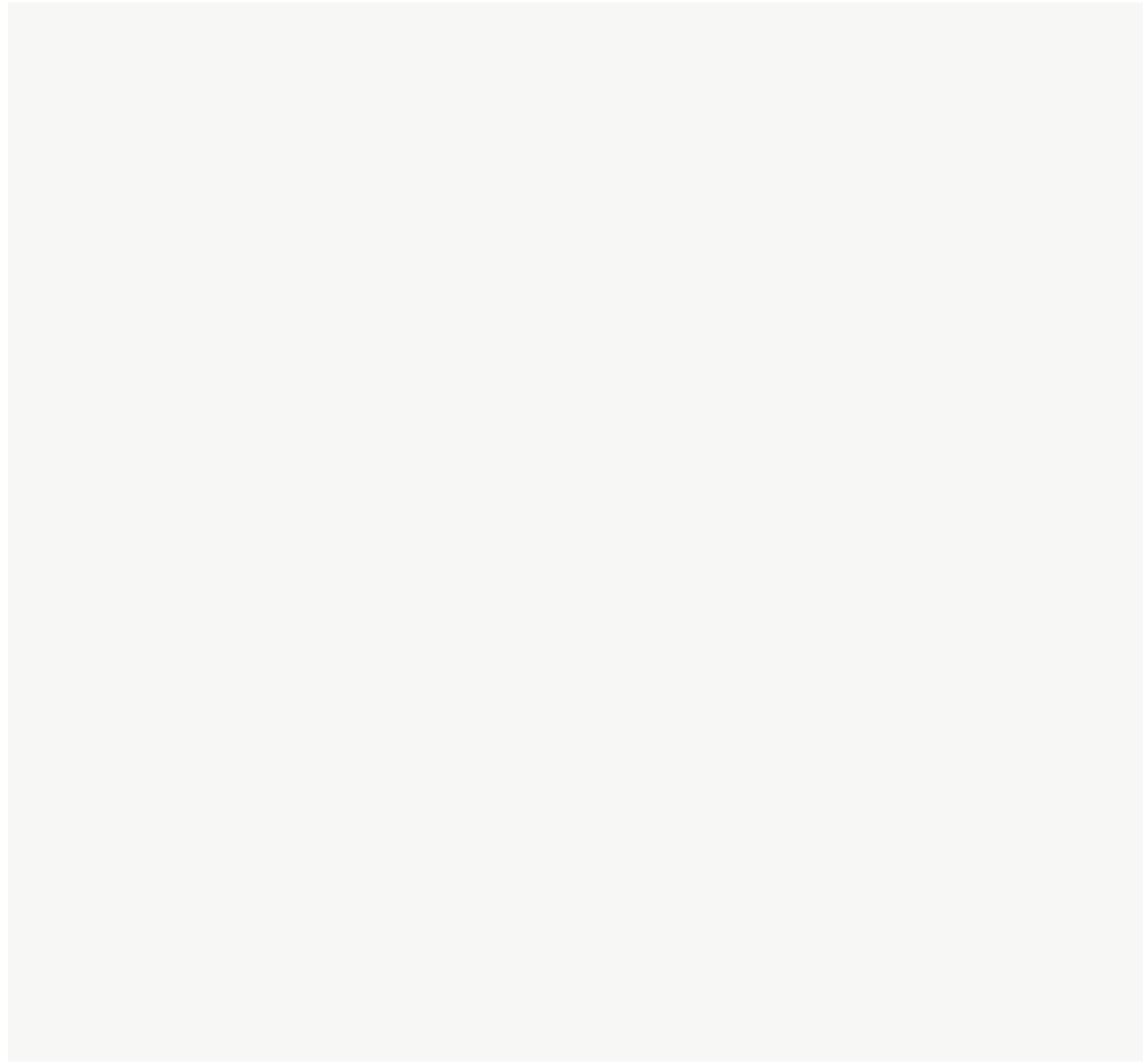
Suggested prompt	Sample student response
<i>What did you figure out in the investigation last class?</i>	We saw that a strong acid has a lower pH than a weak acid. We saw we could change the pH of an acid.
<i>What surprised you?</i>	The pH of the acid increased when we added the salt to it.
<i>How can we use what we have learned to find solutions to ocean acidification?</i>	Maybe we can add a salt or something to the ocean to raise the pH.

Show **slide B** and discuss the questions on the slide.

Suggested prompt	Sample student response
<i>In what direction do we want to change the pH of the ocean? Why?</i>	We want to raise the pH. We want to raise the pH because it has been decreasing and becoming too low for oysters to survive. Oysters cannot build their shells if the pH is too low.
<i>What are some substances we have worked with so far that have made the pH of a solution shift in that direction?</i>	Bases Molecules with OH in them.

Foreground the idea of pursuing bases as one type of possible solution for raising the pH of ocean water. Say something like, *So maybe trying to raise the pH with a base is one (or another) way we can combat the increase in ocean acidity. Is that all we would need to do? Let's consider that idea a bit further from a particle perspective.*

Display **slide C**. Read the text at the top of the slide to remind students of some bases they have used before (NaOH, KOH, NH₄OH). Point to the ion concentration table shown on the slide and remind students that they have seen it in a prior reading from Lesson 3. Cue students to take out *Measuring pH* and use the table to help them think about their answer to the question on the slide. Give students a minute to do this and then discuss as a class.



ALTERNATE ACTIVITY

Instead of having students reference the hard copy of the table in the reading, you could ask them to stand up and gather around the projected image on **slide C**. If you do this, then have students remain standing through the discussions up to **slide I**, when they can return to their seats to work with the cards.

Ask, *How should the concentration of OH^- ions in an acidic solution shift after the addition of a base?* Look for students to say that the concentration of OH^- ions should increase.

Direct students' attention to the H^+ concentration column in the table. Point out that if we are making predictions that increased OH^- concentration from adding base would increase pH, then as we look down this column of the table, we might wonder whether H^+ concentration would also change. Remind students that in the last lesson, they saw how adding one type of ion to a solution shifted the balance of other ions in the solution, and that using a particle-level model to track what is happening to both the H^+ and OH^- ion concentrations can help us visualize how and why they both shift with the addition of base.

2 · USE A MODEL TO VISUALIZE ION CHANGES DURING NEUTRALIZATION

3 min

MATERIALS: science notebook

Model the neutralization process. Display **slide D**, **slide E**, and then **slide F**, pausing briefly to read the text at the top of each slide and cuing students to track where the individual H^+ and OH^- ions are shown on the slides. Together these three slides will take about a minute to walk through.

ADDITIONAL GUIDANCE

The reference to “Most of those added OH^- ions” in the text on **slide F** is a way to recognize that there is some level of dissociation that distilled water undergoes. On average, 1 out of every 10,000,000 water molecules remains dissociated as H^+ and OH^- ions. You do not need to dwell on this idea right now unless students notice or ask about it.

Display **slide G**. Direct students' attention to either of the purple circles and ask what type of molecule will be formed as these two ions (OH^- and H^+) bond together. Students will say *water*.

Display **slide H**. Emphasize that each additional OH^- ion that associates with an excess H^+ ion forms a new water molecule, and that this outcome is called *neutralizing the acid*. Ask students how the meaning of *neutralization* connects to what they already know about charges. Students will say that *neutral* refers to charges canceling out.

Emphasize that this sort of charge cancellation is one way to think about what is happening when we add a base to an acid or an acid to a base, and that adding the right amount of, but not too many, OH^- ions to an acidic solution is called *neutralizing the acid*, while adding the right amount of, but not too many, H^+ ions to a basic solution is called *neutralizing the base*. Point out that either of these can bring about a balance of oppositely charged ions in solution, bringing their concentrations closer to equal and the pH of the solution closer to neutral (7).

ADDITIONAL GUIDANCE

This is an opportunity for students to add the word *neutralization* to their Personal Glossaries if they wish to do so.

Think about neutralization in the ocean. Display slide I. Say something like, *To consider how we might be able to use these ideas to neutralize the acid in the ocean, let's recall what we know about the chemistry of what is causing the ocean to become more acidic in the first place.* Discuss both questions on the slide as a class.

Suggested prompt	Sample student response
What acid do we know is forming in the ocean when CO_2 reacts with H_2O ?	Carbonic acid H_2CO_3
What else do we need to know to figure out how much base is needed to bring the pH of the ocean back to what it was?	How much water there is in the whole ocean. How many H^+ ions there are that we need to neutralize. The difference in H^+ concentration in the ocean now vs. in the past. The concentration (or molarity) and the pH of the base we would want to use.

3 · BALANCE A CHEMICAL EQUATION FOR A NEUTRALIZATION REACTION

9 min

MATERIALS: *Balancing Equations Cards*

ALTERNATE ACTIVITY

Balancing Equations Cards contains a set of complete chemical formulas for the reactants and products, as well as a set of ions. You can use this as a choice opportunity in class by giving students both sets and letting them decide which to use, or give students one set or the other as a differentiation opportunity. For students using the ion cards, encourage them to check the formulas they come up with to ensure that ionic charges combine to make neutral compounds. For example, if students make NaCO_3 instead of Na_2CO_3 , ask them if they have modeled a neutral compound and how they can make it neutral if it is not already.

Use manipulatives to examine a neutralization reaction. Say, *We know that OH^- ions from a base like NaOH will start to react with and cancel out H^+ ions from the carbonic acid to form water molecules. Let's see if we can figure out what else would be produced if we were to combine these substances.*

Display slide J. Distribute the balancing equations cards to each pair of students and read the question on the slide as you do so.* Ask, *What else, besides water, could be produced when H_2CO_3 and NaOH react?*

Students should suggest water and Na_2CO_3 . If students do not realize that the ionic charges in Na_2CO_3 are not balanced, use the prompts below to help them check for this.*

Balance the equation. Say, *We know CO_2 in the ocean makes the acid H_2CO_3 , and we think we can neutralize it with a base such as NaOH .* Display slide K and ask, *But how much NaOH would we need to neutralize H_2CO_3 ? And does this equation account for conservation of mass?* Give pairs more time to balance the equation, and tell them that it may help us think about how much base we would need to neutralize the acid.

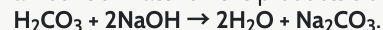
* ATTENDING TO EQUITY

Support for Universal Design for Learning: Physical cards make this activity more accessible for learners who can move them around on their desktop to think about reactants and products. You can continue to improve access by asking students to use the cards to represent what is shown in the chemical equations on subsequent slides (through slide N). This supports representation.

* SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Remind students that they have practiced tracking matter through a chemical reaction because they *balanced chemical equations to ensure the conservation of matter* in Lesson Set 3 of *Space Survival Unit*. (SEP: 5.2)

As students realize they have different amounts of some elements on the two sides of the equation, remind them that they can only add coefficients or add an entire second formula to balance the equation, and that changing subscripts will change the identity of the compound. Students should realize that they would need to start with two NaOH for the equation to be balanced, and that this would also impact the amount of water on the products side. So, the final balanced equation should be:



Suggested prompt	Sample student response
<i>How many H⁺ are combined with CO₃²⁻ on the reactants side?</i>	There are two H ⁺ combined with the CO ₃ ²⁻ .
<i>If only one Na⁺ is combined with CO₃²⁻ on the products side, will that be a neutral salt?</i>	No, it would still be negative. It would be -1 instead of neutral.
<i>If atoms cannot be created or destroyed, where might another Na⁺ for Na₂CO₃ come from?</i>	Another NaOH?

Discuss the balanced equation. After students have had time to balance the equation, have a couple of groups share the balanced equation with coefficients and make sure the class agrees on the final equation. Display **slide L** and give students time to think or discuss the questions on the slide in pairs, then have a whole-class discussion.

Suggested prompt	Sample student response
<i>What do we think the coefficients in the chemical equation mean or refer to?</i>	The coefficients tell us how much of each substance reacts. The coefficients tell us how many molecules of each substance react.
<i>Can you show me what you mean using your cards?</i>	(Students should point out that 2NaOH means an NaOH molecule and another NaOH molecule.)
<i>How can we use this to help us neutralize the acid?</i>	This tells us we need twice as much NaOH as H ₂ CO ₃ . We need two molecules of NaOH for every molecule of H ₂ CO ₃ .

4 • BALANCE ANOTHER CHEMICAL EQUATION

7 min

MATERIALS: *Balancing Equations Cards*

Test our idea with another reaction. Ask students what exactly they mean when they say we need twice as much NaOH as H₂CO₃ and have them think about how to measure that. Point out to students that NaOH is a solid and H₂CO₃ is a liquid, which might make measuring proportional masses difficult. Then ask, *Could we try another reaction with an acid and base that are both solids? Last class we used citric acid-- you saw it as a liquid, but it was a solution prepared by dissolving a solid acid in water. Some other acids, like oxalic acid, do the same thing. Should we try that? Let's balance that reaction so we have some idea of the ratio of substances we should combine.*

* ATTENDING TO EQUITY

Universal Design for Learning: Again encourage students to work with a partner to support *engagement* in this activity as they

Display **slide M**. Tell students we can try balancing this equation, which involves two solids, making it easier to ensure an accurate measurement of the two substances. Give students time to balance the equation using the cards from *Balancing Equations Cards*. *

Then after balancing, display **slide N** and use the prompts on the slide to discuss what these reactions tell us and how testing one of them might help us determine if we have a way to predict how much base is needed to neutralize an acid. *

Suggested prompts	Sample student responses	Follow-up questions
<i>What do both of these balanced equations show us?</i>	You need twice as much base as acid to neutralize these acids.	<i>So if we say we need twice as much NaOH as H_2CO_3, what do we mean by twice as much?</i>
<i>How are they related to the problem we are trying to solve?</i>	They both predict how much base is needed to neutralize a certain amount of acid. The first one is the actual acid that is in the ocean and one possible base that we could use to neutralize it.	<i>How could testing one of these reactions in the lab help us get the evidence we need to see if we have a way to reverse ocean acidification?</i>

ADDITIONAL GUIDANCE

Combining NaOH and $H_2C_2O_4$ in a 2:1 mass ratio will not result in a neutral solution, which is the goal. This outcome in the investigation will provide evidence for students to prove an important idea to themselves – that they need another way to think about measuring and ensuring ratios of substances in chemical reactions. It may feel unproductive, and students may initially feel discouraged, but encourage them to lean into this feeling and remind them that anything worth figuring out in engineering and science involves discovering deadends. Realizing they cannot just measure a mass ratio based on only a molecule ratio will drive students to figure out how to count atoms or molecules and keep track of the mass in that count, which is what they need to figure out in this lesson.

Oxalic acid is used here because it is diprotic, so it does not react with NaOH in a 1:1 ratio. Additionally, it is solid, making it easier for students to measure masses to combine. In this unit, oxalic acid is written as $H_2C_2O_4$ to help students focus on the diprotic nature of the acid when they are predicting the ratio to result in a neutral solution. You may want to point out to students that, since it is an organic acid, oxalic acid is most often written as HOOC-COOH. If they are curious about why that is, it may be helpful to explain to students that the hydrogen in each “COOH” group is the acidic hydrogen that will separate as H^+ in aqueous solutions.

While oxalic acid is considered a weak acid, it is still a relatively strong one, with $K_a = 5.4 \times 10^{-2}$, and it will produce the needed result of neutralizing NaOH. Students will not see the desired result when they try the reaction the first time, but in the second investigation during day 3, they will get a result that is neutral or very close to neutral.

negotiate and share the work of moving the cards on the table. Working with a partner or group on a card sort is often successful because the physical cards provide a shared object for students to focus their attention on.

* SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Students may also need support in thinking through *ratios* to argue that the 2:1 mass ratio is something to try. Have students show their ideas to a partner and ask students to come to the board to show their thinking.

Calculating these ratios is a secondary skill compared to being able to understand the *mathematical meaning of the value of “mass ratio”* and to use this data as a “recipe” for neutralization of acids. (SEP: 5.5)

5 · INVESTIGATE NEUTRALIZATION

18 min

MATERIALS: Neutralization Investigations

ADDITIONAL GUIDANCE

Have weighing stations set up with enough NaOH and $\text{H}_2\text{C}_2\text{O}_4$ so that each group can measure out 1 gram of each. If you have more than 2 digital scales, consider having multiple weighing stations for each substance.

Agree on a mass ratio to test. Keep slide N displayed. Say, *We said we need twice as much base as acid for either of these to neutralize completely and we said the second equation is one that represents two solids we could easily work with when we measure. How can we measure to be sure we have the right amount of each?* Students will likely suggest measuring out twice the mass of NaOH.

Evaluate, and if needed, modify the procedure. Display slide O and distribute *Neutralization Investigation #1*. Ask students if they want to add anything from the discussion to the procedure.

ALTERNATE ACTIVITY

Students may, for example, suggest trying other 2:1 mass ratios. If so, modifying the procedure to include doubling the mass used for both reactants, or halving the mass used for both, are two suggested conditions for different groups to test.

Review safety information. Explain the safety guidelines on slide P before students begin. Remind students that acids and bases can cause burns to skin and eyes. Ensure that all students are wearing proper protective equipment before they collect any lab materials.

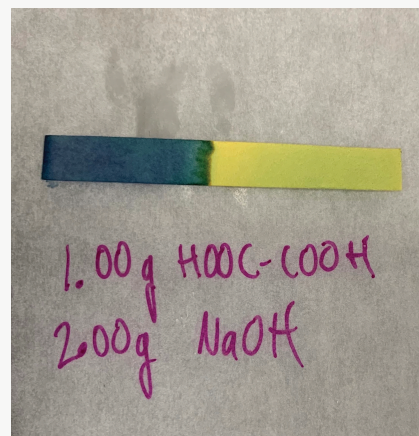


Display slide Q. Give students time to complete the procedure for question 1 of *Neutralization Investigation #1* in their groups. Check to make sure that students' plans include:

- measuring out 1 g of $\text{H}_2\text{C}_2\text{O}_4$ (or masses in that ratio) and dissolving it in distilled water as a first step;
- using a universal pH strip to check the pH of the oxalic acid solution before adding a base;
- adding twice as much NaOH to the solution;
- checking the pH of the solution again.

As students are carrying out their investigation, they should observe that instead of neutral, the final solution is very basic. Remind students that after measuring the final pH of their solution, they should complete questions 2–3 on *Neutralization Investigation #1*.

After students have had time to think and write, ask them to share their ideas for question 3 and come to a class consensus. Students should then record the class consensus on question 4 of *Neutralization Investigation #1*.



* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

A Building Understandings Discussion is a useful kind of discussion following an investigation because the purpose is to focus students on drawing conclusions based on evidence. Your role during the discussion is to invite students to share conclusions and claims and push them to support these claims with evidence. Students can disagree with each other, and the class does not need to reach consensus on all ideas shared. Areas of disagreement can motivate future investigations. Helpful prompts during these kinds of discussions include:

- *What can we conclude?*
- *How did you arrive at that conclusion?*
- *What is your evidence?*
- *Does any group have evidence to support Group A's claim?*
- *What data do we have that challenge Group B's claim?*

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

Emphasize to students that they will use *models for a purpose*. Models are dynamic and can change as new information is learned, and models need to be “applied” to be useful. Explain that the balanced chemical equation and what coefficients mean is a model for chemical reactions to show that matter is conserved. Highlight that this is an example to show us that models are not used to describe something, but rather they are used to develop an explanation. Avoid asking students to simply repeat back an element of a model or even an entire model as an inert “fact.” (SEP: 2.2)

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: on *Neutralization Investigation #1*:

- Question 1: A **planned investigation** with a question (a), a procedure (c), and safety equipment use (d). (SEP: 2.2)
- Question 1(b): Student thinking includes **proportional reasoning** about **ratios of amounts** (this should not be in moles yet; it is logical to keep students working with masses to allow the test to fail, which will motivate looking at moles). (CCC: 3.1)
- Question 1(e): A prediction referencing one or more **matter interaction ideas at a particle level, related to the balanced equation**. (DCI: PS1.B.3) This could include:
 - The amount of each type of atom cannot change in the reaction.
 - This represents the relative amount of particles needed to neutralize the excess H^+ ions.
 - This represents the formation of one water molecule for every excess H^+ ion that associates with an added OH^- ion.
- Question 2: Students **describe observations of a failure point in the system design** or other qualitative and quantitative data they gathered. (SEP: 3.6)
- Question 3: Accept all answers; students share initial ideas for how to account for the discrepant results.

What to do: If student's investigation plans are missing key steps, ask clarifying questions and prompt them to revise the plan. Support student's mathematical thinking by ensuring that they are providing units of measurement.

Building toward 8.A.1 Plan and carry out an investigation of a **neutralization reaction** by predicting and manipulating the amounts **using mass and mole proportions** and **collecting data** to identify failure points to improve the reaction outcome. (SEP: 2.2, 3.6; DCI: PS1.B.3; CCC: 3.1)

SAFETY PRECAUTIONS

Students will have to measure out and use NaOH, which is a very strong base. All students must wear safety goggles, nitrile gloves, and a non-latex chemical apron. Be sure to review the safety guidelines on **slide P**.



Discuss the discrepant results. Display **slide R**. Ask students what ideas they have to explain their unexpected results. Facilitate a Building Understandings Discussion using the prompts below to help students realize that the 2:1 ratio must not be a mass ratio.*

Suggested prompt

What was the final pH of the solution after adding the base? Did we neutralize the acid?

Sample student response

The final pH was high, way above 7.

The final pH was very basic.

We did not neutralize the acid. We went way past neutral.

Suggested prompt	Sample student response
<i>What might these results tell us about the amount of each substance we used?</i> <i>What might these results tell us about what the coefficients in the chemical equation mean (and do not mean)? *</i>	We must have used too much base. If the pH was that high, there was more base than acid. Maybe using masses was not the right idea. We said it might be molecules earlier. Maybe that is the right idea.
ASSESSMENT OPPORTUNITY	What to look/listen for in the moment: Students describe observations of a failure point in the system design or other qualitative and quantitative data they gathered. (SEP: 3.6) What to do: If students do not immediately see a problem with the pH, ask them what pH a neutral substance should have and what color the pH paper should be. Help them reason through why the pH would be so high: <i>Which substance must we have used too much of?</i> Also see the Strategies for this Building Understandings Discussion for additional support. Building toward 8.A.2 Plan and carry out an investigation of a neutralization reaction by predicting and manipulating the amounts using mass and mole proportions and collecting data to identify failure points to improve the reaction outcome. (SEP: 2.2, 3.6; DCI: PS1.B.3; CCC: 3.1)
ASSESSMENT OPPORTUNITY	What to look/listen for in the moment: - Students identify that the coefficients in a balanced chemical equation must not represent mass ratios, but instead represent particle-number ratios. (DCI: PS1.B.3; CCC: 3.4) - Students use a mathematical model to measure or count molecules, even though we cannot see them, when we measure out a certain amount of a substance. (SEP: 5.2; CCC: 3.4) What to do: If students are struggling with what to do next, have them think back to when they balanced the equations, what each card represented, and what they were accounting for when they added coefficients. Ask students if this model makes sense in terms of what they did when they balanced the equations; they should see that it does. Building toward 8.B.1 Use a mathematical model of molecules in a chemical reaction and macro-scale evidence to determine what is happening at the particle level. (SEP: 5.2; DCI: PS1.B.3; CCC: 3.4)
Ask, <i>How might we use the coefficients to help us figure out how much of a substance to use when we are trying to neutralize an acid?</i> Accept all student responses.	

End of day 1

6 · NAVIGATE

5 min

MATERIALS: science notebook

Navigate. Display slide S. Discuss the related question on the slide and follow up with the second question below.

Suggested prompt	Sample student response
<i>What did we decide the coefficients in a balanced chemical equation must represent?</i>	They don't represent mass ratios. We think they may represent the numbers of molecules.
<i>What ideas do we have for how we can count or measure molecules?</i>	Something with the periodic table maybe? We cannot count molecules; they are too small to see. In an earlier lesson, we saw that moles are one way to simplify how we keep track of a large number of molecules. Maybe those could help us here.

7 · THINK ABOUT RATIOS IN WATER

5 min

MATERIALS: Periodic Table

Think about ratios in a water reaction. Suggest that to help us think through how to count molecules in reactions, it could be helpful to visualize the number of particles involved at different scales. Say, *Let's try that first with an even simpler reaction.* Display slide T.

Suggested prompt	Sample student response
<i>Is this equation balanced?</i>	No.
<i>What do we need to do to ensure we are accounting for conservation of mass?</i>	We need to balance the equation.

Have students quickly balance the equation for the decomposition of water.

Display slide U.

Suggested prompt	Sample student response
<i>Do you think that we will end up with twice as many grams of hydrogen compared to oxygen?</i>	I don't think so because that isn't what happened in our neutralization investigation.

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

Because *atoms and molecules are too small to directly see or measure*, students need a way to *quantify large numbers of molecules* at once. The mole allows students to do this, and molar mass allows students to calculate the relative number of particles in a given mass or the mass of a substance needed to react with a given quantity of another substance. (CCC: 3.4)

Suggested prompt	Sample student response
<i>What tool have we used in the past that allows us to determine the mass of elements?</i>	The periodic table.
Distribute <i>Periodic Table</i> to students and have them use it to look up hydrogen and oxygen on the periodic table. They should see that hydrogen has a much smaller mass than oxygen, and even twice the amount of hydrogen gas will have a much smaller mass than oxygen gas.*	
Suggested prompt	Sample student response
<i>Do we think the hydrogen here has twice the mass of the oxygen?</i>	There are twice as many hydrogen molecules, but hydrogen is lighter than oxygen. Hydrogen will not weigh twice as much as the oxygen.
<i>We know the masses from the periodic table, but how can we use this information to help us determine how much of a substance we need to neutralize an acid?</i>	Maybe it will help us figure out how much will react? Maybe it will tell us how much we need to combine.
Ask students what ideas they have for how we can use the atomic masses to “count” a measurable number of particles in something like a gram of that substance. Suggest using something larger but still small, like paper clips, as a way to help us visualize and think about how we can “count” large numbers of small things.	

8 • INVESTIGATE HOW TO “COUNT” SMALL THINGS

10 min

MATERIALS: science notebook, calculator, ~225 g paper clips, digital scale, plastic bag (sealable)

“Count” the paper clips in a large bag. Suggest that it can be challenging to think about how to count molecules because they are too small for us to see, and that it might help if we first thought about counting something small but still visible. Ask students for a few examples of objects that are very small but still visible, or that are too numerous to easily count.

Display **slide V**. Show students a large resealable bag full of paper clips. Ask students how many paper clips they think are inside. Then ask students how we could determine the number of paper clips without taking the time to count every one. Facilitate a discussion of different strategies we could use--finding dimensions of the bag and paper clips, weighing the whole bag of paper clips and the empty bag, or other ideas--and ask students which one(s) seems the simplest and/or quickest.

Display **slide W**. As a class, weigh one paper clip, record its mass on the slide or somewhere else where the class can see, then weigh the entire bag of paper clips. Students may realize they also need to account for the mass of the bag; if they do not, ask them about this. Weigh the bag by itself, then have students subtract the bag's mass from the total mass. Have students record these measurements in their notebooks and then complete the calculation of the number of paper clips in the bag, independently or in pairs. Then ask a few students to share their answers and ensure the class agrees on the number of paper clips in the bag.

Slide Q

Consider Paper Clips



Mass of 1 paper clip: 1.00 g
Mass of bag: 2.16 g
Mass of bag + paper clips: 252.19 g
Take a moment to calculate the number of paper clips, and be prepared to share your answer!



9 · DETERMINE MASS OF OTHER SMALL OBJECTS

5 min

MATERIALS: staples, digital scale, plastic bag (sealable)

Students determine the mass of the same quantity of a different small object. Now show students another bag with the same number of another object of a different mass--staples, larger paper clips, push pins, etc. Display **slide X**. Ask students, *If this bag contains the same number of staples (for example) as the other bag had paper clips, do we think it has the same total mass?* Help students think through the calculation they just performed--dividing the total mass by the mass of one object to get the total number of objects.

Then ask students to list what information we have or can easily get for the staples. Students should suggest that we need to know:

- how many staples, and
- the total mass of the staples.

Ask students, *Would that allow us to determine the mass of one staple?* Have students measure the bag and do the calculation, then discuss if the answer students got makes sense. The two bags contain the same number of objects but have different masses. Ask students why that is, and make sure the class agrees that the masses are different because the individual objects (paper clip and staple) have different masses. Use the suggested prompts below to facilitate that discussion.

Suggested prompt	Sample student response
<i>Would the bag of staples weigh the same as the bag of paper clips?</i>	No, the paper clips will weigh more.
<i>Why do we not expect the two bags to have the same mass?</i>	One staple is smaller than one paper clip, so it will probably have a smaller mass. The staples have lower masses, so the bag of staples will have a lower mass.
<i>Do you think we could use a similar strategy to “count” and compare the number of atoms or molecules found in a certain amount of mass for any two substances?</i>	Yes. If we know the mass of a molecule and the total mass, we can calculate how many molecules there are.

10 · APPLY THIS IDEA TO ATOMS

10 min

MATERIALS: *Periodic Table*, science notebook

Students apply the counting-by-weighting idea to molecules. Direct students back to the equation for the decomposition of water with particle models. Display *slide Y*. Ask students, *Do we know how much a single hydrogen atom and a single oxygen atom weigh?* Have students look up the atomic masses for hydrogen and oxygen on *Periodic Table*.

Say, *We know that the atomic mass of hydrogen is 1.01. What is the mass of a hydrogen molecule, H_2 ?* Students should calculate 2.02.

Repeat with oxygen by having students use the periodic table to calculate the mass of O_2 --32. Tell students, *This is the mass of one molecule, in amu. This is far too small for us to see or count or measure.*

Facilitate a discussion to help students think about how they might use atomic mass to figure out how many molecules are present in a sample. Use prompts such as:

- *How might we scale this up?*
- *How can we use grams to make sure we have the same number of hydrogen and oxygen molecules?*

11 · REINTRODUCE THE MOLE

10 min

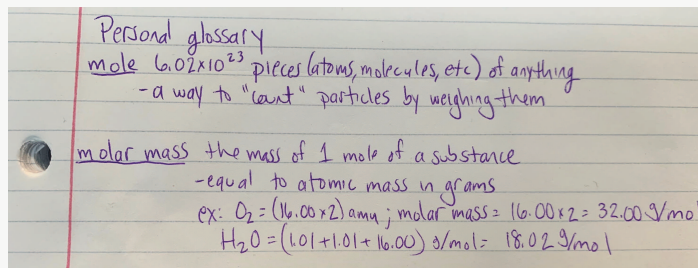
MATERIALS: *Periodic Table*, science notebook, calculator

Relate atomic mass to molar mass and reintroduce moles. Tell students, *We know from the periodic table that the mass ratio of oxygen to hydrogen is 32 to 2 or 16 to 1. As long as we have the same number of particles of each molecule, we should always have the same mass ratio of 16 to 1. Scientists have a way to use this to “count” and keep track of the very large numbers of particles found in just a few grams of any substance. It is called the mole.*

Ask students to refer to their Personal Glossaries to recall how many particles are in 1 mole. When they are ready, have them share out. They should say that 1 mole is equal to about 6×10^{23} particles of a substance.

Briefly describe how the unit was derived. Say something like, *A scientist named Avogadro figured out a way to compare equal numbers of particles in different substances by comparing equal volumes of gas at the same temperature and pressure. He found that they contain the same number of particles. This gave other scientists a way to compare relative masses of all substances, because they now had a way to ensure they were comparing the same number of particles under these conditions.*

Display *slide Z*. Say, *From this, other scientists eventually figured out that an amount equal to a substance's atomic mass in grams contains 6.02×10^{23} particles of that substance. We call this amount a **mole**. One mole of any substance always contains 6.02×10^{23} particles, and its **molar mass** is its atomic mass in grams per mole.*



* SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Unit conversions, especially with moles, are not intuitive for many students. Students may want to work together on these calculations, and they may need to see an extra example or use scaffolds. It is important to emphasize that the *conversion factors* students are using, such as g/mol , are really *equivalent ratios* to get to a unit they can measure. (SEP: 5.5)

Suggested prompt	Sample student response
<i>Let's use this to think about molar mass. One hydrogen atom has a mass of 1.01 amu. One mole of hydrogen atoms would simply be that same number but with a unit of grams associated with it. So what is the molar mass, or the mass of 1 mole, of helium?</i>	Helium is 4.00 grams per mole.
<i>What is the molar mass of carbon?</i>	Carbon is 12.01 grams per mole.

ADDITIONAL GUIDANCE

The mole concept was introduced in Lesson 4. A mole is not intuitive for many students. If they are struggling with the idea of a term to represent a large quantity, give them the examples of a dozen or a century, then ask them to think about how many donuts are in a dozen, how many eggs, etc. Emphasize that a dozen is *always* 12 things, and likewise a mole is *always* 6.02×10^{23} things. Like a dozen, a mole provides a shortcut to counting and comparing large numbers of particles.

Molar mass can also be challenging, and using the example of a dozen can help here too. Ask students to think about a dozen Ping-Pong balls and a dozen bowling balls (or choose any objects with a small mass and a large mass). Ask if they would weigh the same (the obvious answer being no). Explain that the same number of two objects can have very different masses if one object has a greater mass than the other.

Update Personal Glossaries. Display **slide AA**. Have students pause now to update their Personal Glossaries with a more exact value and definition for 1 mole, and a definition for *molar mass*.

Convert from moles to mass. Display **slide BB**. Ask students, *If we know the mass of one mole, what is the mass of two moles of O_2 ?* Tell students to think back to *Polar Ice Unit* when they used unit conversion to complete calculations about polar ice melt and energy transfer. Help students think through how to use the molar mass ($1 \text{ mol} = 32.00 \text{ g}$) as their conversion factor and set up the calculation so that mole units cancel and their final answer is 64 grams. Tell them we can use the same idea of unit conversion to convert between mass and moles.

Use mole ratios in a calculation. Display **slide CC**. Tell students, *We know that the ratio of coefficients refers to particles, not mass. We cannot count individual particles, but we know that a mole of anything is the same number of particles, so we can also call the ratio of coefficients a **mole ratio**. Let's use this mole ratio and unit conversion to figure out how much mass of hydrogen is produced in the water decomposition reaction.* * Give students time to work through the calculation in pairs, and help them reason through how to set up the calculation and what numbers and units need to go where to end up with moles of H_2 and then grams of H_2 . After students complete the calculation, have them add *mole ratio* to their Personal Glossaries. You may wish to tell students that the use of mole ratios to solve problems is called *stoichiometry*. If students struggle to set up and complete the calculation, use the prompts below.

Suggested prompt	Sample student response	Follow-up questions
<i>What is our starting amount?</i>	2 moles H_2O .	<i>So we put that first. What goes under that?</i>
<i>Before we can get GRAMS of H_2 we need MOLES of H_2. How do we get that?</i>	From the coefficients in the equation.	<i>Great! And what is the mole ratio of H_2 to H_2O in the equation?</i>

Display **slide DD**. Emphasize that while this slide looks similar to the previous slide, the way the unit conversion is set up is incorrect and will not yield a valid result. Give students a minute to study this on their own to prepare to share their ideas with the class. When students share, establish consensus that the problem is in how the second conversion factor (in pink) is set up (the numerator and denominator are flipped), which will not allow the mole units to cancel.

ADDITIONAL GUIDANCE

When dealing with atomic masses and molar masses, rounding to the hundredths place is a good general rule to use with students so that everyone is completing the calculations the same way. The provided periodic table rounds atomic masses to the hundredths, so all calculations of molar mass should be rounded to the hundredths. Remind students to do the same for other related calculations.

 **Convert from mass to moles and moles to mass.** Display slide EE. Tell students, *Now let's try a similar calculation, but let's add a step. In the lab, when we are calculating how much of a substance we end up with given a starting amount, we measure that starting amount in grams. So let's start there, with 10.00 grams of water, and perform the same calculations to figure out how many grams of hydrogen will be produced. Pay attention to something important here—the order in which the conversion factors are listed are different from how they are arranged in the equation. The color coding indicates how you can set up the multiplication in this example. Again, help students reason through how to set up the calculation in order to end up with grams of hydrogen.*

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use a **molar mass ratio** and **coefficients** from a **balanced chemical equation** to **predict amounts of various substances** formed as a **result of the chemical reaction**. (SEP: 5.5; DCI: PS1.B.3)
- Students identify that the **proportional relationships** of **molar mass and coefficients** in a chemical equation can be **used to determine relative amounts of substances** needed for or produced by a **chemical reaction**. (SEP: 5.5; CCC: 3.1)

What to do: Students will complete a similar calculation on day 3 to determine how much NaOH to combine with $\text{H}_2\text{C}_2\text{O}_4$ to neutralize the acid. This calculation on day 2 with H_2O and H_2 can be another formative assessment opportunity, but if students struggle or you feel they have not mastered the concept yet, know that there is another opportunity for them to try this next class.

Building toward 8.C.1 Use **proportions of different scales (ratios)** to **move between masses and numbers of particles** that represent **conservation of matter in a chemical reaction**. (SEP: 5.5; DCI: PS1.B.3; CCC: 3.1)

End of day 2

12 · NAVIGATE

5 min

MATERIALS: None

Navigate. Tell students, *Let's recall what we figured out yesterday and think about how this can help us with our neutralization reaction.* Display slide FF and have students discuss the questions in pairs. After students have had time to discuss with a partner, ask for volunteers to share their ideas. If students do not recall that they can use coefficients and molar mass to calculate an exact mass that will react or be produced, have them review the calculations from the previous class and ask them to explain what they did to figure out how much water would be produced.

Suggested prompt

What did we figure out about moles and how to “count” molecules?

Sample student response

A mole is 6.02×10^{23} particles.

A mole of anything is the same number of things.

Suggested prompt	Sample student response
<i>What did we figure out about how to calculate molar mass?</i>	Molar mass is the mass of one mole of something. Molar mass of an element is its atomic mass in grams. We can find the molar mass of a compound by adding up the molar masses of all the elements in the compound.
<i>What did we decide coefficients in chemical equations represent?</i>	The coefficients tell us the ratio of molecules. The coefficients tell us the ratio of moles.
<i>How can these ideas of moles, molar mass, and molar ratios help us with our neutralization reaction?</i>	We can use molar mass to figure out how much base we need to neutralize the acid. The coefficients in the equation tell us how many moles react, and we can use molar mass to figure out how many grams that is.

13 · CALCULATE MOLAR MASS

15 min

MATERIALS: *Neutralization Investigation #2*, *Periodic Table*, calculator



Practice calculating molar mass. Distribute *Neutralization Investigation #2*. Ask for a volunteer to remind the class how they calculated molar mass. Display **slide GG**. Have a discussion about why we need the molar mass of these substances and what we are trying to figure out by doing these calculations. Give students a few minutes to use *Periodic Table* to calculate the molar masses of NaOH and $\text{H}_2\text{C}_2\text{O}_4$ on questions one and two of *Neutralization Investigation #2*. Have students share their answers and ask other students to confirm that they got the same results. If there is disagreement or confusion, it may help to have students with the correct answers show their work to the class on a whiteboard and explain their process. Then use the prompts below to help students think through how to use the molar masses to figure out how much NaOH is needed to neutralize $\text{H}_2\text{C}_2\text{O}_4$.

Suggested prompt	Sample student response
<i>Someone remind us--why are we doing these calculations for sodium hydroxide and oxalic acid again?</i>	We are trying to figure out how to neutralize an acid. We are trying to figure out how much sodium hydroxide is needed to neutralize oxalic acid.
<i>If we know how many moles of acid we have, can we figure out how many moles of base would neutralize it?</i>	We can use the molar mass to convert from grams to moles.

Calculate masses needed for neutralization. Display **slide HH**. Refer students back to the balanced neutralization equation and the ratio of acid to base needed for neutralization. Say, *The ratio of coefficients in the chemical equation tells us the mole ratio of the reactants. So, we know that NaOH and $\text{H}_2\text{C}_2\text{O}_4$ react in a 2:1 ratio. Let's use this mole ratio to figure out how much mass of each substance we need for this reaction. If we*

start with 1 gram of acid like before, how much NaOH do we actually need? Help students with the order of the calculations--first they convert the mass of $\text{H}_2\text{C}_2\text{O}_4$ to moles, then they determine the moles of NaOH needed according to the balanced equation, and finally they convert that number of moles of NaOH to grams. Students should complete this calculation on question three of *Neutralization Investigation #2*.

After students have completed the calculation, ask, *If we know we are starting with one gram of oxalic acid, how do we use that to figure out how much base we need? What calculations do we need to do?* Look for students to suggest:

- We need to calculate how many moles one gram is.
- We know sodium hydroxide and oxalic acid react 2:1, so if we know moles of acid, we know we need twice that many moles of sodium hydroxide.
- Once we know moles of NaOH we can convert to grams.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students use a molar mass ratio and coefficients from a balanced chemical equation to predict amounts of various substances formed as a result of the chemical reaction. (SEP: 5.5; DCI: PS1.B.3)
- Students identify that the proportional relationships of molar mass and coefficients in a chemical equation can be used to determine relative amounts of substances needed for or produced by a chemical reaction. (SEP: 5.5; CCC: 3.1)
- See *Neutralization Investigation #2 Key*.

What to do: If students struggle to set up and complete the calculations, it may be helpful to have them talk through what they are trying to find and the steps needed to get there. Remind students that they already decided that coefficients do not represent mass but moles, and that they now know how to find the mass of a mole of a substance.

Building toward 8.C.2 Use proportions of different scales (ratios) to move between masses and numbers of particles that represent conservation of matter in a chemical reaction. (SEP: 5.5; DCI: PS1.B.3; CCC: 3.1)

14 · RETRY THE NEUTRALIZATION REACTION

15 min

MATERIALS: Neutralization Investigations

ADDITIONAL GUIDANCE

Have weighing stations set up with enough NaOH and $\text{H}_2\text{C}_2\text{O}_4$ so that each group can measure out 1 gram of each. If you have more than 2 digital scales, consider having multiple weighing stations for each substance.

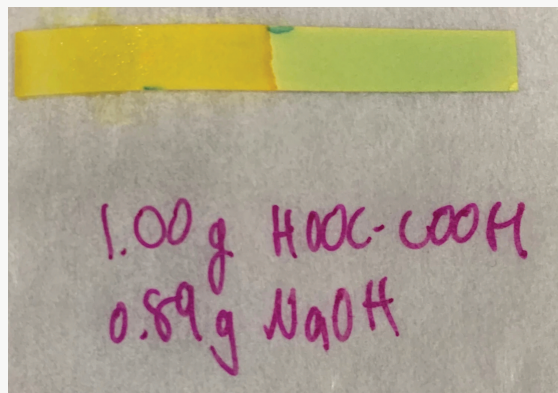


Discuss procedure for the second neutralization reaction. Ask students what they think they need to change about the procedure from day 1. Students should tell you they need a different mass of NaOH, but otherwise will likely keep the rest of the procedure the same. Display *slide II* and ask students if there is anything they would like to change. If so, agree on changes to the procedure and have students document their revised procedure in question 4 of *Neutralization Investigation #2*.

Have students revisit *Neutralization Investigation #1* to ensure they are documenting a procedure plan that follows a similar order of steps, to ensure a safe outcome. As students prepare to do this, display *slide JJ* as a safety reference.

Then have students repeat the neutralization reaction with the revised mass. The solution may not reach an exactly neutral pH, but it should get much closer, and students should see that they are on the right track with this method.

After students clean up, cue them to complete questions 5-6 on *Neutralization Investigation #2*.



ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: on *Neutralization Investigation #2*: Question 4: Students' investigation procedure identifies the amounts of substances used. (SEP: 2.2; CCC: 3.1)

What to do: If student's investigation plans are missing key steps, ask clarifying questions and prompt them to revise the plan.

Building toward 8.A.3 Plan and carry out an investigation of a neutralization reaction by predicting and manipulating the amounts of reactants using mass and mole proportions and collecting data to identify failure points to improve the reaction outcome. (SEP: 2.2, 3.6; DCI: PS1.B.3; CCC: 3.1)



Discuss Neutralization Investigation #2 results. Display slide KK.

ADDITIONAL GUIDANCE

Students should get a final pH close to neutral, but it may not be exactly neutral. If students do not get a neutral pH, this is a good time to discuss possible sources of error in their investigation. Students may bring up that oxalic acid is a weak acid, which they saw in the previous lesson. If so, ask what they remember about how weak acids behave--for example, that weak acids do not completely dissociate or ionize in solution the way strong acids do.

Suggested prompt

Sample student response

What was the final pH?

The final pH is about 7 (neutral).

Was your group successful in neutralizing the acid?

Yes.

What are some possible sources of error in your investigation?

We could have mismeasured the mass of the acid or base.

We could have spilled a little bit of acid or base after we measured it.

Do your results indicate that using molar mass ratios allows us to determine how much of a substance to use in a chemical reaction? Why or why not?

Accept all responses.

After discussing results as a class, have students answer question 7 on *Neutralization Investigation #2*.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: on *Neutralization Investigation #2*: Question 6: Students identify that the *investigation results indicate* that using *molar mass proportions* is *successful*. (SEP: 2.2; CCC: 3.1)

What to do: If students are unconvinced that using mole ratios and molar mass to determine the mass of NaOH was the correct strategy, have them compare the final pHs from the two Neutralization Investigations. It may also be helpful to have a brief discussion about weak acids and reversible reactions and how that may be impacting the final pH of the reaction. One other option might be to suggest trying the test again together as a class using a larger quantity of base and acid (10 times more of each), if you have sufficient supplies for this.

Building toward 8.A.4 Plan and carry out an investigation of a *neutralization reaction* by predicting and manipulating the amounts of reactants *using mass and mole proportions* and collecting data to identify failure points to improve the reaction outcome. (SEP: 2.2, 3.6; DCI: PS1.B.3; CCC: 3.1)

15 · UPDATE PROGRESS TRACKERS

5 min

MATERIALS: *Progress Tracker*

Add new information to a new row of our trackers. Display slide LL. Possible ideas students add to their *Progress Tracker* are found in *Progress Tracker Key* in Lesson 12.

16 · NAVIGATE

5 min

MATERIALS: None

Discuss how we can use what we have learned today. Display slide MM. Cue students to think about how we can apply our new knowledge next class to helping the oysters. Give students a few minutes to discuss the prompt with a partner, then ask for volunteers to share what they discussed with their partners.

Additional Lesson 8 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HSN.Q.A.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

Students need to be able to calculate molar mass to determine the mass of equivalent amounts (moles) of molecules. And because students are not able to count or measure a specific number of molecules, they need to be able to convert from moles to grams using molar mass.

LESSON 9: How much NaOH would we need to add to make ocean water safe for oysters?

PREVIOUS LESSON We modeled acid-base neutralization and argued that the ratios in balanced chemical equations are mass ratios. We tested this model and figured out that these are particle-number ratios rather than mass ratios. We applied a mathematical model using these ratios and molar masses to predict the amount of base needed to neutralize an acid and carried out a second investigation to test this.

THIS LESSON

INVESTIGATION

2 days



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We use pH to determine current and ideal H^+ concentrations at an oyster hatchery and calculate the number of moles of H^+ that must be neutralized to bring pH to safe levels for baby oysters. We calculate the moles and mass of NaOH needed to neutralize that amount of H^+ . Then we scale up those calculations to determine the amount of NaOH that would be needed for the whole ocean. We wonder whether this solution would be feasible, effective, or safe for other organisms.

NEXT LESSON We will investigate how different pH levels affect oyster shells by dissolving limestone in vinegar and in ocean water. We will also read about how oysters build their shells and model how decreasing pH affects this process at the particle level.

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-1,
HS-ETS1-2



WHAT STUDENTS WILL DO

9.A. Use a mathematical model to calculate the amounts of reactants for desired products, assuming conservation of matter, across scales from molecular to lab-measurable quantities. (SEP: 5.5; DCI: PS1.B.3; CCC: 3.1)

WHAT STUDENTS WILL 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.

Lesson 9 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Help students recall what they figured out last class about mass and moles and think about how to apply this knowledge to develop solutions to help oysters.	A	
2	5 min		EVALUATE A PLAN Identify how testing the water in a smaller-scale system (tanks in oyster hatcheries) could help us evaluate that solution for a larger-scale system (the ocean).	B	
3	35 min		CALCULATE AMOUNT OF BASE NEEDED TO NEUTRALIZE OCEAN WATER Have students work with a partner to complete <i>Ocean Water Calculations</i> . Lead class discussions at certain points to provide space for partners to share the approaches they used to solve the questions on the handout.	C-I	<i>Ocean Water Calculations</i> , calculator
<i>End of day 1</i>					
4	5 min		NAVIGATE Navigate into another use of the mathematical model by helping students articulate how it could be applied to adjust the pH of the entire ocean.	J	<i>Ocean Water Calculations</i>
5	15 min		CALCULATE BASE NEEDED TO ADJUST pH OF OCEAN Have students calculate the mass of NaOH that would be needed to raise the pH of the ocean from 7.8 to 8.2.	K	<i>Ocean Water Calculations</i> , calculator
6	5 min		UPDATE PROGRESS TRACKERS Give students time to summarize what they have figured out in their Progress Trackers.	L	<i>Progress Tracker</i>
7	8 min		COMPLETE AN ELECTRONIC EXIT TICKET Have students complete an Electronic Exit Ticket.	M	Link to class copy of the Electronic Exit Ticket, computer with internet access
8	9 min		CONSIDER THE SCALE OF THIS SOLUTION Have students use a conversion factor (the mass of 1 large car) to determine how many car-sized loads of NaOH would be needed for the ocean and discuss what this tells us about the scale of matter required for this approach.	N-O	calculator
9	3 min		NAVIGATE Lead a discussion that prompts students to decide that they need to focus on the ocean system.	P	<i>Stoichiometry Practice</i> (optional)
<i>End of day 2</i>					

Lesson 9 • Materials List

	per student	per group	per class
Lesson materials	• <i>Ocean Water Calculations</i> • science notebook • calculator • <i>Progress Tracker</i> • Link to class copy of the Electronic Exit Ticket • computer with internet access • <i>Stoichiometry Practice</i> (optional)		

Materials preparation (20 minutes)

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

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

Three-hole-punch all handouts so they can be added to student’s notebooks.

Create the Electronic Exit Ticket for this lesson using the directions found on *Electronic Exit Ticket* from Lesson 4.

Lesson 9 • Where We Are Going and NOT Going

Where We Are Going

The targeted disciplinary core idea that we are beginning to develop is:

- **PS1.B.3: Chemical Reactions.** The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.

Crosscut Explanation: The primary concern of this lesson is stoichiometry, which relies on balanced chemical equations. Other lessons in this unit address the rest of this DCI, especially where students account for the differences in the degree to which different acids and bases will dissociate.

This lesson focuses on applying what students determined about mole ratios and molar mass to figure out how to raise the pH of water within the oyster tank. Students use mole ratios and molar mass to calculate the amount of base that would need to be added to oyster hatchery tanks to return the pH to safe levels. This is one step toward helping students use stoichiometry to define engineering problems and develop solutions in Lesson Set 3 (**PS1.B.3**; **CCC: 3.1**).

This lesson comprises several opportunities for students to practice with stoichiometry, unit conversions, and applying contextual information in the pursuit of predicting chemical reactions. Because these are complex, multi-step mathematical calculations, this lesson provides ample opportunities for support and practice (**SEP: 5.5**; **CCC: 3.1**).

