Changing Ocean Chemistry

A High School Curriculum on Ocean Acidification's Cause, Impacts, and Solutions

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Written by Brain Erickson and Tracy Crews; designed and laid out by Heidi Lewis; edited by Rick Cooper, Brian Erickson, and Tracy Crews; cover photo by Tiffany Woods; inset photos by iStock.com/heinstirrer (top) and Tiffany Woods (middle and bottom).

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Acknowledgments

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Numerous other individuals provided guidance, ideas, and suggestions along the way. While we most certainly have forgotten to mention some of you, among those we would like to thank are Mark Koker (Lab-Aids); Claudia Ludwig (Institute for Systems Biology); and from Oregon State University, Jack Barth, Kelly Biedenweg and the Human Dimensions lab, Hilary Boudet, Francis Chan, Cait Goodwin, Bill Hanshumaker, Kathryn Hawes, Krissi Hewitt, Jane Lubchenco, Virginia Lesser, Mark Needham, Lydia Newton, Samm Newton, the SMILE program, Justin Smith and the OSU video team, and George Waldbusser. Additionally, the Oregon Department of Fish & Wildlife's shellfish program provided helpful resources for classroom instruction, and my fellow Marine Resource Management program colleagues were immensely helpful and inspirational. Many thanks as well to our talented graphic designer, Heidi Lewis, and to Rick Cooper (editor) and Tiffany Woods of Oregon Sea Grant, for their attention to detail and help in making this publication a reality.

Finally, this curriculum builds upon years of work from many other educators who have come before us. We cite those we intentionally borrowed from, but we want to highlight that our work rests upon the shoulders of numerous other educators who worked at creating fantastic resources.

—Brian Erickson

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LETTER TO EDUCATORS

Dear Educators,

This curriculum was created as a part of a master's thesis, with the goal of providing a resource that presents students with an in-depth look at actions households can take to reduce ocean acidification (OA). The lessons were developed using Understanding by Design principles (Wiggins & McTighe, 2006) and are based on high-school teaching standards, evaluation of existing curricula, and current research.

The ideas contained within were developed through a reiterative process after a review of 90 existing OA teaching resources and three rounds of classroom testing. There are other excellent resources available designed to match various teaching styles, contexts, and needs; we hope this resource provides you with a few new ideas for how to teach about OA. Knowing that curriculum development is an ongoing process, the most updated resources are available online at bit.ly/2FXmNaD.

This curriculum includes several features that distinguish it from other available resources. It uses a narrative that presents OA as a problem that is already affecting people, incorporates recommendations from the National Network for Ocean and Climate Change Interpreters (available at bit.ly/2HjAG3G) on communicating about OA, avoids the frequently used "shells in acid" lab in hopes of avoiding common misconceptions, incorporates a formative probe to gauge student preconceptions about the impacts of OA, explores a range of predicted impacts beyond shell dissolution, and focuses on solutions to help address the issue.

Several new components were added during the latest round of revisions and have not yet been tested in a classroom. In Lesson 1, the carbon cycle section is new. Lessons 2 and 3, included for teachers wanting to go deeper into the chemistry, are optional and expanded. Lesson 4 now includes a formative probe and has been transformed into a student research project. Additionally, a final Call to Action project was added. Finding the right balance between explaining enough and getting too deep into the chemistry has been an ongoing struggle.

We would love to hear your thoughts and feedback. If you'd be willing to share your modifications, please send them our way (see e-mail addresses below) so we can share them with other educators!

Sincerely,
Brian Erickson (brian.erickson@oregonstate.edu)
Tracy Crews (tracy.crews@oregonstate.edu)

TARGET GRADES 9–12
ESTIMATED DURATION 5–10 days

INTRODUCTION

Ocean acidification is the change in ocean chemistry due to increasing concentrations of anthropogenic carbon dioxide (CO_2) in the atmosphere. It is sometimes called "the other CO_2 problem" because, like climate change, it is a major environmental issue caused by human carbon dioxide emissions. Yet unlike climate change, far fewer members of the public have heard about OA. Ocean acidification is already impacting the shellfish industry along the west coast of North America, and is predicted over the next few decades to have major cascading impacts on marine ecosystems and the humans who rely on them for food and income. In recent years, researchers have made significant strides in understanding the causes, consequences, and complexities of OA. In light of these findings, there have been calls for substantial action to limit the causes and mitigate the impacts of OA. However, despite efforts by educators and researchers to raise awareness and inspire public support for action around OA, public discourse and action remain limited in the United States.

This five-lesson high school curriculum seeks to increase student understanding about OA and leave students with a sense that it is an issue that can be addressed. Lesson 1 begins by exploring a real-life story of the near collapse of the oyster industry that occurred from 2007 to 2009 along the U.S. west coast. The lesson continues with an overview of OA and exploration of how humans have altered the carbon cycle. Lessons 2 and 3 focus on the chemistry of OA. In Lesson 2, students focus on pH and how carbon dioxide "acidifies" water. In Lesson 3, students learn about changes in carbonate ion concentration, something important to calcifying marine organisms that make shells and hard structures out of calcium carbonate (for example, shellfish and corals). Students apply their learning by interpreting water quality data from Whiskey Creek Shellfish Hatchery. In Lesson 4, students research the possible impacts of OA to ecosystems and humans. In Lesson 5, students examine possible solutions to OA by brainstorming ways to reduce CO_2 emissions, identifying barriers to taking action, and exploring which household actions have the greatest potential impact. A recommended culminating Call to Action project has students identify a target audience and try to persuade their chosen audience to take action.

BIG IDEAS*

- Anthropogenic CO_2 emissions are leading to multiple changes in the ocean's chemistry in a process called ocean acidification.
- Ocean acidification is impacting marine organisms and the humans who rely on them.
- There are ways to reduce ocean acidification.