On day 1, students work with a partner in a more scaffolded way to practice with *Ocean Water Calculations* by calculating how much base would need to be added to a small oyster hatchery operation with only 1000 L of water (**DCI: PS1.B.3**).

On day 2, students can choose to work with a partner or to work alone, with or without the scaffolds from the prior day, as they scale up the calculation of the amount of NaOH that would be needed to neutralize the excess hydrogen ions in the ocean (**SEP: 5.5**; **DCI: PS1.B.3**; **CCC: 3.1**).

Students demonstrate their understanding on an Electronic Exit Ticket and relate their bigger-picture thinking on their Progress Tracker.

Where We Are NOT Going

Although students are calculating pH change using a strong base and a weak acid, they will not be using the concepts of equilibrium constants and equivalence points, as those are outside the scope of the PEs. Students also are not focusing on the distinction between strong and weak acids and bases in this lesson, only the stoichiometric ratios from balanced chemical equations. Finally, this lesson does not push students to think about gas stoichiometry, as this lies outside the bounds of the NGSS.

LEARNING PLAN for LESSON 9

1 · NAVIGATE

5 min

MATERIALS: None

Discuss what we figured out last class. Display **slide A**. Have students share what they figured out in Lesson 8. Ask them to list the important ideas, such as what the coefficients in balanced equations mean, how we can “count” particles, and any other tools we can use to help oysters. Students should recall:

- When we balance chemical equations with coefficients, we show the mole ratios of atoms or molecules that are reacting with each other.
- We can use the atomic masses on the periodic table to determine the mass of one mole of a substance.
- One mole of anything is the same number of particles or objects.
- We can use molar mass and mole ratios to calculate an exact amount of base to use to neutralize an acid.

If one or more of these ideas are not brought up, you can prompt students with these questions:

- *What did balancing chemical equations show us?*
- *How did thinking about what a mole is help us?*
- *What information did the periodic table provide us that we needed?*
- *How can we use these ideas we figured out to help oysters?*

2 · EVALUATE A PLAN

5 min

MATERIALS: None

Decide what to neutralize. Ask students if they think we should dump NaOH in the ocean and see what happens. Display **slide B**. After discussing possible benefits and downsides to dumping NaOH in the ocean, ask students if perhaps scaling down our solution might be a better place to start.

Suggested prompt	Sample student response
<i>Do we think we should try to dump NaOH into all of the world's oceans? Why?</i>	Dumping NaOH in the ocean would raise the pH, and that is what we want. It would probably take a lot of NaOH, and that may be really expensive. We do not know if NaOH would be harmful, so we should not dump it in the oceans.
<i>Why might this not work as planned?</i>	It could be harmful to plants or animals in the ocean. If the acid in the ocean comes from CO ₂ , would more CO ₂ just go in and make more acid?

Say, *Why might engineers or scientists want to test such an approach at a smaller scale first, before testing it in the ocean?* Accept all ideas.

Ask students for examples of smaller-scale systems one could use to test the outcomes of such an approach. Students may suggest one bay or tidal area, or the tanks at a hatchery. If students do not bring up the hatchery tanks, ask them how testing with something relatively small, like a single tank, could then be scaled up to a larger system. Listen for students to suggest that mathematical thinking could help us scale up the results of calculations.

3 · CALCULATE AMOUNT OF BASE NEEDED TO NEUTRALIZE OCEAN WATER

35 min

MATERIALS: *Ocean Water Calculations*, science notebook, calculator

Develop a plan. Display **slide C**. Ask students what information we need to bring the pH in an oyster tank back down to prior ocean pH levels and to explain how we can use that information. Give students time to write some ideas in their notebooks, then have students share what information they think they need. Possible responses include:

- the size or volume of the tank;
- the pH of the water, which tells us the H^+ concentration;
- the ideal pH of the water for oysters;
- the current and ideal pH levels to calculate how much we need it to change.

Compare ocean pH values. Display **slide D**, which contains some of the information students just specified.* This includes:

- the historical average pH of the ocean before the industrial revolution, 8.2, and the H^+ concentration that it corresponds to, 6.3×10^{-9} mol/L;
- the projected average ocean pH in 2100, 7.8, and the H^+ concentration that it corresponds to, 1.6×10^{-8} mol/L;
- the size of one tank at a hatchery, 1000 L.

ADDITIONAL GUIDANCE

The transition from **slide C** to **slide D** is a moment where students say what information they need to do an investigation and you then share it with them in response. There are many ways to present this kind of just-in-time information in storyline instruction so it positions students as evaluating what we need and whether the direction we are headed is in line with that. You can say, *I thought about this too and here's some information I thought could help us out.* Another approach is to ask students to critique the information immediately, saying, *Let's look at this table. Is something like this helpful?*

After students have had a moment to look at the pH values, direct their attention to the concentration units in the table on the handout. Say, *We have talked about concentration before, but it has been a few lessons since we have worked with these units related to molarity, in mol/L. Let's think about that unit. What is mol? What is L? So, what is M or molarity?* Students should recall that:

- Mol is a unit that stands for moles; it is a standard measure for a large quantity of particles (6.02×10^{23}).
- L is a unit that stands for liters; it is a standard measure for volume.
- Molarity is the ratio of moles to liters. It is the ratio of a number of particles to a certain volume.

It may be helpful to have students look back at earlier lessons to remind themselves of what these pH values mean in terms of relative acidity. Students may notice that the ocean's pH is not actually acidic and wonder why we are referring to acidification. Point out that decreasing pH means moving the pH closer to acidic levels and that the water is in fact getting *more* acidic. Then discuss what our target pH should be, using the prompt on the slide: *What pH should we aim for, and why?* Students will say things like:

- *No, the pH is already above neutral. And we need it to go higher.*
- *We just need to get the pH back to 8.2.*

* SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Mathematical thinking requires students to do more than “plug and chug” through decontextualized procedures. Students should also be able to compare and evaluate each others' ideas. Asking students to **share their mathematical thinking and practices** builds a culture of “figuring out” that regards math as a social, three-dimensional tool, as reflected in A Framework for K-12 Science Education: “mathematics and computation are fundamental tools for **recognizing, expressing, and applying** quantitative relationships” (2013, p.51). Avoid using stoichiometry as a rote, decontextualized mathematical task.

* SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Students will use *unit conversions to calculate the mass* of NaOH needed to neutralize a specific number of moles of H^+ . They also need to be able to use and understand the *mole ratio*, and that acidic hydrogen and basic hydroxide will combine 1:1 to form neutral water. The final calculated mass of NaOH will be very small. If students are confused by this result, reviewing scientific notation or encouraging students to convert scientific notation to standard notation should help them understand why. (SEP: 5.5)

ADDITIONAL GUIDANCE

For the ocean pH values, remind students that these are averages and may be different in different locations, which is why oysters are struggling more in some places than in others. The average pH is already lower than the historical pH, about 8.1. You can also tell students that in some areas the projected average pH by 2100 is even lower—7.7—and that such a low pH (7.7 or 7.8) is a problem for oysters everywhere. Hatcheries in some locations are already seeing pH values as low as 7.8. For more information or to explore pH projections, see <http://www.nnvl.noaa.gov/view/globaldata.html#ACID>.



Calculate moles of H⁺. Display slide E. Ask students, *If we know the molarity (mol/L) of H⁺ in the oyster tank from the pH, and we know the volume of the oyster tank, how can we calculate the amount (moles) of H⁺ at two different points in time?* Cue students to start discussing the questions on the slide as you distribute *Ocean Water Calculations*. They will work in pairs and check their work with their partners at each step of question 1.

Share calculations for question 1. After students complete the steps for time point #1, review. Ask a pair of partners to share their work with the class.* Then ask others to signal whether they used the same process. Try to keep the focus on the process for now, rather than “correctness.” One worked example of the final equation is shown:

$$\frac{1.6 \times 10^{-8} \text{ mol}}{1 \text{ L}} \times \frac{1000 \text{ L}}{1} = 1.6 \times 10^{-5} \text{ mol H}^+$$

When students have had an opportunity to clarify the process they used with their peers, move on to question 2. Using the same step-by-step supports, allow students time to work the questions with a partner. One worked example of the final equation is shown:

$$\frac{6.3 \times 10^{-9} \text{ mol}}{1 \text{ L}} \times \frac{1000 \text{ L}}{1} = 6.3 \times 10^{-6} \text{ mol H}^+$$

Reflect on what we have figured out and discuss what we need to do next. Display slide F. Give students a minute to think on their own about the two prompts on the slide and then share their ideas as a class.

Suggested prompt

What did we figure out on this page of our handout?

How can we use this to figure out the number of moles of excess H⁺ we will need to neutralize?

Sample student response

We know how many moles of H⁺ are in 1000 L of water at pH 8.2 and 7.8.

These represent the number of ions in that water at two different points in time.

Whatever there is at a pH of 7.8 that was not there at 8.2.

The difference between a pH of 7.8 and a pH of 8.2.

Calculate how much H⁺ to neutralize. Remind students that we only need to neutralize the excess H⁺. Students should see that they can find the difference in the two amounts of moles because the volume of the tank is constant.

Display slide G. Have students flip to the second page of *Ocean Water Calculations* and calculate the moles of excess H⁺ in question 3 (which they do by subtracting the final amounts in questions 1 and 2). This should take only a couple of minutes. Before they move on to questions 4 and 5, review with students what they have figured out and ask how we can raise the pH of the water in the tank.

The scaffolding for SEP5 has been reduced gradually in questions 4 and 5 of *Ocean Water Calculations* to support students in independent work. This scaffolding is reduced even further in question 6.

* ATTENDING TO EQUITY

Supporting Multilingual Learners

Students often benefit from a sentence starter in short writing exercises because it can orient them to the task of writing their ideas. Once the first idea is out, a second idea or more details can flow more easily. The basis of this cognitive science is rooted in *schema-setting*, whereby activating a base of knowledge and language can result in deeper thinking over time.

Suggested prompt	Sample student response
What did we figure out?	$1.6 \times 10^{-5} \text{ mol H}^+ - 6.3 \times 10^{-6} \text{ mol H}^+ = 9.7 \times 10^{-6} \text{ mol H}^+$ We just subtracted the two amounts to see how much “extra” there was.
How can we raise the pH of the water in the tank by the correct amount?	We can add NaOH or some other base to neutralize the excess H^+ .

Calculate the moles of hydroxide. Display [slide H](#). Ask students in what ratio hydroxide and hydrogen ions react to form neutral water. Students should recall that they react one to one: $\text{H}^+ + \text{OH}^- \rightarrow \text{H}_2\text{O}$. Have students use this ratio to individually calculate the amount of hydroxide ions needed to adjust the pH of the oyster tank, in question 4 of *Ocean Water Calculations*. Students should realize it is equal to the moles of excess H^+ that they calculated in the previous step.

$\frac{9.7 \times 10^{-6} \text{ mol H}^+ \times 1 \text{ mol OH}^-}{11 \text{ mol H}^+} = 9.7 \times 10^{-6} \text{ mol OH}^- = 9.7 \times 10^{-6} \text{ mol NaOH}$

Calculate the mass of sodium hydroxide needed. Remind students that we are getting the hydroxide from sodium hydroxide, so when we measure it we need to account for all of the atoms in the base molecule. Ask students how we got the molar mass of NaOH last class. Have them recalculate or find it in their notebooks and then use the molar mass of NaOH as the conversion factor to calculate the mass of NaOH needed for the neutralization reaction, in question 5 of *Ocean Water Calculations*.* Have students check their work with a partner as needed.

Summarize the day's work. Display [slide I](#). In their notebooks, students reflect on how they have been working to predict the amounts of reactants and products using stoichiometry as a tool. Say, *We have been doing a lot of steps and math to figure this out. Next time let's see how we might apply this approach to the entire ocean. To prepare for that, let's take a moment to summarize our process so we can be ready to apply it on a much larger scale tomorrow.* Provide the sentence starter: “The first thing to figure out is ____.”*

Collect *Ocean Water Calculations* to review and redistribute for the second day of this lesson.

ASSESSMENT OPPORTUNITY	What to look/listen for in the moment: See <i>Ocean Water Calculations Key</i>. What to do: If students are struggling with how to determine moles of OH^- or why they need to figure this out, have them revisit their work from Lesson 8. Students can refer back to the calculations they did in Lesson 8 to review how to use dimensional analysis as they complete the current calculations. Building toward 9.A.1 Use a mathematical model to calculate the amounts of reactants for desired products, assuming conservation of matter, across scales from molecular to lab-measurable quantities. (SEP: 5.5; DCI: PS1.B.3; CCC: 3.1)
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End of day 1

4 • NAVIGATE

5 min

MATERIALS: *Ocean Water Calculations*

Navigate. Display [slide J](#). Give students two minutes to turn and talk with a partner using the prompts on the slide. Ask partners to share an idea they heard with the whole class.*

Suggested prompts	Sample student responses	Follow-up questions
<i>How did unit conversions help us yesterday?</i>	We multiplied with them to figure out how to neutralize the acid in the tank.	<i>How did they help us determine quantities, ratios, or proportions needed in our system?</i>
<i>How can our mathematical model help us figure out what is needed for doing something similar in the entire ocean?</i>	We can figure out how much base to dump into it.	<i>What else would we need to know to figure that out?</i>

Redistribute *Ocean Water Calculations* to students. Emphasize that students are going to take the approaches they used yesterday and use them to figure out what we need to do something similar in the entire ocean.

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

The framing of the prompts foregrounds thinking about *scale, proportion and quantity*. Students have used conversion factors in prior units to support similar thinking, particularly in *OpenSciEd Unit C.1: How can we slow the flow of energy on Earth to protect vulnerable coastal communities? (Polar Ice Unit)*. Stoichiometry is just a new instance of this. If students are unfamiliar with the use of *scale and proportion*, remind them that to *scale up* means to grow or expand our system. Bigger systems result in more “stuff.” Stoichiometry helps us consider the series of *proportional relationships* we can use to figure out the process. (CCC: 3.4)

5 • CALCULATE BASE NEEDED TO ADJUST pH OF OCEAN

15 min

MATERIALS: *Ocean Water Calculations*, calculator

 **Students calculate the mass of NaOH needed for the whole ocean.** Display [slide K](#). Give students time to complete question 6 on *Ocean Water Calculations*. Students may consult a partner if needed; they will have an independent assessment later in the lesson.

As an optional support, you can have students share with the class to review how they completed each step of the calculation for the oyster tank. The discussion prompts below may be helpful for individual check-ins with students. The solution to the ocean neutralization calculation can be found in *Ocean Water Calculations Key*.

Suggested prompt	Sample student response
<i>Look back at your earlier work. How did we figure out the moles of H⁺?</i>	We used the molarity from the pH and the volume of the container to get moles.
<i>If we know moles of H⁺, how can we use that to figure out how much base we need?</i>	We know H ⁺ and OH ⁻ react one to one, so it should be the same amount.
<i>How can we convert moles of something to grams?</i>	By using the molar mass.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Ocean Water Calculations Key*.

What to do: Have students review, restate, and follow the same steps they used for their oyster tank calculations from last period, but for a new volume of water. For equity and accommodation, consider working directions with small groups of students who struggled with calculations earlier in the lesson.

Building toward 9.A.2 Use a mathematical model to calculate the amounts of reactants for desired products, assuming conservation of matter, across scales from molecular to lab-measurable quantities. (SEP: 5.5; DCI: PS1.B.3; CCC: 3.1)

6 · UPDATE PROGRESS TRACKERS

5 min

MATERIALS: *Progress Tracker*, science notebook

Students update their Progress Trackers. Display slide L. Students should add what they have figured out to the science ideas and possible solutions sections of *Progress Tracker*. Sample student entries are found in *Progress Tracker Key* in Lesson 12.

7 · COMPLETE AN ELECTRONIC EXIT TICKET

8 min

MATERIALS: science notebook, Link to class copy of the Electronic Exit Ticket, computer with internet access

ADDITIONAL GUIDANCE

See the instructions on *Molecule Deck*, a Lesson 4 reference, for how to create the Electronic Exit Ticket by making a copy of https://docs.google.com/forms/u/2/d/1Ut_HHwUBSCgORSKLwOxxPtdOT_r7uqlxzZ4TWHnm6KQ/copy for your class.



Complete an Electronic Exit Ticket. Display slide M. Have students complete the exit ticket using the link you created for your class. Encourage students to use their notes and models to help them answer the questions on the Electronic Exit Ticket.

Consider showing the aggregate results of the Electronic Exit Ticket to see how the class did on different types of questions. You can use the evidence generated by the exit ticket to determine how much additional practice the class needs.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Electronic Exit Ticket Key*.

What to do: In the Electronic Exit Ticket, students are asked to reflect on the mathematical reasoning they have used in the lesson. Rather than perform calculations, students describe and reason about parts of the mathematical model they are leveraging in stoichiometry, especially unit conversions. *Stoichiometry Practice* is provided as an additional practice at the end of this lesson if needed, with *Stoichiometry Practice Key* provided for scoring guidance.

Building toward 9.A.3 Use a mathematical model to calculate the amounts of reactants for desired products, assuming conservation of matter, across scales from molecular to lab-measurable quantities. (SEP: 5.5; DCI: PS1.B.3; CCC: 3.1)



8 · CONSIDER THE SCALE OF THIS SOLUTION

9 min

MATERIALS: science notebook, calculator

Problemalyze the issue of scale. Remind students that they determined the amount of NaOH needed to shift the pH of the ocean, 5.0×10^{11} kg. Ask students if this is a large or small amount of NaOH. They should say that it is relatively large, based on the exponent.

Suggest that even though we anticipated needing a large amount of NaOH because of the scale of the ocean itself, it can be challenging to visualize exactly *how* large an amount this is. Emphasize that this is a situation where the significance of a solution is difficult to evaluate based on quantity alone, unless we can consider it in the context of scale.* Display **slide N**.

Give students two minutes to discuss the prompts on the slide with a partner. Then discuss students' ideas as a class.

Suggested prompt	Sample student response
<i>How many car-sized loads of NaOH would be needed to do this?</i>	250,000,000
<i>What does that tell you about the scale of matter required for this approach?</i>	That's a lot of vehicles. That is about equal to the number of people in the United States. Do we have that much NaOH?

Discuss neutralizing the entire ocean. Now that students have calculated the mass of NaOH needed for both an oyster tank and for the entire ocean, ask students how these two systems might differ in other ways besides size. Display **slide O**. Encourage students to refer back to the carbon cycle model and to think about how the proposed changes would impact the ocean-atmosphere system before responding. *

Ask, *Now that we have figured out how much base (NaOH) is required to adjust the pH of the entire ocean... should we actually consider this as a possible solution? Why or why not?* Look for students to suggest:

- Yes, because it will save the oysters.
- Maybe not, because it might be bad for some other animals or plants. We learned in earlier reading that different organisms have different pH needs.
- If CO₂ is constantly going into the ocean, wouldn't more acid form and then we would have to add more base?
- How would we actually do this? Wouldn't we have to spread out where we dump it? Do we actually have that much NaOH?
- Maybe this could have unintended effects that we haven't considered.
- Maybe there are other solutions that we should consider.

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

This is an explicit reference to the idea that: *The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.* (CCC: 3.1)

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

Students may initially think that because they have *calculated the masses of base needed to adjust the pH of an oyster tank and the ocean, the solution may be as simple as scaling up*. Students may need some support in reasoning through this. It is not only that *the ocean is much larger and would require significantly larger quantities* of base. A tank is a closed system where it is possible to prevent more CO₂ from entering it and forming more acid, but this is not true of the ocean. (CCC: 3.1)

MATERIALS: *Stoichiometry Practice* (optional)

Revisit subproblems to think about other solutions. Once students realize that dumping NaOH into the ocean may have unintended consequences or might not be feasible, or at least might not be the ideal solution, have them think about what else we should do or figure out to find solutions that won't harm oysters or other marine life while working to restore oysters as a food source. *

Display **slide P**. Have students turn and talk with a partner about the prompts on the slide. After a minute or two, ask students to share their discussion.

Suggested prompt	Sample student response
<i>What subproblems do we still need to investigate?</i>	Acidity hurts the oyster shells. (subproblem 3) Oyster die-off hurts ecosystems and communities. (subproblem 4)
<i>How might investigating these subproblems help us think of alternative solutions?</i>	Accept all responses.

ALTERNATE ACTIVITY

As an optional activity, you may provide *Stoichiometry Practice* for students to work on independently. If students are not comfortable with unit conversions, this handout may serve as additional practice. However, it is important that you support students in fully grasping the “why” of unit conversions, not just the rote calculations. For this reason, *Stoichiometry Practice* is designed to help students practice applying the mathematical tools from the last two lessons using the phenomenon of carbon sequestration. Carbon sequestration is another notable, if imperfect, technology to help slow ocean acidification and climate change. See *Stoichiometry Practice Key* for solutions.

ADDITIONAL GUIDANCE

We recommend that any additional practice in this or other units be contextualized within the unit or support the figuring out of other phenomena that are interesting to students.

*** ATTENDING TO EQUITY**

Universal Design for Learning. *Engagement* and sustained effort and persistence are intentionally developed here as we connect oysters back to issues of food sovereignty. Oysters are not compelling to all students on their own, but reminding students that oysters are an important food source to many people, as they heard about in the Lesson 1 videos, can increase engagement.

If needed, reconnect students to the locally-sourced foods they rely on.

Additional Lesson 9 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HSN.Q.A.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

Students need to be able to calculate molar mass to determine the mass of equivalent amounts (moles) of molecules. Since students are not able to count or measure a specific number of molecules, they need to be able to convert from moles to grams using molar mass.

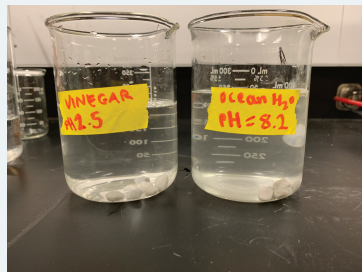
LESSON 10: How does ocean acidification hurt oysters?

PREVIOUS LESSON We used current and ideal H^+ concentrations at an oyster hatchery to determine the moles and mass of NaOH needed to bring pH to safe levels for baby oysters. We scaled up those calculations to determine the amount of NaOH that would be needed for the whole ocean. We wondered whether this solution would be feasible, effective, or safe for other organisms.

THIS LESSON

INVESTIGATION

2 days



We investigate how different pH levels affect oyster shells and see that ocean water does not dissolve shells as we predicted. We read about the oyster's life cycle to get some answers and figure out that oysters build their shells by filtering out calcium and carbonate ions from the water. We model this and notice that as acidity increases, hydrogen ions bond with carbonate, preventing calcium from bonding with carbonate during shell formation. 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.

NEXT LESSON We will investigate how temperature and concentration influence how much product a reaction makes in a given time, like during shell formation. We will model what is happening at a particle level when reactions speed up and use our model to figure out how adding calcium carbonate helps oysters.

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-1,
HS-ETS1-2



WHAT STUDENTS WILL DO

10.A Develop a model to generate qualitative data of ionic bond types in the ocean acidification system to analyze how particle-level changes cause larger-scale effects in oyster susceptibility to ocean acidification. (SEP: 2.6; DCI: PS1.B.2; CCC: 2.2)

10.B Use multiple types of models to identify how particle-level changes cause larger-scale effects in oyster susceptibility to ocean acidification and carbon movement through Earth's systems. (SEP: 2.4; DCI: PS1.B.2, ESS2.D.3; CCC: 2.2)

WHAT STUDENTS WILL 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.

Lesson 10 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Have students examine their Progress Trackers with a partner to identify a new subproblem to investigate.	A-C	<i>Progress Tracker</i> , Driving Question Board
2	7 min		DESIGN AN INVESTIGATION Plan how to visualize the effects of various pH levels on oyster shells.	D-H	<i>Marble Chips Demonstration</i>
3	8 min		REACT MARBLE CHIPS WITH VINEGAR AND OCEAN WATER Observe how marble chips interact with substances with different pH levels and interpret these results.	I-K	Marble Chips Demonstration
4	10 min		OBTAIN INFORMATION FROM A READING Have students read about the oyster life cycle and shell-building process.	L-N	<i>Oyster Life Cycle</i> , <i>Our DQB Questions</i> from Lesson 7
5	15 min		MODEL SHELL-BUILDING IN AN ACIDIFIED ENVIRONMENT Students build a model to explain how different pH levels may affect the shell-building process.	O	<i>Shell-Building Model</i> , M-E-F triangle
<i>End of day 1</i>					
6	10 min		COMPARE SHELL-BUILDING MODELS Identify similarities and differences in shell-building models.	P-Q	<i>Shell-Building Model</i>
7	15 min		DEVELOP CLASS CONSENSUS MODEL Develop a class consensus model of how oysters build their shells in an acidified environment.	R-V	<i>Shell-Building Model</i> , chart paper, chart paper markers
8	5 min		CONSIDER DESIGN SOLUTIONS Identify new ideas for protecting oysters by considering how to help them build their shells more effectively.	W-Y	<i>Progress Tracker</i> , <i>Shell-Building Model</i>
9	12 min		INCORPORATE CARBONATE INTO CARBON CYCLE MODEL Examine where carbonate is found within the greater carbon cycle and the rate at which it is introduced into the ocean, and add this to the carbon cycle model.	Z-CC	<i>Oyster Life Cycle</i> , <i>Shell-Building Model</i> , chart paper markers, carbon cycle model from Lesson 5, class consensus model
10	3 min		NAVIGATE Motivate students to consider solutions on a workable timescale for restoring oysters as a food source.	DD	
<i>End of day 2</i>					

Lesson 10 • Materials List

	per student	per group	per class
Marble Chips Demonstration materials	• <i>Marble Chips Demonstration</i> • safety goggles		• 2 250-mL beakers • 150 mL vinegar • 150 mL tap water adjusted to ocean water pH • 2 sets of 5 g marble chips • Driving Question Board
Lesson materials	• <i>Progress Tracker</i> • <i>Marble Chips Demonstration</i> • <i>Oyster Life Cycle</i> • <i>Our DQB Questions</i> from Lesson 7 • <i>Shell-Building Model</i> • science notebook		• Driving Question Board • M-E-F triangle • chart paper • chart paper markers • carbon cycle model from Lesson 5 • class consensus model

Materials preparation (60 minutes)

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

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

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

Have the Driving Question Board visible.

Have the M-E-F triangle visible.

Prepare to refer to the carbon cycle model from Lesson 5, which you will be revising in this lesson.

Day 1: Marble Chips Demonstration

- **Group size:** Whole-class demonstration
- **Setup:** Prepare the following in an area large enough for a lab demonstration where all students can see:
 - 2 250-mL beakers
 - 150 mL vinegar
 - 150 mL tap water adjusted to ocean water pH, using *Adjusting Water pH* as guidance
 - 2 sets of 5 g marble chips
- **Notes for during the lab:** None.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*. Ensure that students are wearing safety goggles during the demonstration.
- **Disposal:** Use a scoopula, tweezers, or another long tool to scoop out the remaining marble chips at the end of the day. Dispose of the marble chips in the trash. Then dilute all the liquid waste with twice as much water before disposing down the drain.
- **Storage:** Store unused solutions in lockable corrosives cabinets and the marble chips in a cool, dry area.

Lesson 10 • Where We Are Going and NOT Going

Where We Are Going

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

- **ESS2.D.3: Weather and Climate.** Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.
- **PS1.B.2: Chemical Reactions.** In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.

This lesson comprises an investigation about oyster-shell building, a reading, modeling the ratios and interactions of ions, and a consensus model about Earth's systems.

This lesson establishes that oyster shells are **not dissolving**, rather that baby oysters **cannot build shells** because of insufficient calcium and carbonate ions. In previous lessons, students likely have assumed that increasing ocean acidification causes oyster shells to dissolve into the ocean. It is imperative that they have shifted their conception by the end of the lesson. Students will model the process of hydrogen ions from acid competing with calcium ions to bond with free-floating carbonate ions, thus limiting the concentration of carbonate ions available to baby oysters to build a calcium carbonate shell. Students determine the particle-level interactions between ions involved in oyster-shell building and increasing acidification (DCI: PS1.B.2). They must create a model of this condition-dependent balance, leveraging ratio thinking and change over time in systems (SEP: 2.6).

Students will then investigate how carbonate ions get into the ocean, only to realize that the erosion of limestone into the ocean occurs on a geological timescale that pales in comparison to the rate at which oysters are dying. Students use multiple types of models (consensus models, models of the Marble Chips Demonstration, and models of Earth systems) to compare and integrate their understanding of ions and particles. They extend particle models of molecules from *Electrostatics Unit* and *Space Survival Unit* by adding ionized molecules like H^+ to their models of possible arrangements of matter. Merits and limitations of these models are considered as students transition to needing a broader Earth systems model (SEP: 2.4).

The lesson-concluding consensus model expands the system to include the atmosphere and hydrosphere as related entities in an Earth systems model of ocean acidification. Human interactions with Earth systems are included and important for determining ideal solutions. We add the carbon cycle model from Lesson 5 into this class consensus model to end the lesson (DCI: ESS2.D.3).

The idea that small-scale changes can cause large-scale effects is a theme of the entire unit, but it is practiced throughout this lesson as students are identifying the specific chemical factors that have led to seawater being inhospitable to baby oysters (the large-scale change) (CCC: 2.2).

Where We Are NOT Going

Students can recognize that the increase in hydrogen ions and the resulting formation of bicarbonate will decrease the probability of calcium carbonate formation. However, we intentionally avoid comparing the kinetics and energetics between bicarbonate formation and calcium carbonate formation because a satisfactory explanation for these differences is beyond the realm of high school-level DCIs in the NGSS.

LEARNING PLAN for LESSON 10

1 · NAVIGATE

5 min

MATERIALS: *Progress Tracker*, Driving Question Board

Motivate a return to the subproblems. Display **slide A**. Ask students to turn and talk to discuss the solution proposed at the end of the last lesson and why we are uncertain about that particular solution.

Suggested prompt	Sample student response
<i>What solution did we discuss at the end of our last lesson?</i>	We talked about putting base in the ocean to neutralize the acid.
<i>What uncertainties or concerns did we have about this particular solution?</i>	It might hurt other organisms or even oysters in ways we do not know yet. We would need a lot of the base to neutralize the whole ocean.

Emphasize that students' idea of neutralizing the entire ocean with base is a potential solution but that, given our concerns, we would benefit from considering other solutions as well. Say, *Let's take advantage of our Progress Tracker to determine what we have not explored yet; perhaps we will find some inspiration for our investigation.* Display **slide B** and ask students to look back at the subproblems to figure out where we should go next.

Suggested prompts	Sample student responses	Follow-up questions
<i>Which of the four subproblems do we still need to investigate?</i> 1. <i>CO₂ gets into the atmosphere and ocean.</i> 2. <i>Water becomes more acidic.</i> 3. <i>Acidity hurts the oyster shells.</i> 4. <i>Oyster die-off hurts ecosystems and communities.</i>	We have already investigated the first two subproblems in previous lessons. We have not looked at how acid hurts oyster shells. I am pretty sure acid just dissolves the oyster shell, but we have not investigated that yet.	<i>What evidence have we collected as a class already?</i> <i>What do you want to know more about?</i> <i>Where do we need to start to understand the root causes of oyster die-off that hurts ecosystems and communities?</i>

Display **slide C**. Say, *We know that acidity somehow negatively affects oyster shells but we have not investigated how and why.* Point out the Driving Question Board and the ideas for investigations generated throughout the unit.

Suggested prompts	Sample student responses
<i>Which questions from the DQB might be useful to investigate this subproblem?</i>	How does an acid "eat away" at things? How do oysters grow their shells?

Suggested prompts	Sample student responses
<i>What investigations could help us figure out what is going on?</i>	Putting shells in acids. Research how oysters grow their shells.

Let students know that testing what happens when shells or shell-like substances are placed in acid is a great first step if those materials are available in the classroom or lab setting.

2 · DESIGN AN INVESTIGATION

7 min

MATERIALS: *Marble Chips Demonstration*

Elicit initial ideas for how acidity hurts oyster shells. Display **slide D**. Introduce that the composition of oyster shells is mostly (95%) calcium carbonate. Prompt students to consider their initial ideas for the molecular process with a Turn and Talk. Give them time to brainstorm ways to design this investigation.

Suggested prompts	Sample student responses	Follow-up questions
<i>How do you think acidity of ocean water affects oyster shells at the particle level?</i>	I am not really sure. Maybe the acid breaks bonds between the atoms in the calcium carbonate in the shell. I think the acidic ocean somehow dissolves the oyster shells and separates the atoms like salt in water. Maybe it undergoes a chemical reaction to turn the shell into a gas that leaves the water.	<i>What do you notice or think of when acid breaks stuff down?</i> <i>What makes you think that?</i>
<i>How would you design an investigation to test your ideas?</i>	Put oyster shells into acids. Put oyster shells into ocean water.	<i>What are we trying to figure out in this investigation?</i> <i>How can we see changes in oyster shells in our classroom?</i> <i>What about the ocean water is changing?</i> <i>How do we make sure other parts of the ocean water are not causing the issues with oyster shells?</i>

Remind students of constraints created by the classroom. Point out the key components of the investigation students are proposing, ocean water and oyster shells. Then point out the fact that these materials may not be available in the classroom setting. Display **slide E**. Have students turn and talk about the prompts on the slide.

Suggested prompts	Sample student responses	Follow-up questions
<i>What could we use in place of oyster shells?</i>	Other shells? Other substances that are similar to oyster shells. Anything made of calcium carbonate.	<i>There are other substances that are made up of the same compounds as oyster shells – calcium carbonate. One common material is marble chips. Would these be a good substitute for oyster shells?</i>
<i>What could we use in place of ocean water?</i>	Tap water mixed with salt. Tap water with the pH adjusted to be the same as the pH of the ocean.	<i>What is it about the ocean water that we are testing on the shells?</i>

Display **slide F**. Distribute *Marble Chips Demonstration*. Have students start by tracking the ways we will represent oyster shells and ocean water in our investigation.

Use predictions to push for a more thorough investigation. Display **slide G**. Briefly check in with students about the relationship between acidity and pH by asking, *When something is acidic, is its pH value low or high?* Clarify that acidic substances have low pH values. Then, prompt students to make predictions in *Marble Chips Demonstration* about how marble chips might change in very acidic liquids and in the ocean water model. Quickly poll students on their predictions to see what they think.

Display **slide H**. Acknowledge concerns that maybe we will see nothing happen, and ask students to turn and talk about how we could make sure that we see something happen to the marble chips. Then share ideas as a class. Listen for students to suggest things like putting the marble chips in a liquid with a very low pH or using something very acidic to see how it affects the marble chips compared to ocean water.

Validate students' suggestions by explaining that we can carry out any test using the materials that are available, such as vinegar, which has a pH of about 2.5. This can be used undiluted or diluted to a higher pH level. Remind students that we can dilute acid with water in a 1:10 ratio to increase the pH by 1 whole value (e.g., from 2.5 to 3.5).

3 · REACT MARBLE CHIPS WITH VINEGAR AND OCEAN WATER

8 min

MATERIALS: Marble Chips Demonstration

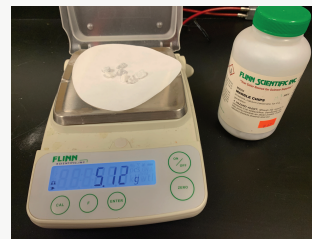
SAFETY PRECAUTIONS

Ensure that everyone is wearing safety goggles during this demonstration.

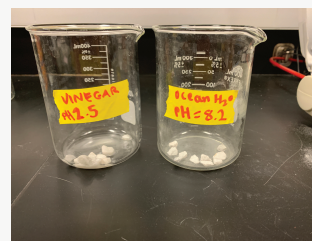


Demonstrate marble chips in vinegar and in water with ocean water pH. Display **slide I**. Talk through each step of the demonstration as you set it up. Ask students to jot down any observations they make during the demonstration in *Marble Chips Demonstration*.

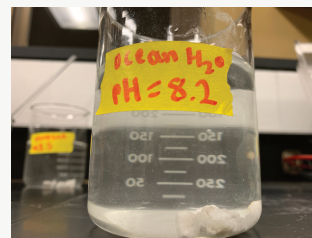
1. Measure out two sets of marble chips that are approximately 5 g each.



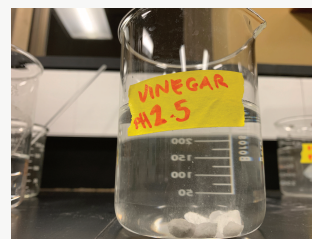
2. Place a set of marble chips into each beaker.



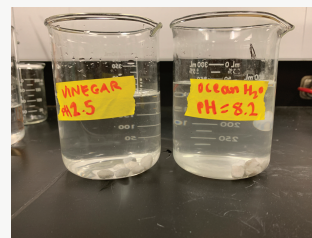
3. Into the first beaker, pour 150 mL of water adjusted to an ocean pH level of 8.2.



4. Into the second beaker, pour 150 mL of vinegar with a pH of 2.5.



5. Allow each student to closely observe the marble chips. Ask students to record their observations about the marble chips.



Ask students to share their observations from the demonstration. Display **slide J**. Have students turn and talk with a partner to share their observations. After a minute, ask, *What did you see in the demonstration?* Look for students to share:

- The marble chips in vinegar bubbled and slowly dissolved into the vinegar.
- The marble chips in ocean water did not seem to do much of anything. There was no chemical reaction we could see.

Discuss the implications of the demonstration for oysters in the ocean. Display **slide K**. Have students use the prompts to consider what it means for the marble chips not to dissolve in water adjusted to an ocean pH level. Then have students share their ideas in a class discussion.

Suggested prompts	Sample student responses
<i>Why did the marble chips interact with the vinegar differently than with the ocean water?</i>	The vinegar was so much more acidic than the ocean water, so it could dissolve the marble chips much faster.
<i>What would happen if oysters interacted with ocean water in the same way we just observed?</i>	Oysters would not be dying because nothing would happen to their shells. Oysters might be affected but their shells would not dissolve like they would if they were in a more acidic liquid.
<i>How does that compare to what we have learned about the oyster die-off occurring in the ocean?</i>	I am not sure, since the ocean is at the same pH as what we tested in the lab. In the ocean, oysters are living creatures rather than non-living marble chips. We learned that the oyster die-off is mostly a problem for oyster larvae.

ALTERNATE ACTIVITY

Extension opportunity: Model the reaction between vinegar and marble chips. If students are motivated to investigate the particle-level dissolution of calcium carbonate in acid, prompt them to add a model to their science notebook with their ideas of how H^+ ions from acid may chemically react with the shell. Note that students just learned that oyster shells are made of calcium carbonate and may have models that show H^+ ions reacting with “shell particles.” Also use this opportunity to point out that if students’ models were accurate, both oyster larvae and adults would experience die-offs at equal rates, but in reality larvae are much more strongly impacted.

Students may need an additional prompt to begin considering the various life stages of oysters and how they are affected by ocean acidification in different ways. If this is the case, ask a follow-up question about which oysters are more severely affected by ocean acidification.

Say, *Recall what we know about the problem. Which oysters did the oyster farmers say are most affected by ocean acidification?*

ALTERNATE ACTIVITY

If students need a refresher, show <https://youtu.be/UIOSbJD92og>.

Direct students to learn about the oyster life cycle. Point out that on the Driving Question Board some students wanted to better understand how oysters grow to maturity and develop their shells over time. Say, *So our investigation results suggest that current ocean water pH levels might not be a problem for adult oysters but might affect oyster larvae. If we can better understand oyster development, we could figure out why that might be the case.*

4 · OBTAIN INFORMATION FROM A READING

10 min

MATERIALS: *Oyster Life Cycle*, *Our DQB Questions* from Lesson 7

Read about the oyster life cycle. * Display slide L. Distribute *Oyster Life Cycle* to each student and direct them to take out *Our DQB Questions* from Lesson 7.

Say, *This reading should answer the types of questions we have. As you read, underline any key ideas in the handout that address a question we had on Our DQB Questions.*

Key ideas in the reading include that oysters’ shells are made of $CaCO_3$, that they form from compounds in the water, that to build their shells oysters use energy from food to filter out anything they do not need, and that this process is especially hard for oyster larvae, who have very little energy in reserve.

Clarify current thinking. Display slide M. Offer time for students to turn and talk with a partner about what they figured out from the reading. Then discuss the following prompts as a class.

* ATTENDING TO EQUITY

Literacy. Students benefit from options for reading. You may read the text aloud to the class or provide options such as having students read aloud with a partner or in a small group. The *prosody* or pace of a reading, with pauses and inflection, is more obvious when read aloud for many students and it can support meaning-making.

Suggested prompts	Sample student responses
What did you figure out from the reading?	Oyster shells are made of calcium carbonate, the same stuff as chalk and limestone. Oysters get calcium and carbonate from the ocean water.
Why are oyster larvae so much more vulnerable than adult oysters? When are they vulnerable?	It takes energy to build a shell, and oyster larvae do not have enough energy to filter out stuff they do not need when building a shell. They only have a short amount of time (a couple days) to build a shell before they die.
When oyster larvae die, what are they not getting enough of from the ocean?	They are not getting enough Ca^{2+} and CO_3^{2-} ions to build their shells.

Revisit how acidity affects the oyster shells. Acknowledge that students have figured out important ideas about oyster-shell building from the reading. Say, *It sounds like we agree that the lack of Ca^{2+} and CO_3^{2-} is what hurts oyster larvae. But we have evidence from Lesson 1 that ocean acidification is what is hurting oysters. How can both of these things be true?* Display **slide N**. Help students recall what increasing acidity means for ocean chemistry with a one-minute Turn and Talk.

Suggested prompts	Sample student responses
What do we mean when we talk about ocean acidification?	The ocean is getting more acidic. The ocean has a lower pH than it used to.
What does increased acidity mean at the particle level?	There are more H^+ ions in the water when it is more acidic.

Say, *We know there are more H^+ ions in the water when it is more acidic. We also know oyster larvae die when they are not getting enough Ca^{2+} and CO_3^{2-} ions to build their shells. Let's use a model to help us figure out how these ideas might relate to each other.*

5 • MODEL SHELL-BUILDING IN AN ACIDIFIED ENVIRONMENT

15 min

MATERIALS: Shell-Building Model, M-E-F triangle



Integrate key ideas from the reading into a model. Display **slide O**. Distribute *Shell-Building Model* to each student. Say, *What happens when an oyster is building its shell in an acidified environment? Let's try to develop a model of this process. To do this, make sure your model includes the following components:*

- chemical formation of CaCO_3
- where materials to build the shell come from
- how increased acidity interferes with the shell-building process

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

In order to meet high school standards for modeling, students must *use mathematical thinking (ratios) to generate data to support*

Suggest that students think about the last bullet point from both a matter and forces perspective. Reference the M-E-F triangle.

Point out the provided data and list of ions in *Shell-Building Model* to support students with their models. Give students the rest of the class period to work on their models independently, and let them know they will start class the next day by sharing their models. ✱

their explanation and analyze the changes in the system. In this activity, look for students to match up particles differently *before* and *after* the water becomes more acidic. Students should use evidence from the reading that the ratio of available calcium is lower because the H^+ ions “grab” it before it can be made into shells. (SEP: 2.6)

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students' **models include qualitative data about the ratios of ions to help predict and analyze system-level increases and decreases** of ionic bond types and ratios (e.g., excess hydrogen ions means that the calcium gets “interrupted” on its way to the oyster shells). (SEP: 2.6)
- Students include the **dynamic and condition-dependent balance of CaCO_3 and excess H^+ ions** in the sea water. (DCI: PS1.B.2)
- Students describe how **particle-level changes at this small scale cause large-scale system problems** for oysters and pH. (CCC: 2.2)

What to do: If students do not include information from the reading, then press them to cite where they found the information in their model. It is okay if students do not show the source of calcium carbonate as limestone rock specifically, as this information will be introduced on day 2.

If students are struggling to recall the relationship between pH and H^+ ions at the particle level, encourage them to revisit Lessons 3 and 4 in their Progress Tracker or refer back to *Measuring pH*. If students do not include a particle-level interaction between H^+ and the shell-building reaction, prompt students to consider how the presence of H^+ relates to the oysters in the model. It is fine if students do not yet show the interaction between H^+ and CO_3^{2-} specifically, as that will be reviewed as a class.

Building toward 10.A.1 Develop a model to generate qualitative data of ionic bond types in the ocean acidification system to analyze how **particle-level changes cause larger-scale effects in oyster susceptibility to ocean acidification**. (SEP: 2.6; DCI: PS1.B.2; CCC: 2.2)

End of day 1

6 · COMPARE SHELL-BUILDING MODELS

10 min

MATERIALS: *Shell-Building Model*, science notebook

ADDITIONAL GUIDANCE

Students will move into a Scientists Circle and remain there for the rest of the lesson after this activity. To save time, consider having students move their chairs into the Scientists Circle before they start the gallery walk.

Begin by looking at peers' models. Display slide P. Have students open their science notebooks to a new page and make a T-chart with the title “Compare shell-building models.” Students should follow the example shown in the slide and make two columns: “Similarities” and “Differences.” Have students display their models around the room. Then give them about five minutes to look at one or two other models in a gallery walk. Remind students to jot down in their notebook the similarities and differences they see while viewing the models.

Discuss the similarities and differences in the shell-building models. Display slide Q. Direct students to find a partner to discuss their observations from the gallery walk for five minutes.

7 • DEVELOP CLASS CONSENSUS MODEL

15 min

MATERIALS: *Shell-Building Model*, chart paper, chart paper markers

KEY IDEAS

Purpose of this discussion: To determine the different particle-level interactions between ions involved in oyster-shell building and increasing acidification in the ocean.

Listen for these ideas:

- Calcium (Ca^{2+}) and carbonate (CO_3^{2-}) ions in the ocean react to form calcium carbonate, which is what oyster shells are made of.
- When the ocean becomes more acidic, that means there are more H^+ ions in the water.
- The additional H^+ ions in the water react with CO_3^{2-} to form HCO_3^- , which is an ion that oysters cannot use to build their shells.
- The increased formation of bicarbonate when the ocean gets more acidic decreases the amount of carbonate in the ocean. This prevents the chemical reaction needed for oysters to build their shells.

Elicit similarities. Display **slide R**. Meet in a Scientists Circle to share students' observations from the gallery walk. Have students share their models' similarities aloud, especially that Ca^{2+} and CO_3^{2-} are ions in the water that oysters use to make their shells.

Sketch a version of the model on chart paper that is visible to the class. Add the components that students mentioned earlier, such as the calcium and carbonate ions in the water coming together in the oyster to form a shell.*

Elicit the interaction between ions to build an oyster shell. Display **slide S**. Point out the calcium and carbonate ions that are coming together on the class model. Ask, *Why do Ca^{2+} and CO_3^{2-} ions in the water interact with each other the way that they do?* Listen for responses about positive and negative forces.

Add attraction between ions to the model. Incorporate the attraction between Ca^{2+} and CO_3^{2-} to form calcium carbonate in the oyster shell on the class consensus model.

* STRATEGIES FOR THIS CONSENSUS DISCUSSION

As you write students' ideas on chart paper or a whiteboard, it is important to ask everyone to weigh in on each proposed idea —i.e., students should consider if they had a similar idea. It is also important for students to work on restating and rephrasing the ideas to make sure each idea captures what everyone thinks is essential. Revise the ideas as students make suggestions.

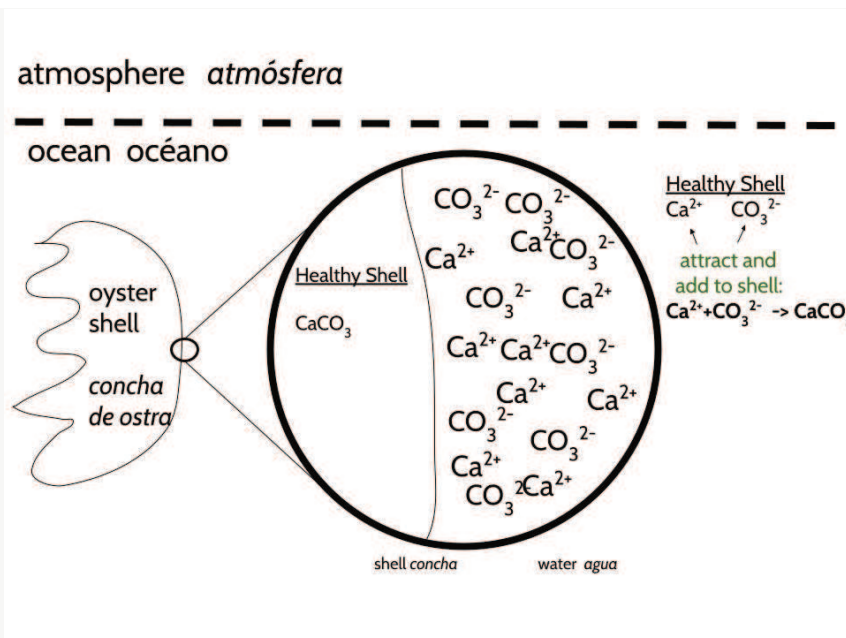
Do not have students write down ideas at this time. Have them work on listening and linking to the ideas that their classmates share.

* SUPPORTING STUDENTS IN DEVELOPING AND USING CAUSE AND EFFECT

This is an opportunity to help students recognize the *cause-and-effect relationship between the increased concentration of H^+ in the ocean (cause) and the decrease in CaCO_3 (effect)*, and to consider the mechanistic *how* or *why* explanations for this relationship. Use the language of cause and effect introduced in earlier lessons to clarify that these concepts are crosscutting. For example, say, *How does this cause-and-effect relationship lead to the trend we learned about at the start of the unit, where oyster larvae are not reaching full maturity?* (CCC: 2.2)

* ATTENDING TO EQUITY

Supporting Emerging Multilingual Learners. Encourage students to express the new ideas from the Consensus Discussion on their individual models using a mode that makes sense for them. For some emergent



multilingual students, encourage them to use space to express ideas in the language that they feel most comfortable with. Remind students that the model they built from the Consensus Discussion is a low-stakes opportunity to make sense of what they are learning without the worry or anxiety that comes with graded work.

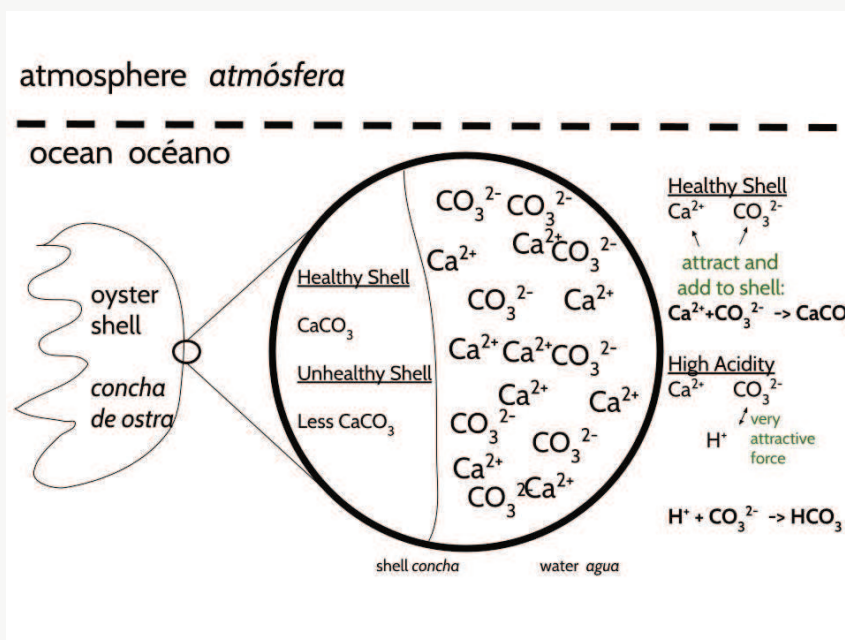
Guide students to consider the H⁺ reactions happening in the water. Display slide T. Point out the various chemical reactions that students have encountered in previous lessons as a starting point.