ESSENTIAL QUESTIONS*

- To what degree do humans and natural ecosystems rely on each other for survival?

ENDURING UNDERSTANDINGS*

- Marine ecosystems and the humans who rely on them are interconnected.
- Human actions lead to changes in ecosystems.
- Changes in one portion of a system can lead to multiple changes in the rest of the system.
- Individual and collective actions are needed to effectively manage resources for all.

STANDARDS

- While standards addressed in this module were identified prior to lesson creation, as recommended by *Understanding by Design* methodology, alignment is noted with each lesson, and standards used are listed after the lesson materials in an attempt to make it easier for teachers to focus on teaching the lessons.

MATERIALS INCLUDED

Materials included in this resource:

- Teacher lesson plans with sample scripting and materials lists
- Content background
- Student handouts and teacher answer keys
- Online supplementary materials (PowerPoint presentations, videos)

*Big Ideas, Essential Questions, and Enduring Understandings are components of Understanding by Design (Wiggins & McTighe 2006).

STUDENT PRIOR KNOWLEDGE

This module was designed for broad use and can be used in various high-school science classes, including chemistry, biology, environmental science, and marine science. Students will be better prepared for this module if they are familiar with pH; chemical notation, equations, and reactions; the carbon cycle; ecological food webs; and photosynthesis and respiration. As such, this module would be a good review of concepts learned throughout the year. If students are not familiar with key concepts presented in the module, teachers should expect that additional time may be needed.

LESSON 1

What Is Ocean Acidification?

OVERVIEW

This lesson introduces students to ocean acidification (OA). To begin, students watch a 5½-minute video about the Pacific oyster hatchery failures of 2007–09. Afterwards, the process of OA is introduced. Students then examine the carbon cycles and try to explain how carbon moves through various reservoirs. Students are challenged to apply this discussion to a NASA visualization of CO_2 in the atmosphere over the course of a year and to graphs of historic atmospheric CO_2 concentrations.

MATERIALS

- Copies of student handout (one per student)
- Computer, projector, and speakers
- Presentation slides and videos (bit.ly/2W1CTLI)

STANDARDS

NGSS: HS-LS2-6; Engaging in Argument from Evidence; ESS2.D

CCSS: 9-10.SL.1; 9-10.WHST.10

OLP: 6b, d, e

OELS: 1b, c; 3b

Located on the edge of Netarts Bay, Oregon, the Whiskey Creek Shellfish Hatchery grows and sells oyster, mussel, and clam larvae. (Photo by Tiffany Woods)

KEY POINTS

- Ocean acidification is the change in ocean chemistry due to increasing concentrations of anthropogenic carbon dioxide (CO_2) in the atmosphere.
- The Pacific oyster hatchery failures of 2007–09 made it clear that OA is already impacting marine organisms and humans in the Pacific Northwest.
- Human activities have altered the natural carbon cycle.

ENDURING UNDERSTANDINGS

- Marine ecosystems, and the humans who rely on them, are interconnected.
- Human actions lead to changes in ecosystems.
- Changes in one portion of a system can lead to multiple changes in the rest of the system.

OBJECTIVES

Students will be able to:

- Define ocean acidification.
- Describe evidence of ocean acidification's current impacts in the Pacific Northwest.
- Describe how atmospheric CO_2 concentrations vary over short and long timescales.

SETUP

- Make copies of student handouts and homework (one per student).
- Open PowerPoint presentation (bit.ly/2W1CTLl) and preload video (bit.ly/2G20fFH).

LESSON PLAN

Engage Discussing Existing Knowledge

1. **Students respond to the Do Now questions** in their notes. Give them two minutes to work on their own.

2. **Have a brief class discussion** to hear what students already know about the topic.

Explore The Case of the Dying Oysters

We use a 5½-minute video to introduce students to an example of how OA is already affecting some businesses in the Pacific Northwest. This narrative is helpful in presenting OA as an issue that is already affecting people and ecosystems.

1. **Introduce the video:**

   "We're going to explore a story that took place from 2007 through 2009 in the Pacific Northwest. This story served as a wake-up call for many scientists. But first I want to define a few terms that will come up often in the next several days."

2. **Define "shellfish" and oyster "seed"** (see slides at bit.ly/2W1CTLl).

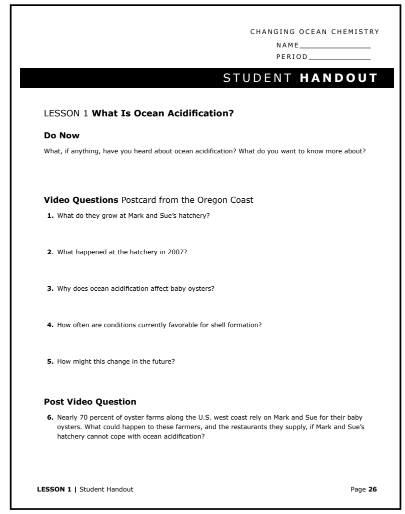
   "There will be a lot of talk about 'seed' in the upcoming video. Seed oysters are small oysters, about 2–25 mm long. They are provided primarily to oyster growers, but they can also be used to restore natural oyster populations or natural ecosystems, and for research.

   "Oyster seed production starts with parent oysters (broodstock) which provide eggs and sperm (gametes). Fertilized eggs become microscopic oyster larvae, which swim freely for about two weeks before metamorphosing, or changing, into oyster "spat," or juvenile oysters. After a few weeks or months, the spat are considered seed oysters."

3. **Show video** (*Postcard from the Oregon Coast*, bit.ly/2G20fFH). Students answer the viewing questions in their notes.

   If you don't want to show the video, use the alternate readings (see Appendix). While this video is from Greenpeace, it has a neutral tone and the story is fairly presented. An alternative video is available on our website (bit.ly/2KyAHWz).

Some teachers may want to use a survey to test prior knowledge. See our online resources (bit.ly/2VAmcm4) for a sample mini-survey.


CHANGING OCEAN CHEMISTRY
NAME____________
PERIOD____________

STUDENT **HANDOUT**

LESSON 1 **What Is Ocean Acidification?**

Do Now

What, if anything, have you heard about ocean acidification? What do you want to know more about?

Video Questions Postcard from the Oregon Coast

1. What do they grow at Mark and Sue's hatchery?
2. What happened at the hatchery in 2007?
3. Why does ocean acidification affect baby oysters?
4. How often are conditions currently favorable for shell formation?
5. How might this change in the future?

Post Video Question

6. Nearly 70 percent of oyster farms along the U.S. west coast rely on Mark and Sue for their baby oysters. What could happen to these farmers, and the restaurants they supply, if Mark and Sue's hatchery cannot cope with ocean acidification?

LESSON 1 | Student Handout Page **26**

We originally presented this story in murder mystery format, where OA was not immediately revealed as the cause of the problem. This approach didn't work as well as we had hoped (students presumed OA was the cause, since we planned to talk about OA for the next several days).

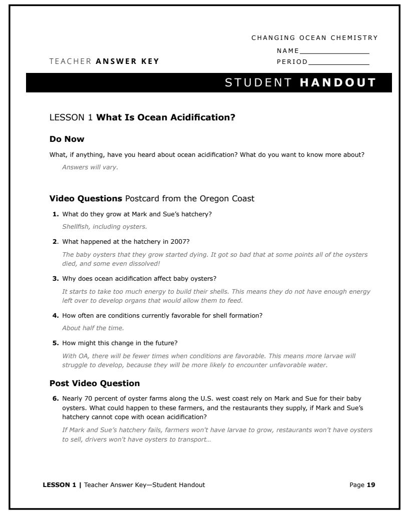
Some students may confuse salmon and shellfish hatcheries.

For more on the oyster seed issues on the U.S. west coast, see Barton et al. (2015).

4. **Discuss the viewing questions** (see Teacher Answer Key).

   A few important ideas to keep in mind while discussing the video:

   - It is a common misconception that all shelled organisms will dissolve due to OA. While baby oysters are especially vulnerable, not all organisms or life stages will dissolve. See the Avoiding Misconceptions section of this lesson's Teaching Notes and Lesson 4 for more information.
   - Larval oysters cannot feed until they build their first shell. With OA, larvae can run out of energy before they can start feeding, resulting in death.
   - Oysters are a $100 million/year industry in the Pacific Northwest.


CHANGING OCEAN CHEMISTRY
TEACHER **ANSWER KEY**
NAME________
PERIOD________
STUDENT **HANDOUT**

LESSON 1 **What Is Ocean Acidification?**

Do Now

What, if anything, have you heard about ocean acidification? What do you want to know more about?

Answers will vary.

Video Questions Postcard from the Oregon Coast

1. What do they grow at Mark and Sue's hatchery?
   Shellfish, including oysters.
2. What happened at the hatchery in 2007?
   The baby oysters that they grow started dying. It got so bad that at some points all of the oysters died, and some even dissolved!
3. Why does ocean acidification affect baby oysters?
   It starts to take too much energy to build their shells. This means they do not have enough energy left over to develop organs that would allow them to feed.
4. How often are conditions currently favorable for shell formation?
   About half the time.
5. How might this change in the future?
   With OA, there will be fewer times when conditions are favorable. This means more larvae will struggle to develop, because they will be more likely to encounter unfavorable water.

Post Video Question

6. Nearly 70 percent of oyster farms along the U.S. west coast rely on Mark and Sue for their baby oysters. What could happen to these farmers, and the restaurants they supply, if Mark and Sue's hatchery cannot cope with ocean acidification?
   If Mark and Sue's hatchery fails, farmers won't have larvae to grow, restaurants won't have oysters to sell, drivers won't have oysters to transport…

LESSON 1 | Teacher Answer Key—Student Handout Page **19**

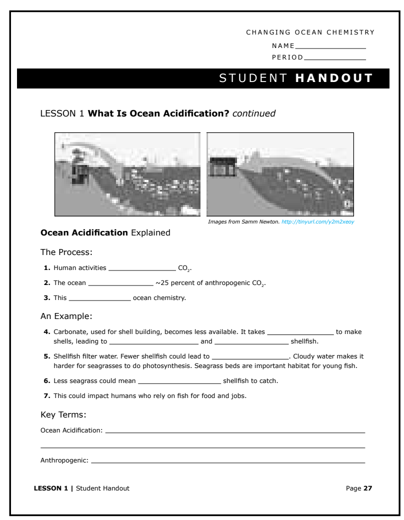
Explanatory chains explain how causes lead to effects. The process outlined here represents one possible causal chain for OA. It differs from one used by Simon et al. (2014), who say, "less carbonate leads to fewer and smaller shellfish, which leads to fewer fish." Ocean acidification experts we interviewed said the notion of fewer fish as a direct result of fewer and smaller shellfish was a stretch. While there could be fewer fish due to decreased plankton availability (leading to a trophic cascade) or loss of coral habitat, we decided to emphasize the potential losses to fish nursery habitat.

Explain What Is Ocean Acidification

1. **Introduce the ocean acidification explanatory chain** (see slides at bit.ly/2W1CTLl and Teacher Answer Key). Students take/fill in their notes with each step.

2. **Define OA and "anthropogenic."**

   We define OA as "the progressive decrease in marine pH and carbonate ion concentrations that result when the ocean absorbs anthropogenic CO_2 from the atmosphere" (Frisch et al., 2015). Note that "anthropogenic" is likely new for some students. We define anthropogenic as something "human created."