Say, *Normally, we see oysters build their shells with the first chemical equation. We also know how more CO₂ in the water leads to more H⁺ ions in the water, which we see in the second equation. We just added these H⁺ ions to the water, along with the Ca²⁺ and CO₃²⁻ ions that naturally end up in the water. How do you think the H⁺ ions will interact with Ca²⁺ and CO₃²⁻? Listen for these ideas:*

- *Positive and negative ions attract.*
- *H⁺ is positive and CO₃²⁻ is negative, so they are probably bonding with each other.*
- *There would be less CO₃²⁻ available because the H⁺ might bond to it.*

Model why oysters cannot form calcium carbonate shells in high-H⁺ environments. ✱ Display slide U. After students turn and talk about the prompts for one minute, ask the class to share their ideas. Listen for ideas about H⁺ bonding with CO₃²⁻, leading to more positive ions and a shortage of negative carbonate.

Incorporate the attraction between H^+ and CO_3^{2-} to form bicarbonate, leading to fewer CO_3^{2-} ions in the system and less frequent formation of CaCO_3 , on the class consensus model.



Sample class consensus model.

Revise individual models based on class consensus ideas. Display slide V. Direct students to revise their own models in *Shell-Building Model* to add any key ideas from the class consensus model that were not included. Say, *You do not need to completely alter your model to copy the class consensus model. What is important is that you incorporate key ideas that we all agree on into your model if they are not represented yet.* *

8 • CONSIDER DESIGN SOLUTIONS

5 min

MATERIALS: *Progress Tracker*, *Shell-Building Model*, science notebook

ADDITIONAL GUIDANCE

Keep the Scientists Circle set up, but provide students the option to move around as they update their Progress Trackers. Then, have them return to the Scientists Circle to consider new solutions.

Update Progress Trackers. Display slide W. Have students summarize their annotated models from *Shell-Building Model* on their *Progress Tracker*. A sample entry can be found on *Progress Tracker Key* in Lesson 12.

Consider new solutions. Display slide X. After students finish adding to their Progress Trackers, ask if we can use this knowledge to support new solutions to help oysters. Give students a chance to brainstorm in pairs, then discuss as a class.

Suggested prompts	Sample student responses	Follow-up questions
<i>How could we use this understanding to develop new solutions that help oysters build up shells while they are still larvae?</i>	We could try to prevent the H^+ from reacting with the CO_3^{2-}, like when we neutralize acid with a base. We could try speeding up the shell-building process so H^+ has less of an effect on the oysters. We could add more CO_3^{2-} to the ocean so that oysters have more CO_3^{2-} to build their shells with.	<i>What actually causes problems for oysters' shells at the particle level?</i> <i>What chemistry ideas have we figured out that help us change concentrations of H^+ and CO_3^{2-}?</i>

Clarify the proposed solutions to focus on carbonate. Point out that we have already explored neutralization as a potential solution, and that we would benefit from a better understanding of where to obtain additional carbonate to address the other two proposed solutions.

Address the merits and limitations of a carbonate-based solution. Display **slide Y**. Have students jot down their ideas in their science notebook about the prompts before sharing with the class.

Suggested prompts	Sample student responses	Follow-up questions
<i>What are the merits of a carbonate-based neutralization solution?</i>	It's already something that's in the ocean. We wouldn't be adding a new substance to the ocean.	<i>Where did the carbonate in the ocean come from in the first place?</i>
<i>What are the limitations of a carbonate-based neutralization solution?</i>	We would have to add a lot of carbonate to the ocean.	<i>Where could we get additional carbonate to put in the ocean?</i>

9 • INCORPORATE CARBONATE INTO CARBON CYCLE MODEL

12 min

MATERIALS: *Oyster Life Cycle*, science notebook, *Shell-Building Model*, chart paper markers, carbon cycle model from Lesson 5, class consensus model

Identify carbon in a chemical reaction we are familiar with. Have the carbon cycle model from Lesson 5 visible. Point out that the carbonate in the ocean must have gotten there somehow due to the cycling of carbon. Display **slide Z**. Ask students to identify where carbon shows up in the chemical equation of the shell-building process and think about where it may have come from. Have them refer back to the class consensus model or *Shell-Building Model*.

Suggested prompts	Sample student responses
<i>Where is the carbon in the shell-building reaction?</i>	Carbonate is made with carbon, and carbonate shows up on both sides of the equation.

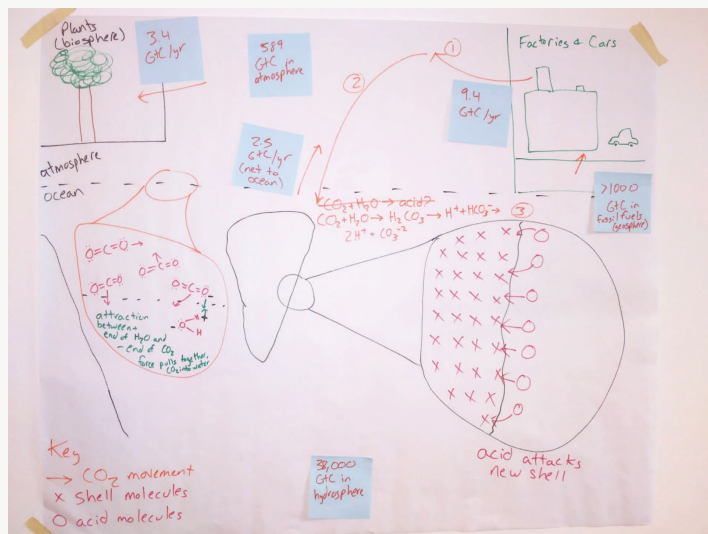
Suggested prompts	Sample student responses
Where did the carbon come from for this reaction to occur?	Rocks can erode into water, so maybe carbonate came from eroded limestone. CO₂ from the atmosphere might have turned into carbonate in the water.

 **Revise carbon cycle model.** Display slide AA. Push the students to identify the *limitations* of the carbon cycle model using the information from *Shell-Building Model*, the class consensus model, and *Oyster Life Cycle*. For example, it currently does not address where the carbon in limestone comes from. Ask students if the oysters and limestone should be incorporated into the model as parts of the biosphere, geosphere, hydrosphere, or atmosphere.

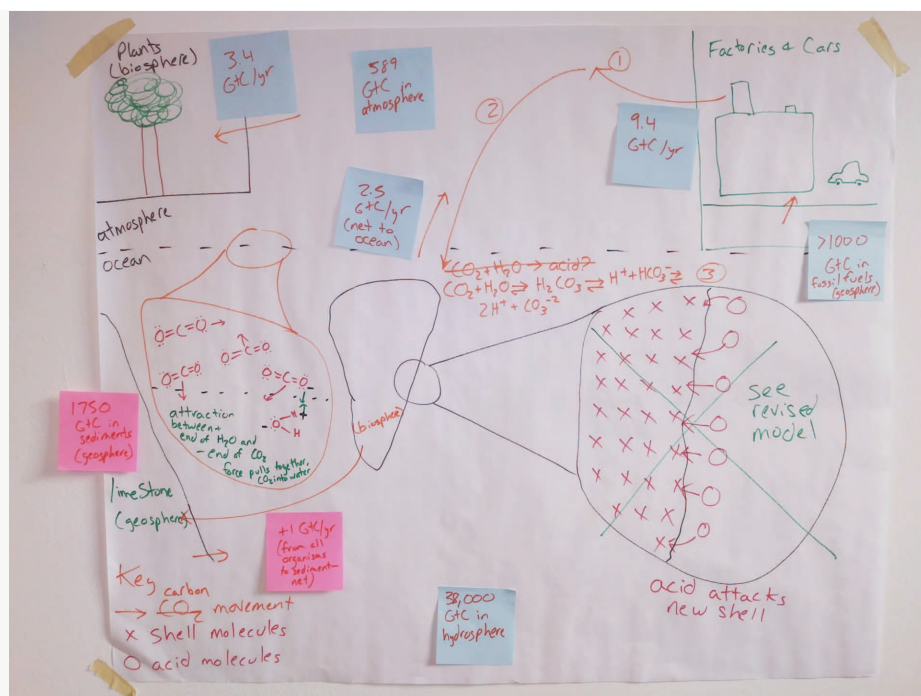
Suggested prompt	Sample student response
Where did the carbon in limestone come from?	The reading says limestone is a sedimentary rock made up of dead organisms' bones and shells.
What "spheres" (biosphere, geosphere, hydrosphere, atmosphere) should we incorporate oysters and limestone into?	Oysters are part of the biosphere. Limestone is part of the geosphere. Limestone is made up of stuff from the biosphere.

As students suggest where the carbon is located within the shell-building reaction and where it came from, map out their ideas on the carbon cycle model on chart paper. An example is shown.

1. Start with the original model.
2. Add the ocean bottom and limestone rocks as components of the model.
3. Then connect limestone to the ocean via erosion.
4. Lastly, connect how carbon moves from the biosphere to the geosphere.



Original carbon cycle model



Revised carbon cycle model

Compare timescales of carbon flow between different parts of the carbon cycle. Display slide BB. Prompt students to turn and talk with a partner using the prompts on the slide to consider how the rate of carbon flow into the ocean from increased CO₂ emissions compares to the rate of carbon flow into the ocean from limestone erosion.

Say, *Let's take a look at some carbon flow data.* Display slide CC. Give students a few minutes to look over the data then ask, *How does the rate of carbon flow from the atmosphere into the ocean compare to the flow rate from limestone into the ocean?* Look for students to say:

- We are emitting a lot of CO₂ into the atmosphere, which is dissolving into the ocean fast enough for us to notice a difference within a decade or two.
- The gain of carbonate into the ocean is negligible; it does not even have a number!
- We cannot see rocks erode in our lifetime because it happens so slowly.

Ask students to consider how these data affect our goal for the unit. Listen to student conversations as evidence to formatively assess them. Alternatively, students may write a response in their science notebooks.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students identify that **changes in the atmosphere due to human activity have increased CO₂ and affect the ocean water** at a rate much greater than the rate at which carbon flows from limestone deposits into the ocean. (DCI: ESS2.D.3)
- Students explain that the **dynamic and condition-dependent balance of CaCO₂ and excess H⁺ ions** in the sea water is a key mechanism in storing carbon, but it takes a very long time. (DCI: PS1.B.2)
- Students guide carbon cycle model revision to include a flow of carbon indicating how **cause-and-effect relationships in much larger Earth systems** (limestone-based carbon sequestration) **can be suggested and predicted by smaller mechanisms in the system** (the chemical reactions that store carbon in oyster shells over time). (CCC: 2.2)
- Students **incorporate ideas from the multiple types of models present in this lesson to provide a mechanistic account** of how carbon cycles from the biosphere (oysters) to the geosphere (limestone deposits) and back to the hydrosphere (ocean) as they work to revise the carbon cycle model. (SEP: 2.4)

What to do: Because this assessment opportunity is not necessarily recorded in students' science notebooks or on a handout, be sure to listen to students' conversations during turn-and-talk discussions to assess this lesson-level performance expectation. Ask students to map what they included in their particle-level models onto the macro-scale model of the carbon cycle and Earth "spheres".

If students are getting caught up in the complexity of the different components of the carbon cycle, help scaffold the model building by tracking the carbon movement step by step. Emphasize that the flow of carbon between the ocean, geosphere, and biosphere from oysters is almost negligible in comparison to the flow of carbon from the atmosphere into the ocean.

Building toward 10.B.1 Use **multiple types of models** to identify how **particle-level changes cause larger-scale effects** in **oyster susceptibility to ocean acidification** and **carbon movement through Earth's systems**. (SEP: 2.4; DCI: PS1.B.2, ESS2.D.3; CCC: 2.2)

10 · NAVIGATE

3 min

MATERIALS: None

Encourage students to focus on solutions within a workable timescale. Display slide DD. Use students' ideas about the rate at which the ocean is acidifying from dissolved CO₂ in the water to motivate new ideas for potential solutions. Ask students to share ideas with a partner about how humans can speed up the process of shell-building so that oysters can stand a chance against the acidification of the ocean.

Suggested prompt

Is this fast enough for the Swinomish Tribal Community to restore oysters?

Sample student response

They have to build the shells in just the right time.

Suggested prompt	Sample student response
Can we optimize shell-building in the oyster larvae stage so that oysters can build shells in time to survive?	Add a lot of carbonate to the ocean ASAP. Maybe tweak the shell-building reaction somehow to make it happen faster.

Say, *These are some great ideas! We can investigate them in our next lesson.*

Additional Lesson 10 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.9-10.5: Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy).

Students read about how oyster shells form and later develop a model that visualizes relationships among the terms presented in the text (calcium and carbonate ions, calcium carbonate, limestone).

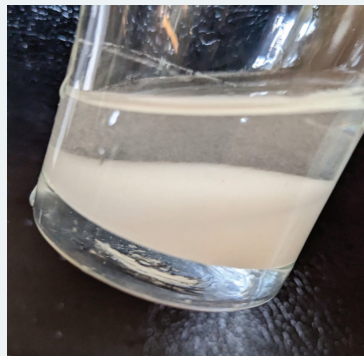
LESSON 11: How can we help oysters build shells quickly?

PREVIOUS LESSON We figured out that as water acidity increases, hydrogen ions bond with carbonate, preventing calcium from bonding with carbonate during oyster shell formation. We thought that increasing the amount of carbonate in the ocean might help oysters but realized that carbonate takes a long time to end up in the ocean. We decided to find ways to speed up the process.

THIS LESSON

INVESTIGATION

3 days



We want to figure out how we can best help oysters build shells in a short time by adding calcium carbonate to the water. We generate possible factors that might help the reaction go faster. We design an investigation to test how temperature and concentration might influence how much product a reaction makes in a given time. We decide that we need to understand what is happening on a particle level to cause the observations that we see. We work in groups to build a reaction rate model and use this model to identify how adding calcium carbonate provides plenty of carbonate ions for oysters and slightly reverses acidification.

NEXT LESSON We will develop a list of possible solutions to prevent oyster die-off and narrow it down based on the criteria and constraints for our design, the information gathered about the priorities of impacted communities, and our own knowledge and experiences. We will choose a promising solution to develop in groups.

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-1,
HS-ETS1-2



WHAT STUDENTS WILL DO

11.A Plan an investigation to produce data as evidence to determine how rates of change in reactions differ under different conditions. (SEP: 3.1; DCI: PS1.B.1; CCC: 7.2)

11.B Build a model based on evidence that explains how changes in the oyster-water system affect reaction rates and equilibrium. (SEP: 2.3; DCI: PS1.B.1, PS1.B.2; CCC: 7.1)

WHAT STUDENTS WILL 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.

Lesson 11 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	3 min		NAVIGATE Lead students in a brief reflection on takeaways from Lesson 10.	A	
2	7 min		BRAINSTORM METHODS TO SPEED UP A REACTION Help students brainstorm different methods by which they could help oysters build shells more quickly.	B-F	Shell-Building Demonstration
3	5 min		PREPARE TO PLAN THE INVESTIGATION Set up the space for investigation and give students time to plan.	G-H	
4	10 min		PLAN THE INVESTIGATION Organize students into seven small groups to plan their investigations.	I	<i>Shell-Building Investigation Planner</i> , 6 250-mL beakers, 1 scoopula, 6 pieces weighing paper, 0.1M CaCl ₂ solution, Na ₂ CO ₃ , 1 glass stir rod, 6 pieces filter paper, 1 funnel
5	15 min		CONDUCT AN INVESTIGATION Encourage students as they test their ideas using the CaCl ₂ -Na ₂ CO ₃ system.	J-K	Shell-Building Investigation
<i>End of day 1</i>					
6	7 min		COMPILE DATA AS A CLASS Have students summarize their data and conclusions in a class chart.	L	<i>Shell-Building Investigation Planner</i> , chart paper (optional), chart paper markers (optional), dry erase markers (optional)
7	10 min		EXAMINE CLASS DATA Lead students in examining their classmates' data.	M-N	
8	20 min		DISCUSS EXPLANATIONS OF THE RESULTS Build understanding through students' discussions in increasingly larger groups.	O-R	
9	8 min		APPLY CHEMICAL ENGINEERING TO HELP OYSTERS Discuss in pairs and as a class how increasing the concentration or temperature could be applied to help oyster larvae build shells quickly.	S-T	<i>Progress Tracker</i>
<i>End of day 2</i>					
10	7 min		NAVIGATE Reorient students to how they can apply their findings from the lesson so far to help oysters.	U	<i>Progress Tracker</i>
11	10 min		BUILD AN INTERACTIVE MODEL WITH CARDS Support students in modeling how adding calcium carbonate compounds can help oysters.	V-W	prepared <i>Reaction Cards</i>

Part	Duration		Summary	Slide	Materials
12	8 min		SHARE MODELS Direct students to share their models with another group.	X	prepared <i>Reaction Cards</i>
13	17 min		BUILD A CLASS CONSENSUS MODEL Have students move into a Scientists Circle. Lead a Consensus Discussion that results in a class consensus model of how adding calcium carbonate to water can help oysters build shells.	Y-AA	chart paper, chart paper markers, prepared <i>Reaction Cards</i> , invisible tape, carbon cycle model from Lesson 10
14	3 min		NAVIGATE Have students update their Progress Trackers again.	BB	<i>Progress Tracker</i>

End of day 3

Lesson 11 • Materials List

	per student	per group	per class
Shell-Building Demonstration materials	indirectly vented chemical splash goggles		1 250-mL beaker 1 scoopula 1 piece weighing paper 50 mL 0.1M CaCl₂ solution 1 g Na₂CO₃ 1 glass stir rod 50 mL vinegar 1 funnel 1 piece filter paper - safety shield
Shell-Building Investigation materials	<i>Shell-Building Investigation Planner</i> - safety goggles - disposable gloves - chemical apron	6 250-mL beakers 1 scoopula 6 pieces weighing paper 300 mL 0.1M CaCl₂ solution 6 g Na₂CO₃ 1 glass stir rod 6 pieces filter paper 1 funnel	- digital scale - ice or some other cooling apparatus - hot plate or some other heating apparatus
Lesson materials	- science notebook <i>Shell-Building Investigation Planner</i> <i>Progress Tracker</i> - prepared <i>Reaction Cards</i>		6 250-mL beakers 1 scoopula 6 pieces weighing paper 0.1M CaCl₂ solution - Na₂CO₃ 1 glass stir rod 6 pieces filter paper 1 funnel - chart paper (optional) - chart paper markers (optional) - dry erase markers (optional) - chart paper - chart paper markers - prepared <i>Reaction Cards</i> - invisible tape - carbon cycle model from Lesson 10

Materials preparation (90 minutes)

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

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

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

Review the *Sample Investigation Data* to understand the lab outcomes and nuances. The water must be very cold for the controls in both reactions. Consider putting water on ice for the day and use that ice water as the solvent for the chemicals.

Students will need a place to collectively record lab results. This may be done collaboratively on a whiteboard with **slide L** projected, but you may instead wish to make a digital, editable version of **slide L** to share with each class or a poster version with chart paper.

Print **single sided** copies of *Reaction Cards*. Cut out enough copies so that every student has a deck of reaction cards. The same decks can be reused between classes.

Have the carbon cycle model from Lesson 10 visible on day 3.

Day 1: Shell-Building Demonstration

- **Group size:** Whole class
- **Setup:** Gather materials for the demonstration. Prepare 2500 mL of an approximately 0.1M calcium chloride solution per class. If using volumetric flasks to do so, use 5.55 g of anhydrous CaCl_2 for each of 5 500-mL volumetric flasks, for a total of 27.75 g of anhydrous CaCl_2 . Students will use this solution during the Shell-Building Investigation. This will provide over 300 mL of CaCl_2 solution for each lab group for up to six total trials.
- **Notes for during the lab:** None
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*. These include:
 - When working with hazardous chemicals, wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and takedown segments of the activity.
 - When diluting acids or bases, the acid or base should be added to water and not water to the acid or base.
 - Observers of activities involving hazardous chemicals must have appropriate PPE eye protection (indirectly vented chemical splash goggles) and non-latex aprons in addition to being positioned approximately 15 feet in front of a demonstration safety shield or closed fume hood sash.
 - Secure loose clothing, wear closed-toe shoes, and tie back long hair.
 - Never eat any food items used in a lab activity.
 - Never taste any substance or chemical in the lab.
 - Only combine substances and amounts as instructed by your teacher.
 - Follow your teacher's instructions for disposing of waste materials.
 - Use caution when working with glassware, which can shatter if dropped and cut skin.
 - Immediately clean up any liquid spilled on the floor so it does not become a slip/fall hazard.
 - Never pour chemicals, either used or unused, back into their original container.
 - If you get a hazardous chemical on your clothing or have a clothing fire, use the emergency shower.
 - If you get a chemical in your eye, use an eyewash station immediately.
 - Point the test tubes, beakers, or other vessels away from yourself and other people when the vessels contain reactants or other substances.
 - Never use mouth suction to fill pipets.
 - Wash your hands with soap and water immediately after completing this activity.
- **Disposal:** All waste can be washed down the sink. A small amount of vinegar can help dislodge stuck calcium carbonate powder.
- **Storage:** All the other materials can be reused from year to year if stored in a sealed container. Anhydrous CaCl_2 is deliquescent, meaning it absorbs enough moisture to turn into a brine over time, so the exact ratios of substances will become less accurate the longer the material is stored.

Day 1: Shell-Building Investigation

- **Group size:** 5 students
- **Setup:** Gather materials for each group.
- **Notes for during the lab:** Make sure that students have access to some means of changing the temperature of their solutions so as to test multiple temperatures. This may include **brief heating** on a hot plate or in a microwave, or **cooling** using ice or a refrigerator. Even hot and cold tap water can provide a measurable difference in reaction rates.
- **Safety:** Follow standard safety considerations listed in the *OpenSciEd Teacher Handbook: High School Science*.
- **Disposal:** See disposal directions for the Shell-Building Demonstration.
- **Storage:** See storage directions for the Shell-Building Demonstration.

Lesson 11 • Where We Are Going and NOT Going

Where We Are Going

The targeted disciplinary core idea that we are developing in this lesson is:

- **PS1.B.1: Chemical Reactions.** Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.
- **PS1.B.2 Chemical Reactions.** In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.

Crossout explanation: Students do not need bond energies or endo- and exothermic reactions to explain the phenomenon of oyster die-off, so these are not coherent to student learning in this unit. The remaining ideas in PS1.B.1: Chemical Reactions about bond energies and endo- and exothermic reactions are deeply modeled, explained, and assessed in detail in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*. Postponing the learning of these two ideas does not reduce the DCI to middle school grade level. Middle school grade levels of the PS1 disciplinary core ideas are concerned with much larger-scale properties of matter and do not include the ideas of bonds, equilibrium, or rate.

Students have already developed multiple ideas that are leveraged in this lesson: oyster larvae build their shells by combining calcium and carbonate ions, hydrogen ions interfere with this process by bonding with carbonate ions, and reactions can be reversible.

Through an investigation that students plan in order to produce data to marshal as evidence, students gather data that show that increasing the concentration and temperature of an Na_2CO_3 and CaCl_2 reaction changes the speed of the reaction (SEP: 3.1; DCI: PS1.B.1; CCC: 7.1). Students specifically identify this as the reaction rate (DCI: PS1.B.1).

After gathering and combining our data, students develop a model and provide the model's components and interactions as evidence for how particle-level collisions determine the rate of reactions that build oysters' shells (SEP 2.3; DCI: PS1.B.1, PS1.B.2).

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

Where We Are NOT Going

Students do not need to develop the idea of catalysts or the role of surface area in reaction rate, as these concepts are outside the scope of the NGSS and catalysts require prior knowledge that students will not develop until *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*. Students also do not consider the possible unintended consequences of adding calcium carbonate to the ocean until Lesson Set 3. Finally, the typical reaction rate investigations of antacid tablets in water or chalk in vinegar have been avoided as the focal reaction because it would be more difficult for students to make the connection to shell-building when they do not observe a solid product; however, either reaction can work in tandem with the calcium chloride-sodium carbonate reaction. As such, this lesson does not derive the equation for reaction rate; to do that, students would need to observe the product and dry it out fully.

LEARNING PLAN for LESSON 11

1 · NAVIGATE

3 min

MATERIALS: None

Reflect on where we came from. Display slide A. Lead students into this lesson by asking what the class had figured out and was wondering at the end of Lesson 10.

Suggested prompt	Sample student response
What did we figure out in Lesson 10?	Oysters build their shells by combining Ca^{2+} and CO_3^{2-} ions to make calcium carbonate. This happens in a very short time frame. It is harder for oysters to build their shells when the water is more acidic because there are a bunch of H^+ ions floating around that can bond with CO_3^{2-} ions. Limestone rocks are also made of calcium carbonate, which makes sense because they are made of calcium and carbonate ions from the bones and shells of dead organisms.
What were we wondering at the end of Lesson 10?	Would something like adding calcium carbonate (limestone or eggshells) help give more materials for oysters to build their shells?
What is the key time to help oysters build their shells?	Oysters do a lot of shell formation within the first couple days of their lives, so that period seems important.

2 · BRAINSTORM METHODS TO SPEED UP A REACTION

7 min

MATERIALS: Shell-Building Demonstration, science notebook

Open up a space for brainstorming. Say, *We want to improve the reaction so that more shell is formed in the early hours of an oyster's life—in other words, we want the shell to form faster. One idea was to add calcium carbonate to the water so oysters have plenty of ions to build their shells.* Show **slide B**. Give students a chance to answer the prompts on the slide in their notebooks, then bring the class together and discuss.*

Suggested prompt	Sample student response
<i>What is another chemical reaction or other process in our daily lives that we want to happen relatively quickly?</i>	Cooking or baking. Starting a fire.
<i>What do we do to speed up those processes or to help the reaction keep going?</i>	We can increase the temperature to speed up cooking or dissolve a drink faster. Sometimes adding more material helps, like adding more wood to a fire.
<i>When we talk about one reaction happening more quickly than another, what does that mean?</i>	It makes more product in the same amount of time.
<i>In this class, where else have we seen examples of how quickly something happens?</i>	In Lesson 5 and Lesson 10 we added data to our model showing how quickly carbon is moving between different Earth spheres.

Tie back to speeding up shell-building. Display **slide C**. Say, *Let's see if any of these techniques can be applied to oysters.* Lead students in a short discussion of how these techniques could be applied to oysters.

Ask, *How could we apply these same techniques to help oyster larvae build shells in the first 24-48 hours?* Listen for ideas about increasing the temperature of the water and adding more calcium and carbonate ions.

ADDITIONAL GUIDANCE

At this point it is fine if students do not use the specific terminology of modifying temperature or concentration to describe their ideas. This terminology will be clarified shortly as students think about how they can apply their ideas to a version of the actual shell-building reaction.

Students may also bring up ideas related to stirring the solution—in other words, increasing the surface area. If students are passionate about this idea, you may wish to have them pursue it, but make sure that you are encouraging these students to think at a particle level.

Show **slide D**. Explain to students that in the ocean, oysters already have access to dissolved Ca^{2+} and CO_3^{2-} ions, but to test how we can influence shell-building in the classroom, we must supply the ions ourselves using the common powders listed on the slide.

* SUPPORTING STUDENTS IN DEVELOPING AND USING STABILITY AND CHANGE

This is the first time students have considered rates in the context of reactions. (CCC: 7.2) If students struggle with the last two prompts, you may ask, *What do we mean when we talk about a vehicle moving or a person running quickly?* If students still struggle to articulate the idea that something is happening over a relatively short period of time, you may wish to help them with one of the following demonstrations:

- Ask two students to walk across the room, one very slowly and the other very quickly. Time how long it takes for them to cross the room and ask students how they would figure out the speed of each.
- Ask two students to walk across the room, one very slowly and one very quickly, for a set time. Measure how far they went in this time and ask students how they would figure out the speed of each.
- Ask two students to pour water from one container to another—one quickly, one slowly. As with walking across the room, hold either time or the amount of substance constant while measuring the other.

SAFETY PRECAUTIONS



Be sure to wear proper personal protective equipment, like goggles, while completing this demonstration.

Demonstrate the reaction. Say, *This reaction might work a little bit differently than you anticipate.* Demonstrate the reaction and point out that the milky substance that forms consists of small particles of calcium carbonate. Run some of the sample through filter paper and show students what the substance looks like on the filter paper. The fact that the product is not a whole shell will surprise and bother some students, so lead a brief discussion. Display **slide E**.

Suggested prompt

Why would the calcium carbonate form small particles here instead of a whole shell like when oysters are involved?

How could we know for sure that the product is the same material as an oyster shell?

What reactions have we seen with CaCO_3 that we could use?

Sample student response

The oysters have to use energy to build the shell and there is nothing organizing the building here.

We could look at it under a microscope.

We could see if it reacts the same way as CaCO_3 .

We could add vinegar like in Lesson 10 and see what happens.

Show students how adding approximately 50 mL of vinegar causes the formed CaCO_3 to dissolve, much as vinegar started to dissolve the marble chips in Lesson 10.

Think about how techniques to speed reactions could be applied to oysters. Show **slide F**. Give students a minute to turn and talk to a partner about the question on the slide, then discuss as a class. Be sure to follow up with the additional prompts.

Suggested prompt

How can we test our different ideas for speeding up shell-building using this reaction?

How would particles move differently at higher temperatures? How would that help speed up the reaction?

How would particles interact differently with more of them in the solution? How would that help speed up the reaction?

Sample student response

We can increase the temperature.

We can increase the amount of the powders that we put in the water.

Particles would be moving faster. That might help speed it up somehow.

There would be more particles, so there would be more chances for reactions.

3 · PREPARE TO PLAN THE INVESTIGATION

5 min

MATERIALS: science notebook

Prepare students to plan an investigation. Show **slide G**. Ask students to turn and talk with a partner about the questions on the slide. After a couple of minutes, bring the class together to share. Ask, *How can we describe these two strategies (increasing temperature or adding more stuff) in scientific terms?* Listen for ideas about temperature and concentration.

Students should have used the term *temperature* to refer to kinetic energy in *Polar Ice Unit*. Students used the word *concentration* in Lesson 4 of this unit. If students have not used the terms *temperature* or *concentration* yet in this discussion, point out the connections to students' ideas—for example, by heating or adding more substance, we are modifying the temperature and concentration, respectively. Then continue the investigation planning discussion.

Suggested prompt	Sample student response
<i>How can we know if the reaction is actually speeding up?</i>	We have to measure it somehow.
<i>How do we measure the speed of moving objects in everyday life?</i>	We measure how far something went in a certain time. We measure how much time it took to go a certain distance.
<i>How could we measure the speed of the reaction?</i>	We could measure how much stuff is made in an amount of time or measure how long it takes for the reaction to finish.

Define the idea of reaction rate. Show slide H. Say, *Everyday speed is a distance traveled in a certain time, which mathematically is distance divided by time.* Reference the equation on the slide and continue, *We decided reaction speed is how much product is made in a given time. This is kind of a different idea. What should we call it?*

Give students a chance to individually brainstorm ideas in their notebooks, then take all student suggestions. Student ideas should focus on the concepts of “speed” or “rate”. Connect these ideas to the term scientists generally use, *reaction rate*, and have students add this term to their Personal Glossaries. Reaction rate describes how quickly a reaction forms a product.

4 • PLAN THE INVESTIGATION

10 min

MATERIALS: *Shell-Building Investigation Planner*, 6 250-mL beakers, 1 scoopula, 6 pieces weighing paper, 0.1M CaCl₂ solution, Na₂CO₃, 1 glass stir rod, 6 pieces filter paper, 1 funnel

ADDITIONAL GUIDANCE

If you would like details about what students should consider designing, see sample investigation data in *Sample Investigation Data*. Support is also provided to help students with using stoichiometry to determine the quantity of Na₂CO₃ needed.



Plan the investigation. Break students into at least seven lab groups and direct each group to test either temperature or concentration. Make sure multiple groups are investigating each factor.

Distribute *Shell-Building Investigation Planner* and show **slide I**. Show students the investigation materials they will have available. Explain how students could use the filter and filter paper to quantify what is formed in the reaction. Before having groups plan their investigation, ensure that they correctly use stoichiometry to figure out the quantities of Na₂CO₃ that they will need (question 1 on the handout). *

Ask each group to work together to plan their investigation. Say that each person in the group should set up a data table on their handout to record any data they expect to collect.* Remind students that they will conduct multiple trials and test at least two different temperatures or concentrations. Once everyone in a group has completed their data tables, sign off on them and allow groups to gather materials and begin the investigation. *

* SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

Students have to use *ratio thinking and mathematical tools* developed in Lessons 8 and 9 to determine how to proceed with this investigation. (SEP: 5.5)

* SUPPORTING STUDENTS IN DEVELOPING AND USING STABILITY AND CHANGE

Push students to have a plan to *measure the speed of the reaction quantitatively or semi-quantitatively*. Use examples like those discussed previously in class (walking across the room, pouring water) to help students think of different ways to measure these reactions. (CCC: 7.1)

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Student **investigation plans** allow for measurement of a dependent variable (amount of product produced over time) that helps provide some **quantification of the rate of change in the reaction**. (SEP: 3.1; DCI: PS1.B.1)
- Students **plan to investigate** how a **specific change in their factor will influence how the reaction proceeds** and can describe what they expect to see, **providing evidence that they will be able to answer the investigative question**. (SEP: 3.1; CCC: 7.2)

What to do: If student plans do not include measurement of a specific variable, take them back to the original problem of oysters building shells in a short time and ask students to think about how we could measure whether a shell is being built fast enough. Also ensure that students are able to make a prediction about what they will measure, as that means their investigation should be able to produce meaningful results that can be applied to the greater problem.

Building toward 11.A.1 Plan an investigation to produce data as evidence to determine how **rates of change** in reactions **differ under different conditions**. (SEP: 3.1; DCI: PS1.B.1; CCC: 7.2)

* SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

Students develop *hypotheses* in this lesson as a way to *make predictions about how their factor will influence reaction rate*. They also gain experience with how scientists work to gather evidence for their hypotheses, sometimes figuring out how something does not work and eliminating those hypotheses. Point this out to students to help lessen any frustration with the “extra step” of predicting what will happen, or with the investigation if the process is not working as students anticipated. (SEP: 3.5)

5 · CONDUCT AN INVESTIGATION

15 min

MATERIALS: Shell-Building Investigation

Set up the investigation. Show slide J and remind students of the safety guidelines.

SAFETY PRECAUTIONS



Be sure to follow (and support students in following) all safety precautions. Sodium carbonate is a base and direct skin or eye contact or inhalation can cause irritation, rash, and burns. Flush the affected area thoroughly with water if contact occurs. Calcium chloride can also dry out skin and can lead to severe health effects if ingested.

Conduct the investigation. Display slide K. Allow each group to conduct the investigation and collect data. Remind students to record data as they go. *Sample Investigation Data* includes some possible data. As students finish, have them answer questions 6 and 7 on their handouts.

End of day 1

6 · COMPILE DATA AS A CLASS

7 min

MATERIALS: *Shell-Building Investigation Planner*, science notebook, chart paper (optional), chart paper markers (optional), dry erase markers (optional)

Explain how data will be compiled. Display slide L, which shows a data table with space for each group to summarize their results. Have each group add their summary to the table. If possible, you may wish to project the slide on a whiteboard and ask students to write their responses on the board. You may also make a similar table on chart paper or share a digital version with the class instead. In any case, be sure

to take a picture or retain a copy of the final product.

What we tested	What we saw	What it means
1 - temperature	faster reaction in warmer temperature	▲ reaction rate at ▲ temperatures
2 - temperature	▲ reaction rate at ▲ temperatures	
3 - temperature	▼ reaction rate at ▼ temperatures	
4 - molarity	▼ reaction rate at ▼ molarity	▲ reaction rate at ▲ molarity
5 - molarity	▼ reaction products at ▼ molarity	
6 - molarity	reaction was cloudier at ▲ molarity	

7 • EXAMINE CLASS DATA

10 min

MATERIALS: science notebook

Examine the data from day 1. Make sure all students can see the data summary. Display **slide M**. Ask students to write in their science notebooks a summary of if changing temperature and concentration seem to slow down, speed up, or have no effect on the reaction rate.

Discuss the data as a class. Display **slide N**.

Suggested prompt	Sample student response
<i>What were we trying to figure out in this investigation?</i>	We were trying to figure out if we can speed up shell formation in oysters. We were trying to figure out if we can speed up reaction rates.
<i>How did we look for evidence of reaction rate in this investigation?</i>	We timed how long it took for the reaction to finish. We found the mass of the products after a set amount of time. We estimated the percentage of the sample that was cloudy.
<i>How did temperature impact the rate of calcium carbonate formation?</i>	When the temperature was higher, more calcium carbonate was formed faster.
<i>How did concentration impact the rate of calcium carbonate formation?</i>	When the concentration of reactants was higher, more calcium carbonate was formed faster.



8 • DISCUSS EXPLANATIONS OF THE RESULTS

20 min

MATERIALS: science notebook

Have students explain their results. Display slide O and ask students to answer the question individually in their notebooks. Tell them that their best ideas are fine at this point—they do not need to be sure. Remind students to think at the particle level.

Move students into lab groups. Display slide P. Tell students that they will get back with their lab groups and have a few minutes to work together to explain why they think their factor changed the reaction rate. Ask groups to be ready to share their ideas with others.



Pair up like groups. Show slide Q. Pair each group with another group that tested the same factor (temperature or concentration) and give them a few minutes to come to a consensus. Each pair of groups should select a representative to share with the class.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: Students discuss or show how **increasing temperature or concentration can increase how hard particles collide and/or how often they collide, increasing the likelihood of a reaction and therefore the reaction rate.** (DCI: PS1.B.1, PS1.B.2; CCC: 7.1)

What to do: Students should be cued to think about these processes in particle terms after Lesson 10, but if students are not discussing how particle motion affects their observations from the investigation, ask them to sketch out simple models in their notebooks or, in whole-class discussion, tell you how to draw them on the board. If students do not state evidence from the experiments, push them to do so. If students have trouble describing the evidence they based their model on, consider asking how their model would change if some aspect of the investigation changed—for example, if temperature did not affect reaction rate.

Building toward 11.B.1 Build a model based on evidence that explains how **changes in the oyster-water system** affect **reaction rates** and **equilibrium.** (SEP: 2.3; DCI: PS1.B.1, PS1.B.2; CCC: 7.1)

Discuss explanations as a class. Bring the class back together, display slide R, and lead the class in a Building Understandings Discussion. Begin by asking for representatives to share why they think temperature and concentration had the effects that they did, then follow up using the provided prompts.

KEY IDEAS

Purpose of this discussion: Here students need to think specifically about how particles are interacting in these different situations. Students should progress toward the conclusion that reactions can actually go faster when there are more opportunities for particles to break old bonds and form new ones.

Listen for these ideas:

- When we increased temperature or concentration, more calcium carbonate was formed in less time.
- When the temperature is increased, particles move faster so they can hit each other harder and more often.
- When the concentration is increased, reactant particles hit each other more often.
- When particles hit harder or more often, bonds are more likely to break and re-form, which means the reaction is happening more quickly.

Suggested prompt	Sample student response
<i>How does temperature affect reaction rate at the particle level?</i>	When the temperature is higher, particles are going faster and hit each other harder and more often. Then bonds break more easily because more force is applied to them.
<i>Why are particles going faster when the temperature is higher?</i>	Because the particles have more energy.
<i>Why do more particle hits mean that bonds are going to break and form more “easily”?</i>	In order for bonds to break and form, the right particles have to come in contact with each other. So the more hits of particles, the more chances the right ones are going to come together to react.
<i>Why does concentration affect reaction rate at the particle level?</i>	When there is a higher concentration, particles hit each other more often, so they can break and form bonds more easily.
<i>Why does a higher concentration mean particles hit each other more often?</i>	If particles are more packed in, they will be more likely to hit each other as they move around.

9 · APPLY CHEMICAL ENGINEERING TO HELP OYSTERS

8 min

MATERIALS: Progress Tracker

Discuss the solution in pairs. Show slide S. Split the class in half and ask each half of the class to turn and talk with a partner about one of the prompts on the slide. Give students a few minutes to discuss, then ask a few volunteers to share their discussion.

Suggested prompt	Sample student response
<i>How could what we have figured out about temperature and reaction rate help oyster larvae build their shells?</i>	Oysters might be able to build their shells faster in higher temperatures, so maybe we could increase the temperature in oyster tanks.
<i>How could what we have figured out about concentration and reaction rate help oyster larvae build their shells?</i>	If we added something that has calcium and carbonate ions in it, we could speed up shell-building.

Update Progress Trackers. Display slide T. Say, *These are really interesting ideas! Let’s add them to our Progress Trackers.* Give students time to update their *Progress Tracker*. Encourage them to work with a partner.

Use *Progress Tracker Key* for teacher guidance.

End of day 2

10 • NAVIGATE

7 min

MATERIALS: *Progress Tracker*

Connect back to thinking about helping oysters. Display **slide U** and ask students to take out their *Progress Tracker*. Ask students to turn and talk with a partner to recall what they were thinking about when they updated their Progress Trackers. Then take responses from the class, making sure to follow up with the last two prompts.

Suggested prompt	Sample student response
<i>Which potential solutions were we considering at the end of the last class?</i>	We discussed adding something with calcium and carbonate to increase the concentration of the ions oysters need and the reaction rate. We discussed increasing the temperature of oysters' water to increase the reaction rate.
<i>What did we want to keep in mind about these solutions' effects on people and the environment?</i>	Whatever we add has to be safe for the environment. Whatever we add has to be relatively inexpensive. Increasing temperature might backfire—it could be bad for oysters in other ways, and it would be really bad for other organisms to try to increase the temperature of the ocean. It could also increase the rate of reactions that we know are harmful, like H_2CO_3 formation.
<i>Where could we get calcium and carbonate ions?</i>	We could get them from anything made of calcium carbonate—old oyster shells, limestone, chalk, or eggshells.
<i>Could we help oysters by throwing big chunks of rock into the ocean?</i>	Maybe, but the ions need to dissolve into the water in order to react, so it would be better to break up the rock first.
<i>Which solution looks more promising, adding calcium carbonate or increasing the temperature?</i>	Adding calcium carbonate looks more promising because it does not have as many obvious negative impacts.
<i>Do we know for sure that adding calcium carbonate would help oysters?</i>	No. It is possible there is something we have not considered yet.

ADDITIONAL GUIDANCE

There are several additional factors at play in ecosystems that are outside the scope of the NGSS but which may occur to the teacher. Do not pursue these ideas with students unless they have already suggested the concepts based on evidence.

1. Carbon dioxide, like many gasses, dissolves more easily in lower-temperature water, as the gas molecules do not escape as easily when the particles around them are moving relatively slowly.
2. Calcium carbonate formation from dissolved ions is actually favored in the long run at lower temperatures. This occurs because of the relative bond energy of the intermolecular forces that water forms with the dissolved ions compared to the bond energy of the calcium-carbonate bond. This will not show up in classroom-level investigations, but it is a nuanced part of aquaculture chemistry.
3. Other compounds that do not contain carbonate may also support marine ecosystems. For more information, see <https://www.frontiersin.org/articles/10.3389/fclim.2019.00007/full>.

11 • BUILD AN INTERACTIVE MODEL WITH CARDS

10 min

MATERIALS: prepared *Reaction Cards*

Individually model how adding calcium carbonate can help oysters. Display slide V. Distribute the cards from *Reaction Cards* and say, *Now that we have agreed on a potential solution, we need to model it to help us decide if it could really help oysters build their shells. These cards include the ions that oysters need to build their shells, as well as the hydrogen ions that we figured out can interfere with the process. You will use these cards to model what happens when we add calcium carbonate to the water. You will have a few minutes to think on your own first, then you will work with a partner to come up with an interactive model that you will share with classmates. Your model should show how the ions move and how bonds break and form at different points in the process.*

Give students three minutes to model on their own using the cards. Emphasize to students that their model should be interactive; meaning, it should show ion movement and interactions over time. *

Reaction Cards

H ⁺	H ⁺	H ⁺	CO ₃ ²⁻
H ⁺	H ⁺	H ⁺	
Ca ²⁺	Ca ²⁺	CO ₃ ²⁻	CO ₃ ²⁻
Ca ²⁺	Ca ²⁺	CO ₃ ²⁻	CO ₃ ²⁻

continued

H ⁺	H ⁺	H ⁺	CO ₃ ²⁻
H ⁺	H ⁺	H ⁺	
Ca ²⁺	Ca ²⁺	CO ₃ ²⁻	CO ₃ ²⁻
Ca ²⁺	Ca ²⁺	CO ₃ ²⁻	CO ₃ ²⁻

continued

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

At the high school level, students should *develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system*. Individual time gives students an opportunity to synthesize evidence and formulate their ideas before they begin to work as a class to build a model from evidence of the entire system. Students should be prepared to defend their ideas and evaluate others' ideas when they share in small groups and with the whole class. As students work, circulate among them, prompting them to defend their model (or part of their model) using evidence collected during investigations. This can help students think through where their model may have a hole prior to the collaborative group sharing. (SEP: 2.3)

ADDITIONAL GUIDANCE

Some students may get confused and think that additional CO₃²⁻ ions would be a problem, because they would bond with H⁺ ions to form HCO₃⁻ and then to form H₂CO₃, carbonic acid. Use this as an opportunity to remind students that H₂CO₃ is not in itself harmful; we figured out in Lesson 10 that free hydrogen ions instead hurt oyster larvae by bonding with the free CO₃²⁻ that the larvae need.



Model with a partner how adding calcium carbonate can help oysters. After three minutes, show slide W. Have students join a partner and come to a consensus.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students can articulate the **evidence that caused them to add ideas to their models** (or explanations). (SEP: 2.3)
- Students' models show the **relationships between the components of the ocean acidification system** (Ca^{2+} , CO_3^{2-} , and H^+ ions). (SEP: 2.3)
- Students discuss or show how **increasing the concentration** of calcium carbonate ($\uparrow \text{CaCO}_3$) can **increase frequency/force of collisions** ($\uparrow$ collisions), **increasing the likelihood of a reaction** and therefore the **reaction rate** ($\uparrow$ reaction rate). (DCI: PS1.B.1, PS1.B.2)
- Students show how **increasing the concentration of carbonate ions** ($\uparrow$ concentration CO_3^{2-}) that can bond with H^+ ions also leaves plenty of CO_3^{2-} ions available for shell-building. (DCI: PS1.B.1, PS1.B.2)
- Students use words or images to **explain how changing** two types of **variables in the water/ CaCO_3 system can result in changes**, while other combinations of variables **cause the system to remain stable**. (CCC: 7.1)

What to do: Circulate and look at students' models in development. It is fine if students do not show all components, but they should be able to represent some portions and articulate some evidence for what they are representing. In particular, the prompt about pH will be a challenge and may be more fully fleshed out in class discussion. If a student seems to be struggling, you may wish to spend more time with their group as they share models to see how their ideas interact with others', and prompt the group to consider evidence and prior understanding of particle motion.

Building toward 11.B.2 **Build a model based on evidence** that explains how **changes in the oyster-water system** affect **reaction rates** and **equilibrium**. (SEP: 2.3; DCI: PS1.B.1, PS1.B.2; CCC: 7.1)

12 · SHARE MODELS

8 min

MATERIALS: prepared *Reaction Cards*

Have students share their models with another pair. Show slide X. Gain all students' attention and tell them that they will meet with another pair. Each pair should take turns giving a three-minute demonstration of their model, using card movement to answer the questions on the slide.

MATERIALS: chart paper, chart paper markers, prepared *Reaction Cards*, invisible tape, carbon cycle model from Lesson 10

 **Begin to develop a class consensus model.** Say, *Now that you have had a chance to see each other's models, let's build a class consensus model that reflects all our learning from the last few days.* Gather students into a Scientists Circle with a piece of chart paper clearly visible to all students, and, if you wish, the cards from *Reaction Cards* taped on the board.*

KEY IDEAS

Purpose of this discussion:

In this discussion, students come to consensus on how to represent the big ideas from the last two lessons. This is the last whole-class representation of the unit, so it is important that by the end all students have a clear understanding of the ideas that are being developed. This activity pushes students to apply the same particle-level model to both reaction rates and equilibrium in reversible reactions.

Listen for these ideas:

- Oyster larvae build shells by combining Ca^{2+} and CO_3^{2-} .
- This is more difficult when the water is more acidic because the excess H^+ ions can bond with CO_3^{2-} ions, making them unavailable for oysters to use.
- Adding CaCO_3 to the water provides extra Ca^{2+} and CO_3^{2-} ions, which speeds the reaction rate and allows for more shell formation because the ions can collide with each other more frequently, breaking and forming bonds more quickly.
- Adding extra CaCO_3 can also slightly increase the pH of the water, as seen in *Acid Behavior Assessment*, because the additional CO_3^{2-} ions shift equilibrium in the acidification reaction.

Show slide Y. Ask students to share ideas that are similar between models. If the whole class agrees with an idea, write it on chart paper to include in the class consensus model at the end of the discussion.

Suggested prompts	Sample student responses	Follow-up questions
<i>What similarities did you see between models?</i>	Calcium and carbonate ions combine to form oyster shells. When the water is acidic, extra H^+ ions bond with CO_3^{2-} to form HCO_3^-, leaving less carbonate. When there is more CO_3^{2-} these ions can collide with Ca^{2+} more often, speeding the reaction. If the calcium carbonate is broken up into little pieces, more Ca^{2+} and CO_3^{2-} ions will collide and be able to react.	<i>What evidence do we have for these ideas?</i> <i>How can we show these ideas happening with the Reaction Cards?</i>

* ATTENDING TO EQUITY

You may wish to tape some of the cards from *Reaction Cards* on the board to help show speakers' thinking throughout this discussion. This can help students track their peers' ideas more easily. You may additionally wish to leave card decks with any students who want to use them throughout the discussion so that students can engage with the ideas in the way that is most meaningful to them.

Suggested prompts	Sample student responses	Follow-up questions
<i>What differences did you see between models?</i>	Some people had CaCO_3 dissolving as a separate step.	<i>Which of these differences are important?</i> <i>Which ideas are supported by the evidence from our investigations?</i>

Expand the class consensus model to include other reactions. Display slide Z.