CHANGING OCEAN CHEMISTRY
NAME________
PERIOD________
STUDENT **HANDOUT**

LESSON 1 **What Is Ocean Acidification?** *continued*

Images from Samm Newton. http://tinyurl.com/y2m2xeoy

Ocean Acidification Explained

The Process:

1. Human activities ________ CO_2.
2. The ocean ________ ~25 percent of anthropogenic CO_2.
3. This ________ ocean chemistry.

An Example:

4. Carbonate, used for shell building, becomes less available. It takes ________ to make shells, leading to ________ and ________ shellfish.
5. Shellfish filter water. Fewer shellfish could lead to ________. Cloudy water makes it harder for seagrasses to do photosynthesis. Seagrass beds are important habitat for young fish.
6. Less seagrass could mean ________ shellfish to catch.
7. This could impact humans who rely on fish for food and jobs.

Key Terms:

Ocean Acidification: ________

Anthropogenic: ________

LESSON 1 | Student Handout Page **27**

Elaborate The Carbon Cycle

Teacher Note *Prior versions of this curriculum did not include direct instruction on the carbon cycle. However, we found that many students had difficulty connecting the dots between photosynthesis, respiration, and ocean pH. Thus, we've included a brief introduction to the carbon cycle here, modified from a longer lesson by Earth Labs. Your students' needs will depend on their background knowledge.*

This activity is a condensed version of Earth Labs' Lab 2: Carbon on the Move. We highly recommend their lab series, Climate and the Carbon Cycle: bit.ly/2G6pHcS

Some students will need a more in-depth discussion of the carbon cycle than provided here. For an interactive walk through the cycle, see Maria Laws' activity on BetterLesson: bit.ly/2UoUsnP

1. **Connect the carbon and water cycles.** Students will be more familiar with the latter.

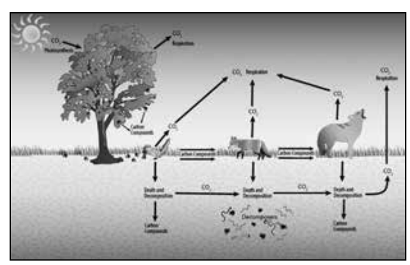
   "Carbon moves through a system just like water does: it takes on different forms in different places. Water is found in clouds, in our blood, in ground water, and in many other places. Carbon also moves from place to place, taking different forms along the way."

2. **Brainstorm examples of carbon-containing molecules:**

   "What are some forms that carbon might take?" (CO_2, methane, carbohydrates [sugars], lipids [fats], nucleic acids, proteins, etc.)

3. **Students examine and discuss the short-term carbon cycle** diagram in their notes with a partner. This image helps students explore how carbon moves through parts of the food web via photosynthesis and respiration.

Lesson 2a from University of Otago's Oceans of Tomorrow (bit.ly/2IjYEhu) is a good source for examining connections between photosynthesis, respiration, and the carbon cycle within the context of ocean acidification.



Source: Valerie Martin/Earth Labs, TERC (bit.ly/2IdlAzR).

4. **Discuss small-group interpretations as a class.**

   Writing the simplified equations for photosynthesis and respiration on the board might be helpful for students. You could have students count the number of atoms of each element written on each side of the equations (e.g., 6 carbons on the left and right sides, 18 oxygens on both sides), to help emphasize that the equations are balanced, and thus, the carbon is transformed from one molecule into another.

   Photosynthesis (simplified): $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

   Respiration (simplified): $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

   Potential guiding questions for discussion:

   "In what form do trees (and other plants) take in carbon? Where do we see this in the diagram?" (CO_2. The CO_2 arrow pointing toward the tree that says photosynthesis.)

"In what form does it store carbon?" (Carbohydrates. In the simple equation for photosynthesis, we describe plants storing carbon as glucose.)

"How does carbon get into animals? Where do we see this in the diagram?" (They eat the plants, called ingestion.)

"Through what natural processes is carbon re-released to the atmosphere? Where do we see this in the diagram?" (Respiration and decomposition/decay. The arrows pointing to the atmosphere from the tree, animals, and soil show respiration.)

"What types of organisms respire?" (All living organisms respire, including plants.)

"How long do you think it would take for carbon, taken in by a plant, to be returned to the atmosphere?" (It takes between days and several years.)

MAIN IDEA: Carbon is removed from the atmosphere by plants (and other photosynthesizers). They convert CO_2 into sugars. When animals eat plants, the carbon is transferred from the plants to the animals. CO_2 is returned to the atmosphere via respiration. This process happens over days to years.

5. **Discuss this challenge question** in small groups, then as a class:

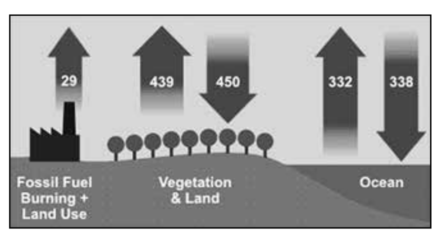
   "Is human breathing responsible for the rise of CO_2 in the atmosphere?" (No. The CO_2 that humans respire comes from "burning" the food we eat [plants or an animal that ate plants or ate something that eats plants]. Thus, the CO_2 we breathe out was already previously removed from the atmosphere, leading to no overall change.)

Several students mentioned this misconception during testing of this curriculum. If you find that this idea persists with your students, you might have them read the brief discussion on the topic found at Skeptical Science: bit.ly/2OXCzXe

The Global Carbon Cycles

1. **Show global carbon cycle slide** (see slides at bit.ly/2W1CTLl and student handouts).
2. **Students examine and discuss what this image shows** with a partner for one to two minutes.
3. **Discuss the image as a class.** Use guiding questions:

   "In this simplified diagram, what do the arrows represent?" *(Movement of carbon between four reservoirs, or places where carbon is stored.)*



Gigatons of Carbon Moving per Year. (Source: IPCC 2004, accessed from Earth Labs Lab 2: bit.ly/2IdlAzR)

"What are the four reservoirs shown?" *(The ocean, vegetation and land, fossil fuels, and the atmosphere. Notice that the atmosphere is not labeled and some reservoirs, like rocks, are not listed.)*

"Carbon sinks are places where more carbon moves in than moves out. Carbon sources are the opposite; they release more carbon than they take in.

"Take a look at the numbers in the diagram:

"Are the vegetation and land currently serving as carbon sinks, or sources? In other words, overall, are they taking in or releasing carbon?" *(Vegetation and land are carbon sinks; they take in more carbon than they release. We know this because 450 – 439 = 11. So they absorb 11 gigatons of carbon per year. That's a lot!)*

These values may seem small when expressed in gigatons of carbon. Earth Labs mentions that 1 Gt of carbon equals 1 billion metric tons of carbon. The average Asian elephant weighs 4 metric tons. This means the vegetation and land takes in enough carbon each year to equal the weight of 2.8 billion Asian elephants (11 billion metric tons divided by 4 metric tons per elephant)!

"What process moves 450 Gt of carbon per year from the atmosphere into the vegetation and land?" *(Photosynthesis.)*

"What process moves 439 Gt of carbon per year from the vegetation and land into the atmosphere?" *(Respiration.)*

"Are fossil fuel burning and land use carbon sources or sinks?" *(Carbon sources. They release 29 Gt/year of carbon into the atmosphere.)*

"Is the ocean currently a carbon source or sink?" *(Carbon sink. It absorbs 6 Gt/year of carbon.)*

The shift from releasing to absorbing carbon is what is leading to OA.

"The carbon cycle is "balanced" when the amount of carbon moving into the atmosphere is equal to the amount leaving the atmosphere. Does the carbon cycle in this diagram appear to be in balance or out of balance? Use specific evidence to support your answer." *(Out of balance. There are 29+439+332 = 800 Gt/yr moving into the atmosphere, but only 450+338 = 788 Gt/yr moving out of the atmosphere. This means about 12 Gt of carbon is added to our atmosphere each year.)*

Evaluate Short-Term Changes in Atmospheric CO_2

Teacher Note *This could be used as either an in-class assignment or homework. (See Lesson 1 student homework.)*

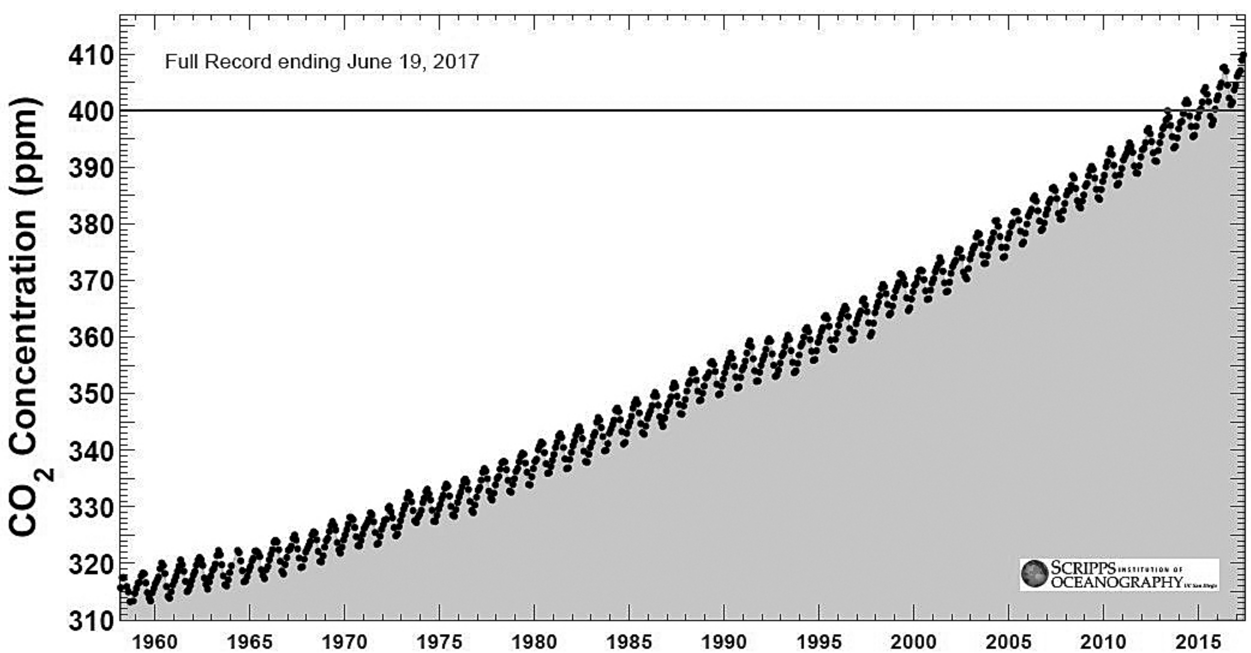
1. **Students watch** NASA's "A Year in the Life of Earth's CO_2" (3:10).