Suggested prompt	Sample student response
<i>What other reactions might calcium or carbonate ions undergo in the water?</i>	The Ca^{2+} ions could react with random negative ions if there are any. The CO_3^{2-} ions could bond with H^+ to make HCO_3^-.
<i>How could the pH be affected when CaCO_3 is added to the water?</i>	It might go up slightly like in the earlier assessment, since CO_3^{2-} could bond with H^+ . A lesser concentration of H^+ means a higher pH and less acidity.
<i>How could the extra CO_3^{2-} impact acidification? Where have we seen this before?</i>	Extra CO_3^{2-} would react with H^+ and push the reaction slightly toward the left (reactant) side.
<i>Adding a substance to one side of a reversible reaction causes the reaction to move in the other direction. Why is this?</i>	When there are more particles on one side, they can collide to break and form bonds more easily and make the reaction go the other way.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students can articulate the **evidence that caused them to add ideas to their models** (or explanations). (SEP: 2.3)
- Students' models show the **relationships between the components of the ocean acidification system** (Ca^{2+} , CO_3^{2-} , and H^+ ions). (SEP: 2.3)
- Students discuss or show how **increasing the concentration** of calcium carbonate ($\uparrow \text{CaCO}_3$) can **increase frequency/force of collisions** ($\uparrow$ collisions), **increasing the likelihood of a reaction** and therefore the **reaction rate** ($\uparrow$ reaction rate). (DCI: PS1.B.1, PS1.B.2)
- Students show how **increasing the concentration of carbonate ions** ($\uparrow$ concentration CO_3^{2-}) that can bond with H^+ ions also leaves plenty of CO_3^{2-} ions available for shell-building. (DCI: PS1.B.1, PS1.B.2)
- Students use words or images to **explain how changing** two types of **variables in the water/ CaCO_3 system can result in changes**, while other combinations of variables **cause the system to remain stable**. (CCC: 7.1)

What to do: At this point, the majority of students should be getting comfortable with the first three bullets and coming to a consensus on the last idea. If the last idea is a particular struggle, use the cards from *Reaction Cards* to help students reason about possible interactions based on prior learning about ionic bonding.

Building toward 11.B.3 **Build a model based on evidence** that explains how **changes in the oyster-water system** affect **reaction rates** and **equilibrium**. (SEP: 2.3; DCI: PS1.B.1, PS1.B.2; CCC: 7.1)

Add agreed-upon ideas to the carbon cycle model. Point to the list of consensus ideas and say, *We have figured out a lot of interesting things in this lesson! Do we still think that adding calcium carbonate to the water would help oysters?* After students express agreement, direct them to the carbon cycle model and lead a discussion about how to add these ideas. Display **slide AA**.

Suggested prompt

How can we add our ideas to the carbon cycle model?

How can we show something happening step by step, without just making a list?

Sample student response

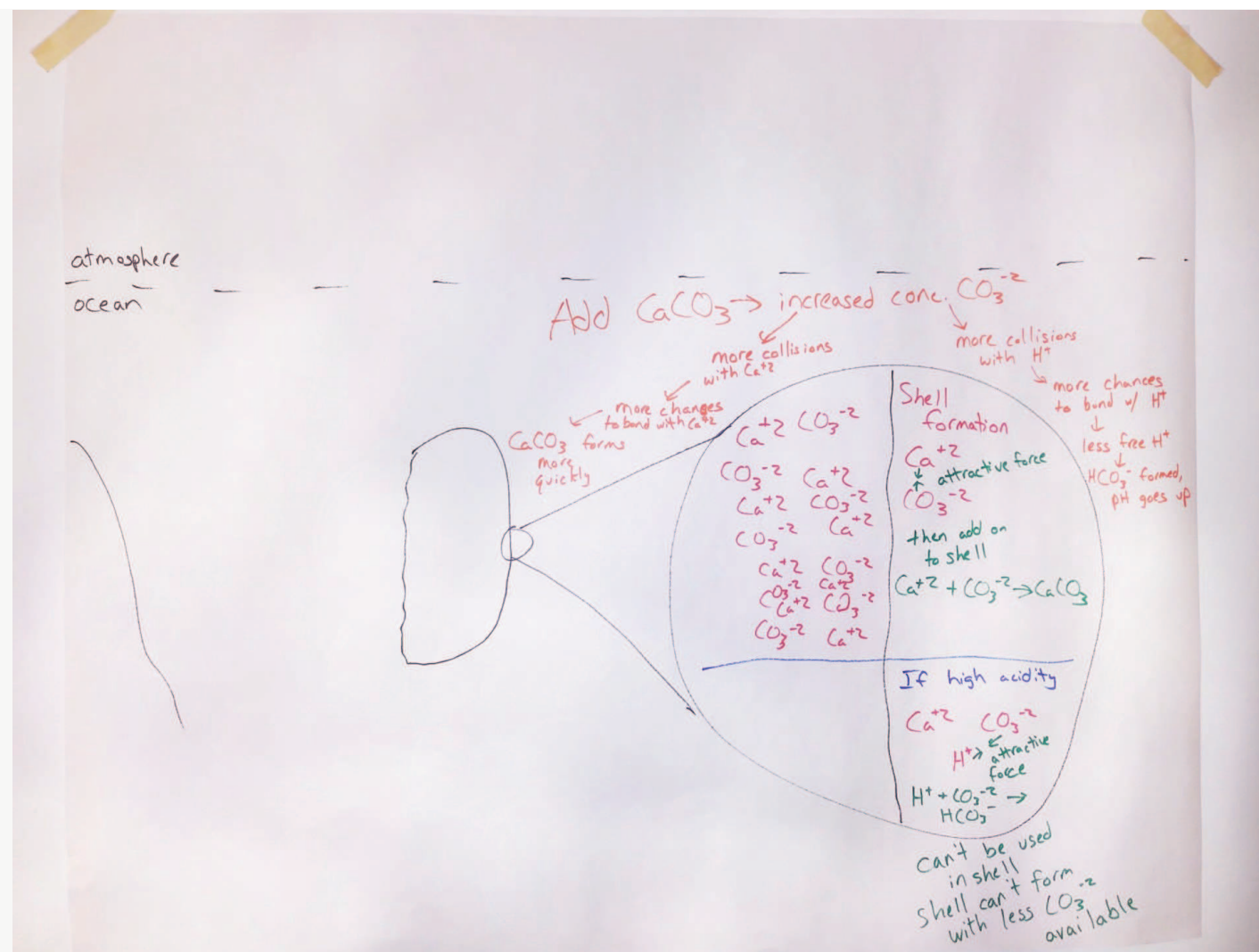
It will not work to add the reaction cards.

It would be difficult to redo the particle model.

We had a lot of steps. Maybe we could just write them.

We could make a flowchart.

Lead students in making a flowchart on a sheet of chart paper that shows how adding calcium carbonate to the water can help oysters build shells more quickly. If the class comes to consensus on other reasonable additions, include those as well.



Example Flow Chart

MATERIALS: *Progress Tracker*

Update Progress Trackers. Show slide BB. Ask students to work with a partner to update their *Progress Tracker* with any new ideas from the day's discussion. Say, *At this point, we have a lot of interesting ways to use chemistry to help oysters. We will need to evaluate these solutions in light of the different criteria and constraints in place. Let's plan to do that tomorrow.*

See *Progress Tracker Key* for a sample *Progress Tracker* entry.

Additional Lesson 11 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HSN.Q.A.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

As students plan their investigation, they have an opportunity to use the stoichiometric tools developed in Lessons 8 and 9 to determine an appropriate amount of sodium carbonate to mix with the given amount of calcium chloride.

LESSON 12: What criteria and constraints do we need to consider when designing solutions to help protect oysters?

PREVIOUS LESSON We investigated how temperature and concentration influence how much product a reaction makes in a given time. We modeled what is happening at a particle level when reactions speed up and used this model to figure out that adding calcium carbonate provides plenty of carbonate ions for oysters and slightly reverses acidification.

THIS LESSON

PUTTING PIECES TOGETHER,
PROBLEMATIZING

1 day



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We review all we have figured out so far and develop a class list of possible solutions to prevent oyster die-off. We narrow down the list of possible solutions by considering criteria and constraints for our design, informed by what we have already learned about the priorities of impacted communities and by our own knowledge and experience. We discuss how these criteria and constraints might be interrelated, contradictory, and context dependent. We choose a promising solution to develop in groups.

NEXT LESSON We will use site profiles to refine our solutions, criteria, and constraints. Then we will develop specific plans to outline the intended and potential unintended consequences and to quantify the impacts of our solutions.

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-
1, HS-ETS1-2



WHAT STUDENTS WILL DO

12.A Define interacting social, technical, and environmental criteria and constraints to alter the systems around oysters in a way that considers societal requirements and reduces environmental degradation. (SEP: 1.8; DCI: ETS1.B.1, ESS3.C.2; CCC: 4.1)

WHAT STUDENTS WILL 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.

Lesson 12 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Direct students to return to their Progress Trackers to think about what we have figured out in this unit.	A	<i>Progress Tracker</i>
2	12 min		INVENTORY POSSIBLE SOLUTIONS Help students collect possible solutions to oyster larvae die-offs based on what we have figured out in this unit.	B-C	3 3x3 sticky notes, permanent marker, <i>Progress Tracker</i> , carbon cycle model, https://newsroom.ucla.edu/releases/using-seawater-to-reduce-co2-in-atmosphere (optional), chart paper (optional), chart paper markers (optional)
3	15 min		CONSIDER COMMUNITY PRIORITIES Motivate and support thinking about community priorities with regard to proposed solutions.	D-G	<i>Progress Tracker</i> , <i>Discuss Interested Parties</i> , <i>Extension Opportunity</i> (optional), <i>Poultry Farmers</i> , <i>Northwest Indian Fisheries</i> , <i>Oyster Farmers</i> , <i>Restaurant Personnel</i> , chart paper (optional), chart paper markers (optional)
4	13 min		IDENTIFY AND BEGIN TO DEVELOP PROMISING SOLUTIONS Begin developing a solution of interest and realize that more information is needed.	H-I	

End of day 1

Lesson 12 • Materials List

	per student	per group	per class
Lesson materials	• <i>Progress Tracker</i> • 3 3x3 sticky notes • permanent marker • <i>Discuss Interested Parties</i> • science notebook • <i>Extension Opportunity</i> (optional)		• carbon cycle model • https://newsroom.ucla.edu/releases/using-seawater-to-reduce-co2-in-atmosphere (optional) • chart paper (optional) • chart paper markers (optional) • <i>Poultry Farmers</i> • <i>Northwest Indian Fisheries</i> • <i>Oyster Farmers</i> • <i>Restaurant Personnel</i>

Materials preparation (30 minutes)

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

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

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

Make sure the class consensus model from Lesson 11 is visible to students.

Students will need to access *Discuss Interested Parties* from Lesson 7.

Consider providing class copies of Lesson 7 readings *Poultry Farmers*, *Northwest Indian Fisheries*, *Oyster Farmers*, and *Restaurant Personnel*.

Lesson 12 • Where We Are Going and NOT Going

Where We Are Going

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

- **ETS1.B.1: Developing Possible Solutions.** When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.
- **ESS3.C.2: Human Impact on Earth Systems.** Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.

This lesson requires “putting the pieces together” from several prior lessons to develop students’ engineering design thinking about the unit problem of oyster die-off. Students begin by returning to their Progress Trackers and considering the societal requirements and ecosystem needs to design solutions which reduce environmental degradation.

The lesson begins with students revisiting their Progress Trackers and class consensus model to consider additional solutions. Students revisit emerging ideas about technical and social requirements and limitations for design solutions, which they first developed in Lesson 7 (SEP: 1.8; CCC: 4.1). At the high-school level, students should generate their own criteria and constraints rather than be provided a list. Students develop a list of criteria and constraints based on what they have figured out

Students revisit the perspectives of interested parties and in doing so, deepen their engineering design thinking by including broader, more complex elements of the system. Students also consider how criteria and constraints are interrelated, are sometimes contradictory, and may need to be quantified when planning a particular solution, motivating the idea that solutions must be developed in context.

In the final activity, students brainstorm possible locations in the system where their engineering design thinking can have an impact. When evaluating these solutions, students take into account a range of constraints including cost, safety, reliability, and aesthetics, and they consider social, cultural, and environmental impacts (DCI: ETS1.B.1; CCC: 4.1). These considerations are addressed contextually throughout the lesson: cost, safety, and reliability with slides D and E, and aesthetics and cultural impacts with slides E and F.

In this final activity, students engage with the design problem as engineers who make major contributions by developing technologies (such as oyster die-off prevention systems) that produce less pollution and waste and that preclude ecosystem degradation (DCI: ESS3.C.2).

Where We Are NOT Going

It will not be possible to quantify criteria and constraints in this lesson, as that level of detail is context dependent. In Lesson 13, students select a context in which to develop their solution of interest and use information about the context to quantify criteria and constraints.

LEARNING PLAN for LESSON 12

1 · NAVIGATE

5 min

MATERIALS: *Progress Tracker*

Navigate. Say, *Last class we updated our Progress Trackers, but it has been a while since we have reviewed what we have figured out. What else have we learned about the phenomenon of oyster die-off that can help us figure out how to restore this important food?**

Display **slide A**. Direct students to revisit their Progress Trackers and discuss ideas with a partner, then quickly debrief partner discussions. Ask, *What new ideas have we figured out?* Listen for ideas such as the quantities of reactants needed to neutralize acid, how oysters build shells, supporting shell growth with calcium carbonate, Earth system interactions, and reaction rate.

Say, *We have figured out a lot in this unit and answered quite a few of our questions. We have already done some thinking about possible solutions to protect oysters, but let's take this opportunity to think more about ways we could prevent larvae die-offs.*

* ATTENDING TO EQUITY

Universal Design for Learning. *Engagement* and sustained effort and persistence are intentionally developed here as we connect oysters back to issues of food sovereignty. Oysters are not compelling to all students on their own, but reminding students that oysters are an important food source to many people, as they heard about in <https://youtu.be/zKyfbGbRz7c> and <https://youtu.be/2ZkXdmWXHdE>, can increase engagement.

If needed, reconnect students to the locally-sourced foods they rely on.

2 · INVENTORY POSSIBLE SOLUTIONS

12 min

MATERIALS: 3 3x3 sticky notes, permanent marker, *Progress Tracker*, carbon cycle model, <https://newsroom.ucla.edu/releases/using-seawater-to-reduce-co2-in-atmosphere> (optional), chart paper (optional), chart paper markers (optional)

Ask students to individually record possible solutions. Display **slide B**. Say, *Way back when we first learned about what was happening to oysters, we made a list of possible solutions and shared them on 3x3 sticky notes. We know a lot more now, so let's try doing that again.*

Ask students to jot down ideas on 3x3 sticky notes about how we can apply what we have learned in this unit to help prevent oyster larvae die-off and its impacts on ecosystems and communities. Direct students to write each possible solution and how it would work on a new sticky note.

ADDITIONAL GUIDANCE

In Lesson 2 students likely listed general ideas for solutions, such as “Make the ocean less acidic.” In this lesson, student’s proposed solutions will likely mirror similar approaches but they should draw on ideas students have figured out in Lessons 3-11 as well as be more specific. For example, “Add a carbonate source like crushed oyster shells to the water to support shell building.”

In this step, encourage students to defer judgment about whether an idea is good or bad and instead get all ideas on the table. Tell students that it is OK to include ideas that we have already examined in class as well as any new or untested ideas.

Give directions for going public with ideas. Continue to display **slide B**. After students have had time to write down ideas individually, invite students to post their 3x3 sticky notes in a designated area in the classroom. Ask that students try to place their idea next to a similar or related idea so that there are clusters of approaches.

Build a class list of solutions. Review the posted 3x3 sticky notes and summarize out loud the various approaches students have generated. Be sure to name the ideas that appear in clusters, as well as any outliers. Write a summary of the list of ideas in large letters on a whiteboard, a piece of chart paper, or a slide.

Refer back to the carbon cycle model. Say, *We want to make sure we are being thorough and bringing in everything we have figured out in this unit.* Display **slide C**. Ask students to examine the carbon cycle model which we last updated in Lesson 11. Ask them to consider if there is any other place within the system where it might be useful to intervene to prevent oyster die-off and related impacts. Update the class list of solutions with any new ideas shared. The final list should include, but not be limited to:

- Plant kelp or other aquatic plants to pull carbon dioxide from the water and increase pH.
- Add limestone or other carbonate sources to the water to increase carbonate ion concentration and support shell building.
- Add a base to the water to increase pH.
- Organize for laws or policies that limit the burning of fossil fuels and prevent ocean acidification at its source.

ALTERNATE ACTIVITY

When developing engineering solutions, it can be helpful to learn about how others have attempted to solve the problem. The article below details real-world attempts to use seawater to reduce CO₂ in the atmosphere and enhance ocean alkalinity. Consider presenting this to students if they need more support.

- <https://newsroom.ucla.edu/releases/using-seawater-to-reduce-co2-in-atmosphere>

3 · CONSIDER COMMUNITY PRIORITIES

15 min

MATERIALS: *Progress Tracker, Discuss Interested Parties*, science notebook, *Extension Opportunity* (optional), *Poultry Farmers, Northwest Indian Fisheries, Oyster Farmers, Restaurant Personnel*, chart paper (optional), chart paper markers (optional)

Motivate revisiting criteria and constraints. Display **slide D**. Say, *We have a lot of ideas! How should we decide which of these solutions to develop?* Invite students to discuss this question with a partner, then call on several students to summarize their discussions.

Suggested prompt	Sample student response
How should we decide which direction to pursue?	Some ideas will work better for certain groups of people, or in certain places, than others. We could narrow it down by those groups or locations. We have thought about some solutions but not others. It might be interesting to try something new, or better.
What should we prioritize?	Some ideas might be based on science and actually work, but could be costly, dangerous, or unreliable. We need to think about what oyster farmers could actually do.

openscienced.org

Unit C.4 • Lesson 12 • 5/28/26

Page 254

ADDITIONAL GUIDANCE

The DCI is **ETS1.B.1: Developing Possible Solutions**. When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.

This discussion should attend to reliability, safety, and cost. Consider asking about these ideas directly. Students may also bring up aesthetics, which is connected to the cultural significance of oysters; their shells are beautiful and part of many jewelry and clothing traditions.



Link the ideas shared to the “What should we keep in mind about how solutions might affect and be affected by people and the environment?”, column of the Progress Tracker to priorities of impacted communities. Say, *It sounds like we need to compare our ideas to the requirements of our design, and also to the limitations that our design needs to work within. These criteria and constraints are closely connected with the effects on people and the environment. Let’s take some time to revisit our ideas about how solutions might affect and be affected by people and the environment that we recorded in our Progress Trackers.* Give students a minute to do so and take a few suggestions from the class for ideas found in their Progress Tracker.

Display slide E. Say, *We have talked before about the importance of consulting with multiple interested parties. Let’s start with what we know about criteria and constraints from the perspectives of those most impacted.*

Direct students to review the initial ideas they wrote in *Discuss Interested Parties* in Lesson 7 about criteria and constraints related to interested party priorities, and have students discuss these ideas in groups.

ADDITIONAL GUIDANCE

Instruct students to reference their own copy of *Discuss Interested Parties*. You can also find a list of possible student ideas for criteria and constraints related to the interested parties’ priorities in the *Discuss Interested Parties Key* from Lesson 7.

Lead the class in a discussion about criteria and constraints important to interested parties. Write a new summary of the criteria and constraints students raise on a whiteboard, a piece of chart paper, or a slide. Ask students to record the list in a T-chart in their science notebooks.

Suggested prompt	Sample student response
<i>What criteria and constraints are important to the various interested parties who are most impacted by this problem?</i>	Chefs, restaurant owners, and people/animals who eat oysters still need to be able to cook, sell/buy, and eat them. The solution cannot add pollution to the waterways and make oysters inedible. Poultry farmers need the solution to ensure that the oyster shells still have plenty of calcium in them to produce strong eggshells.
<i>Where might there be contradictions or conflict between interested parties’ criteria?</i>	The Northwest Indian Fisheries Commission requires that the solution not interfere with or prevent ceremonial subsistence harvests, which might conflict with the oyster farmers’ need to maintain or exceed current profits. So, farmers might be tempted to over-harvest.
<i>Whose perspectives are we missing?</i>	The oysters!

Begin to surface ideas about the interrelated nature of criteria, constraints, and trade-offs. Display **slide F**. Before moving on to the next step, invite students to consider how there may be variation in those priorities within and across interested parties, as well as perspectives that are missing. There will be more time to develop these ideas in Lessons 13 and 14. The extension opportunity also highlights some options for deepening this discussion.

Suggested prompts	Sample student responses	Follow-up questions
<i>How might priorities for criteria and constraints vary within and across communities?</i> <i>What trade-offs might impact groups differently?</i>	Not all oyster farmers have the same budgets or operating systems. Some might be able to implement a solution that others cannot based on cost or location. Not all Indigenous communities have the same ceremonies or relationship to oysters and waterways. The Northwest Indian Fisheries Commission might have different priorities than a tribal nation in another part of Turtle Island.	<i>How should we make decisions in instances where there may be disagreement about what is most important?</i> <i>What else would we need to know about possible trade-offs that might affect which substances we use in a design solution?</i>
ADDITIONAL GUIDANCE	Consider annotating the class summary to indicate alignment or contradiction between various interested parties' criteria and constraints. For example, you could draw a red line or "X" to indicate conflicting priorities, a green line or "=" to indicate alignment, or lines with arrows to indicate one consideration impacting another.	
ALTERNATE ACTIVITY	Extension opportunity: <i>Extension Opportunity</i> is an additional opportunity for practice with balancing trade-offs, this time in a different ecosystem. The included Iowa Public Radio article https://www.iowapublicradio.org/ipr-news/2021-04-22/des-moines-water-works-advances-plans-to-build-new-wells-in-light-of-river-pollutants discusses how Des Moines, Iowa, is dealing with nitrate pollution in drinking water. You may also locate reputable news stories that highlight social, technical, and scientific dimensions of the problem, as well as tensions in the priorities of various interested parties. Local public radio affiliates and environment-focused publications often report on such issues.	

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students state how the **criteria and constraints relate** to **scientific, technical, and social considerations**. (SEP: 1.8; DCI: ETS1.B.1)
- Students surface ideas about **how these scientific, technical, and social criteria and constraints are interrelated**. (SEP: 1.8)

What to do: If students are struggling to articulate how criteria and constraints might be interrelated, contradictory, or contextual, refer back to the Lesson 7 readings *Poultry Farmers*, *Northwest Indian Fisheries*, *Oyster Farmers*, and *Restaurant Personnel* and discuss possible examples. For instance, a solution that supports supply-chain issues and cost effectiveness for restaurants in the Pacific Northwest might interfere with ceremonial harvests (aesthetics, values) in Indigenous communities.

See STEM Teaching Tool Practice Brief 64 <http://stemteachingtools.org/brief/64> for additional resources for supporting students to develop criteria and constraints.

Building toward 12.A.1 Define interacting social, technical, and environmental criteria and constraints to **alter the systems around oysters** in a way that **considers societal requirements and reduces environmental degradation**. (SEP: 1.8; DCI: ETS1.B.1, ESS3.C.2; CCC: 4.1)

Consider other possible criteria and constraints we are missing. Display **slide G**. Say, *We have also figured out quite a bit more science since the first time we discussed criteria and constraints. And, we have our own knowledge and experiences that can help us build out this list. What else do we need to consider?* Invite students to turn and talk, then share with the whole class any criteria and constraints that are not already presented.

Suggested prompt

What other criteria and constraints should we consider as we develop our solution?

Sample student response

We should also consider the safety of those who have to implement the solution.

We have some solutions that are risky. How will we weigh risks?

We should consider our options for materials, and their sustainability.

We need to know the time frame we are working within.

4 · IDENTIFY AND BEGIN TO DEVELOP PROMISING SOLUTIONS

13 min

MATERIALS: science notebook



Invite groups to identify a solution of interest. Display slide H. Remind students of the list of possible solutions generated at the beginning of class. Then invite students to decide in groups which solution seems most promising to them based on the criteria and constraints. Tell students to record their thinking in their science notebooks. Circulate among the groups to discuss which solution was selected and why. Possible group answers include, but are not limited to:

- We would like to add old oyster shells to the water to increase carbonate ion concentration and support shell building. This might reduce the supply of oyster shells for poultry farmers at first, but it is less likely to cause negative unintended consequences in the ecosystem or make the oysters unsafe to eat. It will be similar to restoring the ecosystem to what it was like when there were lots of oyster reefs.
- We would like to add a base to the hatchery water to increase the pH. We know how to perform the calculation to neutralize the acid and have more control in the tanks. This will have an immediate benefit to larvae survival.

Prompt groups to begin to develop their solution. Display slide I. Once groups have identified a solution of interest, ask the groups to map out their solution. During the mapping-out process they should consider the criteria and constraints as well as some of the preliminary calculations for implementing the solution based on what they have learned about the mole.

Say, It seems like all of the groups have identified a solution. Let's use these last few minutes to start mapping out how these solutions will work. As you work, keep a record of any other information you are noticing that you will need to fully build out your plan.

Check in with the groups. It should become apparent that students do not have enough information to build out their plan and that they need to know more about the specific context in which they hope to implement their solution.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **choose possible solutions** that both **fit within the criteria and constraints** and **do not have negative environmental impacts**. (SEP: 1.8; DCI: ESS3.C.2)
- Students identify **impacts of their chosen solutions** on the **systems around oysters**. (DCI: ESS3.C.2; CCC: 4.1)

What to do: If students are not yet noticing that context will impact the development of their solution, ask follow-up questions:

- *_____ solution sounds scientifically and technically sound. How would _____ (interested party) implement it? Where would it be best to use this type of approach?*
- *You selected _____ solution. How much _____ will you need in order to _____? What do you need to know to calculate _____?*

See STEM Teaching Tool Practice Brief 64 <http://stemteachingtools.org/brief/64> for additional resources for supporting students to develop criteria and constraints.

Building toward 12.A.2 Define interacting social, technical, and environmental criteria and constraints to **alter the systems around oysters** in a way that **considers societal requirements and reduces environmental degradation**. (SEP: 1.8; DCI: ETS1.B.1, ESS3.C.2; CCC: 4.1)

Summarize next steps. Say, *After listening in on your conversations in groups, it sounds like we need to know more about the specific local contexts in which we will develop our solutions. I will start to dig up some information and bring that to our next class.*

LESSON 13: How can we apply our science ideas to develop a solution to help protect oysters?

PREVIOUS LESSON We developed a class list of possible solutions to prevent oyster die-off. We narrowed down the list based on the criteria and constraints for our design, the information gathered about the priorities of impacted communities, and our own knowledge and experiences. We chose a promising solution to develop in groups.

THIS LESSON

PUTTING PIECES TOGETHER,
INVESTIGATION

2 days



NOAA, New Hampshire Sea Grant

We brainstorm a list of information that helps us refine our solutions, criteria, and constraints from the last class. Then we examine three site profiles to help us refine and quantify criteria and constraints and think about where our solutions could be implemented. We work in groups to plan our solutions and think about both intended and unintended consequences. We also quantify our plans' impacts on pH, atmospheric or ocean CO₂ levels, and/or carbonate availability for oyster shells. Then we display our solutions on posters for peer feedback.

NEXT LESSON We will identify the main points of our design solution and rank the criteria that guided our solution. We will present our design solution and receive peer feedback. We will decide how to use the peer feedback to refine our solution. We will compare our design solutions and discuss the chemistry and Earth science ideas that we used to develop them.

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-1,
HS-ETS1-2



WHAT STUDENTS WILL DO

13.A Use computational thinking to quantify criteria for a solution that will positively affect oysters. (SEP: 5.2; DCI: ETS1.A.1; CCC: 2.3)

13.B Design a solution to cause specific outcomes to mitigate the impacts of ocean acidification on oysters. (SEP: 6.5; DCI: ESS3.C.2; CCC: 2.3)

WHAT STUDENTS WILL 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.

Lesson 13 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	2 min		NAVIGATE Help students recall solutions from the previous lesson.	A	
2	5 min		BRAINSTORM TYPES OF INFORMATION Organize students into small groups to brainstorm types of information needed to refine criteria and constraints.	B	
3	7 min		EXAMINE SITE DATA Have students meet in small groups to examine site profiles for three different oyster operations.	C-D	<i>Solutions Fact Sheet, Site Profile 1, Site Profile 2, Site Profile 3</i>
4	15 min		REFINE CRITERIA AND CONSTRAINTS Have groups use site profiles to develop site-specific criteria and constraints. Use the “3 stay, 1 stray” protocol for groups to share their criteria and constraints.	E-G	<i>Solution Planning Document, Solutions Fact Sheet, Site Profile 1, Site Profile 2, Site Profile 3</i>
5	16 min		START TO DEVELOP SOLUTIONS Have groups use the <i>Solution Planning Document</i> to develop their chosen site-specific solution and quantify the impacts of the proposed solution.	H	<i>Solution Planning Document, Solutions Fact Sheet, Site Profile 1, Site Profile 2, Site Profile 3, carbon cycle model</i>
<i>End of day 1</i>					
6	5 min		SHARE PROGRESS WITH OTHER GROUPS Have groups pair up with one other group and update each other on their site-specific solution.	I	<i>Solution Planning Document, Solutions Fact Sheet, Site Profile 1, Site Profile 2, Site Profile 3</i>
7	15 min		FINISH THE SOLUTION PLANNING DOCUMENT Have groups complete their site-specific solution using <i>Solution Planning Document</i> .	J	<i>Solution Planning Document, Solutions Fact Sheet, Site Profile 1, Site Profile 2, Site Profile 3</i>
8	22 min		CREATE POSTERS TO SHARE SOLUTIONS Have groups create a poster to share their site-specific solution and the anticipated impacts of the solution.	K-L	<i>Solution Planning Document, chart paper, chart paper markers</i>
9	3 min		NAVIGATE Reflect on how sharing site-specific solution ideas is helpful.	M	<i>Solution Planning Document, design solution posters</i>
<i>End of day 2</i>					

Lesson 13 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • <i>Solutions Fact Sheet</i> • <i>Solution Planning Document</i>	• <i>Site Profile 1</i> • <i>Site Profile 2</i> • <i>Site Profile 3</i> • chart paper • chart paper markers • design solution posters	• carbon cycle model

Materials preparation (30 minutes)

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

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

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

Teachers are not expected to be shellfish experts. Teachers will have sufficient preparation to answer students' questions if they carefully review the student reference pages ahead of time. If students have additional questions, please encourage them to do additional research since oyster restoration statuses change year to year depending on climate variation.

Have the carbon cycle model visible during the lesson.

Make sure that students' reference handouts from previous lessons in their science notebooks that they have gotten feedback so that all students are working with good information.

Students will start day 1 by talking to someone they did not work with in the previous class, so you may wish to plan those pairings ahead of time.

Students should be in groups of 3 to 4 to develop their solutions. Make enough copies of *Site Profile 1*, *Site Profile 2*, and *Site Profile 3* so that each group has access to one set of site profiles. Make enough copies of *Solutions Fact Sheet* so that each student has a copy.

On day 2, groups will need 1-2 sheets of chart paper each to model their solutions.

Lesson 13 • Where We Are Going and NOT Going

Where We Are Going

The targeted disciplinary core ideas that we are continuing to develop are:

- **ETS1.A.1: Defining and Delimiting Engineering Problems.** Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.
- **ESS3.C.2: Human Impacts on Earth Systems.** Scientists and engineers can make major contributions by developing technologies that produce less pollution and waste and that preclude ecosystem degradation.

The beginning of the lesson picks up with the list of criteria and constraints generated in Lesson 12. Students apply engineering principles to quantify their criteria and constraints and use these to develop solutions ([SEP: 6.5](#)).

Students use mathematical thinking to quantify and model the impacts of solutions on oyster systems ([CCC: 2.3](#)) in a poster presentation to the class ([SEP: 5.2](#)). Students listen to each other and consider the quantified impacts of these solutions and the extent to which they satisfy requirements set by society ([DCI: ETS1.A.1](#)).

Students continue to focus and define the effects of the oyster-raising system for a number of sites and systems with different criteria and constraints ([CCC: 2.3](#)) as they synthesize information from the planning documents.

Students are reminded that scientists are key to developing contributions through technologies that produce less ecosystem degradation ([DCI: ESS3.C.2](#)). As students share their ideas, they leverage the designed solution to the real-world problem. They will evaluate these solutions in the next lesson. Finally, students will link desired outcomes to specific changes they are proposing to a particular system.

Where We Are NOT Going

Students will not be evaluating solutions in this lesson, or explaining why they prioritized the criteria they did. This will be addressed in the next lesson. Students will not apply their mathematical model or what they have learned about criteria and constraints to new problems, but they will apply these understandings in the Lesson 15 assessment.

LEARNING PLAN for LESSON 13

1 · NAVIGATE

2 min

MATERIALS: science notebook

Review what students decided during the previous class. Display **slide A**. Pair students so they are with someone they did not work with last class. Give students time to turn and talk to share with each other the general solutions their groups came up with, as well as current lists of criteria and constraints. Possible solutions from last class include:

- Plant kelp or other aquatic plants.
- Add limestone or other carbonate sources to the water to increase carbonate ion concentration.
- Petition for laws or policies that limit the burning of fossil fuels.

Possible criteria and constraints include:

- Raise the pH of a body of water.
- Increase the number of oyster larvae that survive.
- Remove CO₂ from the air or water.
- Stay within certain cost limits.
- Follow laws or regulations.
- Do not harm other organisms.

ADDITIONAL GUIDANCE

Students begin this activity by talking to someone they did not work with last class. This provides students the opportunity to hear or think about more than one solution before they decide which solution to develop more fully with their group. Having this conversation with a different classmate means that groups are potentially hearing three or four other ideas. Students can then consider a range of ideas as they work with their groups to quantify criteria and constraints and develop a solution.

2 · BRAINSTORM TYPES OF INFORMATION

5 min

MATERIALS: science notebook

Develop a list of information we need. Ask students if they feel like they have a complete solution or a complete list of criteria and constraints from last class. If students feel that they do, encourage them to think about where they want to implement their solution, how much they think it will cost, or other questions they will want to answer. Display **slide B**. Give students some time to brainstorm in smaller groups. Have them work in their groups from the previous class to develop a list of information they think they are missing. After brainstorming in groups, have students share their ideas with the whole class.

Ask, What types of information would help us refine our criteria and constraints? Look for students to suggest:

- Where to implement the solution; that place's laws/policies.
- Costs.
- Amount of water to adjust the pH of.

3 · EXAMINE SITE DATA

7 min

MATERIALS: science notebook, *Solutions Fact Sheet*, *Site Profile 1*, *Site Profile 2*, *Site Profile 3*

Introduce site data to students. Say, *We know oysters are cultivated in lots of different places. Do we think one big global solution is the way to go?* Have a brief discussion with students to motivate the need for local solutions and local data. Ask, *What did we decide in the last class that we needed to consider or learn more about?*

Look for students to suggest:

- We need to know more about specific places that are dealing with ocean acidification.
- We need to know what is already being done.

Say, *It seems like we would like to know more about different locations and conditions, and the specific people who may need to implement these solutions or who may already be working on solutions. I have some information here that may help us with that.* Distribute *Site Profile 1*, *Site Profile 2*, and *Site Profile 3* to groups. Distribute a copy of *Solutions Fact Sheet* to each student. Display **slide C**. Say, *I have three site profiles. Each has specific information about that region and a group of people who cultivate oysters there. You have also each received a general fact sheet with some information that may be relevant to any of the sites.*

Preview the references. Display **slide D**. Have students preview the references before reading them.

Ask, *What are some of the main parts?* Listen for details such as location, the people profiled, and some of the strategies already being used to cultivate oysters in water with decreasing pH. Tell students that each group member is responsible for one site profile (*Site Profile 1*, *Site Profile 2*, or *Site Profile 3*) and that everyone must read *Solutions Fact Sheet*. * As they read the site profiles, students should think about the criteria, constraints, and trade-offs they have already come up with. Explain to students that the goal of these references is to help them pick a site to focus on so that they can develop more specific criteria and constraints and targeted solutions.

Solutions Fact Sheet

Recent ocean CO ₂ activity	Amount of water in tidal zone (L)	H ⁺ molarity at relevant pH values
6 × 10 ¹⁸ mol/L	Acid-test = 1304000 L per acre (Acid-test approximately 4000 mL 1% acetic)	pH 8.2 = 6.3 × 10 ⁻⁹ M pH 8.0 = 1.0 × 10 ⁻⁸ M pH 7.8 = 1.6 × 10 ⁻⁸ M pH 7.6 = 2.5 × 10 ⁻⁸ M pH 7.4 = 4.0 × 10 ⁻⁸ M

When CO₂ dissolves in H₂O, about 9% becomes H₂CO₃.

Source of carbonate
Limestone
Chicken eggshells
Old oyster shells

opensci.org

Page 1

* ATTENDING TO EQUITY

Universal Design for Learning & Literacy. *Representation.* You can have students read individually or aloud with a partner. Allowing students a choice in how the information is represented to them can support comprehension for a wider range of learners.

Multilingual Learners. You may encourage students to use a translator device if the text is not in their home language.

ALTERNATE ACTIVITY

The suggested method is that each student gets one site profile—*Site Profile 1*, *Site Profile 2*, or *Site Profile 3*--and student groups complete the activity as a Jigsaw. After reading their assigned site profile, students can take turns summarizing or explaining the material to the group. If time permits or you would like everyone to read all the reference materials, give each student all three site profiles.

4 · REFINE CRITERIA AND CONSTRAINTS

15 min

MATERIALS: science notebook, *Solution Planning Document*, *Solutions Fact Sheet*, *Site Profile 1*, *Site Profile 2*, *Site Profile 3*

Use site data to refine criteria and constraints. Ask students, *Now that we know a little more about some places where oysters are cultivated, can we refine our criteria and constraints from last class based on these site profiles?* Display **slide E** and distribute *Solution Planning Document* to students. Have students work in their groups and use the site profiles and their initial solutions to develop a more specific list of criteria and constraints for the site profile they choose.* Students should record their ideas in the *Refining Criteria and Constraints* section of *Solution Planning Document*.

The prompts below can be used as a whole-class discussion to get groups started, or as a check-in with individual groups who may be struggling with this step in the lesson. If students are struggling to come up with criteria or constraints, encourage them to think about the specific site they are focusing on. Have them think about what the people in that location are already doing and what limitations they may face.

Suggested prompt	Sample student response
<i>How do these site profiles help us refine our criteria, constraints, and solutions?</i>	We know more about the people in these places. We know more about the water pH and other organisms there. We have some ideas about how effective some of our solutions might be.
<i>What can we add to our criteria and constraints?</i>	We can think of specific amounts of plants we might need. We might have better ideas of cost limitations.



Quantify criteria and constraints. As groups work, circulate and check in. Remind students that the more specific their criteria and constraints are, the more useful they will be in developing a solution. Students should quantify criteria and constraints wherever possible. For example, if a criterion is raising the pH, students should specify the pH change needed for that location as well as the required change in H^+ concentration. Students may also quantify constraints by specifying what costs are allowable in a particular site.

Allow for cross-group sharing. Display **slide F**. Use the “3 stray, 1 stay” protocol to help students learn from other groups. In this protocol, one group member stays put while the rest visit other groups. Each “straying” group member should go to a different group to maximize the number of ideas each group can consider. Once students move, the group member who stays seated tells the visiting students about their group’s site-specific criteria and constraints. Give groups two to three minutes to listen to the “stayer” and ask follow-up questions. Then have students return to their original groups and take turns sharing what they have heard.

Once students have had the opportunity to hear from other groups, continue with the next activity, even if not all groups feel confident that their criteria lists are complete. As students work to develop their solutions in the next activity, they will continue to think about criteria and constraints.

Focus on the purpose of quantifying criteria and constraints. After everyone has returned to their seats, display **slide G**. As a class, discuss how clarifying and quantifying criteria and constraints helps us to design solutions.

* SUPPORTING STUDENTS IN ENGAGING IN CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

Part of applying scientific ideas to design a solution is selecting specific criteria. Having students engage in the process of selecting criteria for their designs is a critical step in the design process. Different combinations of sites and solutions provide student groups complementary opportunities to think about solutions, which can lead to productive discourse about prioritizing criteria.

Suggested prompt	Sample student response
Why is it important to quantify our criteria and constraints, or make them as clear and specific as possible?	It helps us figure out what we can and cannot do, or what we do and do not want to do. It helps us figure out if our solutions will do what we want them to do. It gives us a way to check or evaluate our solutions.
How will this help us develop solutions?	We know exactly what we need to create or design.
ASSESSMENT OPPORTUNITY What to look/listen for in the moment: - Students use stoichiometric (mathematical) and other calculations to quantify design solution impacts of pH, carbonate, and/or CO₂. (SEP: 5.2) - Students quantitatively represent criteria and constraints. (DCI: ETS1.A.1) - Students articulate the importance of criteria and constraints in ensuring positive outcomes for oysters. (DCI: ETS1.A.1; CCC: 2.3) What to do: If students are having difficulty quantifying criteria and constraints, have them review their original lists alongside the site data. Questions such as “How much/many?”, “When?”, or “How long?” may help students refine their criteria and constraints. Building toward 13.A.1 Use computational thinking to quantify criteria for a solution that will positively affect oysters. (SEP: 5.2; DCI: ETS1.A.1; CCC: 2.3)	

5 · START TO DEVELOP SOLUTIONS

16 min

MATERIALS: science notebook, *Solution Planning Document*, *Solutions Fact Sheet*, *Site Profile 1*, *Site Profile 2*, *Site Profile 3*, carbon cycle model



Use the Solution Planning Document to develop the solution. Tell students, *Now that we have more specific criteria and constraints and know more about these locations, let's try to build some solutions and figure out just how we might impact these ecosystems.* Display **slide H**. Groups should work together to answer the questions in the *Designing a Solution* section of *Solution Planning Document*. They should be as specific and thorough as possible, and quantify their solutions and impacts where appropriate. For example, if students want to raise the pH of water tanks at an oyster hatchery, they will need to use volume and pH to calculate a specific quantity of the substance to be used. Students need to explain how that substance will help them achieve their goal. Encourage students to use the class consensus model and/or models from individual lessons to help them predict the impacts of their solutions.

If groups are struggling, the discussion prompts below may help students think through what they are trying to accomplish. Students likely will not complete the *Solution Planning Document* by the end of day 1, but should aim to be at least halfway through. This will give students time to finish the handout and make their poster on day 2.

Suggested prompt	Sample student response
What types of solutions are we trying to develop in these ecosystems?	Raise the pH or increase the concentration of carbonate ions for shell building. Remove CO₂ so that less carbonic acid forms.
What are the intended impacts of those solutions?	Make the pH more ideal for shell building (make the water less acidic).
What types of unintended impacts might we want to consider?	We might improve ecosystems in other ways by replanting kelp or seagrass. The solution could impact other shellfish or other organisms too. We might anger people if we do not go about it the right way.
ADDITIONAL GUIDANCE	If students are struggling to complete parts of their planning documents, direct them to the relevant information in the reference materials. If they are still struggling to find information on their own, help them come up with some useful search terms. If Internet access is available, talk with students about prioritizing the criteria for which they already have information. There are several different solutions that students may want to develop, depending on the criteria, constraints, and site they choose. There is not one list of “correct” or “acceptable” solutions, and the goal in this activity is not that students select a particular solution. The important part is that students engage with the engineering process and work to use the science ideas and mathematical models they have developed throughout the unit.
ASSESSMENT OPPORTUNITY	What to look/listen for in the moment: - Students’ posters indicate a specific designed solution to oyster die-off that is based on science, prioritized criteria, and trade-off considerations. (SEP: 6.5) - Students articulate what effects their proposed changes will have on the oyster-raising system. (CCC: 2.3) - Students describe how their proposed solution will change pH, carbonate availability, or atmospheric or ocean CO₂ levels. (DCI: ESS3.C.2) What to do: See <i>Sample Solution Planning</i> to support students. If students are struggling with calculations, encourage them to refer back to the work they did in Lessons 8 and 9 and use that as a guide. If students are struggling with anticipated effects of solutions, have them look at the models they developed during the unit and identify the specific components they are planning to change. Ask students to predict how those changes will affect other components of that system and connected systems. Building toward 13.B.1 Design a solution to cause specific outcomes to mitigate the impacts of ocean acidification on oysters. (SEP: 6.5; DCI: ESS3.C.2; CCC: 2.3)

End of day 1

6 · SHARE PROGRESS WITH OTHER GROUPS

5 min

MATERIALS: science notebook, *Solution Planning Document*, *Solutions Fact Sheet*, *Site Profile 1*, *Site Profile 2*, *Site Profile 3*

Groups give updates on their progress. Have each group pair up with another group. Display the prompts on **slide I** and encourage one group from each pair to answer as many of the questions as they can in two minutes. Then the other group in each pair has two minutes to answer the questions. It is OK if groups do not get all the way through the prompts. The goal is for each group to learn about other ideas that are being considered.

7 · FINISH THE SOLUTION PLANNING DOCUMENT

15 min

MATERIALS: science notebook, *Solution Planning Document*, *Solutions Fact Sheet*, *Site Profile 1*, *Site Profile 2*, *Site Profile 3*

Groups complete their planning documents. Display **slide J**. Now that students have had time to review their progress and hear from other groups, have them return to *Solution Planning Document* and complete their plan. If students have answered all of the questions, encourage them to check all calculations to ensure their numbers are accurate. If groups finish early, have them review each other's planning documents and provide feedback.

8 · CREATE POSTERS TO SHARE SOLUTIONS

22 min

MATERIALS: science notebook, *Solution Planning Document*, chart paper, chart paper markers

Discuss the need to share solutions. Display **slide K**. Ask students, *Now that we have completed our Solution Planning Documents, are we finished?* Students are probably familiar with sharing their work in class to get peer feedback. If not, discuss the value of sharing ideas and how best to share them.

* ATTENDING TO EQUITY

Calling out the work of scientists can encourage all young people, especially those in groups which historically have not been included in STEM subjects, to consider futures in science and engineering. This instructional moment is important for highlighting that scientists are key to developing contributions through technologies that produce less ecosystem degradation. (DCI: ESS3.C.2)

Suggested prompt	Sample student response
Why might we want to share our solutions with each other?	Sharing solutions gives us a chance to give and receive feedback from other people. Someone else may see something we missed. Seeing other ideas may help us to improve our own ideas.
How could we share them—should we just read each other's planning docs? What might be better?	We should make a visual representation of our solutions. We can make models or posters.

Suggested prompt	Sample student response
<i>What could we include in our representations? What exactly do we want to represent?</i>	We could include calculations. We could have a before and after, or some way to show change over time. We could have arrows or a flow chart to help show the impacts of our solutions.
 Students create posters of their solutions. Display slide L. Frame the work in terms of science and engineering: <i>Scientists are key to developing contributions through technologies that produce less ecosystem degradation.</i> * Distribute one piece of chart paper and chart paper markers to each group. Before students begin their posters, have a discussion about what their posters should include and how students can represent those ideas. Encourage students not to use too much text in their posters--the goal is not simply to copy the planning document onto bigger paper. The purpose of the posters is to explain or show how the solutions will impact oyster habitats and how those impacts will benefit oysters and people. General guidelines for the components of the poster are listed on slide L; aside from including those elements, students can structure their posters how they choose.	

Seagrass in the Puget Sound

Criteria:

- Protect oyster larvae
- Raise pH from 7.9 to 8.2
- Work within the ecosystem
- Keep costs low
- 0.5692 mol H^+ need to be removed - 2x/day (due to tides)

Constraints:

- Indigenous communities have access to private tideland at harvest
- Water shallow (~3 ft)
- Water quality low due to boat traffic
- 15 acres tribally owned in use case
→ 58,680,000 L H_2O

Going with seagrass

- Can remove 2.26 mol $CO_2/m^2/day$
- One-time investment
- Worries w/ ecosystem (native)

@ 8.2
 $6.3 \times 10^{-9} \text{ mol } H^+/L \cdot 58,680,000 L = 0.3697 \text{ mol}$
 Same calc → 0.9389 mol @ pH=7.9
 $1\% \text{ of } CO_2 \rightarrow H_2CO_3 \rightarrow \frac{2H^+}{H_2CO_3} \rightarrow \text{remove } 0.5692 \text{ mol } H^+$
 But that's 1% of $CO_2 \rightarrow 0.2846 \text{ mol } CO_2$
 $12 \text{ mol/day} = 56.92 \text{ mol } CO_2$
 $1 m^2 \text{ of seagrass makes/grows } 68g \text{ a day. If it's } C_6H_{12}O_6 \dots$

$\frac{68g}{180.16g} \cdot \frac{6 \text{ mol } CO_2}{1 \text{ mol } C_6H_{12}O_6} = 2.26 \text{ mol } CO_2 \text{ removed by } 1 m^2$
 $\frac{56.92 \text{ mol removed a day}}{2.26 \text{ mol/day removed by } m^2} = 25.2 \text{ m}^2 \text{ needed}$
 $2.26 \text{ mol/day removed by } m^2 \times \$100/m^2 = \$2500 - \text{cheap!}$

Effects

- Raise pH to safe level for oysters
- Improve water quality & provide potential habitat
→ people enjoy too
- Might need to work w/ boaters & fishers to find compromise space to ensure water quality, avoid caught propellers

Recycled Shells in Tanks!!

Family Aquaculture

- sell oysters
- pick up empty shells
- crush shells
- Add to tank
- Ca^{2+} and CO_3^{2-} from shells dissolve in tank
- extra CO_3^{2-} bonds with H^+ so there is plenty for new shells and....
- new oysters!

the oyster cycle

Nearby customers & cheap/free used shells

4000 L $\times \frac{5 \times 10^{-5} \text{ mol}}{1 L} = 0.2 \text{ mol}$
 $1 \times 10^{-4} M = 0.5 \times 10^{-4} M$
 $\frac{0.2 \text{ mol}}{0.5 \times 10^{-4} M} = 400,000 L$
 $\frac{0.2 \text{ mol}}{1 \text{ mol per day}} = 0.2 \text{ days}$
 $\frac{0.2 \text{ mol}}{1 \text{ mol per day}} = 0.2 \text{ days}$
 $\frac{0.2 \text{ mol}}{1 \text{ mol per day}} = 0.2 \text{ days}$

Positives

- very cheap to do, so do it!
- can free up a lot of CO_3^{2-} for shells!

Negatives

- Can add too much so be careful!
- takes time

The images here show two possible student products. The image on the left is meant to be an exemplar and contains all needed or useful information. The image on the right is missing some elements that you might want to see in students' work, but shows what a different solution might look like. An exemplar of the Student Planning Document can be found in *Sample Solution Planning*.

Once students have had an opportunity to discuss how their solutions will benefit oysters and people, they should work in their groups to figure out how to include those benefits on their posters. The discussion prompts can be used to check in with and formatively assess groups as they are working on their posters.