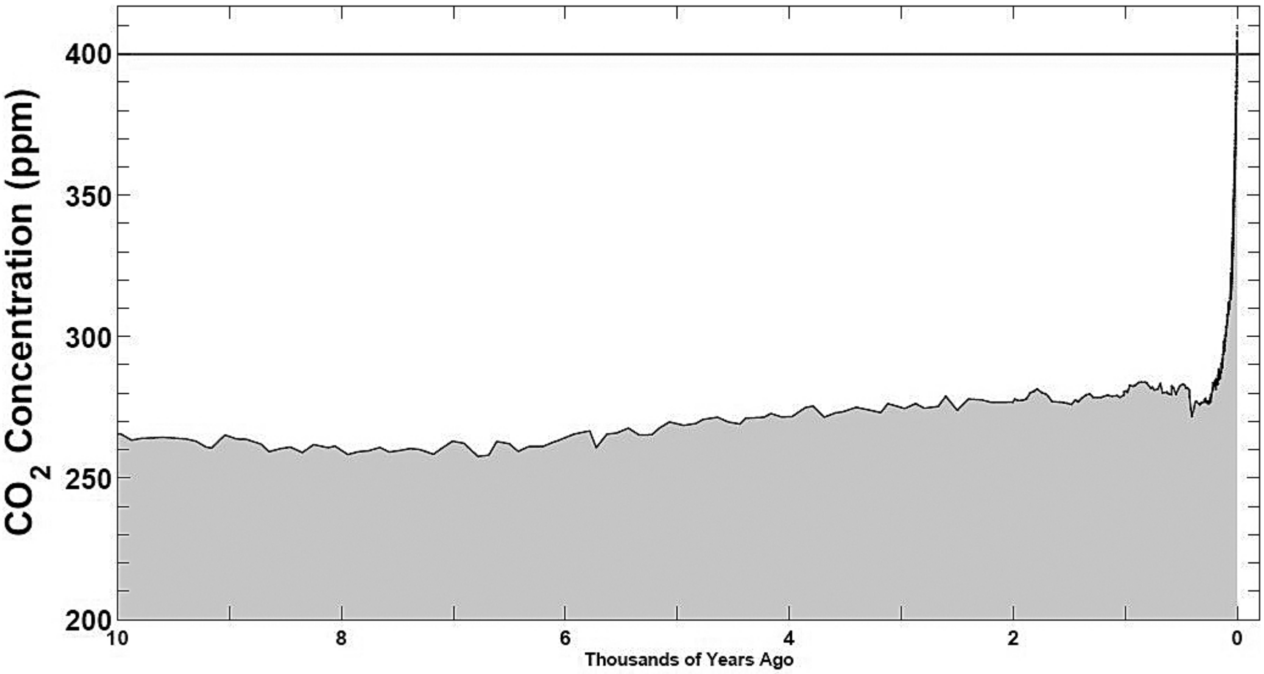
Available on YouTube: bit.ly/1HhFfWd

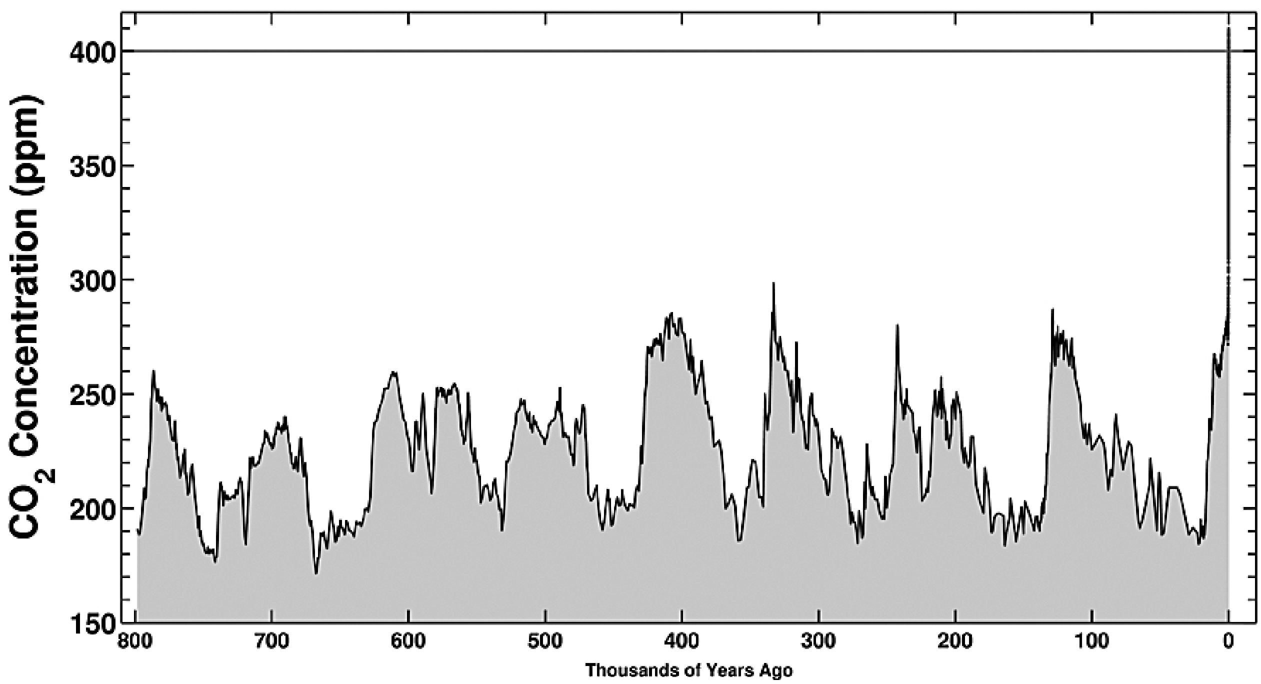
2. **Students describe in writing** what happens to CO_2 in the atmosphere over the course of a year.
3. **Students analyze three graphs** of CO_2 levels in the atmosphere over different time periods—since 1957 (direct observation), in the past 10,000 years (recent geologic past), and over the past 800,000 years ("longer" view)—and answer the questions on their handout.

All three graphs from Scripps Institute of Oceanography's The Keeling Curve website: bit.ly/1C3b6FA

4. **Students answer synthesis questions,** also on their handout.




400
350
300
250
200
CO_2 Concentration (ppm)
10
8
6
4
2
0
Thousands of Years Ago


400
350
300
250
200
150
CO_2 Concentration (ppm)
800
700
600
500
400
300
200
100
0
Thousands of Years Ago

EDUCATOR BACKGROUND

Ocean Acidification

Ocean acidification is the change in ocean chemistry due to increasing amounts of carbon dioxide (CO_2) in the atmosphere as a result of human activities, primarily the combustion of fossil fuels (oil, coal, gasoline, natural gas), land use changes (such as deforestation), and cement production (Doney et al., 2009). Ocean acidification can be described with the following explanatory chain (modified from Bales et al., 2015): (i) human activities release CO_2 into the atmosphere; (ii) the ocean absorbs roughly 25 percent of these human-created CO_2 emissions; (iii) the chemistry of the ocean changes; (iv) one result is that dissolved carbonate ions, something shellfish need to build their shells, become more scarce, making it more difficult for shellfish like oysters and mussels to build shells; (v) carbonate, used for shell building, becomes less available and it takes more energy to make shells, leading to fewer and smaller shellfish; (vi) shellfish filter water, so fewer shellfish could lead to cloudier water, making it harder for seagrasses to do photosynthesis; (vii) seagrass beds are important habitat for young fish, so less seagrass could mean fewer fish to catch; (viii) this could impact humans who rely on fish for food and jobs.

Since the mid-1700s, human activities, mostly the burning of fossil fuels, have led to dramatic increases in the concentration of CO_2 in the atmosphere (Tans, 2009). Current concentrations of atmospheric CO_2 are higher than they have been at any point in at least the past 800,000 years (Ciais et al., 2013). This buildup of anthropogenic, or human generated, CO_2 creates a concentration gradient between the atmosphere and the surface ocean, which leads to the absorption of CO_2 from the atmosphere into the surface ocean. It is estimated that roughly 25 percent of anthropogenic CO_2 emitted is absorbed by the ocean, another 25 percent is absorbed by land plants, and the rest remains in the atmosphere.

When CO_2 enters the ocean, a series of acid-base equilibrium reactions occur, changing the ocean chemistry. While OA was traditionally defined as “the pH reduction associated with the long-term ocean uptake of anthropogenic CO_2” (Caldeira & Wickett, 2003), it can be helpful to think of it as a suite of chemical changes, not just a decrease in pH.

Ocean Acidification Is an Active Area of Research

Ocean acidification is a relatively recent phenomenon in ocean research, despite roots stretching back across most of the 20th century. Researchers knew for decades that the ocean played a key role in absorbing heat and carbon dioxide from the atmosphere; however, it wasn't until the 21st century that potential environmental problems were fully realized (Brewer, 2013). There has been tremendous growth in research on OA since the mid-2000s. A *Web of Science©* search (May 2018) for "ocean" *and* "acidification" returns 5,461 publications dating back to 1990. The pace of research and publication has quickly accelerated, such that 93 percent of all papers on OA have been published since 2010. In fact, one in five papers on "ocean acidification" have been published since the start of 2017. This means knowledge about OA is relatively new and ever expanding. Despite the pervasiveness of OA in scientific publications over the past decade, surveys suggest the American public remains largely unaware of OA (Bales et al., 2015; The Ocean Project, 2012).

Changes in Ocean Acidification Understanding

Much of the "early" (pre-2010) work on OA described a global phenomenon, mentioned that the average pH of ocean surface waters had fallen by 0.1 units from 8.2 to 8.1 since the Industrial Revolution, and projected decreases in average pH of 0.3-0.4 by 2100 (Feely et al., 2009; Orr et al., 2005). As recently as 2013, OA was described by some researchers as an "open-ocean" issue (Duarte et al., 2013). Thus, less than six years ago, OA was considered by some to be a global ocean problem that would have future impacts largely away from where humans lived and worked. While this understanding is generally correct, research in the past few years has revealed that some coastal ecosystems are already being impacted by OA, some "hotspots" will be impacted sooner and more severely, and different organisms exhibit varying responses to OA.

Major developments in the past few years, as revealed in literature review and expert interviews, include: discovery of impacts of OA on shellfish larvae (Barton et al., 2012; Waldbusser et al., 2015a; Waldbusser et al., 2015b); expansion of the discussion of impacts beyond pH to also include omega and other pieces of the carbonate system (see Lessons 2 and 3 Educator Background for more information); a shift toward identifying hotspots and geographic/spatial patterning and away from global averages (Gruber, 2011; Mabardy et al., 2015; Strong et al., 2014); a shift in the timescale of anticipated impacts from 2100 to 2025; expansion of ecosystems impacted from just coral reefs and open oceans to include many other marine ecosystems, such as nearshore and estuarine ecosystems along the Pacific Northwest coast; and a dramatic increase in the number of published studies, including several meta-analyses (papers that analyze several other papers on the same subject to identify larger patterns, conclusions, and gaps in knowledge).

Shellfish in the Pacific Northwest

Shellfish harvesting has occurred in the Pacific Northwest for thousands of years. Commercial harvests began during the San Francisco gold rush in the late 1800s (Shabica et al., 1976). Overharvesting greatly reduced the naturally occurring populations of oysters, and over time the industry shifted to growing nonnative Pacific oysters, *Crassostrea gigas*, as the primary farmed species in the region. Today there are a few naturally reproducing populations of Pacific oyster, mostly in Willapa Bay and parts of Puget Sound, Washington, but their success is not reliable enough to maintain the shellfish industry. Since the 1970s, the industry has become increasingly reliant on hatcheries for their larvae, and there are currently three major commercial hatcheries that provide seed to support the majority of the nearly $270 million per year Pacific Northwest shellfish industry (Barton et al., 2015). One of these hatcheries, Whiskey Creek Shellfish Hatchery, provides seed to ~70 percent of independent oyster growers throughout the west coast.