Suggested prompt	Sample student response
Which specific system or part of a system are you focusing on?	We are focusing on tanks at an oyster hatchery. We are focusing on a section of a bay. We are focusing on the pH of the water. We are focusing on adding carbonate to the water. We are focusing on removing CO₂ from the water.
How will your solution change this system?	Our solution will raise the pH of the water. Our solution will prevent carbonic acid from forming or cause less to form. Our solution will provide more ions for oysters to use to build shells.
How will these changes impact people and oysters?	This will help oysters build shells, which will benefit the people who raise and sell oysters. This will help oysters survive. This will help oyster farmers stay in business. This will help seafood restaurants stay in business. This will benefit ecosystems because if more oysters survive, it will improve water quality.
ASSESSMENT OPPORTUNITY	What to look/listen for in the moment: See <i>Poster Feedback Guide</i>. What to do: Use <i>Poster Feedback Guide</i> to guide feedback to students. Building toward 13.A.2 Use computational thinking to quantify criteria for a solution that will positively affect oysters. (SEP: 5.2; DCI: ETS1.A.1; CCC: 2.3)
ASSESSMENT OPPORTUNITY	What to look/listen for in the moment: See <i>Poster Feedback Guide</i>. What to do: Use <i>Poster Feedback Guide</i> to guide feedback to students. Building toward 13.B.2 Design a solution to cause specific outcomes to mitigate the impacts of ocean acidification on oysters. (SEP: 6.5; DCI: ESS3.C.2; CCC: 2.3)

MATERIALS: science notebook, *Solution Planning Document*, design solution posters

Students show their solutions. Display **slide M**. As students finish their posters, display them in the classroom or in a nearby public space such as a hallway. In the next lesson, students will be presenting their solutions to each other and providing feedback. Tell students that they will have an opportunity to learn from each other in the next class. Have a brief discussion with students about the benefits of peer evaluation and having the opportunity to see each other’s solutions.

Suggested prompt	Sample student response
<i>How did sharing solutions help your group refine the solution?</i>	Accept all responses.
<i>How was giving and receiving feedback helpful?</i>	It helps us think about things we might have missed or overlooked. Giving other groups feedback helps us think about where we can improve our own solutions. It is helpful to have other people look at our ideas since they may think of stuff we did not.

Additional Lesson 13 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA	CCSS.ELA-LITERACY.RST.9-10.10: By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently. Students will use reference materials to help them quantify their criteria and constraints. They will also use the information from the reference materials to help them develop site-specific solutions to mitigate the impacts of ocean acidification.
SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH	CCSS.MATH.CONTENT.HSN.Q.A.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. Students will use units and unit conversions to determine such quantities as volume of water in a given space, concentration of hydrogen ions, mass of base needed to adjust pH, and mass of CO ₂ absorbed, in order to quantify the impacts of a given solution.

LESSON 14: How well do our different design solutions address our criteria and constraints?

PREVIOUS LESSON We looked at site profiles for several locations to help us refine our solutions, criteria, and constraints. Then we developed specific plans and quantified their impacts on pH, carbonate, and CO₂. After we developed our plans, we modeled them on posters for everyone to see.

THIS LESSON

PUTTING PIECES TOGETHER

2 days



jstuby

We identify the main points of our design solution and prepare to share them with our peers. We identify the criteria that guided our solution and rank them in order of importance. We present our design solution to a group of our peers and receive feedback, then decide how we can use the peer feedback to refine our solution. We compare our design solutions and identify similarities and differences across the class. We engage in a discussion to come to a consensus on the chemistry and Earth science ideas that we used in our design solutions.

NEXT LESSON We will return to the Driving Question Board to identify which questions we have answered and to celebrate all that we have figured out in this unit. We will finish with an assessment (transfer task), where we analyze a process and refine a solution related to ammonia fertilizer production.

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-1,
HS-ETS1-2



WHAT STUDENTS WILL DO

14.A Refine design solutions based on trade-offs of relevant criteria that account for changes at multiple scales of the consensus model. (SEP: 7.1; DCI: ETS1.C.1; CCC: 3.4)

14.B Compare design solutions that impact interacting Earth systems at multiple scales to stop oyster die-off. (SEP: 6.5; DCI: ESS2.D.3; CCC: 3.4)

WHAT STUDENTS WILL FIGURE OUT

- 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.

Lesson 14 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Facilitate a discussion about the purpose of participating in peer feedback about students' design solutions.	A-B	<i>Peer Feedback Guidelines</i>
2	10 min		PREPARE FOR PEER DISCUSSIONS Arrange students in their design solution groups to discuss what ideas they want to share with other groups.	C-E	<i>Peer Discussions Guide, Solution Planning Document</i> , design solution poster from Lesson 13
3	10 min		DEFINE TRADE-OFFS Facilitate a whole-class discussion about trade-offs in engineering design.	F-G	<i>Peer Discussions Guide</i>
4	15 min		DISCUSS DESIGN SOLUTIONS Arrange students into mixed groups to share their design solutions.	H-I	<i>Peer Discussions Guide</i> , 4 3x3 sticky notes, design solution poster from Lesson 13
5	5 min		REFLECT ON OUR DESIGN SOLUTIONS Have students reflect individually on their design choices.	J	<i>Peer Discussions Guide, Design Solution Reflection</i>
<i>End of day 1</i>					
6	3 min		NAVIGATE Facilitate a whole-class discussion of what students learned during yesterday's small-group sharing.	K	
7	7 min		EVALUATE OUR DESIGN SOLUTIONS Arrange students into their design solution groups to review and synthesize peer feedback.	L	<i>Design Solution Reflection</i> , design solution poster from Lesson 13
8	15 min		GALLERY WALK Facilitate an individual gallery walk of all design solution posters.	M-N	design solution poster from Lesson 13
9	15 min		CONSENSUS DISCUSSION Gather students in a Scientists Circle and facilitate a Consensus Discussion.	O	<i>Discussion Mapping Tool</i>
10	5 min		EXIT TICKET Give students time to individually complete the exit ticket.	P	<i>Exit Ticket</i>
<i>End of day 2</i>					

Lesson 14 • Materials List

	per student	per group	per class
Lesson materials	• <i>Peer Feedback Guidelines</i> • <i>Peer Discussions Guide</i> • <i>Solution Planning Document</i> • science notebook • 4 3x3 sticky notes • <i>Design Solution Reflection</i> • <i>Exit Ticket</i>	• design solution poster from Lesson 13	• <i>Discussion Mapping Tool</i>

Materials preparation (25 minutes)

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

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

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

Post the carbon cycle model from Lesson 11 for students to refer to on day 1.

Distribute groups' design solution posters from Lesson 13.

Lesson 14 • Where We Are Going and NOT Going

Where We Are Going

The targeted disciplinary core ideas developed in this lesson are:

- **ETS1.C.1: Optimizing the Design Solution.** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.
- **ESS2.D.3 Weather and Climate.** Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.

In the first half of this lesson, students will build on the initial criteria that they developed in Lessons 7 and 12 to evaluate competing design solutions in light of the complete set of evidence, explanations, limitations, and trade-offs of relevant criteria and constraints, as well as ethical issues they have encountered (SEP: 7.1; DCI: ETS1.C.1). Students have to build the tool they will use to evaluate each others' ideas (CCC: 3.4).

Students will share solutions and discuss the decisions they made to prioritize certain criteria over others as they addressed a specific subproblem in a specific context (DCI: ETS1.C.1). Students will use their criteria and constraints to evaluate the engineering design solutions they developed in Lesson 13 (SEP: 7.1). Students will continue to highlight the importance of context and orders of magnitude to a design solution as they provide feedback on another group's design (CCC: 3.4).

Students will synthesize the key science ideas from this unit as they compare design solutions and consider the different options for preventing oyster die-off (SEP: 6.5). Students encounter the root cause of oyster die-off events: the production of atmospheric CO₂ by humans that impacts climate, which they have already investigated and modeled in *Polar Ice Unit* (DCI: ESS2.D.3).

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

Where We Are NOT Going

Students are not ranking solutions or identifying a “best” solution in this lesson or unit. They will have the opportunity to do this in subsequent units. In this unit, students are considering each design solution in the context for which it was designed. After receiving peer feedback, students will reflect on changes they might make to their design solution, but they will not return to their posters to make extensive revisions.

LEARNING PLAN for LESSON 14

1 · NAVIGATE

5 min

MATERIALS: *Peer Feedback Guidelines*

Discuss the purpose of peer discussions. Display **slide A**. Remind students that we decided to share our solution posters with other groups for peer feedback. Ask, *How will having peer discussions about our design solutions help us?* Call on several students to share their responses.

Look for students to suggest:

- We will learn more about the decisions that other groups made.
- We will receive feedback from our peers about how our solution could be stronger.

Review structures for peer feedback. Display **slide B** and distribute *Peer Feedback Guidelines*. Give students two minutes to scan *Peer Feedback Guidelines*. Say, *What is one tip from this reference sheet or your own experience that you will focus on during peer feedback today?* Have students turn and talk with a neighbor about their ideas.

2 · PREPARE FOR PEER DISCUSSIONS

10 min

MATERIALS: *Peer Discussions Guide*, *Solution Planning Document*, design solution poster from Lesson 13

Revisit our solution posters. Arrange students into their design solution groups. Display **slide C**. Say, *You will be sharing your design solution poster with another group for peer feedback today. Let's think about what your peers will know from your poster and what else they might need to know.* Ask students to review their poster as a group and make sure that it addresses the questions on *Solution Planning Document* from Lesson 13.

Summarize our thinking. Display **slide D** and distribute *Peer Discussions Guide*. Say, *Our classmates can learn about our design solution from our posters, but there might be more information that we want to share to really help them understand how we decided on our solution.* Direct students to the prompts listed in part 1 of *Peer Discussions Guide*. Ask students to discuss the prompts and record their ideas in the organizer. Let students know that they will have this handout with them as they share their design solutions with another group, and they can use these notes to help explain their thinking.

Prioritize criteria. Display **slide E**. Say, *Each group developed criteria and a solution based on a specific location and context. We make decisions based on the science ideas we know and on what is important to us and the people affected by the solution.* Ask students to discuss their criteria with their group and rank them from most to least important for deciding if the solution is effective. Also explain that it is important to provide reasons for their rankings during their discussion.

Name: _____ Date: _____

Peer Discussions Guide

1. Use the organizer below to summarize additional information about your design solution that might not be included on your poster. You can refer to this organizer when you are sharing your design solution with your peers.

	Our Ideas
What chemical process on the data cardstock model does this solution target?	
What subproblem does this solution address?	
What is the location or context of the solution?	
How does this solution address the needs of people in the area who are most impacted by system shut-off?	
Why is this the best solution to prevent system shut-off in this context?	

opensci.org Lesson 14 • 5/28/26 Page 1

3 · DEFINE TRADE-OFFS

10 min

MATERIALS: *Peer Discussions Guide*, science notebook

Discuss how we prioritize criteria. Display **slide F** and say, *We are not able to address every criterion that we can think of in an engineering design project. How do we decide which criteria are most important for a specific design solution?* Facilitate class discussion to build the idea of trade-offs.

Suggested prompt	Sample student response	Follow-up questions
<i>How do we decide which criteria are most important for a specific engineering design project?</i>	Sometimes we have to choose which criterion we think will have a greater effect on the solution. We have to balance the needs of those most impacted, ecosystem degradation, and costs.	<i>How did you decide what to prioritize in your own design solution?</i> <i>What might happen if you made a different choice?</i>

Update Personal Glossaries. Display **slide G**. Ask students to add a definition of *trade-offs* to their Personal Glossary.

Say, *Differences in how we considered trade-offs led us to prioritize criteria differently in our design solutions. Let's see how everyone used what we learned about chemistry and Earth science in this unit to create their own design solutions.*

4 · DISCUSS DESIGN SOLUTIONS

15 min

MATERIALS: *Peer Discussions Guide*, 4 3x3 sticky notes, design solution poster from Lesson 13

Share solutions. Split design solution groups into pairs and have each pair of students team up with a pair from another group. Display **slide H** and direct students to look at the list of feedback prompts on *Peer Discussions Guide*. Groups will visit one of their design solution posters and the first pair will explain their solution, context, criteria, and constraints. Then the group will move to the other poster and the second pair will explain their solution, context, criteria, and constraints. Encourage students to ask clarifying questions as they learn about another group's solution.

ADDITIONAL GUIDANCE	Students remain with a partner from their original group so that they have someone to evaluate the poster with. They can decide together on what feedback to leave in the next step. This allows students who may feel less comfortable asking questions or evaluating another group's design solution on their own to have the social support of a partner as they explain their design solution and provide feedback to another group. This activity gives students the opportunity to learn about one other design solution in detail. Students will have the opportunity to view all posters during the gallery walk on day 2. If time permits, you could have students find a second set of partners and repeat the sharing and feedback steps.
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Provide peer feedback. Once students have explained their design solutions to each other, separate groups back into pairs from the same design solution group. Display **slide I**. Ask partners to discuss the design solution that they learned about, using the questions on *Peer Discussions Guide* as a guide. Then, have students use 3x3 sticky notes to leave feedback on the other pair's design solution poster. Suggest that students write one idea on each sticky note, balancing praise and constructive critique.

Once all students have finished providing feedback, give students a few minutes to return to their own design solution posters to read the 3x3 sticky notes. Say, *Now that you have had the chance to learn about another design solution and receive peer feedback on yours, let's take some time to reflect on what we have learned.*

5 · REFLECT ON OUR DESIGN SOLUTIONS

5 min

MATERIALS: *Peer Discussions Guide, Design Solution Reflection*



Individually reflect on design solutions. Display **slide J**. Ask students to refer back to their notes on *Peer Discussions Guide* as well as the peer feedback they received on their design solution poster. Give students time to write a response to the first question on *Design Solution Reflection*: *After learning from other groups and discussing potential trade-offs, what would you change about your own engineering design solution? Use the following to evaluate your solution.*

Consider:

- our current class explanation and consensus model
- evidence you have gathered throughout the unit
- constraints
- ethical issues
- how you broke criteria/problems into subproblems
- whether your trade-offs and priorities are clear
- how orders of magnitude matter (tiny particles → big solution)

Say, *Next class you will have a chance to review the peer feedback and reflect on your design solution as a group.*

Collect *Design Solution Reflection* and look over student responses. Provide any feedback before the next class.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students **compare and evaluate** at least two of the following **competing arguments**: 1) current class explanation and consensus model, 2) evidence gathered throughout the unit, 3) constraints, 4) ethical issues. (SEP: 7.1)
- Students include at least one of the following: 1) **how criteria/problems are broken into subproblems**, 2) **clear tradeoffs**, 3) **clear priorities**. (DCI: ETS1.C.1)
- Students include chemistry reasoning, i.e., how **orders of magnitude matter** (tiny particles → big solution). (CCC: 3.4)

What to do: Remind students that engineering design requires constant refinement, and making improvements does not mean the initial design solution was “bad.” Encourage students to be specific about what they would change and why, and suggest that they review their criteria as they refine their solution. Some students may choose to refine their criteria prioritization and use the new list to improve their design solution.

Building toward 14.A.1 Refine design solutions based on trade-offs of **relevant criteria** that account for **changes at multiple scales of the consensus model**. (SEP: 7.1; DCI: ETS1.C.1; CCC: 3.4)

End of day 1

6 • NAVIGATE

3 min

MATERIALS: None

Summarize the previous day's learning. Display **slide K**. Say, *What did you learn from hearing about your classmates' design solutions yesterday?* Call on several students to share their responses. Listen for ideas about prioritizing criteria or difficulty in decision-making.

7 • EVALUATE OUR DESIGN SOLUTIONS

7 min

MATERIALS: *Design Solution Reflection*, design solution poster from Lesson 13

Prepare students to use their peer feedback. Return *Design Solution Reflection*. Say, *Let's think about how we could use the peer feedback we received to make our design solutions stronger.* Display **slide L**. Ask students to work with their groups to discuss the feedback they received. Students will individually record the feedback on the second page of *Design Solution Reflection*.

8 • GALLERY WALK

15 min

MATERIALS: science notebook, design solution poster from Lesson 13

Introduce the gallery walk. Display **slide M** and ask students to make a note-taking T-chart in their science notebooks using the example on the slide. Tell students that they do not need to copy the bulleted list under the *Engineering & Science* column, it is there to give them ideas of things they could include. Explain that they will use their notes to identify how the groups used chemistry and Earth science ideas to help oysters.

Display **slide N** and keep it visible during the gallery walk. Encourage students to pay attention to the different scales of the design solutions by asking them to think about the prompts on the slide.*

1. How are others' solutions based on evidence, criteria, and trade-offs?
2. How are we engineering chemical interactions in our Earth's atmosphere and hydrosphere?
3. What is the impact at different orders of magnitude (molecules → Earth systems)?
4. How long will these solutions take?

Facilitate the gallery walk. Continue to display **slide N**. Ask students to circulate silently through the room as they view each other's design solution posters. * Provide students with approximately 10 minutes to view all of the posters and make notes in their science notebook. After students have completed the gallery walk, say, *Look at all of the different ways we can use chemistry to help the oysters! Let's think more about how all of these pieces fit together.*

ADDITIONAL GUIDANCE

The gallery walk helps prepare students for the following Consensus Discussion by giving them the opportunity to consider different types of design solutions. Steer students away from evaluating the design solutions at this point or deciding which one they think is "best." The goal of this activity is for students to think about the many different ways we can use the science ideas we have figured out to help oysters.

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

Questions 3 and 4 prompt students to think about the *different scales at which their solutions are implemented and observed*. For example, a solution in which seagrass is planted to remove carbon dioxide from the ocean causes several orders of magnitude more CO₂ to be removed compared to removal by wild seagrass. Students should also observe that some solutions may take longer to implement or have longer-lasting effects, depending on which part of the class consensus model they are targeting. (CCC: 3.4)

* ATTENDING TO EQUITY

Universal Design for Learning. *Representation* is varied in this lesson by allowing students to move their bodies around the room in a gallery walk as they look for ideas. Support students with all sizes

of bodies and mobility needs by making sure furniture is arranged for easy access to each poster.

9 · CONSENSUS DISCUSSION

15 min

MATERIALS: science notebook, *Discussion Mapping Tool*

 **Facilitate a Consensus Discussion.** Display **slide O**. Gather students in a Scientists Circle with their science notebooks. Direct students to look at the notes they made during the gallery walk. Ask, *How do our design solutions use our knowledge of chemistry and Earth systems to help oysters?*

Consider using *Discussion Mapping Tool* to track the discussion. It contains the 4 key ideas aligned to LLPE 14.B.

KEY IDEAS

Purpose of this discussion: To come to a consensus on the chemistry and Earth systems ideas present in the design solutions and to decide on the changes that occur at different timescales.

Listen for these ideas:

- Carbon dioxide reacts with water to form carbonic acid. This is a reversible reaction.
- We can use our understanding of acids, bases, and neutralization to raise the pH of ocean water.
- According to stoichiometric calculations, it is reasonable to add a base or other compound to a small volume of water, like holding tanks, but not to the entire ocean.
- Carbon cycles between the geosphere, hydrosphere, biosphere, and atmosphere. When too much carbon is entering the hydrosphere from the atmosphere, we can try to move carbon into the biosphere (i.e., plants) or try to reduce the amount of carbon in the atmosphere.
- It takes a long time for carbon to move from the hydrosphere to the geosphere through natural processes, so a solution needs to remove carbon more quickly.
- Shell formation requires calcium carbonate, and adding more calcium and carbonate ions to the water can help strong shells form. We can use what we know about reaction rates to make that reaction happen more quickly or slowly.
- Different contexts require different engineering design solutions based on the specific needs of local interested parties. Some solutions may affect a small population of oysters, while others may change the conditions in a larger region.

Suggested prompt	Sample student response	Follow-up questions
<i>What chemistry and Earth science ideas did we use in our engineering design solutions?</i>	Reversible reactions. Neutralization of an acid. Plants can remove carbon dioxide from the water. We used stoichiometry to calculate how much base to add.	<i>What effect does that have?</i> <i>Can you say more about how that happens?</i>

Suggested prompt	Sample student response	Follow-up questions
What are some similarities we saw across our solutions?	Several of the solutions used what we learned about acidity. Several groups thought about what interested parties needed when they designed their solutions.	Why do you think that idea showed up in multiple solutions?
What are some differences we saw across our solutions?	We removed carbon dioxide from the water, but another group added a new substance to neutralize the acid. Some solutions helped the oysters in an oyster farm, while other solutions helped wild oysters.	What criteria were used to define each of those solutions? Why does that solution make sense for that context?

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Students should **compare, reference, and evaluate others' solutions based on evidence they have gathered, criteria they have prioritized, and trade-offs.** (SEP: 6.5)
- Students articulate that the **chemistry of the atmosphere and hydrosphere has changed with CO₂ production, which can be reduced through human efforts.** (DCI: ESS2.D.3)
- Students make connections between **small particles and large effects (orders of magnitude).** (CCC: 3.4)

What to do: Use the suggested prompts to guide the discussion. Remind students of the different contexts that were addressed in the design solutions and the different criteria and constraints that guided each solution. Use the crosscutting concept of *scale* to note differences in potential impacts, particularly in terms of the size of the area affected and the length of time needed for the desired change to occur. Encourage students to be specific when naming science ideas. For example, if a student says “acidity,” use follow-up questions to elicit a description of the mechanism by which carbon dioxide reacts with water to produce carbonic acid.

Building toward 14.B.1 Compare design solutions that impact **interacting Earth systems** at **multiple scales** to stop oyster die-off. (SEP: 6.5; DCI: ESS2.D.3; CCC: 3.4)

10 • EXIT TICKET

5 min

MATERIALS: *Exit Ticket*

Complete exit tickets. Display **slide P** and distribute *Exit Ticket*. Ask students to reflect on the engineering design process they used in this unit and record their reflections on the exit ticket. Collect exit tickets before students leave the classroom.

EXIT TICKET



The two exit ticket prompts ask students to reflect on the process of using engineering ideas to develop a design solution. Some students may be new to this process, while others may have used engineering design in a previous unit or lesson. Question 1 engages students in self-reflection by asking how they contributed to the design process. Question 2 asks students to compare the engineering design process to other scientific processes, which prepares them to think about what they have learned about engineering in this unit. Before Lesson 15, read through student responses to Question 2 and select a few responses or patterns to share during the opening navigation.

LESSON 15: How can we apply our learning to other situations?

PREVIOUS LESSON We identified the main points of our design solution and the criteria that guided our solution. We ranked the criteria in order of importance. We presented our design solution and received peer feedback. We decided how to use the peer feedback to refine our solution. We compared our design solutions and discussed the chemistry and Earth science ideas that we used to develop them.

THIS LESSON

PUTTING PIECES TOGETHER

2 days



Thirteen Of Clubs, CC BY-SA 2.5

Having had a chance to refine solutions, we return to the Driving Question Board to identify which questions we have answered and to celebrate all that we have figured out in this unit. We finish with an assessment (transfer task), where we analyze a process and refine a solution related to ammonia fertilizer production.

NEXT LESSON There is no next lesson.

BUILDING TOWARD NGSS

HS-PS1-5, HS-PS1-6, HS-PS1-7,
HS-ESS2-6, HS-ESS3-4, HS-ETS1-1, HS-ETS1-2



WHAT STUDENTS WILL DO

15.A Apply scientific ideas, principles, and evidence to explain how changing the temperature or concentration of the reactants affects the reaction rate. (SEP: 6.3; DCI: PS1.B.1, PS1.B.2; CCC: 2.2)

15.B Use student-generated sources of evidence to develop a model to predict how changes in a system would increase the rate of a reversible reaction to produce larger amounts of products by examining smaller scale mechanisms. (SEP: 2.3; DCI: PS1.B.2; CCC: 2.2)

15.C Use mathematical thinking to describe claims about how conservation of matter and chemical properties of the elements involved can be used to predict the scale and significance of chemical reactions. (SEP: 5.2; DCI: PS1.B.3; CCC: 3.1)

15.D Make a claim about the effectiveness of a design solution which reflects evidence about trade-offs and its design criteria by accounting for the flow of energy through the system. (SEP: 7.5; DCI: ETS1.C.1; CCC: 5.2)

WHAT STUDENTS WILL 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.

Lesson 15 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Share student impressions from the exit ticket from Lesson 14 and transition to a return to the Driving Question Board.	A	Lesson 14 Exit Tickets, Driving Question Board
2	20 min		REFLECT ON WHAT WE HAVE ACCOMPLISHED Lead a whole class discussion to revisit the DQB to take stock of all of the questions we have now answered.	B-C	<i>Our DQB Questions</i> , Driving Question Board
3	20 min		BEGIN THE INDIVIDUAL ASSESSMENT Students individually analyze the Haber-Bosch process using tools they have developed in the unit.	D	<i>Ammonia Fertilizer Task</i>
<i>End of day 1</i>					
4	45 min		FINISH THE INDIVIDUAL ASSESSMENT Students finish the unit assessment and may engage in one of several extension activities as time and teacher preference dictate.	E	<i>Ammonia Fertilizer Task, Haber and Bosch</i> (optional)
<i>End of day 2</i>					

Lesson 15 • Materials List

	per student	per group	per class
Lesson materials	• <i>Our DQB Questions</i> • <i>Ammonia Fertilizer Task</i> • science notebook • <i>Haber and Bosch</i> (optional)		• Lesson 14 Exit Tickets • Driving Question Board

Materials preparation (35 minutes)

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

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

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

Read students' responses to the Lesson 14 Exit Ticket. Select a few responses to share with the class that you think are representative of many students' experiences and thinking. Focus on those that share student accomplishments or meaningful insights into how science and engineering differ. Make sure all student responses to these prompts remain anonymous.

You should have created the handout *Our DQB Questions* for your class already in Lesson 7. If a significant number of student questions have been added to the DQB since then, create an updated version with those new questions and prepare to distribute it to students in addition to their original copy.

After day 1, review student assessments to estimate how much additional time students will need to complete them. If the whole class completes the assessment early, decide which of the following instructional strategies makes the most sense for your class:

- Have students read and individually reflect on *Haber and Bosch*.
- Have students research the ways in which engineers are trying to make the Haber-Bosch process more environmentally friendly.
- Begin the next unit.

Lesson 15 • Where We Are Going and NOT Going

Where We Are Going

The targeted disciplinary core ideas that we have developed by the end of this lesson are:

- **PS1.B.1: Chemical Reactions.** Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy.
- **PS1.B.2: Chemical Reactions.** In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.
- **PS1.B.3: Chemical Reactions.** The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.
- **ETS1.C.1: Optimizing the Design Solution.** Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.

Crossout explanation: Students do not need bond energies or endo- and exothermic reactions to explain the phenomenon of oyster die-off, so these are not coherent to student learning in this unit. The remaining ideas in PS1.B.1: Chemical Reactions about bond energies and endo- and exothermic reactions are deeply modeled, explained, and assessed in detail in *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*. Postponing the learning of these two ideas does not reduce the DCI to middle school grade level. Middle school grade levels of the PS1 disciplinary core ideas are concerned with much larger-scale properties of matter and do not include the ideas of bonds, equilibrium, or rate.

This lesson does not introduce new content. The lesson celebrates the questions students have answered in this unit.

This lesson begins with a return to the Driving Question Board to review key content and re-center students on their learning from the unit in preparation for the transfer task assessment.

The transfer task assesses what students have figured out during the unit in the context of a similar phenomenon: the Haber-Bosch process for producing ammonia fertilizer. Students use models to explain the driving question in the transfer task: How can we engineer fertilizer out of hydrogen and nitrogen atoms? The task breaks down as follows (explained further in *Ammonia Fertilizer Key*):

The assessment focuses on both the physical science and engineering DCIs associated with HS-PS1-5, HS-PS1-6, and HS-PS1-7, and may be scored. Teachers are encouraged to give three-dimensional feedback on student learning so that students continue to grow in their thinking. Like ocean acidification, the Haber-Bosch process is reversible and depends on a dynamic and condition-dependent balance that involves the collisions of particles. The first question in the assessment asks students to model and explain with evidence the nature of this reaction (SEP: 6.3; DCI: PS1.B.2, PS1.B.1; CCC: 2.2). Question 2 asks students to model changes in the system to increase reaction rate (SEP: 2.3; DCI: PS1.B.2; CCC: 2.2). Question 3 requires students to explain using mathematical thinking the amounts of grams, atoms, and matter that need to be accounted for as matter and energy are conserved in the Haber-Bosch fertilizer process (SEP: 5.2; DCI: PS1.B.3; CCC: 3.1). Question 4 requires students to trace the flow of energy and matter in this reaction to prioritize criteria and constraints (SEP: 7.5; DCI: ETS1.C.1; CCC: 5.2).

Where We Are NOT Going

Many student questions may remain unanswered. Some may be answered through student investigations in future units, while others are not addressed in this curriculum. Students still generally express satisfaction if a significant percentage of their questions are answered. This lesson, though assessment-heavy, is not intended to be replaced by an assessment focused on decontextualized “problems.” The assessment was designed carefully to address all three dimensions of the NGSS in a context that is meaningful to students’ experiences inside and outside of this unit, without sacrificing rigor or equity.

LEARNING PLAN for LESSON 15

1 · NAVIGATE

5 min

MATERIALS: Lesson 14 Exit Tickets, Driving Question Board

Share impressions from the Lesson 14 Exit Ticket. Thank students for sharing their reflections on the engineering design process at the end of the last lesson. Share a few anonymous student responses or general impressions of responses that you think reflect class thinking, celebrate student accomplishments in the last few lessons, and/or contain insights into how science and engineering differ.

Show **slide A**. Say, *What did you figure out from your work using the engineering design process?* Give students time to turn and talk before taking responses. Accept all answers.

Transition students to a return to the Driving Question Board. Say, *Now that we have had a chance to think about solutions to help protect oysters, let's look back at our Driving Question Board. We have actually figured out a lot of things that we were wondering at the start of the unit and can help answer our big question, "Why are oysters dying, and how can we use chemistry to protect them?"*

2 · REFLECT ON WHAT WE HAVE ACCOMPLISHED

20 min

MATERIALS: *Our DQB Questions*, Driving Question Board

Prepare to return to the Driving Question Board.* Display **slide B**. Have students take out *Our DQB Questions* and provide them with an updated version if you made one. Have students work in pairs for 5 to 10 minutes to mark questions they think the class has answered using the symbols on the handout, replicated here.

- We did not answer this question or any parts of it yet: O
- Our class answered some parts of this question, or I think I could answer some parts of this question: ✓
- Our class answered this question, or Using the ideas we developed, I could now answer this question: ✓+

Mark questions on the DQB, individually. Display **slide C**. Ask individual students to come to the DQB and mark questions that the class has answered in whole or in part through our investigations. Have as many students as possible participate until all the questions that the class has answered have been marked. If there is time, ask students to share evidence that we have answered the questions as each one is checked off. At the end, you may ask students to summarize which groups of questions have and have not been answered. Thank students again for all their hard work on this unit and celebrate just how much we have figured out through our efforts.

Name: _____ Date: _____

Our DQB Questions

Look through the list of questions from our DQB. Mark questions that you think the class has answered by putting different symbols next to each question.

- We did not answer this question or any parts of it yet: O
- Our class answered some parts of this question, or I think I could answer some parts of this question: ✓
- Our class answered this question, or Using the ideas we developed, I could now answer this question: ✓+

Questions from our classroom DQB:

1. (Teacher, list questions here before printing for students.)

openscienced.org Lesson 15 • 5/28/26 Page 1

* ATTENDING TO EQUITY

Revisiting the Driving Question Board is important for students to feel that their questions are valued and recognized. While not all questions will have been addressed (it is more likely that 60–75 percent will be at least partially answered), this activity helps students see the hard work they have done to answer many of their own questions.

3 · BEGIN THE INDIVIDUAL ASSESSMENT

20 min

MATERIALS: *Ammonia Fertilizer Task*, science notebook

ADDITIONAL GUIDANCE

Ammonia Fertilizer Task is different from *Acid Behavior Assessment* in that this new assessment is a transfer task. At the end of the unit it is important to see if students can apply the ideas they have been developing to a novel situation that utilizes many of the same chemistry and engineering principles. Encourage students to use their science notebook as needed.



Navigate into the assessment. Show slide D. Say, *We have figured out a lot of great chemistry ideas in this unit, but we have really only applied these ideas to oysters. Today you will have a chance to look at a different problem that has a lot in common with ocean acidification. This problem involves producing ammonia fertilizer to help crops grow. You will have about 20 minutes today and plenty of time when we see each other again to work through this problem on your own. Distribute Ammonia Fertilizer Task and ask students to take out Periodic Table. Continue, All the information you need to complete this assessment is given here or can be found on the periodic table. Take your time. I will collect your work at the end of the day for safekeeping until next time.**

Allow students to work until class is almost over, then collect assessments before students leave.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Ammonia Fertilizer Key* for detailed, leveled guidance of what to look for to assess student progress.

What to do: See the additional “What to do” information in the Assessment Opportunity box in step 4 of the lesson plan.

Building toward 15.A.1 Apply scientific ideas, principles, and evidence to explain how changing the temperature or concentration of the reactants affects the reaction rate. (SEP: 6.3; DCI: PS1.B.1, PS1.B.2; CCC: 2.2)

Building toward 15.B.1 Use student-generated sources of evidence to develop a model to predict how changes in a system would increase the rate of a reversible reaction to produce larger amounts of products by examining smaller scale mechanisms. (SEP: 2.3; DCI: PS1.B.2; CCC: 2.2)

Building toward 15.C.1 Use mathematical thinking to describe claims about how conservation of matter and chemical properties of the elements involved can be used to predict the scale and significance of chemical reactions. (SEP: 5.2; DCI: PS1.B.3; CCC: 3.1)

Building toward 15.D.1 Make a claim about the effectiveness of a design solution which reflects evidence about trade-offs and its design criteria by accounting for the flow of energy through the system (SEP: 7.5; DCI: ETS1.C.1; CCC: 5.2)

* ATTENDING TO EQUITY

The introduction to this assessment is text-heavy. This is necessary to provide students with important background information, but it may also cause some students to worry or “lock up.” Consider reading the introduction aloud to students to help them feel more comfortable.

End of day 1

4 • FINISH THE INDIVIDUAL ASSESSMENT

45 min

MATERIALS: *Ammonia Fertilizer Task*, science notebook, *Haber and Bosch* (optional)



Return to the assessment. Display slide E. Redistribute student assessments and say, *You have the rest of the period to finish your assessment, if you need it.* Give students instructions about what you would like them to do when they finish. Make sure all student assessments are collected before moving the whole class on to one of the extension opportunities that students can engage with as time allows.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: See *Ammonia Fertilizer Key* for detailed, leveled guidance of what to look for to assess student progress.

What to do: While the answers in *Ammonia Fertilizer Key* show the expected responses and calculations, keep in mind that student thinking may be valuable even if their calculations do not yield these expected responses.

Use the “Key elements” in the rubric to help provide positive feedback and partial credit to students based on their responses. The rubric is designed to help you keep track of students’ use of all three dimensions of the NGSS, rather than only whether or not their statement of science ideas is correct. Consider taking instructional time after the assessment task to review how it went for students using the “What to do” guidance provided.

Building toward 15.A.1 Apply scientific ideas, principles, and evidence to explain how changing the temperature or concentration of the reactants affects the reaction rate. (SEP: 6.3; DCI: PS1.B.1, PS1.B.2; CCC: 2.2)

Building toward 15.B.1 Use student-generated sources of evidence to develop a model to predict how changes in a system would increase the rate of a reversible reaction to produce larger amounts of products by examining smaller scale mechanisms. (SEP: 2.3; DCI: PS1.B.2; CCC: 2.2)

Building toward 15.C.1 Use mathematical thinking to describe claims about how conservation of matter and chemical properties of the elements involved can be used to predict the scale and significance of chemical reactions. (SEP: 5.2; DCI: PS1.B.3; CCC: 3.1)

Building toward 15.D.1 Make a claim about the effectiveness of a design solution which reflects evidence about trade-offs and its design criteria by accounting for the flow of energy through the system (SEP: 7.5; DCI: ETS1.C.1; CCC: 5.2)

Give feedback. As soon as possible, use *Ammonia Fertilizer Key* to provide written feedback to students on their work. Unlike a grade, written feedback gives students the opportunity to continue to think about their work.

ALTERNATE ACTIVITY

Extension opportunity: Students may finish the assessment at different times, so you may wish to utilize an extension activity.

This activity is ideal for students who complete the assessment early on day 2. As students finish, have them read *Haber and Bosch* and respond to the prompt in their science notebooks.

Students should recognize that the technology developed by Haber and Bosch has been used to provide great benefits to the world, but also to commit serious violence against human beings. The information in this reading may be surprising and even disturbing to some students, so prepare for a range of reactions. Allow and encourage those who are interested to conduct further research. Do not engage in a class discussion around this reading unless you have sufficient time and a strong classroom community where students can have a respectful and thoughtful discussion after the mental challenge of an assessment.

Another extension opportunity is to have students research the ways in which engineers are trying to make the Haber-Bosch process more environmentally friendly.

Additional Lesson 15 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.CONTENT.HSN.Q.A.1: Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays.

In *Ammonia Fertilizer Task*, students use stoichiometric calculations to determine the masses of reactants and products in hydrogen production, and use an understanding of this process to show that atoms and mass are conserved in reactions.



Unit C.4 Teacher Reference Materials

ASSESSMENT SYSTEM OVERVIEW

Each OpenSciEd unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the “Assessment Icon” in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

Overall Unit Assessment

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 1	<i>Initial Modeling</i> Driving Question Board <i>Traditional Foods</i>	Pre-Assessment Student work in Lesson 1 can be used as a pre-assessment. It is an opportunity to learn more about the ideas your students bring to this unit. Revealing these ideas early on can help you be more strategic in how to build from and leverage student ideas across the unit. The initial model developed on day 2 of Lesson 1 is a good opportunity to pre-assess students’ use of particle thinking and understanding of what it means for a substance to be “acidified”. The Driving Question Board is another opportunity for pre-assessment. Reinforce for students to generate and post open-ended questions, such as “how” and “why”. However, any questions students share, even if they are close-ended questions, can be valuable. Make note of any close-ended questions and use navigation time throughout the unit to have your students practice turning these questions into open-ended questions when they relate to the investigations underway. Cultural Formative Assessment In the previous lesson, students complete a home learning task where they ask people older than them about food and nourishment. Students should bring these ideas to share on day 2.
Lesson 3	Driving Question Board	Formative This Driving Question Board check-in allows students to add additional questions which may have come up after developing some understanding around the mechanisms related to changing pH values of substances.
Lesson 4	Lesson 4 Exit Ticket (Electronic Exit Ticket) <i>Exit Ticket Key</i>	Summative + Community Building The first Electronic Exit Ticket allows relatively quick individual assessment of students on a key LLPE. Teachers can quickly check students’ understanding of concentration, pH, and molarity to see if more practice is necessary, but students also have an opportunity here to reflect on their classroom culture and contributions and engage with metacognitive questions around their own lives, how they used science and engineering practices and crosscutting concepts in sensemaking, and the value of their classmates in supporting their learning.
Lesson 6	Driving Question Board	Formative This second Driving Question Board check-in allows students to add additional questions about how the pH of a substance can change and then return back to the initial conditions without any visible chemical changes. This helps students to begin building understanding of reversible reactions.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 7	<i>Discuss Interested Parties</i> <i>Discuss Interested Parties Key</i> <i>Acid Behavior Assessment</i> <i>Acid Behavior Key</i> Driving Question Board <i>Our DQB Questions</i>	Formative + Community Building Students work in small groups to reflect on the needs of one interested party as they co-develop responses on <i>Discuss Interested Parties</i>. They share this information with a new group composed of other students who read about a different interested party. Students compile this information to develop a list of criteria and constraints. Summative This mid-unit transfer task has students carry out an investigation comparing how addition of a salt to an acidic solution affects the pH of a weak acid differently than a strong acid. It assesses LLPE 7.B: Develop a predictive and explanatory model based on particle-level interactions found in solutions at different equilibrium states and use it to inform a design solution. (SEP: 2.3, 6.3; DCI: PS1.B.1, PS1.B.2; CCC: 2.2) Additional elements used as part of this Mid Unit Assessment are outlined in <i>Acid Behavior Key</i>. This task is intended to use about 30 minutes of class time including initial instructions, although you may find that it takes more or less time for your students to complete. The scoring on this assessment represents our recommendation for how to weigh questions. Please use scoring that works for your class, and your requirements. We strongly recommend that you encourage students to use their notebooks as a resource for completing all assessments. Formative This third Driving Question Board check-in allows students to clear additional questions from the first lesson set and add questions pertaining to chemical engineering solutions to solve ocean acidification and how to evaluate those solutions. These questions set students up for their activities in lesson sets 2 and 3.
Lesson 8	<i>Neutralization Investigation #2</i> <i>Neutralization Investigation #2 Key</i>	Formative This task is intended for students to practice stoichiometric calculations to determine the amount of a base to add to a solution in order to neutralize that solution. At this point, students are working collaboratively. In Lesson 9 and later lessons, students practice using stoichiometric calculations individually.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 9	<i>Ocean Water Calculations</i> <i>Ocean Water Calculations Key</i> Lesson 9 Exit Ticket (Electronic Exit Ticket) <i>Electronic Exit Ticket Key</i>	Formative These tasks are intended for students to apply their understanding of stoichiometric calculations and molarity - first collaboratively using the context of adjusting the pH of an oyster tank, then individually using the context of adjusting the pH of the whole ocean. Students will have additional opportunities to apply these techniques in Lesson 12 as they develop solutions to protect oysters and in the final transfer task in Lesson 14, so use this as an opportunity to gauge students' individual comfort with mathematical tools and offer small-group or individual support as needed. We recommend against providing large amounts of de-contextualized practice or asking students who feel comfortable using these techniques to drill them repeatedly. If students need additional practice, <i>Stoichiometry Practice</i> and accompanying key, <i>Stoichiometry Practice Key</i> are provided. Summative + Community Building This second and final Electronic Exit ticket focuses on how they use mathematical reasoning to figure out chemical reactions and their quantities which students will use again in Lessons 11, 12, and 14. It also provides an opportunity for students to share their thinking about the importance of considering scale and proportions when designing possible solutions, and reflect on the role of using ratio thinking in their sensemaking. Finally, students again celebrate how they have helped the class make progress.
Lesson 13	<i>Solution Planning Document</i> <i>Sample Solution Planning</i> Solution Posters <i>Poster Feedback Guide</i>	Formative In this lesson, students are organized into groups to plan a solution for a particular community. They use <i>Solution Planning Document</i> as a tool to help think about their plan. <i>Sample Solution Planning</i> serves as a document to enable teachers to provide just-in-time feedback as students are developing their solution plans. Each group creates a poster to share information about their design. Depending on their particular site and solution, different groups' posters will reflect different combinations of chemical concepts that students have built in this unit. Use posters as an opportunity to identify which ideas seem strongest across the class and which are less visible. You may wish to take time while students examine each others' posters to highlight those which apply concepts that much of the class did not use in their solutions.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 14	<i>Peer Discussions Guide</i> <i>Peer Feedback Guidelines</i> <i>Design Solution Reflection</i> <i>Discussion Mapping Tool</i> <i>Exit Ticket</i>	Peer-Assessment Students share their group's poster from Lesson 13 with another group to provide feedback using <i>Peer Discussions Guide</i>. This provides students with an opportunity to consider how well other groups incorporated the criteria and constraints of the community they designed the solution for. Formative + Self-Assessment Students review their notes from the peer discussion and complete a 3-dimensional discussion reflection on how they would change their own ideas about their engineering design solution. They have to evaluate their solution in light of science, evidence, constraints, and ethics. This serves as a major assessment point for engineering and can be used as a summative task. Formative + Community Building In this lesson, students participate in a Scientists Circle to generate consensus about how the orders of magnitude are present in the engineering design solutions they have created. Teachers should print one map per class and populate the circle with student names. If your class is large you may do inner and outer circles and print two discussion maps. This discussion is directly tied to LLPE 14.B. Self-Assessment Two prompts on this Exit Ticket gives students opportunities to reflect on their own engineering design solution, their role in its development, and how the engineering design process differs from approaching purely scientific problems. These artifacts can provide evidence as to students' individual contributions to and understanding of the group's work in Lesson Set 3, as well as a deeper understanding of how students view engineering.
Lesson 15	Driving Question Board <i>Our DQB Questions</i> <i>Ammonia Fertilizer Task</i> <i>Ammonia Fertilizer Key</i>	Formative + Summative The final Driving Question Board check-in allows students to celebrate everything they have figured out in the unit. Students can also identify questions that were not answered in this unit, which might be addressed in later units or courses, or can serve as areas of independent research. Finally, this Driving Question Board check-in acts as a review of the units' ideas before students engage with the final transfer task. Summative This end of unit transfer task engages students with the novel phenomenon of Ammonia Fertilizer Production, which can be explained using ideas from the unit. It assesses students on: HS-PS1-5: Apply scientific principles and evidence to provide an explanation about the effects of changing the temperature or concentration of the reacting particles on the rate at which a reaction occurs. HS-PS1-6: Refine the design of a chemical system by specifying a change in conditions that would produce increased amounts of products at equilibrium. HS-PS1-7: Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction. The ideas, crosscutting concepts, and practices students engage with as part of completing this assessment can be found at the top of the Scoring Guidance (rubric). Please use scoring that works for your class and your requirements. We strongly recommend that you encourage students to use their notebooks as a resource for completing all assessments. This task is robust, and will take approximately 45-60 minutes, stretching across two periods.

When	Assessment and Scoring Guidance	Purpose of Assessment
After each lesson	Lesson Level Performance Expectation Assessment Guidance	Formative Assessment Use this document to see which parts of lessons or student activity sheets can be used as embedded formative assessments.
Occurs in several lessons	<i>Progress Tracker</i> <i>Progress Tracker Key</i>	Formative and Student Self-Assessment The Progress Trackers are thinking tools designed to help students keep track of important discoveries that the class makes while investigating phenomena and figure out how to prioritize and use those discoveries to develop a model to explain phenomena. It is important that what the students write in the Progress Trackers reflects their own thinking at that particular moment in time. In this way, the Progress Trackers can be used to formatively assess individual student progress or for students to assess their own understanding throughout the unit. Because the Progress Trackers are meant to be a thinking tool for kids, we strongly suggest it is not collected for a summative “grade” other than for completion. Students add or revisit their progress trackers in Lessons 2, 5, 6, 8, 9, 10, 11, 12
Occurs in several lessons	Teacher Background Information	Self-Assessment This resource is available in the <i>OpenSciEd Teacher Handbook: High School Science</i> . The student self-assessment discussion rubric can be used anytime after a discussion to help students reflect on their participation in the class that day. Choose to use this at least once a week or once every other week. Initially, you might give students ideas for what they can try to improve for the next time, such as sentence starters for discussions. As students gain practice and proficiency with discussions, ask for their ideas about how the classroom and small group discussions can be more productive. Opportunities for individual self-assessment and reflection outside of this tool may be found in the electronic exit tickets in Lessons 4 and 9 as well as the assessments in Lesson 14.
Occurs in several lessons	Teacher Background Information	Peer-Assessment This resource is available in the <i>OpenSciEd Teacher Handbook: High School Science</i> . Facilitating students to give each other feedback will be very valuable for their three-dimensional learning. Additionally, peer feedback can support teachers in managing the time-intensive demands of individualized feedback. We suggest that peer review happen at least two times per unit. Peer feedback is most useful when there are complex and diverse ideas visible in student work. That is, peer feedback works best when not all work is the same. Student models and explanations are good times to use a peer feedback protocol. They do not need to be final pieces of student work. Rather, peer feedback will be more valuable to students if they have time to revise after receiving peer feedback. It should be a formative, not summative, type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities where they can use these experiences as evidence for their feedback. Recommendations for moments in which to use the peer assessment tool may be found in Lesson 13.

For more information about the OpenSciEd approach to assessment and general program rubrics, visit the OpenSciEd Teacher Handbook.

Lesson-by-Lesson Assessment Opportunities

Every OpenSciEd lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to **Science and Engineering Practice(s)**, alignment to **Cross-Cutting Concept(s)**, and alignment to the **Disciplinary Core Ideas**.

The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 1	1.A Develop a model using evidence that compares large-scale carbon dioxide changes to explain small-scale oyster die-offs using particle-level interactions. (SEP: 2.3; DCI: ESS2.D.3; CCC: 3.4) 1.B Ask questions to clarify how oyster populations and changes in climate due to atmospheric carbon dioxide are connected. (SEP: 1.2; DCI: ESS2.D.3; CCC: 7.1)	1.A When to check for understanding: On day 2 as students develop and share their initial models of how increased atmospheric carbon dioxide could be causing ocean acidification and therefore harm to oysters. (slide V) What to look/listen for in the moment: - Students' models use evidence to show how large-scale ocean system changes result in ocean acidification at a particle level. (SEP: 2.3; CCC: 3.4) - Students' models use evidence to show how ocean acidification at a particle level affects small-scale oyster structures (systems). (SEP: 2.3; CCC: 3.4) - Students trace the flow of carbon dioxide from human activities to the atmosphere, and from the atmosphere into the ocean. (DCI: ESS2.D.3) 1.B When to check for understanding: On day 3 as students generate questions for the Driving Question Board and arrange them on the board. (slides BB-CC) What to look/listen for in the moment: - Students' questions are related to changes occurring in the anchoring phenomenon, unresolved portions of the model, and/or related phenomena. (SEP: 1.2; CCC: 7.1) - Students' questions are based on figuring out how increased levels of carbon dioxide in the atmosphere interact with the hydrosphere and/or biosphere. (SEP: 1.2; DCI: ESS2.D.3)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 2	2.A Use <i>consideration of scale</i> and <i>patterns related to scale</i> to <i>evaluate proposals</i> of the most productive <i>design subproblem</i> to pursue to <i>counteract negative human impacts on oysters</i>. (SEP: 7.6; DCI: ETS1.A.2; CCC: 1.1, 3.1)	2.A. When to check for understanding: 1. When students share their arguments with a partner. (slide K) 2. During the whole-class debrief. (slide L) What to look/listen for across opportunities 1-2: • Students reason about the <i>interrelated nature of different approaches to solutions</i>. (SEP: 7.6) <i>For example, that mitigation might be an immediate priority, but will become increasingly difficult to achieve without addressing the root cause.</i> • Students share reasonable ideas about <i>timescales on which we would see results</i> from various <i>approaches to solutions</i> tied back to evidence from Lesson 1. (SEP: 7.6; CCC: 1.1, 3.1) <i>For example you might see results from treating water within hatchery tanks within days, whereas it might take years to see ocean acidification reverse.</i> • Students identify initial ideas about which <i>types of solutions</i> would most <i>benefit from a chemical engineering perspective</i>. (SEP: 7.6; DCI: ETS1.A.2) <i>For example, a chemical engineering perspective might be more beneficial when working on scientific solutions that reduce greenhouse gases caused by human emissions as opposed to providing policy, economic, or political solutions.</i> • Students evaluate <i>competing arguments based on evidence</i> about which <i>subproblems we are best positioned to pursue</i> in the context of our chemistry class. (SEP: 7.6; DCI: ETS1.A.2)
Lesson 3	3.A Plan and conduct an investigation to <i>produce empirical evidence that supports the claim that increased atmospheric carbon dioxide levels causes ocean water to become more acidic</i>. (SEP: 3.1; DCI: PS1.B.2, ESS2.D.3; CCC: 2.1) 3.B Integrate sources of information to answer scientific questions about <i>pH values</i> and <i>how a change in magnitude of hydrogen ions in solution affects pH values</i>. (SEP: 8.2; DCI: PS1.B.2; CCC: 3.4)	3.A When to check for understanding: 1. As small groups develop their investigation plans. (slide F) 2. During the whole-class discussion around investigation results. (slide H) What to look/listen for across opportunities 1-2: • Students <i>collaboratively plan an investigation to produce data to support a scientific claim</i>. (SEP: 3.1) • Students' <i>investigation plan ensures that variables are controlled</i> so that the <i>empirical evidence collected</i> can be <i>used to evaluate a claim</i>. (SEP: 3.1; CCC: 2.1) • Students identify <i>empirical evidence that supports the claim that increased atmospheric carbon dioxide levels have caused ocean water to become more acidic</i>. (DCI: PS1.B.2, ESS2.D.3; CCC: 2.1) • Students <i>consider which pH indicator and water should be used to gather data in future investigations</i>. (SEP: 3.1) 3.B When to check for understanding: 1. As students complete <i>Connect, Extend, Question</i>. (slides J-K) 2. As the class builds "Connect" and "Extend" posters. (slide L) What to look/listen for across opportunities 1-2: • Students <i>integrate information from a reading and website to answer questions about pH values</i>. (SEP: 8.2; DCI: PS1.B.2) • Students explain that <i>pH values indicate the concentration of hydrogen (H⁺) ions in a solution</i>. (DCI: PS1.B.2) • Students identify that an <i>increase by a factor of 10 in the concentration of hydrogen (H⁺) ions in a solution</i> leads to a <i>decrease by 1 in the pH value of the solution</i>. (DCI: PS1.B.2; CCC: 3.4)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 4	4.A Apply ratio thinking in the context of complicated measurement problems involving quantities with compound units (moles/L) to predict how the concentration of an acid or base dissolved in water will affect the pH of the solution. (SEP: 5.5; DCI: PS1.B.2; CCC: 3.1) 4.B Develop a particle-level model that connects the structure of different acids to the measured pH values that explains why those values vary for each acid. (SEP: 2.3; DCI: PS1.B.3; CCC: 6.2)	4.A When to check for understanding: 1. As students use mathematical thinking to relate moles and molecules. (slides H-K) 2. As students complete questions 1 and 3 on <i>Modeling H⁺ Concentrations</i>. (slide P) 3. During the Scientists Circle discussion to identify interactions between different acids and water molecules. (slide R) What to look/listen for across opportunities 1-3: • Students explain that the concentrations of solutions are equal because the ratios of moles/L are equal, even though the quantities of moles (molecules) and water are different. (SEP: 5.5; CCC: 3.1) • Students explain that different acids dissociate unequally to account for differences in the amounts of H⁺ ions in solution as measured by pH values. (DCI: PS1.B.2; CCC: 3.1) 4.B When to check for understanding: 1. As students complete question 2 on <i>Modeling H⁺ Concentrations</i>. (slide P) 2. During the Scientists Circle discussion where students use a forces perspective to explain degree of dissociation. (slide T) 3. As students complete the Electronic Exit Ticket. (slide U) What to look/listen for across opportunities 1-3: • Student models use pH values as evidence to predict rates of dissociation of different acids. (SEP: 2.3; DCI: PS1.B.3) • Students explain that the structure of the acid (strength of bonds between atoms) allows for some to have a higher degree of dissociation than others. (DCI: PS1.B.3; CCC: 6.2) • See <i>Exit Ticket Key</i>.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 5	5.A Revise a model to explain how the increased movement of carbon dioxide from the atmosphere to the ocean results in the decrease of oceanic pH, using data from examining a small-scale system gathered with appropriate investigative tools. (SEP: 2.3, 3.4; DCI: ESS2.C.1, ESS2.D.3; CCC: 2.2)	5.A When to check for understanding: 1. As students work in groups to annotate <i>Investigation Procedure</i> to include additional investigation tools. (slide F) 2. As students work in groups to develop a data table to record investigation measurements. (slide G) 3. After students complete <i>Evaluate Investigation Data</i> and participate in a Building Understandings Discussion. (slides K-L) 4. During a whole-class discussion around student findings from analysis of <i>Carbon Data</i>. (slide R) 5. As students add their annotations to the class consensus model. (slides S-T) What to look/listen for across opportunities 1-5: • Students annotate <i>Investigation Procedure</i> to include additional investigative tools (e.g., pH indicator strips and a timer). (SEP: 3.4) • Students provide reasoning for where they chose to annotate <i>Investigation Procedure</i> to support the appropriateness of their choice. (SEP: 3.4) • Students draft a data table to record qualitative and quantitative data of pH changes caused by increased CO₂ levels. (SEP: 3.4; CCC: 2.2) • Students use data from their investigation to describe the movement of carbon dioxide. (SEP: 3.4; DCI: ESS2.D.3) • Students use a small-scale system to determine a cause-and-effect relationship to explain changes to the pH of ocean water because of water's ability to dissolve and transport materials. (DCI: ESS2.C.1; CCC: 2.2) • Students connect how the movement of CO₂ between Earth's spheres has been altered due to human activity. (DCI: ESS2.D.3) • Students record possible ideas about movement of CO₂ through Earth's spheres to inform revisions to the class consensus model. (SEP: 2.3; DCI: ESS2.D.3) • Students should show the relationship between the amounts of carbon stored in the atmosphere, the hydrosphere, and the geosphere, and the amounts released through human activity. (SEP: 2.3; DCI: ESS2.D.3)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 6	6.A Make an argument about and use a computational model to generate data about small-scale mechanisms underlying the natural system of the reversible reaction that occurs in weak acid dissociation. (SEP: 2.6, 7.4; DCI: PS1.B.2; CCC: 2.2) 6.B Use multiple types of models to make predictions about the relative stability of substances in reversible reactions. (SEP: 2.4; DCI: PS1.B.2; CCC: 7.1)	6.A When to check for understanding: - As students write arguments on graffiti boards and in their science notebook about what is causing the color change. (slides B-D) - As students plan and conduct their investigation using the NetLogo simulation. (slides L-M) What to look/listen for across opportunities 1-2: - Student ideas use particle-level interactions to try to explain the macroscopic color change. (CCC: 2.2) - Students develop arguments about how chemical reactions between water, CO₂, and carbonic acid led to the reversible bromothymol blue indicator color change. (SEP: 7.4; DCI: PS1.B.2) - Students use a computational model to generate particle scale data which explains changes at the macroscopic scale. (SEP: 2.6; CCC: 2.2) 6.B When to check for understanding: On day 3 as students make predictions about the relative stability of reactants and products in reversible reactions. (slides X-AA) What to look/listen for in the moment: - See <i>Bond Data Key</i> for additional guidance. - Students correctly predict unknown information about reversibility, bond strength, substance type, and stability. (DCI: PS1.B.2; CCC: 7.1) - Students cite other model types as evidence. (SEP: 2.4)
Lesson 7	7.A Define criteria and constraints that consider the needs of communities in order to design a solution that supports the stability of the complex system of oyster production. (SEP: 1.8; DCI: ETS1.A.1; CCC: 7.4) 7.B Develop a predictive and explanatory model based on the particle-level interactions found in solutions at equilibrium. (SEP: 2.3; DCI: PS1.B.2; CCC: 2.2)	7.A When to check for understanding: - As home groups develop a list of criteria and constraints after meeting with expert groups. (slide H) - During the whole-class discussion to create a class consensus list of criteria and constraints. (slide J) What to look/listen for across opportunities 1-2: - Students link the criteria and constraints they name to specific considerations from the vignettes or the science ideas figured out in Lesson Set 1. (SEP: 1.8; DCI: ETS1.A.1) - Students discuss the interrelated systems involved in designing a solution, including but not limited to carbon cycling, social and economic systems that are impacted by oysters, and the process of ocean acidification. (SEP: 1.8; DCI: ETS1.A.1) - Students explain how those systems have changed over time, and how a solution might help them gain stability. (CCC: 7.4) 7.B When to check for understanding: During the mid-point assessment on day 2. (slide M) What to look/listen for in the moment: - See <i>Acid Behavior Key</i> for guidance.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 8	8.A Plan and carry out an investigation of a neutralization reaction by predicting and manipulating the amounts of reactants using mass and mole proportions and collecting data to identify failure points to improve the reaction outcome. (SEP: 2.2, 3.6; DCI: PS1.B.3; CCC: 3.1) 8.B Use a mathematical model of molecules in a chemical reaction and macro-scale evidence to determine what is happening at the particle level. (SEP: 5.2; DCI: PS1.B.3; CCC: 3.4) 8.C Use proportions of different scales (ratios) to move between masses and numbers of particles that represent conservation of matter in a chemical reaction. (SEP: 5.5; DCI: PS1.B.3; CCC: 3.1)	8.A When to check for understanding: 1. When students have completed questions 1 through 3 on <i>Neutralization Investigation #1</i>. (slide Q) 2. As students discuss Neutralization Investigation #1 results. (slide R) 3. As students work in groups to complete question 4 on <i>Neutralization Investigation #2</i>. (slides II–JJ) 4. As students discuss Neutralization Investigation #2 results and complete question 6 on <i>Neutralization Investigation #2</i>. (slide KK) What to look/listen for across opportunities 1–4: • on <i>Neutralization Investigation #1</i>: • Question 1: A planned investigation with a question (a), a procedure (c), and safety equipment use (d). (SEP: 2.2) • Question 1(b): Student thinking includes proportional reasoning about ratios of amounts (this should not be in moles yet; it is logical to keep students working with masses to allow the test to fail, which will motivate looking at moles). (CCC: 3.1) • Question 1(e): A prediction referencing one or more matter interaction ideas at a particle level, related to the balanced equation. (DCI: PS1.B.3) • Question 2: Students describe observations of a failure point in the system design or other qualitative and quantitative data they gathered. (SEP: 3.6) • on <i>Neutralization Investigation #2</i>: • Question 4: Students' investigation procedure identifies the amounts of substances used. (SEP: 2.2; CCC: 3.1) • Question 6: Students identify that the investigation results indicate that using molar mass proportions is successful. (SEP: 2.2; CCC: 3.1) 8.B When to check for understanding: As students discuss Neutralization Investigation #1 results. (slide R) What to look/listen for in the moment: • Students identify that the coefficients in a balanced chemical equation must not represent mass ratios, but instead represent particle-number ratios. (DCI: PS1.B.3; CCC: 3.4) • Students use a mathematical model to measure or count molecules, even though we cannot see them, when we measure out a certain amount of a substance. (SEP: 5.2; CCC: 3.4) 8.C When to check for understanding: 1. As students practice a unit conversion problem. (slide EE) 2. As students complete Part A on <i>Neutralization Investigation #2</i>. (slides GG–HH) What to look/listen for across opportunities 1–2: • Students use a molar mass ratio and coefficients from a balanced chemical equation to predict amounts of various substances formed as a result of the chemical reaction. (SEP: 5.5; DCI: PS1.B.3) • Students identify that the proportional relationships of molar mass and coefficients in a chemical equation can be used to determine relative amounts of substances needed for or produced by a chemical reaction. (SEP: 5.5; CCC: 3.1) • See <i>Neutralization Investigation #2 Key</i>.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 9	9.A. Use a mathematical model to calculate the amounts of reactants for desired products, assuming conservation of matter, across scales from molecular to lab-measurable quantities. (SEP: 5.5; DCI: PS1.B.3; CCC: 3.1)	9.A When to check for understanding: 1. As students complete questions 1-5 on <i>Ocean Water Calculations</i>. (slides E-I) 2. As students complete question 6 on <i>Ocean Water Calculations</i>. (slide K) 3. After students complete the Electronic Exit Ticket. (slide M) What to look/listen for across opportunities 1-3: • See <i>Ocean Water Calculations Key</i>. • See <i>Electronic Exit Ticket Key</i>.
Lesson 10	10.A Develop a model to generate qualitative data of ionic bond types in the ocean acidification system to analyze how particle-level changes cause larger-scale effects in oyster susceptibility to ocean acidification. (SEP: 2.6; DCI: PS1.B.2; CCC: 2.2) 10.B Use multiple types of models to identify how particle-level changes cause larger-scale effects in oyster susceptibility to ocean acidification and carbon movement through Earth's systems. (SEP: 2.4; DCI: PS1.B.2, ESS2.D.3; CCC: 2.2)	10.A When to check for understanding: As students develop their initial models of how the shell-building reaction is affected by increasing acidity. (slide O) What to look/listen for in the moment: • Students' models include qualitative data about the ratios of ions to help predict and analyze system-level increases and decreases of ionic bond types and ratios (e.g., excess hydrogen ions means that the calcium gets "interrupted" on its way to the oyster shells). (SEP: 2.6) • Students include the dynamic and condition-dependent balance of CaCO_3 and excess H^+ ions in the sea water. (DCI: PS1.B.2) • Students describe how particle-level changes at this small scale cause large-scale system problems for oysters and pH. (CCC: 2.2) 10.B. When to check for understanding: When the class revises the carbon cycle model to explain the flow of carbonate into the ocean and students discuss rates of carbon flow. (slides AA-CC) What to look/listen for in the moment: • Students identify that changes in the atmosphere due to human activity have increased CO_2 and affect the ocean water at a rate much greater than the rate at which carbon flows from limestone deposits into the ocean. (DCI: ESS2.D.3) • Students explain that the dynamic and condition-dependent balance of CaCO_2 and excess H^+ ions in the sea water is a key mechanism in storing carbon, but it takes a very long time. (DCI: PS1.B.2) • Students guide carbon cycle model revision to include a flow of carbon indicating how cause-and-effect relationships in much larger Earth systems (limestone-based carbon sequestration) can be suggested and predicted by smaller mechanisms in the system (the chemical reactions that store carbon in oyster shells over time). (CCC: 2.2) • Students incorporate ideas from the multiple types of models present in this lesson to provide a mechanistic account of how carbon cycles from the biosphere (oysters) to the geosphere (limestone deposits) and back to the hydrosphere (ocean) as they work to revise the carbon cycle model. (SEP: 2.4)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 11	11.A Plan an investigation to produce data as evidence to determine how rates of change in reactions differ under different conditions. (SEP: 3.1; DCI: PS1.B.1; CCC: 7.2) 11.B Build a model based on evidence that explains how changes in the oyster-water system affect reaction rates and equilibrium. (SEP: 2.3; DCI: PS1.B.1, PS1.B.2; CCC: 7.1)	11.A When to check for understanding: On day 1 as students plan their investigations. (slide I) What to look/listen for in the moment: • Student investigation plans allow for measurement of a dependent variable (amount of product produced over time) that helps provide some quantification of the rate of change in the reaction. (SEP: 3.1; DCI: PS1.B.1) • Students plan to investigate how a specific change in their factor will influence how the reaction proceeds and can describe what they expect to see, providing evidence that they will be able to answer the investigative question. (SEP: 3.1; CCC: 7.2) 11.B When to check for understanding: 1. On day 2 as students explain their experimental results in groups. (slide Q) 2. As students model how the addition of calcium carbonate can help ocean acidification. (slide W) 3. During the discussion to build the class consensus model. (slides Y-Z) What to look/listen for across opportunities 1-3: • Students can articulate the evidence that caused them to add ideas to their models (or explanations). (SEP: 2.3) • Students discuss or show how increasing temperature or concentration can increase how hard particles collide and/or how often they collide, increasing the likelihood of a reaction and therefore the reaction rate. (DCI: PS1.B.1, PS1.B.2; CCC: 7.1) • Students' models show the relationships between the components of the ocean acidification system (Ca^{2+}, CO_3^{2-}, and H^+ ions). (SEP: 2.3) • Students discuss or show how increasing the concentration of calcium carbonate ($\uparrow \text{CaCO}_3$) can increase frequency/force of collisions ($\uparrow$ collisions), increasing the likelihood of a reaction and therefore the reaction rate ($\uparrow$ reaction rate). (DCI: PS1.B.1, PS1.B.2) • Students show how increasing the concentration of carbonate ions ($\uparrow$ concentration CO_3^{2-}) that can bond with H^+ ions also leaves plenty of CO_3^{2-} ions available for shell-building. (DCI: PS1.B.1, PS1.B.2) • Students use words or images to explain how changing two types of variables in the water/CaCO_3 system can result in changes, while other combinations of variables cause the system to remain stable. (CCC: 7.1)
Lesson 12	12.A Define interacting social, technical, and environmental criteria and constraints to alter the systems around oysters in a way that considers societal requirements and reduces environmental degradation. (SEP: 1.8; DCI: ETS1.B.1, ESS3.C.2; CCC: 4.1)	12.A When to check for understanding: 1. As students revisit community priorities and discuss their interrelatedness. (slides E-F) 2. As students work in small groups to begin to develop solutions. (slides H-I) What to look/listen for across opportunities 1-2: • Students state how the criteria and constraints relate to scientific, technical, and social considerations. (SEP: 1.8; DCI: ETS1.B.1) • Students surface ideas about how these scientific, technical, and social criteria and constraints are interrelated. (SEP: 1.8) • Students choose possible solutions that both fit within the criteria and constraints and do not have negative environmental impacts. (SEP: 1.8; DCI: ESS3.C.2) • Students identify impacts of their chosen solutions on the systems around oysters. (DCI: ESS3.C.2; CCC: 4.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 13	13.A Use computational thinking to quantify criteria for a solution that will positively affect oysters. (SEP: 5.2; DCI: ETS1.A.1; CCC: 2.3) 13.B Design a solution to cause specific outcomes to mitigate the impacts of ocean acidification on oysters. (SEP: 6.5; DCI: ESS3.C.2; CCC: 2.3)	13.A When to check for understanding: - As groups quantify criteria and constraints. (slides F-G) - While groups are creating their posters on day 2. (slide L) What to look/listen for across opportunities 1-2: - Students use stoichiometric (mathematical) and other calculations to quantify design solution impacts of pH, carbonate, and/or CO₂. (SEP: 5.2) - Students quantitatively represent criteria and constraints. (DCI: ETS1.A.1) - Students articulate the importance of criteria and constraints in ensuring positive outcomes for oysters. (DCI: ETS1.A.1; CCC: 2.3) - See <i>Poster Feedback Guide</i>. 13.B When to check for understanding: - As groups work on <i>Solution Planning Document</i>. (slide H) - While students are creating their posters on day 2. (slide L) What to look/listen for across opportunities 1-2: - Students' posters indicate a specific designed solution to oyster die-off that is based on science, prioritized criteria, and trade-off considerations. (SEP: 6.5) - Students articulate what effects their proposed changes will have on the oyster-raising system. (CCC: 2.3) - Students describe how their proposed solution will change pH, carbonate availability, or atmospheric or ocean CO₂ levels. (DCI: ESS3.C.2) - See <i>Poster Feedback Guide</i>.
Lesson 14	14.A Refine design solutions based on trade-offs of relevant criteria that account for changes at multiple scales of the consensus model. (SEP: 7.1; DCI: ETS1.C.1; CCC: 3.4) 14.B Compare design solutions that impact interacting Earth systems at multiple scales to stop oyster die-off. (SEP: 6.5; DCI: ESS2.D.3; CCC: 3.4)	14.A When to check for understanding: During the writing prompt on <i>Design Solution Reflection</i> at the end of day 1. (slide J) What to look/listen for in the moment: - Students compare and evaluate at least two of the following competing arguments: 1) current class explanation and consensus model, 2) evidence gathered throughout the unit, 3) constraints, 4) ethical issues. (SEP: 7.1) - Students include at least one of the following: 1) how criteria/problems are broken into subproblems, 2) clear tradeoffs, 3) clear priorities. (DCI: ETS1.C.1) - Students include chemistry reasoning, i.e., how orders of magnitude matter (tiny particles → big solution). (CCC: 3.4) 14.B When to check for understanding: During the Consensus Discussion on day 2. Consider using <i>Discussion Mapping Tool</i> to track the discussion. (slide O) What to look/listen for in the moment: - Students should compare, reference, and evaluate others' solutions based on evidence they have gathered, criteria they have prioritized, and trade-offs. (SEP: 6.5) - Students articulate that the chemistry of the atmosphere and hydrosphere has changed with CO₂ production, which can be reduced through human efforts. (DCI: ESS2.D.3) - Students make connections between small particles and large effects (orders of magnitude). (CCC: 3.4)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 15	15.A Apply scientific ideas, principles, and evidence to explain how changing the temperature or concentration of the reactants affects the reaction rate. (SEP: 6.3; DCI: PS1.B.1, PS1.B.2; CCC: 2.2) 15.B Use student-generated sources of evidence to develop a model to predict how changes in a system would increase the rate of a reversible reaction to produce larger amounts of products by examining smaller scale mechanisms. (SEP: 2.3; DCI: PS1.B.2; CCC: 2.2) 15.C Use mathematical thinking to describe claims about how conservation of matter and chemical properties of the elements involved can be used to predict the scale and significance of chemical reactions. (SEP: 5.2; DCI: PS1.B.3; CCC: 3.1) 15.D Make a claim about the effectiveness of a design solution which reflects evidence about trade-offs and its design criteria by accounting for the flow of energy through the system. (SEP: 7.5; DCI: ETS1.C.1; CCC: 5.2)	15.A When to check for understanding: When students complete <i>Ammonia Fertilizer Task</i>. (slides D-E) What to look/listen for in the moment: See <i>Ammonia Fertilizer Key</i>. 15.B When to check for understanding: When students complete <i>Ammonia Fertilizer Task</i>. (slides D-E) What to look/listen for in the moment: See <i>Ammonia Fertilizer Key</i>. 15.C When to check for understanding: When students complete <i>Ammonia Fertilizer Task</i>. (slides D-E) What to look/listen for in the moment: See <i>Ammonia Fertilizer Key</i>. 15.D When to check for understanding: When students complete <i>Ammonia Fertilizer Task</i>. (slides D-E) What to look/listen for in the moment: See <i>Ammonia Fertilizer Key</i>.



Lesson-Specific Teacher Materials



Lesson 3: Teacher Reference 1

Preparing Water Solutions

You will need to prepare the following water solutions for students to use during the **Measuring Acidity of Water** investigation on day 1.

Salt-Water Solution

Prepare a 1M NaCl solution using:

- 1000 mL of distilled water
- 1.0 mol of NaCl, 58.88 g

1. Add 1000 mL of distilled water to a beaker.
2. Measure out 58.88 g of NaCl using weighing paper and digital scale.
3. Add the NaCl to the distilled water and stir until dissolved.
4. If needed, divide the solution equally into 2 beakers. You will need enough made so that each student group has 100 mL of solution available. This solution will also be used in **Lesson 4**.

“Flat” Carbonated Water Solution

Prepare the solution by opening a container of carbonated water at least a few hours before students begin the investigation.

Citric Acid-Water Solution

Prepare a 1M citric acid solution using:

- 1000 mL of distilled water
- 1.0 mol of citric acid, 192.12 g

1. Add 1000 mL of distilled water to a beaker.
2. Measure out 192.12 g of citric acid using weighing paper and digital scale.
3. Add the citric acid to the distilled water and stir until dissolved.
4. If needed, divide the solution equally into 2 beakers. You will need enough made so that each student group has 100 mL of solution available. This solution may also be used in **Lesson 4** as an extension opportunity.

Other Water Solutions

Have these available for students:

- Carbonated water (Leave bottles tightly sealed until students are ready to use them in their investigation, to reduce loss of dissolved carbon dioxide gas.)
- Distilled water

Lesson 3: Teacher Reference 2

Sample Investigation Plans

These sample group investigation plans and data tables can be used to help guide groups that may be struggling to develop an investigation plan. Be sure to ask students to identify how their investigation plan allows for controls. They may identify either the citric acid solution or distilled water as controls. On day 2, students should identify that we should use distilled water as a control in future investigations when measuring pH.

Sample Investigation Plan 1

Test each of the following using 5 drops of bromothymol blue indicator and 1 universal pH strip:

- Salt-water solution
- Carbonated water
- “Flat” carbonated water
- Distilled water
- Citric acid solution

Water	Bromothymol blue results	pH indicator results
Salt-water solution		
Carbonated water		
“Flat” carbonated water		
Distilled water		
Citric acid solution		

Sample Investigation Plan 2

- 1. Create the following solutions to test:
 - a. Citric acid solution
 - b. Salt-water solution
 - c. Carbonated water
 - d. Salt-water solution (25 mL) + carbonated water (25 mL)
 - e. Salt-water solution (25 mL) + carbonated water (10 mL)
 - f. Salt-water solution (25 mL) + carbonated water (5 mL)
- 2. Add 10 drops of bromothymol blue indicator to each solution.
- 3. Use the universal pH strip to test each solution.

Water	Bromothymol blue results	pH indicator results
Citric acid solution		
Salt-water solution		
Carbonated water		
Salt-water solution (25 mL) + carbonated water (25 mL)		
Salt-water solution (25 mL) + carbonated water (10 mL)		
Salt-water solution (25 mL) + carbonated water (5 mL)		

Sample Investigation Plan 3

- 1. Create the following solutions to test:
 - a. Distilled water
 - b. Salt-water solution
 - c. Carbonated water
 - d. "Flat" carbonated water
 - e. Salt-water solution (25 mL) + carbonated water (25 mL)
 - f. Salt-water solution (25 mL) + "flat" carbonated water (25 mL)
- 2. Add 10 drops of bromothymol blue indicator to each solution.
- 3. Use the universal pH strip to test each solution.

Water	Bromothymol blue results	pH indicator results
Distilled water		
Salt-water solution		
Carbonated water		
"Flat" carbonated water		
Salt-water solution (25 mL) + carbonated water (25 mL)		
Salt-water solution (25 mL) + "flat" carbonated water (25 mL)		

Solution Preparation

If you do not have access to the specific acids and bases indicated below, then it is fine to use substitutes. However, it is strongly recommended that you have at least one strong acid and one strong base, and at least one weak acid and one weak base. And, it will be necessary to produce 1 *M* solutions for Set A and 0.1 *M* solutions for Set B. It will be helpful to refer to this data again in Lesson 5, when reversible reactions are introduced. The visual differences in pH between strong and weak acids or bases will be helpful to students when thinking about reactions that do not go only forward or do not go to completion. Be sure to modify the corresponding slides and handouts if you choose to use substitutes.

Procedure to prepare Set A solutions

Safety note: Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and takedown segments of the chemical procedure.

To make 500 mL of 1 *M* NaCl (sodium chloride):

- Add 500 mL of distilled water to a beaker.
- Measure out 0.50 moles of NaCl (29.44 g).
- Add it to the distilled water in the volumetric flask.
- Stir to dissolve.

To make 500 mL of 1 *M* NaOH (sodium hydroxide):

- Add 500 mL of distilled water to a beaker.
- Measure out 0.50 moles of NaOH (20.00 g).
- Add it to the distilled water in the volumetric flask.
- Stir to dissolve.

To make 500 mL of 1 *M* KOH (potassium hydroxide):

- **Important safety note:** When diluting bases, the base should be added to water and not water to the base.
- Same steps as above, but use 0.50 moles of KOH (28.06 g).

For HCl (hydrochloric acid), H₂SO₄ (sulfuric acid), HC₂H₃O₂ (acetic acid), NH₄OH (ammonium hydroxide):

- **Important safety note:** When diluting acids, the acid should be added to water and not water to the acid.
- These should already be in solution form, but may not be 1 *M*.
- If you have 3 *M* solutions, add 100 mL of 3 *M* acid or base to 200 mL distilled water to make 300 mL of 1 *M* solution. (Adjust the volumes of 3 *M* acid solution and distilled water as needed, but keep the 1:2 acid/base:water ratio.)

Procedure to prepare Set B solutions

To make 0.1 *M* of all solutions:

- Measure out 450 mL of distilled water into a beaker.
- Add 50 mL of the corresponding 1 *M* solution you prepared for Set A.

Procedure to prepare Set A and B stations

To prepare Set A stations:

- Label 2 250 mL beakers with each solution name.
- Add 100 mL of each of the 1 *M* solutions into 2 250 mL beakers.
- Have 2 250 mL beakers of distilled water available for a control.
- Add 1 disposable plastic pipette to each sample.

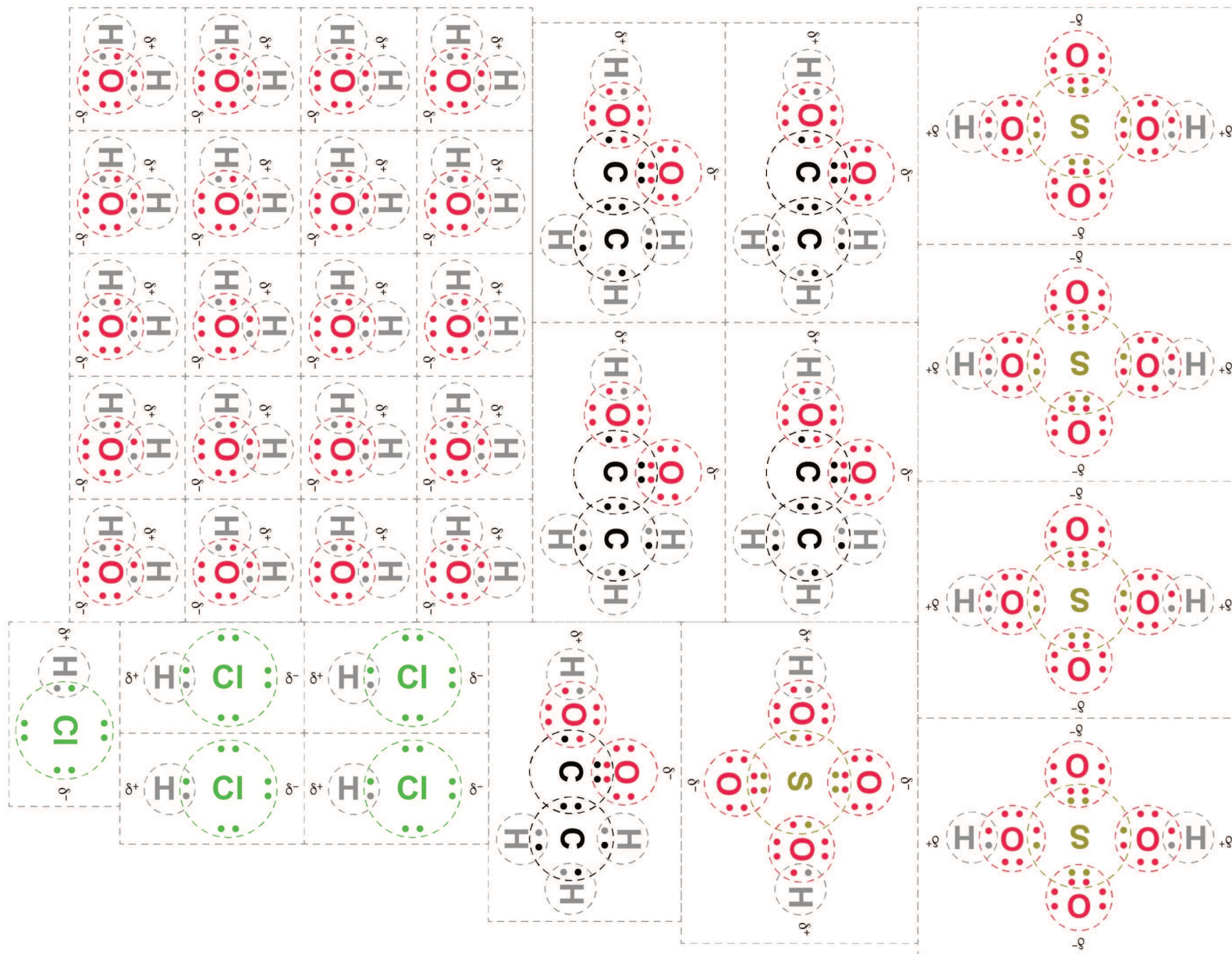
To prepare Set B stations:

- Label 2 250 mL beakers with each solution name.
- Add 100 mL of each of the 0.1 *M* solutions into 2 250 mL beakers.

- Have 2 250 mL beakers of distilled water available for a control.
- Add 1 disposable plastic pipette to each sample.

Sample pH Data

Substance	Set A Observations		Set B Observations	
Distilled H ₂ O	n/a	pH paper turns green; pH of 7	n/a	pH paper turns green; pH of 7
HCl	1 M	pH paper turns red; pH of less than 1	0.1 M	pH paper turns red; pH of less than 1
HC ₂ H ₃ O ₂	1 M	pH paper turns amber; pH of 4-5	0.1 M	pH paper turns chartreuse; pH of 5-6
H ₂ SO ₄	1 M	pH paper turns red; pH of less than 1	0.1 M	pH paper turns red; pH of less than 1
NaOH	1 M	pH paper turns blue; pH of 13-14	0.1 M	pH paper turns dark cyan; pH of 12-13
KOH	1 M	pH paper turns blue; pH of 13-14	0.1 M	pH paper turns dark cyan; pH of 12-13
NH ₄ OH	1 M	pH paper turns teal; pH of 10-11	0.1 M	pH paper turns dark green; pH of 9-10
NaCl	1 M	pH paper turns green; pH of 7	0.1 M	pH paper turns green; pH of 7



Lesson 4: Teacher Reference 4

Electronic Exit Ticket

What are Electronic Exit Tickets?

These are short **formative** assessments that occur 2-3 times per unit, in between other assessments. They include items to check for understanding of lesson-level PEs, to make connections between content and students' lives, and to elicit information about their experiences and to help students reflect on their own progress in focal SEPs and CCCs. They are built in Google Forms, but can be ported to any survey software.

How to create Electronic Exit Tickets

In *OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*, the two Electronic Exit Tickets in this unit are found:

- at the end of **Lesson 4 (slide T)**;
- and at the end of day 3 of **Lesson 9 (slide M)**

Select the link for the Electronic Exit Ticket that corresponds with the lesson you are teaching.

https://docs.google.com/forms/d/16TOaCCQpXvK7D7Y-mOqqZ1SeDK_2-fq7u0JP0stek54/copy

https://docs.google.com/forms/u/2/d/1Ut_HHwUBSCgORSKLwOxxPtdOT_r7uqlxzZ4TWHnm6KQ/copy

Spanish versions are available here:

https://docs.google.com/forms/d/18A9VepN3qsKq73RvdAYgy-4d-LnEUTMLMWeqAH_In2I/copy

<https://docs.google.com/forms/d/1nd6Oxra7coa93yne8pONzAa1wuesrFV8ejvm1FkL9go/copy>

Attending to Equity

Some students may benefit from completing the Electronic Exit Tickets on a printed version. Complete the steps below to create a copy of the Electronic Exit Ticket. Once you have created a copy in your own Google Drive, click on the 3 dots in the upper right side of the form next to the SEND button. This should give you an option to print a paper copy of the Electronic Exit Ticket.

When you select the link, it will ask you to make a copy in your own Google Drive.

Copy document

Would you like to make a copy of **Family and Friends MRE Survey?**

Make a copy



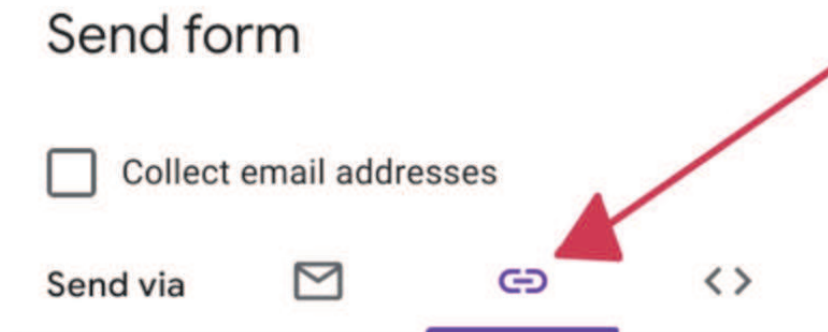
The student Electronic Exit Ticket will open in your own Google Drive.



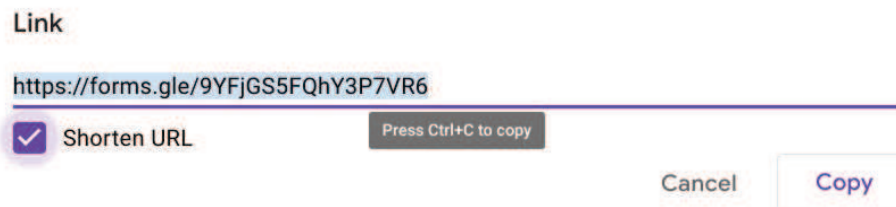
Select the “Send” button in the upper right corner to get a link to give to students.



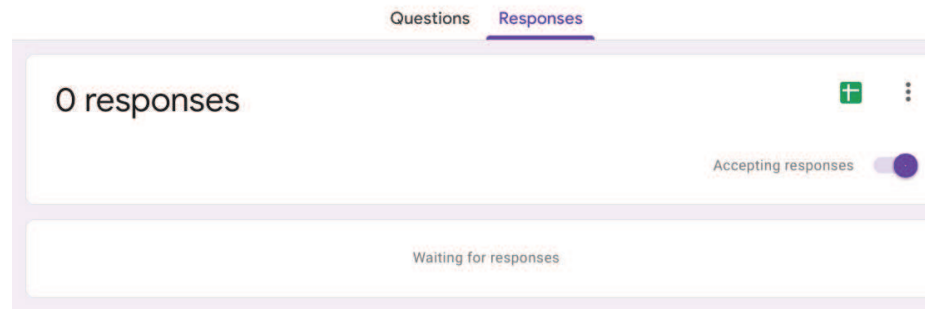
In the “Send via” panel select the middle icon in order to choose to send the Electronic Exit Ticket via a link.



Copy the link it provides you or select the “Shorten URL” box then copy the link. This second option creates a link that will be easier for students to type.



Once people submit responses they will show up in your Google Form under "Responses". Google will automatically provide you with some visualizations of these responses.

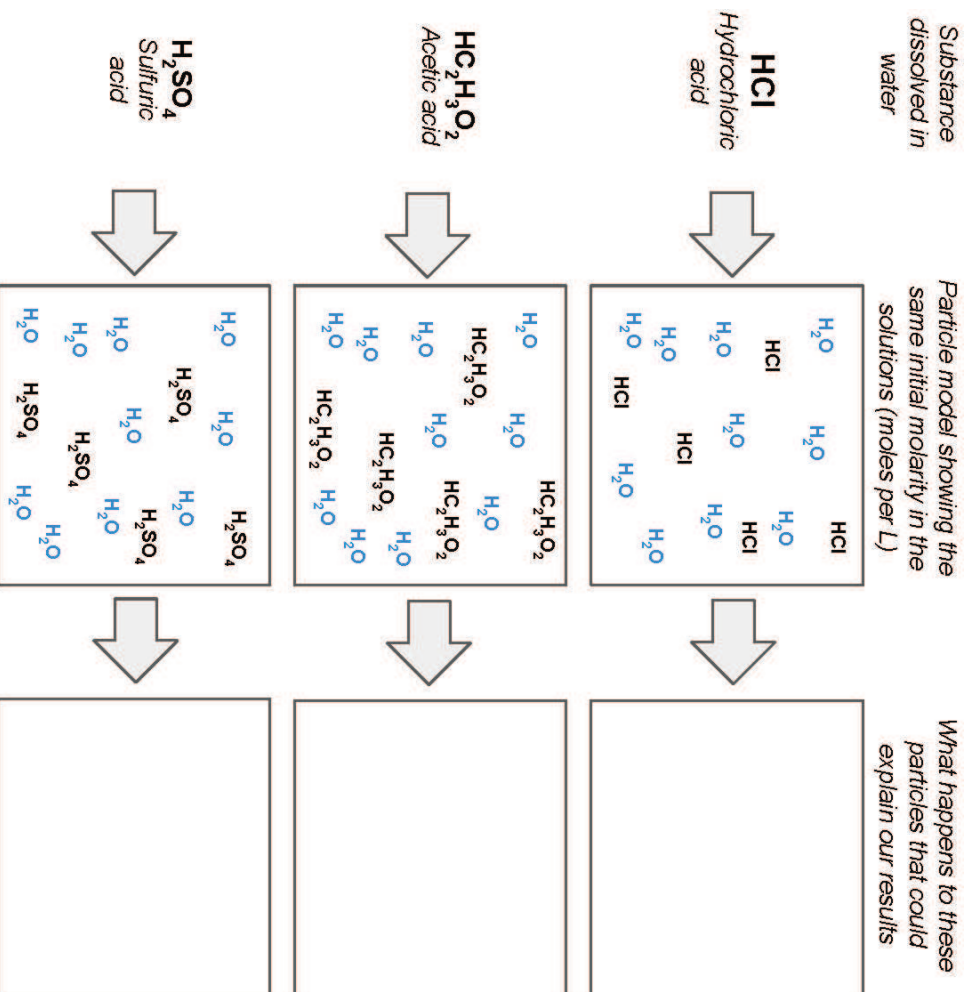


If you want to see the data in a spreadsheet format, click the sheet icon to create a Google Sheet of your data. It will automatically populate when people respond to the Electronic Exit Ticket.

For each Electronic Exit Ticket, you will need to repeat the process above. You can choose to make a copy of the Electronic Exit Ticket for each of your classes or choose to have one Electronic Exit Ticket for all your classes.

Modeling H⁺ Concentrations

- In the diagram below, how do the particle models show the acids were at the same initial concentrations (molarity)?
 - Concentration is a ratio of acid molecules to water molecules.
 - There are the same numbers of molecules of the two substances (acid and water) in each solution (5 acid molecules and 10 water molecules), so the ratio of acid to water molecules is the same (1:2).
- Choose two acids with different pH values. In the empty boxes, show what may be happening to the particles in each of the solutions to explain our observation that one acid produced a higher concentration of H⁺ ions than another.



Students should include:

- Less H⁺ ions in the first solution (Acetic acid) than in the second or third solution (either Hydrochloric acid or Sulfuric acid).

Students may include:

- More negative ions in the solution that has more H⁺ ions in it (Hydrochloric acid or Sulfuric acid) than another (Acetic acid).
- The negative ions have an atom composition, that correspond to what would remain if one (or two) hydrogen atoms dissociated from it (e.g. OH⁻, Cl⁻, C₂H₃O₂⁻, HSO₄⁻, SO₄⁻²).

3. What force interactions may be occurring between the atoms or molecules in these solutions that could help explain how and why this happened?

Possible responses (one or more of the following):

- The result of the collisions between these molecules might be different, due to differences in the size, mass, or shape of the acid molecules..
- Some H atoms might be hit more often because of their location (or geometry) on the different acid molecules.
- Some H atoms might experience greater forces in the collisions because of their location (or geometry) on the different acid molecules.
- The strength of the force interactions between molecules (due to their polarity) might be different (e.g. strength of one force interaction or many).
- The strength of the force interactions between atoms within different acid molecules might be different (e.g. due to differences in the strength of their bonds).

Lesson 4: Answer Key 2

Exit Ticket Key

This Electronic Exit Ticket mainly assesses student's knowledge around LLPE **4.B** Develop a particle-level model that connects the structure of different acids to the measured pH values that explains why those values vary for each acid. (SEP: 2.3; DCI: PS1.B.3; CCC: 6.2).

Additionally, it also assesses the DCI and CCC elements from LLPE **4.A** Apply ratio thinking in the context of complicated measurement problems involving quantities with compound units (moles/L) to predict how the concentration of an acid or base dissolved in water will affect the pH of the solution. (SEP: 5.5; DCI: PS1.B.2; CCC: 3.1). Since the full LLPE is not assessed, this is not considered an additional assessment opportunity

4.B Develop a particle-level model that connects the structure of different acids to the measured pH values that explains why those values vary for each acid. (SEP: 2.3; DCI: PS1.B.3; CCC: 6.2)					
Where these elements are addressed in this assessment	2.3 Developing and Using Models Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.	PS1.B.2 Chemical Reactions In many situations, a dynamic and condition dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present.	PS1.B.3 Chemical Reactions The fact that atoms are conserved, together with the knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.	3.1 Scale, Proportion, and Quantity The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.	6.2 Structure and Function The functions and properties of natural and designed systems can be inferred from their overall structure, the way their components are shaped and used, and the molecular substructures of their various materials.
Q1		X		X	
Q2	X	X			
Q3					
Q4	X		X		X
Q5				X	
Q6	X				

In class you tested different acids and bases at various concentrations (molarities). Three new acidic solutions are shown in the table below. Use the data in this table to answer questions 1 and 2.

Solution	Q	R	S
Substance mixed into the water	HNO ₃	HNO ₃	HCOOH
# of molecules of substance mixed into the water	3.0×10^{22}	3.0×10^{21}	3.0×10^{21}
# of moles of substance mixed into the water	0.05	0.005	0.005
L of distilled water used	1	1	1
Molarity of the solution (moles/L)	0.05 M	0.005 M	0.005 M
pH of the solution	1.3	2.3	3.4
# of H ⁺ ions per L of water	3.0×10^{22}	3.0×10^{21}	2.4×10^{20}

Question 1

Which explanation for why **solution Q** and **solution R** have a different pH is best supported by the **data from the table**?

- A different substance was added to the same amount of water to make these two solutions.
- **A different number of molecules of the same substance was added to the same amount of water to make these two solutions.**
- The same substance was added to a different amount of water to make these two solutions.
- The same number of molecules of a different substance was added to the same amount of water to make these two solutions.

Correct response: A different number of molecules of the same substance was added to the same amount of water to make these two solutions.

Rationale for distractors:

Students should recognize that the same molecular formula indicates that the substances are the same.

Students should recognize that L of water is a measure of the amount of water, and the amounts are the same (1L).

Students should recognize that, although the coefficients are the same for the numbers of molecules of each substance in scientific notation, the exponents are different; or, they need to recognize that the numbers of moles of each substance are different.

What to do: Students may need their attention focused on the **type of particles that pH is a measure of**. If needed, remind students to **consider both the coefficient and the exponents when comparing numbers of molecules of each substance in scientific notation**.

Question 2

Using the model you developed to explain other acids, what prediction can we make about each **solution R** compared to **solution S**, that helps explain why they have a different pH? Choose all that apply.

- pH is a measure of the amount of water molecules in a solution.
- **pH is a measure of the concentration of H^+ or OH^- ions in a solution.**
- The molarity of each solution was different.
- **The molarity of each solution was the same.**
- **The acid molecules that dissolved in the solutions had different degrees of dissociation.**
- The acid molecules that dissolved in the solutions had the same degree of dissociation.

Correct responses:

- pH is a measure of the concentration of H^+ or OH^- ions in a solution.
- The molarity of each solution was the same.
- The acid molecules that dissolved in the solutions had different degrees of dissociation.

What to do: Students may need their attention focused on recalling how they **represented different degrees of dissociation in their individual models** in *Modeling H^+ Concentrations*.

Question 3

Human blood should have a pH between 7.35 and 7.45. The water in fish tanks, and the soil in gardens, must be kept within a certain pH range as well.

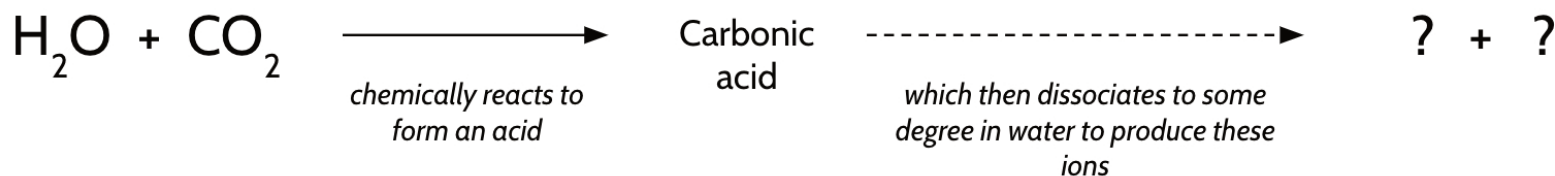
- 3a. Why do you think people or fish might die, or plants might not grow, if those pH values are not kept within optimal ranges?
- 3b. What new question(s) does this raise for you?

What to look for in response: Encourage students to think about how changes in oceanic pH have affected oysters and to consider if other organisms may be affected by pH changes to their body systems or habitats.

What to do: If students don't have any ideas, encourage them to record any other related phenomena this makes them wonder about. The goal of this question is to raise curiosity around this class of phenomena, and increase relevance for students. An optional Home Learning activity, *pH and Organisms*, can provide additional information around this class of phenomena.

Question 4

Our investigation data in Lesson 3 showed that CO_2 in water causes the solution to become acidic. This is because CO_2 chemically reacts with water molecules to form a new substance called carbonic acid. This acid dissociates to some degree in water.



Use the model of the chemical equation above and your knowledge of the structure of acids to choose 1 **formula for carbonic acid** and 1 **product of its dissociation** in water.

- Formula for Carbonic acid: CO_3
- Formula for Carbonic acid: HCO_3
- **Formula for Carbonic acid: H_2CO_3**
- Dissociates to produce C^+ ions
- **Dissociates to produce H^+ ions**
- Dissociates to produce OH^- ions

Correct responses:

- **Formula for Carbonic acid: H_2CO_3**
- **Dissociates to produce H^+ ions**

Rationale for distractors:

- Students should recognize that acids must contain H atoms, so choice A is not a possibility.
- Students should recognize that the product of the reaction must be able to dissociate to form H^+ ions, so it is not a possibility; instead, it is the result of dissociation of carbonic acid.
- Students should recognize that carbon does not dissociate to form ions.
- Students should recognize that bases, not acids, produce additional OH^- ions when they dissociate.

What to do:

If students incorrectly choose the **chemical formula** for carbonic acid, prompt them to think about how the **equation would be balanced given the two reactants**. Encourage them also to consider that this **product** needs to be able to **dissociate into ions**.

If students incorrectly choose the **product of dissociation**, refer them back to this reading from Lesson 3: *Measuring pH*. Point out how substances with more **acidic pH values show an increase in the amount of H^+ ions in solution**.

Question 5

How did comparing the **scale, proportion, and quantity of particles in different solutions** during this lesson help you make sense of why different substances might have different pH values?

What to look for in response: Students to mention examples of activities, experiences, or ways of thinking they engaged in, such as:

- mixing different amounts (in g) of solid into the same amount of water;
- making a drink more or less concentrated or diluted, or considering other related phenomena (e.g., recipes);
- analyzing the data tables showing # of molecules, moles, and molarity;
- working with measured quantities (grams, liters, pH values, # of molecules);
- engaging in proportional/ratio/unit rate reasoning;
- thinking about how a new type of unit (moles) is helpful for representing and working with larger numbers (# of molecules);
- or, using pH strips and scales to compare pH values.

What to do: If students do not cite particular instances of thinking or experiences from the last two days of work, provide the list above and ask them to select one that helped them think about similarities and differences in the **scale, proportion, and quantity of particles in different solutions**, and why that experience was helpful.

Question 6

How did **developing and using particle-level models** help you make sense of why different acids might have different pH values when added to water?

What to look for in response: Students to mention examples of activities, experiences, or ways of thinking they engaged in, such as:

- explaining how two different particle-level models represented the same molarities for different substances in solution;
- drawing individual models to represent different H^+ concentrations produced from those different solutions;
- or, working with manipulatives, or seeing how others worked with them (in small groups or as a class), to try to visualize how force interactions between different atoms and molecules could help explain these outcomes.

What to do: If students do not cite particular instances of thinking or experiences from the last two days of work, provide the list above and ask them to select one that helped them figure out what was happening at a particle level.

Question 7

Did you contribute an idea to class today? Did you feel your idea was heard?

- **Yes, I contributed and my idea was heard.**
- Yes, I contributed but my idea was NOT heard.
- No, I did not contribute my ideas today.
- Other: ____

Correct response: Yes, I contributed and my idea was heard.

What to do: Consider altering your classroom culture or returning to your community agreements if your class has a high percentage of students choosing any of the other options.

Lesson 6: Teacher Reference 1

Graffiti Board Preparation

Students begin this lesson by sharing their ideas around what could have caused the color change to the water in Lesson 5. Students explore this phenomenon by collectively building graffiti boards for different substances that could be involved in the color change. You may recognize this activity as a Chalk Talk, where students move around the room and add thoughts to a collaborative written product.

You will need to prepare eight graffiti boards--two for each substance category--to accommodate groups of no more than five students each. Prepare the graffiti boards as follows:

1. Make two boards for each of the following substance groups. Write the substance(s) at the top of each piece of chart paper as an underlined title.
 - a. Water
 - b. Bromothymol blue indicator
 - c. CO_2
 - d. H_2CO_3 (carbonic acid), HCO_3^- (bicarbonate ion), CO_3^{2-} (carbonate ion), and H^+ (hydrogen ion)
2. If there is time, write the following prompts in the center of each graffiti board, from top to bottom. Alternatively, you may show **slide C**.
 - a. How did the substance get into the system?
 - b. What effect, if any, did the substance have on the blue to yellow color change?
 - c. What could the substance have done in the small-scale system to cause the color change back to blue? What evidence do you have?

Lesson 6: Teacher Reference 2

Transcript: NetLogo Video

Hello, welcome to a brief video intended to help you become familiar with the NetLogo simulation used in lesson five of the oysters unit. You may have noticed in the teacher's guide there's actually a built-in activity to help students become familiar with the same model, and we would encourage you to use that activity with students because it's also intended to help them think about the types of things that they could actually modify when they investigate using this model. You may have seen other NetLogo models before in other units. This one works similarly to the rest. You make it show up by hitting setup and we see a couple things here.

There's graphs on the side that are labeled left container and right container and then in the field here we see the actual left container and right container and there are controls for each. The reason why there's two containers is to allow for direct head-to-head comparisons so you can actually change the starting concentrations of your carbon dioxide and carbonic acid, and then run the experiments against each other. There's nothing different about the chemistry between them. So let's set up an experiment, we'll leave... start... we'll leave the left container as is and on the right container let's simulate a situation where we think maybe the carbon dioxide got in and it all reacted with water to turn to carbonic acid.

So this is pure carbonic acid and water on the right and we have mostly carbon dioxide on the left, I'll hit setup again and then run the experiment by hitting go, you can also pause it.

A couple things we can do while the experiment runs are speed it up. This is helpful if you want to see how the system evolves over time. We can also slow it way down which helps us see what's happening with individual particles. Now it's a little bit tricky in this view to see reactions occur, although it is kind of nice to be able to see that we have water molecules floating around and then we have carbon dioxide molecules floating around here. We can also change it to a circle view, the colors of the circles match the colors and the graphs on the left. And where this is really nice is if we actually see the color change up for a particle, that means a reaction just took place there. We'll take this back up to normal speed and I'll show you a couple other things. Students can track pH using the pH meters, as well as tracking the concentrations of different substances using the graphs on the left.

Now one thing that's a little bit tricky is pH is just a number, right? We can also turn BTB on so we see bromothymol blue in solution. These colors are a little bit exaggerated from the real world, but they'll help students get an idea of approximately how acidic the solution is. This also includes a nice visual pH meter when you turn bromothymol blue on.

The final thing we can alter is we can turn dissociation off and on. And the reason why we set it by default for dissociation to be off, is we figured if it was just water and carbonic acid and carbon dioxide in there that's something that would be easier for students to see without getting overwhelmed. And if they wanted a more realistic view they could turn and leave dissociation on so they could see all the processes moving forward. Hope this was helpful and that this will be a useful simulation to you and your students good luck.

Bond Data Key

The table shows several different acids and bases. All dissociate (break into ions) in water, but for some their dissociation is reversible (represented by $\rightleftharpoons$) while for others it is not ($\rightarrow$). Use this table to answer the prompts below.

Substance formula	Strength of bond(s) holding H^+ or OH^-	Dissociation (actual)	Dissociation (simplified)	pH (0.1 M)	More / Less acidic or basic (Circle one)
Acids					
H_2CO_3	high	$\text{H}_2\text{CO}_3 + 2\text{H}_2\text{O} \rightleftharpoons 2\text{H}_3\text{O}^+ + \text{CO}_3^{2-}$	$\text{H}_2\text{CO}_3 \rightleftharpoons 2\text{H}^+ + \text{CO}_3^{2-}$	3.68	More acidic Less acidic
HI	low	$\text{HI} + 2\text{H}_2\text{O} \rightarrow \text{H}_3\text{O}^+ + \text{I}^-$	$\text{HI} \rightarrow \text{H}^+ + \text{I}^-$	1.08	More acidic Less acidic
H_2SeO_4	low	$\text{H}_2\text{SeO}_4 + 2\text{H}_2\text{O} \rightarrow 2\text{H}_3\text{O}^+ + \text{SeO}_4^{2-}$	$\text{H}_2\text{SeO}_4 \rightarrow 2\text{H}^+ + \text{SeO}_4^{2-}$	1.01	More acidic Less acidic
HCN	high	$\text{HCN} + \text{H}_2\text{O} \rightleftharpoons \text{H}_3\text{O}^+ + \text{CN}^-$	$\text{HCN} \rightleftharpoons \text{H}^+ + \text{CN}^-$	5.12	More acidic Less acidic
Bases					
Ba(OH)_2	low	—	$\text{Ba(OH)}_2 \rightarrow \text{Ba}^{2+} + 2\text{OH}^-$	13.08	More basic Less basic
Hg(OH)_2	high	—	$\text{Hg(OH)}_2 \rightleftharpoons \text{Hg}^{2+} + 2\text{OH}^-$	7.03	More basic Less basic
KOH	low	—	$\text{KOH} \rightarrow \text{K}^+ + \text{OH}^-$	12.88	More basic Less basic
Ni(OH)_2	high	—	$\text{Ni(OH)}_2 \rightleftharpoons \text{Ni}^{2+} + 2\text{OH}^-$	8.37	More basic Less basic

1. In the last column, circle whether each acid is more or less acidic and each base is more or less basic.

The correct answers are bolded above. This prompt is designed to help students think about strong acids and bases having more extreme pH values without giving away the strong/weak terminology. If this prompt confuses students, you can remind them that low pHs are acidic and high pHs are basic, or just skip this prompt and emphasize the importance of extreme pH values in another way.

2. Focus only on the acids. What patterns do you notice? In particular, what do reactions that are reversible have in common? What do reactions that are not reversible (irreversible) have in common?

All acids that undergo reversible dissociation (which the teacher knows as weak acids) have a high bond strength and higher or less acidic pH. Acids that undergo irreversible dissociation (strong acids) have a low bond strength and lower or more acidic pH.

3. Explain how the patterns you noticed might account for the pH of those acids. Remember that a lower pH means a higher concentration of H^+ ions.

If dissociation is reversible, that means the reactant does not dissociate as much. Therefore there will be a lower concentration of H^+ ions and a higher pH.

If dissociation is irreversible, that means the reactant dissociates more. Therefore there will be a higher concentration of H^+ ions and a lower pH.

4. Now look at the bases. What patterns do you notice? Do bases follow the same rules as acids, or different rules? Like acids with reversible dissociation, bases with reversible dissociation have high bond strength--but they have relatively low, or less basic, pHs.

Like acids with irreversible dissociation, bases with irreversible dissociation have low bond strength--but they have relatively high, or more basic, pHs.

Acids and bases follow similar rules for bond strength but different rules for pH--irreversibility means the pH is either very high (in bases) or very low (in acids). Reversibility means the pH is closer to neutral.

5. If the bond strength in a substance is high, what else can you say about that substance? Explain your reasoning.

You can say that its reactions might be reversible and that if it is an acid or base it has a pH that is fairly close to neutral. This follows the patterns that we saw in the data above.

6. Which of the substances above would you say are stable? Explain why you would consider these substances to be stable.

Students will have a variety of answers, which is fine--this prompt is intended to help them think about how either the reactants or products could be stable, or the system as a whole could be viewed as stable at equilibrium.

Lesson 7: Teacher Reference

Preparing Assessment Solutions

In this lesson, you should prepare 50 mL of an approximately 0.05M hydrochloric acid (HCl) solution and 50 mL of an approximately 0.05M citric acid ($\text{H}_3\text{C}_6\text{H}_5\text{O}_7$) solution per group.

Use of Hydrates in Lab

Students add 0.2 g of sodium citrate to each solution (or 0.1 g of sodium acetate, if acetic acid is substituted for citric acid). Hydrates or anhydrous substances are acceptable for this lab. Students may have to use slightly more or less of the sodium salt depending on whether a hydrate is used; any small amount is acceptable as long as the amounts are consistent across the hydrochloric acid and weak acid solutions and the weak acid is observed to change in pH more than the hydrochloric acid solution.

Preparing the 0.05M Hydrochloric Acid Solution

Safety note: Wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and takedown segments of the chemical procedure.

Steps:

1. Use a funnel to fill a 100-mL graduated cylinder to the 5-mL mark with 1M HCl.
 - *Important safety note:* When diluting acids, the acid should be added to water and not water to the acid.
2. Carefully add distilled water to the 100-mL mark.
3. Transfer the solution to the desired container.
4. If you are using a storage bottle, make sure the cap is secure and gently shake it. If using a beaker, carefully stir the solution.
5. Repeat until you have made 500 mL of the solution.
6. Repeat as needed for additional sections.

Notes:

- If you have access to volumetric glassware and have two flasks that are a factor of 10 apart (e.g., 50 mL and 500 mL, or 100 mL and 1000 mL), then you can make a more exact concentration.

Preparing the 0.05M Citric Acid Solution

Steps:

1. Use the scoopula and digital scale to measure out 5.25 g of solid citric acid onto a piece of weighing paper.
2. Add the 5.25 g of citric acid to a 500 mL flask. If any citric acid remains on the weighing paper, use a funnel and a small amount of distilled water to rinse off the weighing paper into the flask.
3. To the same flask, add more distilled water to the 500 mL flask until it is at the 500-mL mark.
4. Cap and gently shake the flask to dissolve the citric acid.
5. Repeat as needed for additional sections.

Note:

- These instructions assume the use of citric acid monohydrate with a formula weight of 210.15 g/mol. If another grade of citric acid is used, calculate the mass of citric acid powder to use as follows:

Volume of solution (in liters) x molarity of desired solution (in M, or mol/L) x formula weight of powder (in g / mol)

Substitution: Preparing 0.05 Acetic Acid Solution

Acetic acid ($\text{HC}_2\text{H}_3\text{O}_2$) may be substituted for citric acid, if necessary. In this case, 0.1 g of sodium acetate should be substituted for the 0.2 g of sodium citrate.

To prepare the acetic acid solution:

1. Use a funnel to fill a 100-mL graduated cylinder with 4.2 mL of 6M acetic acid.
 - *Important safety note:* When diluting acids, the acid should be added to water and not water to the acid.
2. Carefully add distilled water to the 100-mL mark.
3. Transfer the solution to the desired container.
4. If you are using a storage bottle, make sure the cap is secure and gently shake it. If using a beaker, carefully stir the solution.
5. Repeat until you have made 500 mL of the solution.
6. Repeat as needed for additional sections.

Note:

- Vinegar at grocery stores (5% acetic acid by mass) may be used, but test first to ensure that it shows the desired effects when sodium acetate is added to it. The concentration of store-bought vinegar is typically around 0.085M.
- These instructions assume the use of 6 M acetic acid. If another concentration is used, calculate the volume of solution to use as follows:

$0.025 \text{ mol (desired amount of acetic acid for 500 mL of solution) / molarity}$

Acid Behavior Key

Lesson-level performance expectation being assessed: 7.B Develop a predictive and explanatory model based on the **particle-level interactions** found in **solutions at equilibrium**. (SEP: 2.3; DCI: PS1.B.2; CCC: 2.2)

In addition to the SEP, DCI, and CCC associated with this lesson-level performance expectation, this assessment also leverages students' use of one additional SEP element, one additional DCI element, and one additional CCC element.

- *Planning and carrying out investigations* (SEP: 3.5) is incorporated as students carry out an investigation and make a directional hypothesis. Ultimately, students engage with *planning and carrying out investigations* in service of gathering data to develop their models and make a directional hypothesis. Students have previously been assessed in developing directional hypotheses (SEP: 3.5) in *Polar Ice Unit*, so it is not being assessed here.
- *Defining and delimiting engineering problems* (DCI: ETS1.A.1) thinking is used as students complete questions 7a and 7b. Students are hypothesizing and brainstorming ideas based on data from the investigation at this point. After they have formalized their understanding around stoichiometry, students will revisit this DCI understanding to quantify criteria and constraints. Earlier in the lesson, students had opportunities to better develop this DCI element, so it is not being assessed here.
- Students use *stability and change* (CCC: 7.1) thinking as they complete questions 4 and 6. Students discuss how the concentrations of H⁺ and citric acid would change as sodium citrate is added to the solution. They further think about how the pH of the solution would change as a result of this addition. Earlier in the unit, students had opportunities to better develop this CCC element, so it is not being assessed here.

3D Elements Addressed in this Assessment	Question #								
	1	2	3a	3b	4	5	6	7a	7b
Developing and Using Models. Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (SEP: 2.3)			X		X		X	X	
Constructing Explanations and Designing Solutions. Apply scientific ideas, principles, and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. (SEP: 6.3)				X					X
PS1.B: Chemical Reactions Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. (HS-PS1-5)			X	X	X		X		
PS1.B: Chemical Reactions In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. (HS-PS1-6)			X		X		X	X	
Cause and Effect. Cause and effect relationships can be suggested and predicted for complex natural and human-designed systems by examining what is known about smaller scale mechanisms within the system. (CCC: 2.2)			X	X	X		X		

Scoring Guidance. The response elements described below would be considered exemplary at this point in the unit. These are shown in purple text or in purple diagrams below the related question. In some cases different elements of a response are identified with a + symbol. These + elements are not meant to be all inclusive, but are suggestions for different ideas your students might include.

The following scoring guidance can help you identify different elements that students should (or could) include in their responses.

- If several of the elements marked with a + are missing from a student's response, this may indicate that the student has not mastered the science ideas or that the student may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking can provide insight about whether the student is struggling with a science practice or science idea, or both.
- If all or almost all of the elements marked with a + are present in a student's response, this may indicate that the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.
- If the elements marked with a ++ are present in a student's response, this indicates that the student is bringing a deeper understanding of the science ideas or a deeper engagement with the practice to their response. Students should not be penalized if ideas marked with a ++ are not present in their response.

Follow these safety guidelines throughout:

- When working with hazardous chemicals, wear indirectly vented chemical splash goggles, a nonlatex apron, and nitrile gloves during the setup, hands-on, and takedown segments of the activity.
- When diluting acids or bases, the acid or base should be added to water and not water to the acid or base.
- Observers of activities involving hazardous chemicals must have appropriate PPE eye protection (indirectly vented chemical splash goggles) and non-latex aprons in addition to being positioned approximately 15 feet in front of a demonstration safety shield or closed fume hood sash.
- Secure loose clothing, wear closed-toe shoes, and tie back long hair.
- Never eat any food items used in a lab activity.
- Never taste any substance or chemical in the lab.
- Only combine substances and amounts as instructed by your teacher.
- Follow your teacher's instructions for disposing of waste materials.
- Use caution when working with glassware, which can shatter if dropped and cut skin.
- Immediately clean up any liquid spilled on the floor, so it does not become a slip/fall hazard.
- Never pour chemicals, either used or unused, back into their original container.
- If you get a hazardous chemical on your clothing or have a clothing fire, use the emergency shower.
- If you get a chemical in your eye, use an eyewash station immediately.
- Point the test tubes, beakers, or other vessels away from yourself and other people when the vessels contain reactants or other substances.
- Never use mouth suction to fill pipets.
- Wash your hands with soap and water immediately after completing this activity.

What chemical reactions might help us save oysters?

Can we just dump any substance into the hatchery environment to help the baby oysters? Could adding a different substance to the ocean water reverse the acidification process? What about adding an acid, a base, or a salt? In this assessment you will conduct two investigations to figure out what is happening in different types of reactions.

Question 1: How could an investigation of different types of acids with a base help oyster restoration efforts?

Sample student response:

This question is intended to help students make sense of the phenomenon. Accept all responses.

Investigation 1: Determine the pH of two acidic solutions.

Carry out an investigation to measure the pH of two substances. Gather the following investigation materials:

- 1 250-mL beaker containing 50 mL of 0.05M hydrochloric acid (HCl) solution

**Note:* Label the beaker with a marker.*

- 1 250-mL beaker containing 50 mL of 0.05M citric acid ($\text{H}_3\text{C}_6\text{H}_5\text{O}_7$) solution

**Note:* Label the beaker with a marker.*

- 2 universal pH indicator strips

Question 2: Work with your group to measure the pH values of the two substances using the pH strips. Record them in the table below.

Substance	Dissociation in water	Type of acid	pH
0.05M hydrochloric acid (HCl)	$\text{HCl} \rightarrow \text{H}^+ + \text{Cl}^-$	Strong acid	1 or 2
0.05M citric acid ($\text{H}_3\text{C}_6\text{H}_5\text{O}_7$)	$\text{H}_3\text{C}_6\text{H}_5\text{O}_7 \rightleftharpoons 3\text{H}^+ + \text{C}_6\text{H}_5\text{O}_7^{3-}$	Weak acid	2 or 3

As shown in the table, three of the hydrogen atoms in citric acid can dissociate, or break apart into ions.

Sample student response:

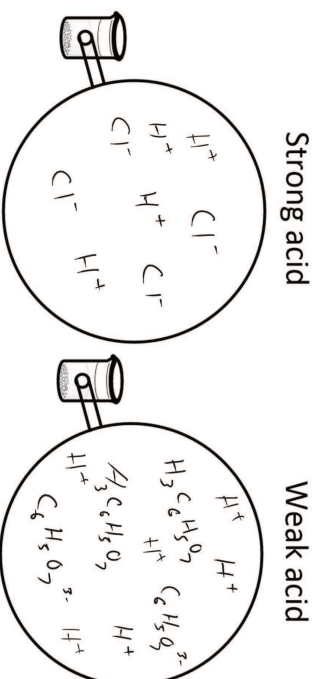
See sample pH measurements in the table above. This question is intended for students to gather data in service of developing models and explanations for questions 3, 4, 6, and 7.

What to do:

Encourage lab groups to place the pH indicator strips on a piece of white paper for more accurate readings.

Question 3a: Use what you know about the properties of acids and the data in the table above to develop a model of the behavior of each acid when dissolved in water. You may omit the water. Be sure to include a key for your models if needed.

A sample student model is shown.



Key elements:

- + Model shows that all HCl molecules are dissociated into H^+ and Cl^- ions.
- + Model shows that some of the $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$ molecules are dissociated into H^+ and $\text{C}_6\text{H}_5\text{O}_7^{3-}$ ions.
- ++ Same number of formula units are treated in each sample (because the concentrations of HCl and $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$ are the same).
- ++ Any dissociated $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$ molecules are broken into three H^+ ions and one $\text{C}_6\text{H}_5\text{O}_7^{3-}$ ion.

Additional accurate element not essential to this item:

- + Model includes the role of water molecules in the dissociation of the acids by showing interactions between the polar water molecules and acidic ions.

Sample student response:

See the sample student model above.

What to do:

Students may notice that the initial pH measurements do not clearly distinguish the two acids as strong or weak. Support students in using the data table to identify this difference. Encourage students to think about the differences in the degree of dissociation of a strong acid versus a weak acid.

Support how students illustrate relationships between the components of each acid + water system they test. Ask, *How can we represent the differences in the dissociation of a weak acid in water compared to a strong acid in water?*

Question 3b: Use your models to briefly explain how the two acids are behaving differently from each other in water.

Key elements:

- + Explanation connects relationships between **type of acid**, **pH value**, and **H⁺ concentration**, e.g.: strong acids have a low pH and high H⁺ concentration; weak acids have a higher pH and lower H⁺ concentration.
- + Identifies that the **pH value (effect)** is determined by how well the acid dissociates in water (cause).

Additional accurate element not essential to this item:

- + Includes specific information about the **concentrations of H⁺ ions in either acid**.

Sample student response:

The pH is a measure of how acidic or basic a solution is. A lower pH means it is more acidic (has more H⁺ ions floating around). A higher pH means it is less acidic (has fewer H⁺ ions floating around). Some acids, called strong acids, have a lower pH because they completely break apart or dissociate into ions. Weak acids do not completely dissociate and so they have some of the original ionic compound floating around, instead of just ions.

What to do:

Encourage students to connect the **type of acid** to explain differences in **H⁺ ion concentrations**. Ask, *What relationship is there between a weak or strong acid and the concentration of H⁺ ions in the solution?*

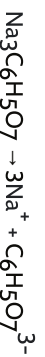
Support students' use of cause-and-effect thinking. Ask, *How can the particle interactions in your model help explain the pH values you recorded?*

Investigation 2: Determine the effects of adding an ionic compound to an acidic solution.

Your group will dissolve the ionic compound sodium citrate (Na₃C₆H₅O₇), in the two different acidic solutions, increasing the concentration of both Na⁺ and C₆H₅O₇³⁻ ions.

Question 4: Use the dissociation models in the first table and your models from **Question 3a** to make predictions about the effects of adding 0.2 grams of sodium citrate (Na₃C₆H₅O₇) to each solution. Record your predictions in the table below.

Sodium citrate dissociates in water as:



Original Solutions	What will happen to the concentration of H ⁺ ions? Will it: - increase? - decrease? - stay the same?	What will happen to the final pH? Will it: - increase? - decrease? - stay the same?
0.05M hydrochloric acid (HCl)	Stay the same	Stay the same
0.05M citric acid (H ₃ C ₆ H ₅ O ₇)	Stay the same	Stay the same

Key elements:

- + Predict that the **H⁺ ion concentration of HCl** will remain the same.
- + Predict that the **pH of HCl** will remain the same.
- + Predict that the **H⁺ ion concentration of H₃C₆H₅O₇** will stay the same.
- + Predict that the **pH of H₃C₆H₅O₇** will stay the same.

Additional accurate element not essential to this item:

++ Predict that the **H⁺ ion concentration of H₃C₆H₅O₇** decreases because the dissociation of citric acid moves to the left in the presence of additional C₆H₅O₇³⁻ ions.

Sample student response:

See sample responses in the table above.

What to do:

Support students' use of their models in **3a** to make predictions. Ask, *What would happen to your model if we added the two ions from the dissociation of sodium citrate?*

Support students' thinking around variables that influence the direction of a reversible reaction. Ask, *How does the addition of ions influence the direction of a reversible reaction?*

Carry out Investigation 2. Gather the following investigation materials:

- 2 pieces of weighing paper
- scoopula
- sodium citrate ($\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$)
- glass stirring rod
- 2 universal pH indicator strips

Procedure:

1. Go to a weighing station and measure 0.2 g sodium citrate ($\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$) onto 1 piece of weighing paper.
2. Add the 0.2 g sodium citrate to your 0.05M hydrochloric acid (HCl) solution and stir for 30 seconds.
3. Measure the pH of the 0.05M hydrochloric solution again.
4. Rinse the stirring rod.
5. Repeat steps 1-3 for the 0.05M citric acid ($\text{H}_3\text{C}_6\text{H}_5\text{O}_7$) solution.

Question 5: Record the pH of each solution in the table.

Substance	Dissociation in water	pH before addition of sodium citrate ($\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$)	pH after addition of sodium citrate ($\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$)
0.05M hydrochloric acid (HCl)	$\text{HCl} \rightarrow \text{H}^+ + \text{Cl}^-$	1 or 2	1 or 2
0.05M citric acid ($\text{H}_3\text{C}_6\text{H}_5\text{O}_7$)	$\text{H}_3\text{C}_6\text{H}_5\text{O}_7 \rightleftharpoons 3\text{H}^+ + \text{C}_6\text{H}_5\text{O}_7^{3-}$	2 or 3	3 or 4

Sample student response:

See sample pH measurements in the table above. This question is intended for students to gather data in service of developing models and explanations for questions 6 and 7.

What to do:

Encourage lab groups to place the pH indicator strips on a piece of white paper for more accurate readings.

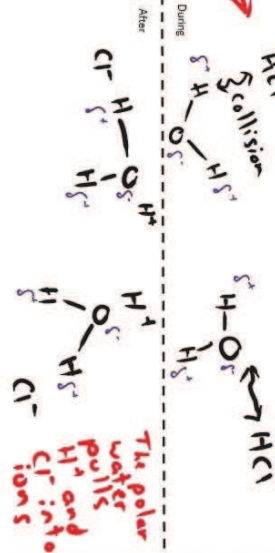
Question 6: What **particle-level interactions** could explain the differences in pH after sodium citrate was added to each acidic solution? Use evidence from the reversible reactions simulation in Lesson 6 or elsewhere in the unit to **develop a model** to explain why the pH differences occurred.

- In your model, show particle motion and interactions.

Sample student response:

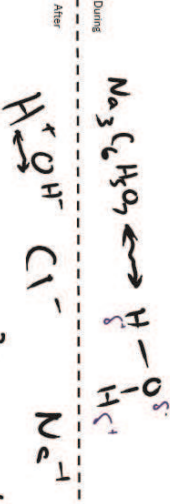
A possible student model and rubric are shown below. Use the rubric to evaluate students' models. Sample student explanations are provided.

HCl + water



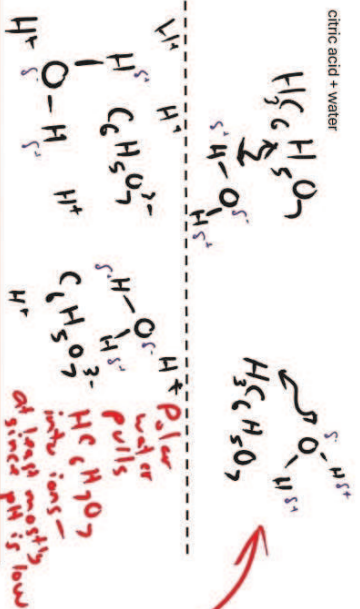
HCl + water + sodium citrate

Same as above, plus:



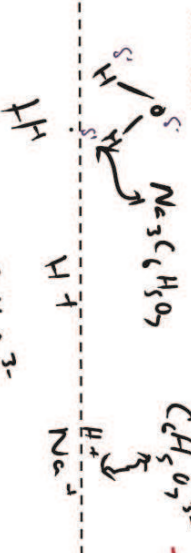
Extra citrate ions can act like a weak base, increasing the pH, but don't put the reactor back.

citric acid + water



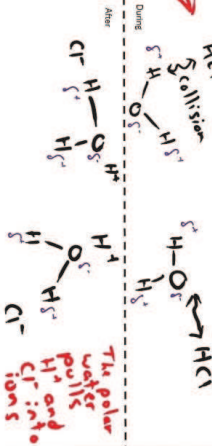
citric acid + water + sodium citrate

Same as above, plus:



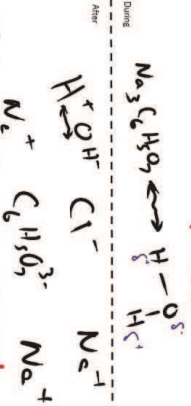
Extra citrate ions can push reaction to left as they reconnect with hydrogen ions that is pH is lower

HCl + water



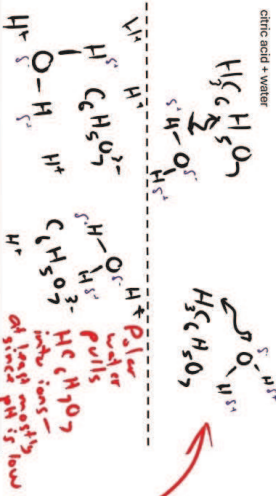
HCl + water + sodium citrate

Same as above, plus:



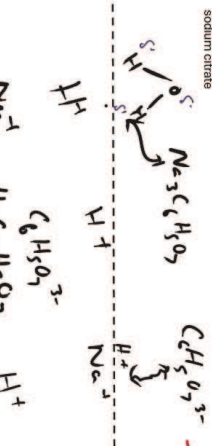
Extra citrate ions can act like a weak base, increasing the pH, but don't put the reactor back.

citric acid + water



citric acid + water + sodium citrate

Same as above, plus:



Extra citrate ions can push reaction to left as they reconnect with hydrogen ions that is pH is lower

Foundational Understanding

Linked Understanding

Organized Understanding

3D Elements	Model illustrates reactants and products of reversible reaction in the solution.	Model illustrates relationships between reactants and products of reversible reaction in the solution.	Model illustrates relationships between reactants and products of a reversible reaction to explain pH changes in the solution.
	Shows collision OR rearrangement of HCl, $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$, and $\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$ into their respective ions.	Shows collision and rearrangement of HCl, $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$, and $\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$ into their respective ions.	Shows collision and rearrangement of HCl, $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$, and $\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$ into their respective ions.
	Uses ion scale mechanisms to show changes to amounts of specific ions (cause).	Identifies that the increased amount of citrate ions in $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$ solution reduces the amount of H^+ ions in solution.	Identifies that the increased amount of a product in the reversible reaction of $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$ dissociation drives the reaction to the left.
	Uses ion scale mechanisms to show changes to amounts of specific ions (cause).	Uses ion scale mechanisms to show changes to amounts of specific ions (cause) without a clear explanation of how this leads to pH changes (effect).	Uses ion scale mechanisms to explain how changes to amounts of specific ions (cause) results in changes to the pH value of the $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$ solution (effect).
Example	The pH value for HCl does not change because HCl is a strong acid.. The pH value of citric acid increases because it is a weak acid. When $\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$ is also dissolved in water, that increases the amount of $\text{C}_6\text{H}_5\text{O}_7^{3-}$ ions. These ions can bond with H^+ ions.	The pH value for HCl does not change because HCl is a strong acid, so it completely dissociates in water. The pH value of $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$ increases because it is a weak acid. This means that it has a reversible reaction when dissolved in water. When $\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$ is also dissolved in water, that increases the amount of $\text{C}_6\text{H}_5\text{O}_7^{3-}$ ions. These ions can bond with H^+ ions. That decreases the amount of H^+ ions, causing an increase in the pH.	The pH value for HCl does not change because HCl is a strong acid, so it completely dissociates in water. It is not influenced by the addition of other ions into the solution. The pH value of $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$ increases because it is a weak acid. This means that it has a reversible reaction when dissolved in water. When $\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$ is also dissolved in water, that increases the amount of $\text{C}_6\text{H}_5\text{O}_7^{3-}$ ions, which is a product in the reversible reaction of the dissociation of $\text{H}_3\text{C}_6\text{H}_5\text{O}_7$. These ions can bond with H^+ ions. This causes the reaction to shift more toward the left, reducing the amount of acid dissociation. That decreases the amount of H^+ ions, causing an increase in the pH.

Feedback/What to do	<i>Linking:</i> How will the addition of more $\text{C}_6\text{H}_5\text{O}_7^{3-}$ ions affect the amount of free H^+ ions in the solution?	<i>Organizing:</i> What happens in a reversible reaction if you increase the amount of reactant or product?	<i>Extending:</i> How can we use this information to think about possible chemicals to add to water to reduce carbonic acid?
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Ideas for Instruction	Foundational Understanding	Linked Understanding	Organized Understanding
	Have students use the simulation from Lesson 6 to support how they think about collisions and interactions between particles that lead to rearrangements of them. Encourage students to record the chemical reactions on their models to help illustrate relationships between reactants and products. Have students explain how adding one type of ion would affect another ion in the solution, leading to pH changes.	Have students revise their models to keep track of the amounts of reactants and products in the reversible reactions both before and after the addition of sodium citrate. Encourage students to record the chemical reactions on their models to illustrate the relationships between reactants and products to develop ideas around how changes to the amount of either affects the direction of the reversible reaction.	Invite students to think about the reversible reaction of carbonic acid in water and brainstorm potential chemicals that would push the reversible reaction to the left.

Question 7a: How could the model you developed to explain the observations from this investigation be used to help the oysters and the people who depend on them?

Key elements:

- + Explanation points to specific portions of the model students developed in question 6.
- + Addition of sodium citrate ($\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$) to the citric acid ($\text{H}_3\text{C}_6\text{H}_5\text{O}_7$) solution causes the pH to increase.
- + Concentration of H^+ ions decreases when sodium citrate ($\text{Na}_3\text{C}_6\text{H}_5\text{O}_7$) is added to the solution.
- + Substances could be added to the ocean to increase the pH value/make it less acidic.

Additional accurate element not essential to this item:

- + Sodium citrate is a type of salt.
- ++ Adding a salt to a weak acid causes the pH value to increase/the solution to become less acidic if the type of ions dissociated from the salt are the same as the ions dissociated from the weak acid.

Sample student response:

The purpose of this question is to provide an opportunity to build relevance between the investigations and the anchoring phenomenon. Accept all responses.

What to do:

Ask, *Where in your model does it show possible solutions to the oyster problem? or How could you use a portion of your model to think about a possible solution to the oyster problem?*

Ask, *How could adding a different substance to the ocean help oysters and the people who depend on them?*

Question 7b: What are some possible unintended effects that we would need to consider when thinking about potential design solutions?

Key elements:

- + Changing the composition of ocean water can impact other species in the ocean.
- + Changing the composition of ocean water can impact geological (rock, sand, etc...) features of the ocean.
- + Changing the composition of ocean water can impact the water quality of the ocean.

Additional accurate element not essential to this item:

- ++ Refer back to other possible unintended effects on interested parties they read about earlier in the lesson.

Sample student response:

The purpose of this question is to see if students are thinking beyond the oyster system. Accept all responses.

What to do:

Provide feedback that gives students space to think more deeply about some of the interactions between systems they may have identified, OR ask students to consider other adjacent systems they allude to in their responses.

Lesson 7: Answer Key

Discuss Interested Parties Key

This chart shows sample student responses to Questions 3 and 4 of *Discuss Interested Parties*. Note that this is not an exhaustive list of responses to these questions. Students may not generate all of these ideas on their own, or they may generate additional ideas beyond the ones listed here.

Reading	Sample Student Responses	
	Which science concepts that we have figured out help us explain what is going on in the place that this group cares about?	What criteria and constraints are important to this group of people?
<i>Poultry Farmers</i>	- We learned about acids and how they react with other materials. We think that the acid in the chicken's stomach is reacting with the oyster shell. We are not sure if this is the same way it happens in the ocean or not. - The pH of the chicken's stomach is 2.5, which we know is very acidic. This means there is a high concentration of H⁺ ions in the stomach.	- The cost of oyster harvesting needs to stay low enough that using oyster shells for feed is cost-effective. - The solution needs to maintain the supply chain that gets oysters from where they grow to restaurants and then to poultry farms. - The solution needs to make sure the oyster shells still have plenty of calcium in them to produce strong eggshells.
<i>Northwest Indian Fisheries</i>	- We learned that carbon dioxide can enter water, and we drew particle models to show how this happens. - We learned that carbon dioxide reacts with water to form carbonic acid, which lowers the pH of ocean water. Ocean plants remove carbon dioxide from water.	- A solution cannot prevent or interfere with ceremonial subsistence harvests. - The solution needs to have support from both the Northwest Indian Fisheries Commission and the Washington Department of Fish and Wildlife. - A solution should work with what they are already doing, like restoring kelp beds and monitoring ocean acidification.
<i>Oyster Farmers</i>	- We learned that the pH of ocean water impacts oyster die-offs. We learned that even though the ocean is basic, it is becoming more acidic and that is harming the oysters. - We learned that pH is a measurement of the concentration of H⁺ ions in solution. - We learned that reactions, such as acid and base reactions, can be reversible.	- It needs to allow oyster farmers to continue harvesting as many or more oysters as they currently do. - It needs to be cheap enough to not cancel out the profit of selling farmed oysters. - It is more effective if it requires less constant monitoring. - It needs to affect the acidity of the water in tanks, which means it could be a solution that changes the ocean water after it is removed from the ocean.
<i>Restaurant Personnel</i>	We learned that the ocean is becoming more acidic and that is causing oyster die-offs. We know that carbon dioxide in the atmosphere transfers to the ocean and makes it more acidic, which hurts oyster shells.	- The solution needs to be cost-effective so that the cost is not passed on to the restaurants and their customers. - The solution cannot create additional pollution in waterways, which could make it dangerous to eat the oysters.

Lesson 8: Answer Key 1

Neutralization Investigation #2 Key

Sample student responses are included for Part A of the *Neutralization Investigation #2* handout. Group investigation procedures and the subsequent findings and discussion will vary.

Part A: Mass Calculation



1. Calculate the molar mass of NaOH (periodic table):



2. Calculate the molar mass of $\text{H}_2\text{C}_2\text{O}_4$ (periodic table):



3. Now use molar masses and coefficients from the balanced equation to calculate the mass of NaOH needed to neutralize 1 g of $\text{H}_2\text{C}_2\text{O}_4$ (chemical reaction equation):

$$\frac{1.00 \text{ g H}_2\text{C}_2\text{O}_4}{90.04 \text{ g H}_2\text{C}_2\text{O}_4} \times \frac{1 \text{ mol H}_2\text{C}_2\text{O}_4}{1 \text{ mol H}_2\text{C}_2\text{O}_4} \times \frac{2 \text{ mol NaOH}}{1 \text{ mol H}_2\text{C}_2\text{O}_4} \times \frac{40.00 \text{ g NaOH}}{1 \text{ mol NaOH}} = 0.89 \text{ g NaOH}$$

Part B: Neutralization Investigation #2

4. Outline your revised procedure for this investigation, including important safety precautions to follow:

5. Summarize your findings and observations:

6. What do you think these results mean? Summarize your ideas here:

7. What did we decide as a class that our results mean?

Ocean Water Calculations Key

Ocean data	pH	H ⁺ molarity (concentration)
Neutral	7.0	$1.0 \times 10^{-7} \text{ M (mol/L)}$
Projected*	7.8	$1.6 \times 10^{-8} \text{ M (mol/L)}$
Historical	8.2	$6.3 \times 10^{-9} \text{ M (mol/L)}$

*The ocean water at some oyster hatcheries is already at this point.

Volume of oyster tank: 1000 L

Time Point #1:

1. Calculate the moles of H⁺ in an oyster tank with a pH of 7.8. (SEP: 5.5; CCC: 3.1)

a. What amounts and units are you starting with? (Make sure your group agrees.)

$$\text{pH} = 1.6 \times 10^{-8} \text{ M (mol/L); Volume} = 1000 \text{ L}$$

b. What units do you need to convert to? (Make sure your group agrees.)

mol H⁺

c. What will you use as a conversion factor?

mol/L

d. Set up your equation below. Do not forget your units. Use colors to track the units if needed.

$$\frac{1.6 \times 10^{-8} \text{ mol}}{1 \text{ L}} \times \frac{1000 \text{ L}}{1} = 1.6 \times 10^{-5} \text{ mol H}^+$$

e. Make sure your group agrees on how you set up your equation.

f. Now work through your equation and compare results with your group.

Time Point #2:

2. Calculate the moles of H⁺ in an oyster tank with a pH of 8.2. (SEP: 5.5; CCC: 3.1)

a. What amounts and units are you starting with? (Make sure your group agrees.)

$$\text{pH} = 6.3 \times 10^{-9} \text{ M (mol/L); volume} = 1000 \text{ L}$$

b. What units do you need to convert to? (Make sure your group agrees.)

mol H⁺

c. What will you use as a conversion factor?

mol/L

d. Set up your equation below. Do not forget your units. Use colors to track the units if needed.

$$\frac{6.3 \times 10^{-9} \text{ mol}}{1 \text{ L}} \times \frac{1000 \text{ L}}{1} = 6.3 \times 10^{-6} \text{ mol H}^+$$

e. Make sure your group agrees on how you set up your equation.

f. Now work through your equation and compare results with your group.

Oyster Tank Neutralization Calculations

3. Calculate the excess moles of H^+ that must be neutralized to adjust the pH to a healthy level for oysters in a single tank. Check with your group as needed. Make sure you have an accurate answer before you move on. (SEP: 5.5; CCC: 3.1)

$$\text{This is simply a subtraction problem.} \\ 1.6 \times 10^{-5} \text{ mol H}^+ - 6.3 \times 10^{-6} \text{ mol H}^+ = 9.7 \times 10^{-6} \text{ mol H}^+$$

The scaffolded sub-questions have been removed for questions 4 and 5, so these are good places to check for individual understanding.

4. How many moles of OH^- are needed to neutralize those excess H^+ ions to form H_2O molecules? Record the balanced equation for this reaction (DCI: PS1.B.3) and use it to set up the molar ratio in a mathematical model to determine the moles of OH^- . (SEP: 5.5; CCC: 3.1)

- a. Record the balanced equation for this reaction.



- b. Set up the molar ratio in a mathematical model to determine the moles of OH^- .

$$\frac{9.7 \times 10^{-6} \text{ mol H}^+ \times 1 \text{ mol OH}^-}{1} = 9.7 \times 10^{-6} \text{ mol OH}^-$$

5. Calculate the mass of NaOH needed to neutralize that amount of H^+ based on your answer to Question 4. (SEP: 5.5; CCC: 3.1)

$$\frac{9.7 \times 10^{-6} \text{ mol NaOH} \times 40.00 \text{ g NaOH}}{1} = 0.000388 \text{ g NaOH}$$

Volume of the ocean: 1.34×10^{21} L

6. Determine the mass of NaOH needed to neutralize the excess H^+ ions in the **entire ocean**.

a. What are the related sub-steps you completed last time that you will need to follow for this problem? (SEP: 5.5)

Figure out the moles of H^+ in each type of water and subtract to find the difference.
Calculate how many moles of NaOH would react with it.

b. Use the space below to document how you used our mathematical model to determine an answer.
(SEP: 5.5; DCI: PS1.B.3; CCC: 3.1)

Sample student work shown.

a. Calculate the moles of H^+ present in the ocean with a pH of 7.8.

$$\frac{1.6 \times 10^{-8} \text{ mol}}{1 \text{ L}} \times \frac{1.34 \times 10^{21} \text{ L}}{1} = 2.1 \times 10^{13} \text{ mol } H^+$$

b. Calculate the moles of H^+ present in the ocean with a pH of 8.2.

$$\frac{6.3 \times 10^{-9} \text{ mol}}{1 \text{ L}} \times \frac{1.34 \times 10^{21} \text{ L}}{1} = 8.4 \times 10^{12} \text{ mol } H^+$$

c. Calculate the moles of H^+ that we need to neutralize to adjust the pH to a healthy level for oysters.

$$2.1 \times 10^{13} \text{ mol } H^+ - 8.4 \times 10^{12} \text{ mol } H^+ = 1.3 \times 10^{13} \text{ mol } H^+$$

d. Calculate the moles of OH^- and NaOH needed to neutralize that amount of H^+ .

$$\frac{1.3 \times 10^{13} \text{ mol } H^+}{1 \text{ mol } H^+} \times \frac{1 \text{ mol } OH^-}{1 \text{ mol } OH^-} = 1.3 \times 10^{13} \text{ mol } OH^- = 1.3 \times 10^{13} \text{ mol NaOH}$$

e. Calculate the mass of NaOH needed to neutralize that amount of H^+ .

$$\frac{1.3 \times 10^{13} \text{ mol NaOH}}{1 \text{ mol NaOH}} \times \frac{40.00 \text{ g NaOH}}{1 \text{ mol NaOH}} = 5.0 \times 10^{14} \text{ g NaOH}$$

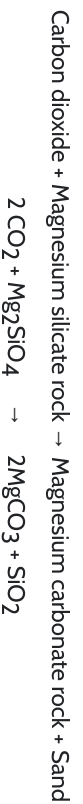
f. Convert that amount to kg.

$$\frac{5.0 \times 10^{14} \text{ g NaOH}}{1} \times \frac{1 \text{ kg}}{1000 \text{ g}} = 5.0 \times 10^{11} \text{ kg}$$

Stoichiometry Practice Key

Can we store carbon dioxide from the atmosphere in sand to slow climate change?

One proposed tool that could help protect oysters from ocean acidification is **carbon sequestration**. In carbon sequestration, carbon dioxide is pulled from the atmosphere and reacted with rocks like calcium oxide (CaO) or magnesium silicate (Mg_2SiO_4). This reaction stores carbon dioxide in the sand. The chemical equation below shows what happens when CO_2 is reacted with Mg_2SiO_4 to form MgCO_3 (magnesium carbonate rock) and SiO_2 (silicon dioxide or quartz, which is a major component of sand).



As long as you can find enough Mg_2SiO_4 rocks, this sounds very exciting --- but is it feasible? If the carbon dioxide emissions of the United States are divided equally among the population, the average is about 15,000 kg of carbon dioxide emissions per person per year. Let's use stoichiometry to take a closer look.

Remember that you may need to use your periodic table to calculate molar masses, even if they are not specifically requested in the problem.

Conversion factors	
1 kg = 1000 g	1 mole = 6.02×10^{23} molecules

This answer key shows one path, but others (including some that might be more straightforward) exist.

1. How many moles of CO_2 are in 15,000 kg? Show your thinking.

Molar mass of CO_2 : $12.01 + (2 * 16.00) = 44.01 \text{ g/mol}$

Mass of CO_2 in grams: $15,000 \text{ kg} * (1000 \text{ g} / 1 \text{ kg}) = 15,000,000 \text{ or } 1.5 \times 10^7 \text{ g}$

Moles of CO_2 : $15,000,000 \text{ g} * (1 \text{ mol} / 44.01 \text{ g}) \approx 340,831.63 \text{ mol CO}_2$

2. How many molecules of CO_2 are in 15,000 kg? Show your thinking.

Molecules of CO_2 : $340,831 \text{ mol CO}_2 * (6.02 \times 10^{23} \text{ molecules} / 1 \text{ mol}) \approx 2.05 \times 10^{29} \text{ molecules of CO}_2$

3. How many moles of SiO_2 are formed when 15,000 kg of CO_2 are reacted with Mg_2SiO_4 ? Show your thinking.

Moles of SiO_2 : $340,831 \text{ mol CO}_2 * (1 \text{ mol SiO}_2 / 2 \text{ mol CO}_2) = 170,416 \text{ mol SiO}_2$

4. What mass of Mg_2SiO_4 is needed to react with 15,000 kg of CO_2 ? Show your thinking.

Molar mass of Mg_2SiO_4 : $(2 * 24.31) + 28.09 + (4 * 16) = 140.71 \text{ g/mol}$

Mass of Mg_2SiO_4 : $340,831 \text{ mol CO}_2 * (1 \text{ mol Mg}_2\text{SiO}_4 / 2 \text{ mol CO}_2) * (140.71 \text{ g Mg}_2\text{SiO}_4 / 1 \text{ mol Mg}_2\text{SiO}_4) \approx 23,979,000 \text{ g Mg}_2\text{SiO}_4$

5. List at least three additional pieces of information you could figure out using the provided data and your periodic table.

Moles of Mg_2SiO_4 to react with 15,000 kg CO_2

Mass of SiO_2 produced in the reaction

Moles or mass of MgCO_3 produced in the reaction

6. About 330 million people lived in the United States in 2020. How much magnesium silicate (in kilograms) would be needed annually to react with the carbon dioxide emissions produced by all of these people? Show your thinking.

Mass of Mg_2SiO_4 per person in kg: $23,979,000 \text{ g} * (1 \text{ kg} / 1000 \text{ g}) = 23,979 \text{ kg per person}$

Total mass: $23,979 \text{ kg} / \text{person} * (330,000,000 \text{ people}) \approx 7.91 \times 10^{12} \text{ kg}$

7. Based on your answers, does carbon sequestration alone seem like enough to “fix” carbon dioxide emissions? If you feel you need more information to answer this question, what other information would you need? Explain your thinking.

Accept all reasonable answers. Students may think that carbon sequestration sounds feasible since there is so much rock in the country, or they may want more information about mineral reserves to see if we actually have enough rock available to carry out carbon sequestration using magnesium silicate.

References

Elkeland, E., Blichfeld, A. B., Tyrsted, C., Paduraru Jensen, A. & Iversen, B. B. (2015). Optimized Carbonation of Magnesium Silicate Mineral for CO₂ Storage. *ACS Applied Materials & Interfaces*, 7(9), 5258–5264. <https://doi.org/10.1021/am508432w>

Lesson 9: Answer Key 3

Electronic Exit Ticket Key

9.A Use a mathematical model to calculate and predict amounts of reactants for desired products, assuming conservation of matter, across scales from molecular to lab-measurable quantities. (SEP: 5.5; DCI: PS1.B.3; CCC: 3.1)

Where these elements are addressed in this assessment	5.5 Using Mathematics and Computational Thinking Apply ratios, rates, percentages, and unit conversions in the context of complicated measurement problems involving quantities with derived or compound units (such as mg/mL, kg/m ³ , acre-feet, etc.).	PS1.B.3 Chemical Reactions The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions.	3.1 Scale, Proportion, and Quantity The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs.
Q1	X	X	X
Q2	X		X
Q3	X	X	
Q4	X		X
Q5	X	X	
Q6			

Question 1

In this lesson, you investigated the amount of base that would be needed to neutralize the acid that is harming oysters. **Predict** what would happen to the **masses and ratios** of the reactants and products when **scaling up** an **acid-base reaction** from a lab to a real-world setting, such as a bay where oyster restoration is taking place.

Select the correct answer.

- The masses will increase, but the ratios will decrease.
- The masses will increase, but the ratios will remain the same.
- The masses will increase and the ratios will increase.
- The masses will decrease and the ratios will decrease.
- The masses will decrease, but the ratios will remain the same.
- The masses will decrease, but the ratios will increase.

Correct response: The masses will increase, but the ratios will remain the same.

Rationale for distractors: Students need proportional and systems thinking to understand how to neutralize an acid. They will have to reason that more mass in a larger, scaled-up reaction would be needed, but that the ratios would stay the same.

What to do: Students may need their attention focused on the phrase “**scaling up**.” Say, *to scale up means to apply it to a larger system.*

Students may not recognize the word “**ratio**.” Point out that this is related to the coefficients in balanced **chemical equations**. Several examples are in the slides. Draw students’ attention to the process that they used to do stoichiometry in *Ocean Water Calculations*.

Question 2

Which of these **ratios (or conversion factors)** can help you **convert a count or number of molecules** in a substance **into a measure of its mass**?

- 6.02×10^{23} molecules in an amount equal to the atomic mass (g)
- the atomic mass in grams (from the periodic table)
- 6.02×10^{23} grams
- the total grams that you have in the supply container or cabinet

Correct response: 6.02×10^{23} molecules in an amount equal to the atomic mass (g)

Rationale for distractors: Students should not memorize Avogadro’s number (6.02×10^{23}) without the context of its importance and usefulness as a **mathematical tool** for working with **scale, proportion, and quantity to predict chemical reactions**. (SEP: 5.5; DCI: PS1.B.3; CCC: 3.1)

What to do: Students may not recognize that Avogadro’s number is a conversion factor by itself. If students select 6.02×10^{23} grams, ask them to look at their handouts from Lesson 9 to review how the **conversion factors were used to scale up the reaction in those situations**.

Question 3

What are some useful steps in **using mathematical thinking** to **predict reaction outcomes from chemical equations**? Select all that apply.

- Identify the amounts and units you are starting with.
- Round amounts of the units you are starting with.
- Identify the unit you want to end with.
- Find some unit conversions that will help you.
- Check that the units cancel out before performing calculations.
- Leave out units when performing your calculations.

Correct responses:

- Identify the amount and units you are starting with.
- Identify the unit you want to end with.
- Find some unit conversions that will help you.
- Check that the units cancel out before performing calculations.

What to do: Students should select all of the responses except “Round amounts of the units you are starting with.” and, “Leave out units when performing your calculations.” *Ocean Water Calculations* encourages them to follow these steps. Students should be paying close attention to units in the context of **using mathematical thinking** to **predict reaction outcomes from chemical equations**.

Review the sub-steps that students performed in *Ocean Water Calculations*.

Question 4

Write a full sentence or two to describe a time that you used **mathematical thinking** to **adjust the scale of a reaction or a chemical process**.

For example, have you ever run short of an important ingredient while cooking or making a drink? How did that affect the end product? How could you use **mathematical thinking** and **scale, proportion, and quantity** to adjust the recipe?

What to look for: This prompt helps connect ideas about scale and conversion factors with students' real-world experiences. Look for examples where students had to limit the products because of insufficient reactants, or where they could double the reaction with enough ingredients. For example:

- If I run short of something, I have to see how much is missing so I can proportionally reduce the recipe. If I only have 1 egg and I need 2, I could cut back the recipe or substitute something with similar properties, like flax meal.

Accept all responses. Validating their responses engages students in activating **relevance** and **interest** in these issues, which can motivate future questions.

What to do: Focus students on what is being explained in the prompt. Ask, *How can math help with that? What did you notice about the ratios involved?* Encourage students to make connections between **scale, proportion, and quantity**. Ask, *How did you scale up or scale down your quantities?*

Question 5

How did this lesson's [stoichiometry practice](#) provide us a way to use the idea that [matter is conserved in chemical reactions](#)?

- There were more atoms at the end of the reaction than at the beginning.
- At each step of the conversion, the amount doubles.
- We balance the equation and only multiply by conversion factors (equal to 1) to ensure that no matter is gained or lost.
- As we work through a conversion problem, we leave off our units.

Correct response: [We balance the equation and only multiply by conversion factors \(equal to 1\) to ensure that no matter is gained or lost.](#)

Rationale for distractors: This question asks students to connect the math to the idea at the heart of stoichiometry, that matter is conserved throughout a chemical reaction. The distractors point students to issues that flout the conservation of matter: the amount changing randomly, using conversion factors not equal to one, and ignoring units.

What to do: If students are having difficulty answering, you may rephrase "[matter is conserved](#)" with terminology like, "no atoms appear or disappear." Students may also eliminate incorrect answers without thinking about the [mathematical processes](#). For example, there cannot be more atoms at the beginning or end of a reaction. Students have experienced this throughout the chemistry course, especially in *OpenSciEd Unit C.3: How could we find and use the resources we need to live beyond Earth? (Space Survival Unit)*.

Question 6

How did your classmates help you develop your fluency in using stoichiometry? Describe one thing they did well and one thing they could do next time to help you learn together even more.

What to look for:

- Students identify a feature of positive partner work.
- Students articulate a constructive way their partner(s) could help.

What to do: These responses do not include student names, so feel free to share the results of this question with students at the beginning of the next class.

Lesson 10: Teacher Reference

Adjusting Water pH

For this lesson you will prepare a 150 mL sample of water with a pH similar to that of the historical ocean, about 8.2. You should prepare a separate sample for each class (ideally the whole day's samples at once). The pH does not need to be exact for the investigation to give students a strong comparison between this “ocean water” and vinegar, but it should be within the ideal range of 7 to 9. If you have access to ocean water, you may even choose to use that!

In many places, tap water has a pH within this range. However, you may find that your tap water is somewhat more acidic. If you choose to use distilled or deionized water for this demo, you may find that it has a pH significantly below 7, or even below 6. This is because water absorbs carbon dioxide from the air to form carbonic acid, as students have seen the ocean do in this unit. With fewer or no dissolved ions to provide a buffering effect (a shift in equilibrium that minimizes changes in pH), distilled or deionized water experiences stronger acidification effects from the carbon dioxide it absorbs than does tap water.

If you are working with distilled or deionized water or otherwise find your water's pH to be outside the ideal range for this investigation, you will need to add substances to adjust it. The exact amount can be calculated, but with dependence on water chemistry, the particular acid or base, and the targeted amount, it is easier to use a “guess-and-check” approach.

If the pH Is Too Low

If the pH of the water is too low (meaning it is too acidic), you will need to add any base in small amounts until the pH has reached the targeted level. Weak bases, such as sodium bicarbonate (baking soda), are preferred for safety and ease of use.

To make one 150 mL sample, use indicator paper to get an idea of the current pH, then add about 20 milligrams of base at a time. After each addition, stir until well mixed and test the new pH. Remember that the more solution you are trying to make, the more base you will need to add. To make 1 L of water, which is enough for roughly six classes, you can add about 1 gram of base at a time. Also keep in mind that the pH scale is logarithmic and a pH of 8 is actually ten times more basic than a pH of 7.

If you do not have any weak bases on hand you may use one of the strong bases instead (NaOH or another hydroxide compound, among others), but you will have to be more careful in how much base you add—it will be easy to overshoot!

If the pH Is Too High

If the pH of the water is too high (meaning it is too basic), you will need to add any acid in small amounts until the pH has reached the targeted level. Weak acids, such as oxalic acid, are preferred for safety and ease of use.

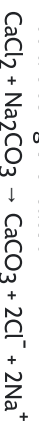
To make one 150 mL sample, use indicator paper to get an idea of the current pH, then add about 20 milligrams of acid at a time. After each addition, stir until well mixed and test the new pH. Remember that the more solution you are trying to make, the more acid you will need to add. To make 1 L of water, which is enough for roughly six classes, you can add about 1 gram of acid at a time. Also keep in mind that the pH scale is logarithmic and a pH of 7 is actually ten times more acidic than a pH of 8.

If you do not have any weak acids on hand you may use one of the strong acids instead (HCl, HNO₃, H₂SO₄, HBr, HI, HClO₃, or HClO₄), but you will have to be more careful in how much acid you add—it will be easy to overshoot!

Sample Investigation Data

Note, only portions of *Shell-Building Investigation Planner* are included. Completed sample data tables for both temperature and concentration factors are included. These are intended to give an indication of possible investigation results and may not be exactly the results yielded by students in your classroom.

You are using the reaction:



1. Each trial you will use approximately 50 mL of 0.1M CaCl_2 at a cold temperature as the control. Use this information and the molar mass to determine the mass of Na_2CO_3 you would need to react with all of the CaCl_2 . This will help you determine a **range** of about how much Na_2CO_3 you should add (you will need to vary the amount somewhat if you want to test concentration).

Use the steps below to help guide groups which may be struggling with completing this question.

Step 1: Find the number of moles of CaCl_2 present in the starting solution:

$$0.1M \text{CaCl}_2 = (0.1 \text{ mole of CaCl}_2 / 1L) * (.05 L / 1) = 0.005 \text{ moles of CaCl}_2$$

Step 2: Find the number of grams in 1 mole of Na_2CO_3 :

$$\text{Na} = 22.990 \text{ g/mol}$$

$$\text{C} = 12.011 \text{ g/mol}$$

$$\text{O} = 15.999 \text{ g/mol}$$

$$22.990(2) + 12.011 + 15.999(3) = 105.988 \text{ grams of Na}_2\text{CO}_3 / \text{mol}$$

Step 3: Find the number of grams of Na_2CO_3 in 0.005 moles (the number of moles needed to react with 0.005 moles of CaCl_2 in a one-to-one ratio as established in the chemical equation):

$$105.988 \text{ g/mol Na}_2\text{CO}_3 * 0.005 \text{ mol Na}_2\text{CO}_3 = 0.530 \text{ grams of Na}_2\text{CO}_3 \text{ needed}$$

Sample completed data table for a group testing temperature:

Title: Measuring Calcium Carbonate Formation by Changing Temperature

Starting Temperature (°C)	Mass of Reactant 1 Na ₂ CO ₃	Concentration of Reactant 2 CaCl ₂	Outcome	Observations
22.1	0.53 g	0.1M (100 mL)	Trial 1: 2.73 g CaCO ₃ (wet) Trial 2: 2.71 g CaCO ₃ (wet)	Trial 1: White cloudiness happened immediately ; started to settle within 10 seconds Trial 2: White cloudiness happened immediately ; started to settle within 10 seconds
6.5	0.53 g	0.1M (100 mL)	Trial 1: 2.63 g CaCO ₃ (wet) Trial 2: 2.65 g CaCO ₃ (wet)	Trial 1: White cloudiness happened immediately ; started to settle within 10 seconds Trial 2: White cloudiness happened immediately ; started to settle within 10 seconds

Sample completed data table for a group testing concentration:

Title: Measuring Calcium Carbonate Formation by Changing Concentration

Starting Temperature (°C)	Mass of Reactant 1 Na ₂ CO ₃	Concentration of Reactant 2 CaCl ₂	Outcome	Observations
3	0.53 g	0.1M (100 mL)	Trial 1: 2.45 g CaCO ₃ (wet) Trial 2: 2.42 g CaCO ₃ (wet)	Trial 1: White cloudiness happened immediately ; started to settle within 10 seconds Trial 2: White cloudiness happened immediately ; started to settle within 10 seconds
3	0.27 g	0.1M (100 mL)	Trial 1: 1.23 g CaCO ₃ (wet) Trial 2: 1.20 g CaCO ₃ (wet)	Trial 1: White cloudiness happened after 5 seconds ; less cloudy than 0.1M Trial 2: White cloudiness happened after a few seconds ; precipitate formed near bottom of beaker first, instead of top

Lesson 12: Answer Key

Progress Tracker Key

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

L2:

1. CO₂ gets into the atmosphere and ocean.
2. Water becomes more acidic.
3. Acidity hurts the oyster shells.
4. Oyster die-off hurts ecosystems and communities.

What are the new science ideas that we figured out that might help us and our communities address this subproblem?	What subproblem(s) might this science idea connect to?	What are some ways we might apply these ideas in practice to design a solution to this subproblem?	What should we keep in mind about how solutions might affect and be affected by people and the environment?
L3: CO ₂ lowers the pH of ocean water which makes it more acidic than it was before, even though the overall pH is still above 7.	1 and 2	It seems like the pH can change and go back and forth. We could find a substance that could react with CO ₂ to prevent it from mixing with water, or we could block it from entering the water.	L3: Changing the pH of the ocean might affect other living things that have adapted to the lower pH. L4: Adding something to the ocean could hurt the people who live near it and the ecosystems they interact with.
L4: CO ₂ makes the ocean more acidic by reacting with water to form an acid, which releases H ⁺ .	2	We could find a way to remove the H ⁺ ions to raise the pH of the ocean back to where it was before.	L5: Adding a barrier to the ocean could prevent people and living things that interact with the ocean surface from getting food or other resources (e.g., recreation).
L5: CO ₂ naturally dissolves into water. It dissolves into the water at the surface and then moves to different levels in the water. The CO ₂ reacts with water to form an acid, which then releases H ⁺ ions into the water.	1	We can create a barrier at the interface between air and water so CO ₂ cannot flow through.	

What are the new science ideas that we figured out that might help us and our communities address this subproblem?	What subproblem(s) might this science idea connect to?	What are some ways we might apply these ideas in practice to design a solution to this subproblem?	What should we keep in mind about how solutions might affect and be affected by people and the environment?
L5: Carbon moves between the atmosphere, hydrosphere, geosphere, and biosphere over time. We call this the carbon cycle. Usually it moves very slowly (geological time scale, like 100,000+ years) but recently, burning fossil fuels has led to rapid movement of carbon from the geosphere to the atmosphere relative to before (significant change in 10 years vs. 100,000+ years). That in turn has caused more carbon to move from the atmosphere into the hydrosphere, which is why the ocean gets more acidic.	1 and 4	We can try to reduce the CO₂ getting into the atmosphere first: • Reduce the burning of fossil fuels and release of CO₂ into the atmosphere. • Reduce transportation of goods. • Build energy-efficient buildings. • Plant more trees to take CO₂ out of the atmosphere. We can also try to take CO₂ out of the ocean by planting more things underwater.	L5: If we stop burning fossil fuels immediately, many aspects of our life would have to change quickly and drastically. L6: The ocean ecosystem is very complex. People could easily create other problems when trying to fix ocean acidification.
L6: Dissolved CO ₂ can leave a solution through random motion.	1	CO ₂ can leave a solution on its own, but there might be a way to force it out.	
L6: Some substances undergo reversible reactions and reach an equilibrium level. If the concentration of a substance is changed, the reaction can move forward or backward.	2	If reactions can reverse, there might be a way to reverse ocean acidification.	

What are the new science ideas that we figured out that might help us and our communities address this subproblem?	What subproblem(s) might this science idea connect to?	What are some ways we might apply these ideas in practice to design a solution to this subproblem?	What should we keep in mind about how solutions might affect and be affected by people and the environment?
L8: Molarity is a measurement of moles of solute (dissolved stuff) per liter of solution. pH tells us the molarity of H^+, and if we know molarity and volume we can calculate moles of H^+.	2	We can use pH to calculate moles of H^+ and then use that to calculate moles of base needed to adjust the pH.	L8: We need to make sure dumping NaOH or some other base into the ocean will not harm oysters or other marine life. How much does NaOH cost? How will oyster shells react to NaOH? L9: We need to make sure dumping NaOH or some other base into the ocean will not harm oysters or other marine life. How much does NaOH cost? How will oyster shells react to NaOH?
L8: The coefficients in balanced equations tell us the mole ratios of reacting substances. We can use these ratios to figure out how many moles, and thus what mass, of a substance will react with some amount of another substance in the reaction.	2	We can calculate the amount of base we need to use to raise the pH of water to a better level for oysters.	
L9: It would take a really small amount of NaOH to adjust the pH of an oyster tank, but it would take A LOT of NaOH to adjust the pH of the entire ocean.	2 and 4	It may make sense to focus on adjusting water pH in oyster tanks instead of the ocean because of the amount of base required.	

What are the new science ideas that we figured out that might help us and our communities address this subproblem?	What subproblem(s) might this science idea connect to?	What are some ways we might apply these ideas in practice to design a solution to this subproblem?	What should we keep in mind about how solutions might affect and be affected by people and the environment?
L10: Oyster shells do not dissolve into the ocean, but oyster larvae are hurt when the ocean gets more acidic because the H^+ ions react with CO_3^{2-} (what is necessary for oyster shell-building) to make bicarbonate, which oysters cannot use to build their shells.	3	We can see if we could get more carbonate into the ocean.	L10: We need to make sure whatever we do to increase carbonate in the water does not negatively affect other living things or the environment.
L10: The timing also matters because oyster larvae have only a short window of time to build their shells, so when the ocean is acidic they are less likely to survive in that time frame.	3 and 4	We can see if we can speed up the process of calcium carbonate formation so that fewer oyster larvae die.	
L11: Increasing the concentration of reactants speeds up a reaction (increases the reaction rate).	3	We could add substances with calcium and carbonate ions to oysters' water to speed up shell-building.	L11: Whatever we add has to be safe for the environment. L11: Whatever we add has to be relatively inexpensive.

What are the new science ideas that we figured out that might help us and our communities address this subproblem?	What subproblem(s) might this science idea connect to?	What are some ways we might apply these ideas in practice to design a solution to this subproblem?	What should we keep in mind about how solutions might affect and be affected by people and the environment?
L11: Increasing the temperature speeds up a reaction (increases the reaction rate).	3	We could increase the temperature of tanks where oyster larvae are kept.	L11: Whatever we add has to be safe for the environment.
L11: Adding CaCO_3 to water can raise the pH because CO_3^{2-} can bond with H^+ ions.	2	Maybe other compounds with negative ions could also change the water's pH.	L11: Whatever we add has to be relatively inexpensive. L11: Increasing temperature might backfire – it could be bad for oysters in other ways, and it could be really bad for other organisms in the ocean. It could also increase the rate of reactions that we know are harmful, like H_2CO_3 formation.

Lesson 13: Teacher Reference 1

Sample Solution Planning

Refining Criteria and Constraints

1. What site have you selected?

Pacific Northwest (Puget Sound)

2. Use the table below to identify and, as necessary, quantify criteria and constraints from your site profile.

Criteria (guidelines used to judge a solution)	Constraints (limits on a solution)
- Protect oyster larvae from dying. - Increase pH to 8.2 from 7.9 (hydrogen concentration down to $6.3 \times 10^{-9}M$ from $1.6 \times 10^{-8}M$). - Work within the natural ecosystem. - Keep costs low. (added after calculation) 0.5692 mol H^+ need to be removed--twice a day, since there are two high tides.	- Indigenous communities have water access only for harvest and no land access to privately owned areas. - Water is relatively shallow (~ 3 ft). - Water quality is low. 15 acres of tribally owned tideland (for one community) (added after calculation) 58,680,000 L of water need to be taken into consideration.
Use this space to quantify criteria. $6.3 \times 10^{-9} \text{ mol H}^+ / \text{L} * 7 \text{ L}$ $6.3 \times 10^{-9} \text{ mol} / \text{L} * 58,680,000 \text{ L} = 0.3697 \text{ mol at pH} = 8.2$ $1.6 \times 10^{-8} \text{ mol} / \text{L} * 58,680,000 \text{ L} = 0.9389 \text{ mol at pH} = 7.9$ $0.9389 \text{ mol} - 0.3697 \text{ mol} = 0.5692 \text{ mol H}^+$ need to be removed--twice a day, since there are two high tides	Use this space to quantify constraints. 15 acres * 1,304,000 L / acre-foot * 3 ft = 58,680,000 L of water need to be taken into consideration $4000 \text{ m}^2 / \text{acre} * 15 \text{ acres} = 60,000 \text{ m}^2$
Once you have quantified any criteria or constraints, edit your lists above to reflect the quantities you identified.	

3. Why are these criteria and constraints important to keep in mind when developing a solution?

We want to make sure that the Indigenous communities in the Pacific Northwest have access to oysters and that their priority of not hurting the local ecosystem is maintained without massive costs.

Designing a Solution

4. Explain the changes your solution requires you to make to the system.

We want to plant enough seagrass to remove more CO_2 from the water in the area. Seagrass can be harmed by pollution, so we will also need to consider how different interested parties can work together to help protect the tideland areas.

5. Over what timescale will the change occur? Is there any way to speed or slow the change, as desired?

The seagrass will use CO_2 immediately. It will grow better (and we may have to restore less if natural seagrass returns) if there is less pollution.

6. What costs will be associated with the change (materials, labor, infrastructure, social or environmental effects)? Calculate approximate costs associated with this solution and show your work.

Seagrass restoration costs \$100/m². Over 15 acres, this would cost:
 $60,000 \text{ m}^2 * \$100/\text{m}^2 = \6 million to restore all 15 acres.

Do we actually need to plant in all 15 acres?

1% of CO₂ becomes H₂CO₃ (which has 2 H⁺ ions)

To remove 0.5692 mol H⁺, need to remove $0.5692/2 = 0.2846 \text{ mol H}_2\text{CO}_3$ or
 $0.2846 \text{ mol H}_2\text{CO}_3 * 100 = 28.46 \text{ mol CO}_2$

Need to do this twice a day due to tides: $28.46 \text{ mol CO}_2 * 2 = 56.92 \text{ mol CO}_2$
Each m² of seagrass can add 68 g of mass (C₆H₁₂O₆) per day.

$68 \text{ g} * (1 \text{ mol C}_6\text{H}_{12}\text{O}_6 / 180.16 \text{ g}) * (6 \text{ mol CO}_2 / 1 \text{ mol C}_6\text{H}_{12}\text{O}_6) = 2.26 \text{ mol CO}_2 \text{ removed per day by } 1 \text{ m}^2 \text{ seagrass}$
 $56.92 \text{ mol CO}_2 \text{ removed} / 2.26 \text{ mol CO}_2 \text{ removed/m}^2 \approx 25 \text{ m}^2 \text{ required.}$

That is WAY cheaper!
 $25 \text{ m}^2 * \$100/\text{m}^2 = \2500

Additional labor to work with boaters and fishers to stay away from tidelands.

Environmental effects should only be positive, since seagrass is native to the area.

7. How do you plan to account for the costs? Use calculations as needed to support your answer.

Because there are positive environmental implications, it could be possible to get grant funding, and \$2500 is a relatively low one-time cost anyway.

Work with boaters and fishers may be on a volunteer basis or be done by community leaders as part of their duties.

8. What are the intended effects of the change? Use our class consensus model or individual models you have developed to help think about how your solution will impact people and ecosystems. Use calculations as needed to support your answer.

As calculated above, we expect that each square meter of seagrass restored will remove 56.92 mol CO₂ per day, which should help restore that area's water to its original pH. This CO₂ will be stored in the seagrass and at least partially stay in the plants when they die, eventually becoming part of the sediments on the bottom of the tideland.

9. How will these intended effects benefit oysters and people? Use your calculations from #8 as needed to support your answer.
Oysters should grow more easily with a higher pH. People will benefit from additional oysters for food and community celebrations. Other organisms may benefit from a more historical water pH as well, and would also benefit from increased water quality if boating and fishing traffic to the area is decreased.

10. What scientific/technical barriers are there to implementing the change?
Tides and the fact that water is always moving around make our calculations more of an estimate than an actual amount, but the costs are low enough that more seagrass could be restored relatively affordably.

11. What social, political, or legal barriers are there to implementing the change?
Recreational boaters and fishers will be disappointed by losing an area where they can be. Private owners will need to be consulted to restore seagrass in other areas that are not tribally/public owned.

12. How might you address those barriers?
Work with recreational boaters and fishers to find compromises around areas that they will avoid while still leaving plenty of space to enjoy. Emphasize that improved water quality will ultimately increase the fish population and make the tidelands a more pleasant place for everyone.

13. What could be unintended effects of the change? Use our class consensus model or individual models you have developed to help you think about how your solution might have unintended impacts on people or ecosystems.
Seagrass takes up space that could otherwise be inhabited by other bottom-dwelling species. It can clog propellers on boats, which might cause frustration among boaters and fishers. Although native species should generally do better with an increased water pH, it is possible that some species will do worse.

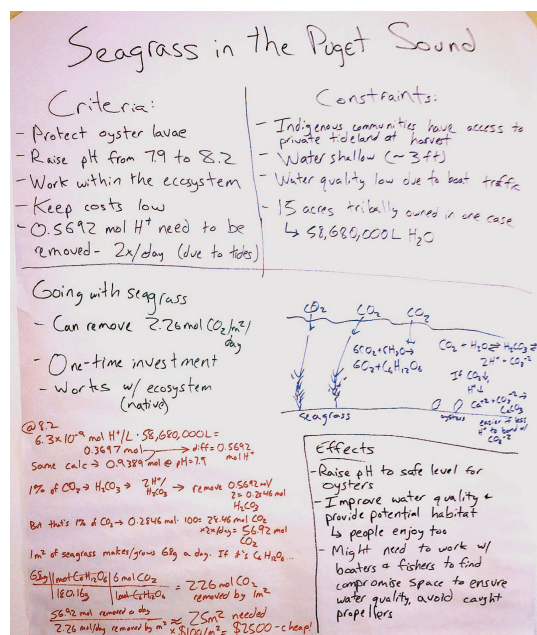
Lesson 13: Answer Key

Poster Feedback Guide

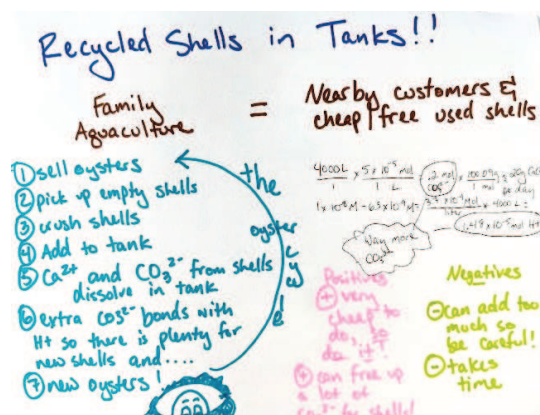
Students create posters using their planning document. An exemplar Student Planning Document can be found in *Sample Solution Planning*.

The images here show two possible student products.

Exemplar containing all needed or useful information.



Example missing some useful information.



Scoring Guidance. The elements described below would be considered parts of an exemplary poster. In some cases different elements of the response are identified with a separate + symbol. These + 's are suggestions for what your students might include.

The following scoring guidance can help you identify different ideas that students should (or could) include in their responses.

- If several of the elements marked with a • are missing from a student's response, this may indicate the student has not mastered the elements or that the student may be struggling to bring those ideas together in a written explanation or model. Additional probing of their thinking can provide insight about whether the student is struggling with a science practice or science idea, or both.
- If all or almost all of the elements marked with a • are present in a student's response, this may indicate that the student has mastered the science ideas and is able to use them in a written explanation or explanatory model.
- If the ideas marked with a ++ are present in a student's response, this indicates that the student is bringing a deeper understanding of the science ideas or a deeper engagement with the practice to their response. Students should not be penalized if ideas marked with a ++ are not present in their response.

Key elements related to Lesson Performance Expectation 13.A Use computational thinking to quantify criteria for a solution that will positively affect oysters. (SEP: 5.2; DCI: ETS1.A.1; CCC: 2.3):

- + Students use stoichiometric (mathematical) and other calculations to quantify design solution impacts of pH, carbonate, and/or CO₂. (SEP: 5.2)
- + Students quantitatively represent criteria. (DCI: ETS1.A.1)
- ++ Students represent constraints along with criteria. (DCI: ETS1.A.1)
- + Students articulate the importance of criteria and constraints in ensuring positive outcomes for oysters. (DCI: ETS1.A.1; CCC: 2.3)

Key elements related to Lesson Performance Expectation 13.B Design a solution to cause specific outcomes to mitigate the impacts of ocean acidification on oysters. (SEP: 6.5; DCI: ESS3.C.2; CCC: 2.3):

- + Students' posters indicate a specific designed solution to oyster die-off that is based on science,
 - + prioritized criteria, and/or
 - + trade-off considerations. (SEP: 6.5)
- + Students describe how their proposed solution will change pH, carbonate availability, or atmospheric or ocean CO₂ levels. (DCI: ESS3.C.2)
- + Students articulate what effects their proposed changes will have on the oyster-raising ecosystem. (CCC: 2.3)

What to do:

Support students to think about the mathematical reasoning that can support their arguments.

- Ask, *Where have we encountered mathematical or numerical data that can help with this?*
- Press for more components of the solution.
- Press for more interactions among components.
- Ask students to view other groups' models to include more mathematical reasoning in their responses.

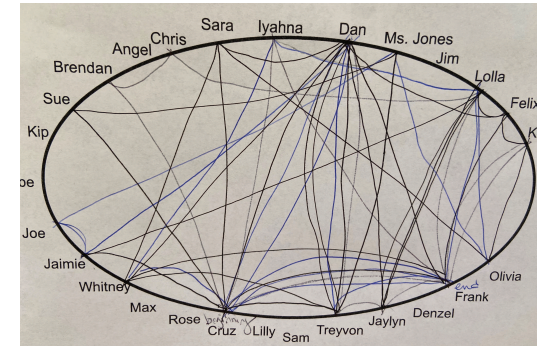
Ensure students understand multiple interested parties' perspectives about this problem. Ask, *Do you think the chicken farmers/tribes/restaurateurs would like your solution? What would you tell them?*

Lesson 14: Teacher Reference

Discussion Mapping Tool

Instructions

1. Print one copy of the second page of this tool for each class section.
2. Add students' names to the circle in the order that students are sitting. You may want to do this ahead of time and then ask students to sit according to the map.
3. Select a student recorder who will map the discussion as it happens. Decide ahead of time if you will have multiple students take turns mapping, and when you will move the map to a new student recorder.
4. If this is the first time you are using a discussion map, explain to students that each time someone speaks, the recorder will draw a line from the previous speaker to the new speaker's name. You may want to mark where the conversation begins and ends, but the goal is to map the overall conversation patterns rather than to be able to retrace the entire conversation.
5. Once the discussion begins, allow students to take the lead on moving the discussion forward. Sit in the circle as a participant rather than standing in front of the class as a facilitator. This will allow students to practice building on each other's ideas directly.
6. Be mindful of group dynamics, especially when displaying the map and discussing patterns of contributions. Avoid focusing on the contributions of single students and instead redirect the class to notice class-level patterns.



Completed Discussion Map

Discussion Mapping Codes

The key at the bottom of the discussion map contains codes that can be used to label the types of student contributions. The first few times that you create a discussion map with your students, you should focus only on recording the flow of the conversation. This allows students to get comfortable with the process. Once students have experience recording and interpreting those initial patterns, you can add discussion mapping codes to future discussion maps. Start by adding “low risk” or more accessible codes first such as claim given, evidence added, agreed, or disagreed. There is an extra column where you can add your own discussion codes as needed based on individual class needs and agreements. You may also choose to use just some of the discussion codes, based on the type of discussion that your students are having. In this case, be sure to cross out the codes that you are not using so that student recorders know not to include them.

Key Ideas 1-4

The key ideas that map to LLPE 14.B are included in the tool. You can note them by number as students mention them to assess students' progress toward that LLPE.

Adaptations

- For a large class, arrange students in an inner and outer circle. Have the inner circle discuss the question while the students in the outer circle map the discussion.
- Consider having sentence frames displayed on a slide or poster to support multilingual learners.

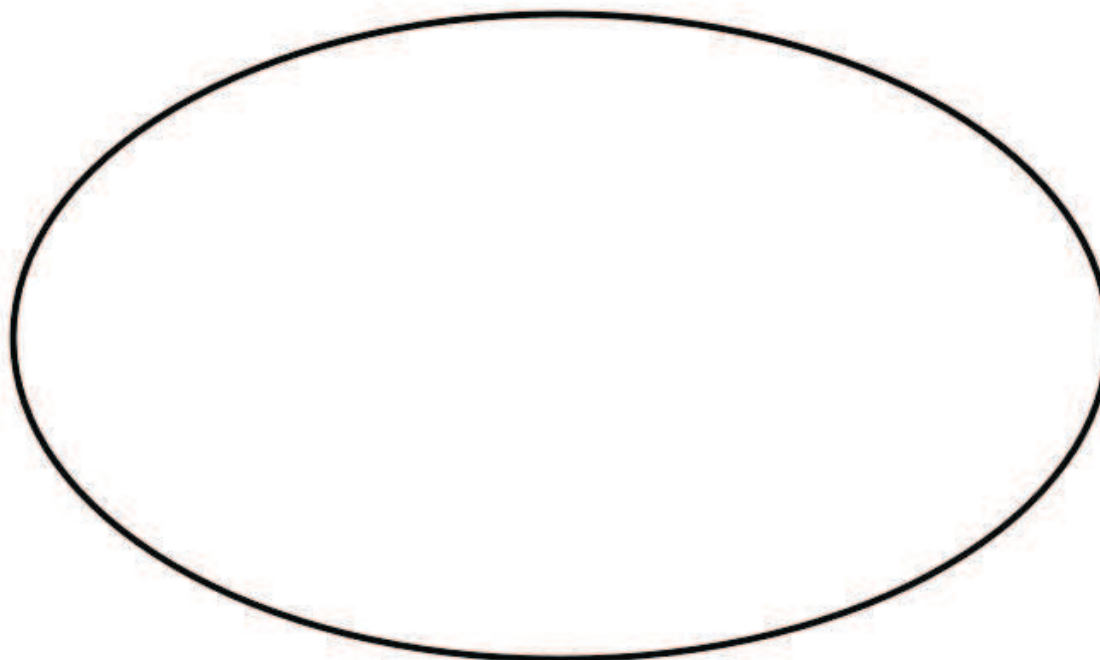
Question we are trying to answer:

How do our design solutions use our knowledge of chemistry and earth systems to help oysters?

Date: _____

L#: _____

Period: ____



Key Ideas
Oysters Lesson 14
 1. Evidence we have gathered throughout the unit
 2. tradeoffs and criteria we consider
 3. the interaction of chemistry in the atmosphere and hydrosphere:
 a. CO₂
 b. carbon
 c. calcium carbonate
 4. order of magnitude: how tiny particles can lead to a big solution

Discussion Codes (Choose up to 3)				
C- claim given	CL- clarified idea	?- asked question	T- tied ideas together	I- interrupted
E- gave evidence	A- affirmed/agreed	NI- new idea added	RP- related phenomena	
OT- off topic	D- disagreed	R- repeated idea	*- idea ended	

Lesson 15: Answer Key

Ammonia Fertilizer Key

Lesson-level performance expectations being assessed:

15.A Apply scientific ideas, principles, and evidence to explain how changing the temperature or concentration of the reactants affects the reaction rate. (SEP: 6.3; DCI: PS1.B.1, PS1.B.2; CCC: 2.2)

15.B Use student-generated sources of evidence to develop a model to predict how changes in a system would increase the rate of a reversible reaction to produce larger amounts of products by examining smaller scale mechanisms. (SEP: 2.3; DCI: PS1.B.1; CCC: 2.2)

15.C Use mathematical thinking to describe claims about how conservation of matter and chemical properties of the elements involved can be used to predict the scale and significance of chemical reactions. (SEP: 5.2; DCI: PS1.B.3; CCC: 3.1)

15.D Make a claim about the effectiveness of a design solution which reflects evidence about trade-offs and its design criteria by accounting for the flow of energy through the system. (SEP: 7.5; DCI: ETS1.C.1; CCC: 5.2)

3D Elements Addressed in This Assessment	Question #										
	1	2a	2b	3a	3b	3c	3d	4a	4b	4c	4d
Constructing Explanations and Designing Solutions. Students apply scientific ideas, principles, and evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects. (SEP 6.3)	X										
Developing and Using Models. Develop, revise, and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system. (SEP: 2.3)		X									
Using Mathematics and Computational Thinking. Use mathematical, computational, and/or algorithmic representations of phenomena or design solutions to describe and/or support claims and/or explanations. (SEP: 5.2)				X	X	X	X				
Engaging in Argument from Evidence. Make and defend a claim based on evidence about the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence. (SEP: 7.5)									X	X	
PS1.B.1: Chemical Reactions. Chemical processes, their rates, and whether or not energy is stored or released can be understood in terms of the collisions of molecules and the rearrangements of atoms into new molecules, with consequent changes in the sum of all bond energies in the set of molecules that are matched by changes in kinetic energy. (HS-PS1-5)	X	X	X								
PS1.B.2: Chemical Reactions. In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the numbers of all types of molecules present. (HS-PS1-6)	X										
PS1.B.3: Chemical Reactions. The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-7)							X				

ETS1.C.1: Optimizing the Design Solution. Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed. (HS-ETS1-2, HS-PS1-6)										X	X
3D Elements Addressed in This Assessment	Question #										
	1	2a	2b	3a	3b	3c	3d	4a	4b	4c	4d
Cause and Effect: Mechanism and Explanation. Cause-and-effect relationships can be suggested and predicted for complex natural and human-designed systems by examining what is known about smaller scale mechanisms within the system. (CCC: 2.2)	X	X	X								
Scale, Proportion, and Quantity. The significance of a phenomenon is dependent on the scale, proportion, and quantity at which it occurs. (CCC: 3.1)						X					
Energy and Matter: Flows, Cycles, and Conservation. Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system. (CCC: 5.2)								X			

Scoring Guidance. The response elements described below would be considered exemplary at this point in the unit. These are shown in purple text or in purple diagrams below the related question. In some cases different elements of a response are identified with a + symbol. These + elements are not meant to be all inclusive, but are suggestions for different ideas your students might include.

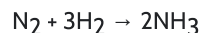
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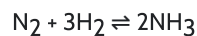
Around the world, people use fertilizer to help ensure that crops have all the nutrients they need. In particular, many plants need nitrogen to grow. While nitrogen is abundant in the air around us, plants cannot use atmospheric nitrogen without some help. Some plants, like soybeans and peanuts, have bacteria in their roots that help turn this atmospheric nitrogen into usable forms. Other crops (like wheat, rice, and corn) benefit from the application of nitrogen in fertilizer in the form of ammonia, NH_3 , to the soil.

How can we use what we know about reactions to make enough fertilizer for worldwide agriculture?

One potential solution is the Haber-Bosch process, where plentiful nitrogen from the atmosphere (N_2) is reacted with hydrogen gas (H_2) to produce ammonia (NH_3), as shown below. **Note: None of the molecules have a charge.**



Much like the reaction you have been studying, the Haber-Bosch process is reversible and all three molecules are present throughout the process. The reaction can be more accurately written as:



To maximize production of ammonia (NH_3), chemical engineers use two strategies.

- Constantly add more N_2 and H_2 into the system.
- Constantly remove NH_3 from the system.

Question 1: Choose one of these strategies (a or b) and develop a **particle-level** explanation of how the strategy would lead to a shift in the equilibrium of the reaction so that more NH_3 is produced. Use what you have figured out in this unit about reversible reactions as evidence to support your explanation.

Sample student response:

Use the rubric below to score student responses. Possible student responses are included in the rubric below.

	Foundational Understanding	Linked Understanding	Organized Understanding
3D Elements	Explains that a reaction is occurring. May include unconnected science vocabulary without causal linkages. Shows/explains that an increase in reactants increases their collisions. Shows/explains that bonds need to be formed or broken. Shows collisions (key cause of reactions). May leave out causality entirely.	Includes science ideas and principles to explain how NH_3 may be formed. May or may not refer to student-gathered evidence in the unit. Identifies either concentration or temperature as increasing the likelihood/force of a collision. May include some reference to previous learning. Explains that the reaction is caused by “hits” or collisions of particles without all components of explanation.	Includes a wide range of science ideas and principles that account for the full mechanism of the reaction. Refers to unit activities (especially Lesson 6 simulation and Lesson 11 investigation) on reversible reactions. Includes all of the following causally related science ideas cohesively: N_2 and H_2 would have to be pushed together to form a bond (bond breaking is outside the scope of this unit and is featured heavily in C.5: Fuels). - Increasing concentration of N_2 and H_2 would mean they hit each other more frequently. - Allowing NH_3 to build up in the system would get “in the way” of them hitting and limit how much could form. Explains that the reaction is caused by collisions that are increased when concentration is increased, leading to an increase in products.

Example	The NH_3 is formed when the N_2 and H_2 bond.	When you increase the concentration of the product in a reversible reaction, it actually causes the reaction to go backward so that the overall ratios stay the same. Getting the NH_3 out of the reaction will give the N_2 and H_2 more space to hit each other and form a bond.	Removing NH_3 from the system increases ammonia production because it affects the equilibrium. When NH_3 is removed, there is a lower concentration of NH_3 molecules so there is a lower chance that two NH_3 molecules will collide, break apart, and form new bonds to make N_2 and H_2 . In fact, with a lower concentration of NH_3 , a higher percentage of the remaining molecules are N_2 and H_2 so those collisions are more common, forming more NH_3 . We saw in the simulation in Lesson 6 that either adding substances on the left side of the reaction or taking away those on the right side caused the product to form.
Feedback/ What to do	<i>To revise toward Linking:</i> How are the nitrogen and hydrogen particles moving in the reaction? What if you add some big chunky NH_3 particles in there?	<i>To revise toward Organizing:</i> What lesson activities did you think about when you wrote this? What does this seem to be like?	<i>To revise toward Extending:</i> Compare this to the ways we altered the ocean water in our investigations. How is this different from what we did in Lesson 11? How is it the same?

	Foundational Understanding	Linked Understanding	Organized Understanding
Ideas for Instruction	Have students use the simulation in https://www.openscienced.org/general/waterco2interactions/ to revisit how changing the “balance” of some reactants can affect how much change happens overall.	Revisit the Progress Tracker to identify where we learned key ideas about collisions, bonds, equilibrium, and concentration. Draw the effects of increasing and decreasing each of them on the amounts of products.	Search for other reversible reactions that are in the local environment. What is preventing them from further completion?

To make ammonia (NH_3) production happen as quickly as possible (that is, to increase the reaction rate), chemical engineers use two strategies.

- Constantly add more N_2 and H_2 into the system.
- Carry out the reaction at a temperature of 450°C (842°F).

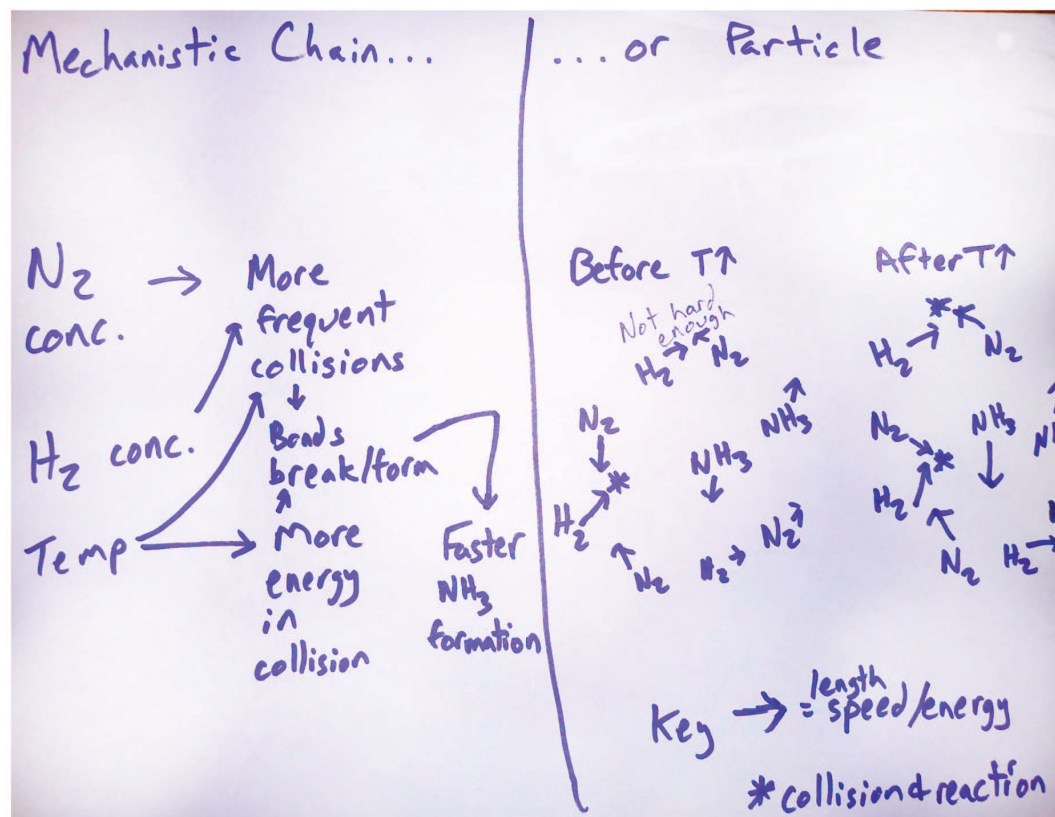
Question 2a: Choose one of these strategies (a or b) and develop a model to illustrate how components in the system would lead to an increase in the reaction rate.

Key elements:

- + Model includes specific reference to an activity in the unit as evidence.
- + Model shows that increased concentration increases the number of collisions OR increased temperature increases particle energy and the number and force of collisions.
- + Predicts how changes to the system result in larger amounts of products produced.

Sample student response:

Accept reasonable variations on the sample model shown.



What to do:

Ask, *What pieces of evidence from our investigations could be used to predict what would happen to the reaction if we used one of the strategies listed?*

Ask, *What effect would strategy (a or b) have on the rate of the reversible reaction?* Why?

Question 2b: Briefly explain what your model shows. Use what you have figured out in this unit about reaction rates to support your explanation.

Key elements:

- + Reactions can occur when molecules collide (with enough energy to break bonds).
- + Increasing the number of collisions (with enough energy to break bonds) makes it more likely that a reaction will occur quickly, increasing the reaction rate.

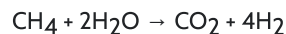
Sample student response:

Increasing the temperature increases the reaction rate because the molecules are colliding harder and more often. There can only be a reaction between two molecules when they collide hard enough to break bonds, so anything that increases the energy of the collision or how frequently collisions happen will make the reaction happen more quickly. Since temperature increases how quickly the particles move, it increases their energy and also makes them collide more often as they move around faster.

What do to:

Ask, *What happens to the interactions between molecules in the reaction when strategy (a or b) is applied? How would that affect the reaction rate?*

However, the Haber-Bosch process is not necessarily eco-friendly. The reactant nitrogen is drawn from the air while the hydrogen is produced by burning methane gas (CH₄). Is the CO₂ released a significant amount? The series of processes can be simplified as:



Question 3a: A small ammonia plant uses 118,000 g of H₂ gas per day. Determine the mass (in g) of CO₂ that will be released as the H₂ is produced. Show all work.

Key elements:

+ Mathematical thinking uses ratios to solve a problem.

Sample student response:

$$118,000 \text{ g H}_2 \times (1 \text{ mol H}_2 / 2.02 \text{ g H}_2) \times (1 \text{ mol CO}_2 / 4 \text{ mol H}_2) \times (44.01 \text{ g CO}_2 / 1 \text{ mol CO}_2) = 642,720 \text{ g CO}_2 \approx 643,000 \text{ g CO}_2$$

What to do:

If students struggle with calculating amounts using ratios, refer them back to strategies used in *Neutralization Investigation #2* from Lesson 8 and *Ocean Water Calculations* from Lesson 9.

Question 3b: To produce that much H₂, the system requires an input of 14,600 mol of CH₄. What is the mass (in g) of this amount of CH₄?

Key elements:

+ Mathematical thinking uses ratios to solve a problem.

Sample student response:

$$14,600 \text{ mol CH}_4 \times (16.04 \text{ g} / 1 \text{ mol}) = 234,184 \text{ g} \approx 234,000 \text{ g CH}_4$$

What to do:

If students struggle with calculating amounts using ratios, refer them back to strategies used in *Neutralization Investigation #2* from Lesson 8 and *Ocean Water Calculations* from Lesson 9.

Question 3c: Use any of the information provided so far to determine the mass (in g) of H₂O required to produce 118,000 g of H₂. Is this a significantly large amount?

Key elements:

+ Mathematical thinking uses ratios to solve a problem.

Sample student response:

Students may use stoichiometry along several paths to determine the correct answer. The simplest is shown here.

$$14,600 \text{ mol CH}_4 \times (2 \text{ mol H}_2\text{O} / 1 \text{ mol CH}_4) \times (18.02 \text{ g H}_2\text{O} / 1 \text{ mol H}_2\text{O}) = 526,184 \text{ g H}_2\text{O} \approx 526,000 \text{ g H}_2\text{O}$$

This is not a significantly large amount of water since it is in grams and that is a small unit of measurement. This would be equal to about 526 kg.

What to do:

If students struggle with calculating amounts using ratios, refer them back to strategies used in *Neutralization Investigation #2* from Lesson 8 and *Ocean Water Calculations* from Lesson 9.

Ask, About *how many kilograms would the amount of water be equal to?* Now, consider *how much water is on Earth, is that a significant amount?*

Question 3d: Explain how your solutions to 3a-3c show how atoms (and therefore mass) are conserved during the chemical reaction, $\text{CH}_4 + 2\text{H}_2\text{O} \rightarrow \text{CO}_2 + 4\text{H}_2$. Remember that since you are working with fairly large numbers, rounding may have affected how “exact” your solutions were.

Key elements:

+ Mathematical thinking compares amounts of products and reactants show that atoms are conserved.

Sample student response:

If atoms and mass are conserved, then the total mass on both sides of the reaction should be the same (within rounding errors).

234,000 g CH_4 + 526,000 g H_2O = 760,000 g reactant

118,000 g H_2 + 654,000 g CO_2 = 772,000 g product

These are about the same, so matter is conserved.

In a partial response, students may instead use moles to show that atoms are conserved during the reaction.

What to do:

If students struggle with calculating amounts using ratios, refer them back to strategies used in *Neutralization Investigation #2* from Lesson 8 and *Ocean Water Calculations* from Lesson 9.

Ask, What *numerical information would you need to know to mathematically determine if atoms are conserved?*

The Haber-Bosch process requires certain reactants to work – CH_4 from underground, H_2O to produce the needed H_2 , and N_2 from the air – and produces both wanted substances (NH_3) and unwanted byproducts (CO_2).

The table below summarizes the process.

Reactant (source)	Reactions	Product (end use/location)
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CH ₄ (mined from underground)	CH ₄ + 2H ₂ O → CO ₂ + 4H ₂	NH ₃ (pumped into tanks, transported, sold)
H ₂ O (from surface or groundwater)	then	CO ₂ (released into the air)
N ₂ (from the air)	N ₂ + 3H ₂ ⇌ 2NH ₃	
	The second reaction is carried out at a temperature of about 450°C (842°F).	

Question 4a: Use the information in the table to trace how matter flows before, during, and after the Haber-Bosch process. You can choose to use images and/or words.

Key elements:

+ Traces movement of matter from the reactant (source) to the product (end use/location).

Sample student response:

This prompt is intended to help students think about what is happening in the process before they answer 4b-4d. Accept all responses.

What to do:

Ask, What is happening to the *different types of matter* before and after the reaction takes place? Where are they *moving to and from*?

Question 4b: A chemical engineer approaches the decision between the different strategies presented in Questions 1 and 2 with these three criteria:

- Maximize production of NH₃.
- Minimize monetary cost.
- Minimize negative environmental impact.

Due to droughts in the area, water access is decreasing. Given this scenario and the evidence above, make a claim about which criteria should be prioritized.

Key elements:

+ Prioritizes criterion iii.

+ Argues that environmental impacts should be more important considerations than human gains.

Sample student response:

Criteria iii should be prioritized over the other two criteria.

What to do:

Ask, Look back to some of the criteria you prioritized for your site-specific design, how would *prioritizing those criteria* be the *same or different* from how you would *prioritize these criteria*?

Question 4c: Explain your reasoning in Question 4b.

Key elements:

+ Provides rationale for which criteria are prioritized over others.

+ Consideration of information or evidence from this assessment or the unit to support the prioritization.

Sample student response:

Because the water needed to make ammonia should be used for other things that would help people and the environment.

What to do:

Ask, *What evidence from the assessment do you have to support which criterion you prioritized?*

Question 4d: What other information would have allowed you to make a more informed decision while prioritizing the criteria in **Question 4b?**

Key elements:

- + More information about exactly how much water is available or will be available in the future.
- + Costs of bringing in additional water from elsewhere.
- + Environmental impact of bringing in additional water from elsewhere.
- + Information about nearby cities, ecosystems, or other possible consumers of water.

Additional accurate element not essential to this item:

- + Target production of NH_3 .
- + Income from selling NH_3 compared to costs of modifications.
- + Costs/feasibility of alternative methods to produce H_2 without water.

Sample student response:

Responses will vary but should include several of the following key elements listed above.

What to do:

Ask, *Think back to the types of information we gathered to develop our site-specific solutions, what types of information were most helpful when making decisions?*

Reference

Ritter, S. K. (2008, August 18). The Haber-Bosch reaction: An early chemical impact on sustainability. *Chemical & Engineering News*. <https://cen.acs.org/articles/86/i33/Haber-Bosch-Reaction-Early-Chemical.html>