Pacific Oyster Hatchery Failures

Starting in 2007, hatcheries saw persistently high levels of larvae mortality (Barton et al., 2015). Initially it was suspected that a bacterium, *Vibrio tubiashii*, was responsible for the die-offs at Whiskey Creek Shellfish Hatchery; however, problems remained even after a newly installed $180,000 filtration system eliminated the pathogen. This led hatchery managers in search of another explanation. In 2008, they began exploring water chemistry as a possible culprit. By 2009, monitoring of water chemistry began, and it was determined that changes in water chemistry were to blame. Thanks to industry-researcher collaborations, hatcheries installed water monitoring and buffering systems and changed their behaviors so that the worst water for larval oysters could mostly be avoided or adjusted.

Currently, the industry manages the effects of OA in their controlled environment. Their ability to continue dealing with water conditions into the future is an ongoing question. Betting that conditions in the Pacific Northwest will become increasingly unfavorable, one hatchery has already moved from Washington to Hawaii, where OA's impacts are projected to be less severe in coming decades (Welch, 2013).

The hatchery failures in the mid-2000s, sometimes called the "Pacific oyster seed crisis" in the media, were a surprise to many researchers. They helped highlight that OA is a current problem occurring in coastal oceans, not an open-ocean problem whose impacts wouldn't be revealed until the century's end. They also highlighted the need for careful research that considers the full chemistry of ocean systems, as it turned out that the oyster larvae die-offs were not specifically a result of pH changes. Instead, they were due to changes in the carbonate saturation state of the water (Barton et al., 2012; Waldbusser et al., 2015b).

TEACHING NOTES

General Comments

Discussions of OA can become chemistry heavy. An emphasis on the chemical equations involved in OA may prevent students from seeing the larger picture and possible impacts of the issue. In hopes of introducing the topic, building emotional investment, and providing a broad understanding before diving into the chemical details, this curriculum begins by introducing a story of how OA is currently impacting the shellfish industry in the Pacific Northwest.

Throughout this curriculum, videos from interviews with hatchery personnel and scientists help tell the story of OA. They give students examples of OA's current impacts and provide a starting point to explore additional possible impacts on ecosystems and humans.

Avoiding Misconceptions

One goal of this curriculum is to avoid reinforcing student misconceptions about OA. In preparation for building this curriculum, we compared existing teaching materials, published journal articles, interviews with OA "experts" (current OA researchers at Oregon State University), and public communications research to uncover differences between how researchers discuss OA and how the public/teachers typically hear about the issue. Several common misconceptions were identified. This module attempts to avoid the following OA-related common misconceptions:

- The ocean will become acidic (below pH = 7).
- The ocean will be inhospitable to all ocean life.
- All shelled organisms will dissolve.
- Ocean acidification only involves a decrease in pH.
- CO_2 is natural, so it can't be bad.

In keeping with this conscious and active effort to avoid misconceptions, this curriculum avoids one of the most common demonstrations used to teach OA: putting shells/chalk (calcium carbonate) in vinegar or another acid and watching bubbles form. This is an engaging visualization; however, we believe it reinforces the idea that all shelled organisms and all life stages of shelled organisms will dissolve. While there is evidence of dissolution in some organisms, this does not seem to be the case across the board. Different life stages seem to exhibit different abilities to avoid dissolution and repair shells, with adults often showing increased resilience. Additionally, different organisms show varying susceptibility based on the composition of their shells (see Lesson 4 Educator Background for more information). While these caveats can be explained to students, the researchers felt it would be best to find other ways to help students think through the possible impacts of OA. This "shells in acid" demonstration was used as part of a research project that accompanied the development of this curriculum, and survey data suggested a reinforcement of misunderstandings following this lab.

Misconceptions to Avoid in this Lesson

MISCONCEPTION | Ocean Acidification Only Involves a Decrease in pH

While OA does cause a decrease in pH (an increase in the hydrogen ion concentration), several other characteristics of seawater chemistry also change simultaneously (see Lesson 3 on carbonate chemistry). Thus, OA is about more than just a change in pH.

MISCONCEPTION | CO_2 is Natural, so It Can't Be Bad

Research conducted by FrameWorks Institute (Bales et al., 2015), focusing on how to talk about climate and ocean change, revealed that many people see carbon dioxide as a natural part of life and assume that natural things cannot also be a problem. It is important for students to realize that too much of anything, natural or unnatural, can throw a system out of balance. Making a distinction between natural and anthropogenic CO_2 seems to help people organize information that could otherwise conflict with how they think about the world.

NAME________________

TEACHER **ANSWER KEY**

PERIOD______________

STUDENT **HANDOUT**

LESSON 1 **What Is Ocean Acidification?**

Do Now

What, if anything, have you heard about ocean acidification? What do you want to know more about?

Answers will vary. It is likely that most of your students have heard little to nothing about ocean acidification, while a few will know quite a bit. Pay attention to common misconceptions that may come up (but don't address them here).

Video Questions Postcard from the Oregon Coast

1. What do they grow at Mark and Sue's hatchery?

Shellfish, including oysters.

2. What happened at the hatchery in 2007?

The baby oysters that they grow started dying. It got so bad that at some points all of the oysters died, and some even dissolved!

3. Why does ocean acidification affect baby oysters?

Ocean acidification increases the amount of energy required to build shells. This causes larval oysters to shift their energy towards shell building, which means there is less energy available for developing organs for swimming and feeding.

4. How often are conditions currently favorable for shell formation?

About half the time.

5. How might this change in the future?

With OA, there will be fewer times when conditions are favorable. This means more larvae will struggle to develop, because they will be more likely to encounter unfavorable water.

Post Video Question

6. Nearly 70 percent of oyster farms along the U.S. west coast rely on Mark and Sue for their baby oysters. What could happen to these farmers, and the restaurants they supply, if Mark and Sue's hatchery cannot cope with ocean acidification?

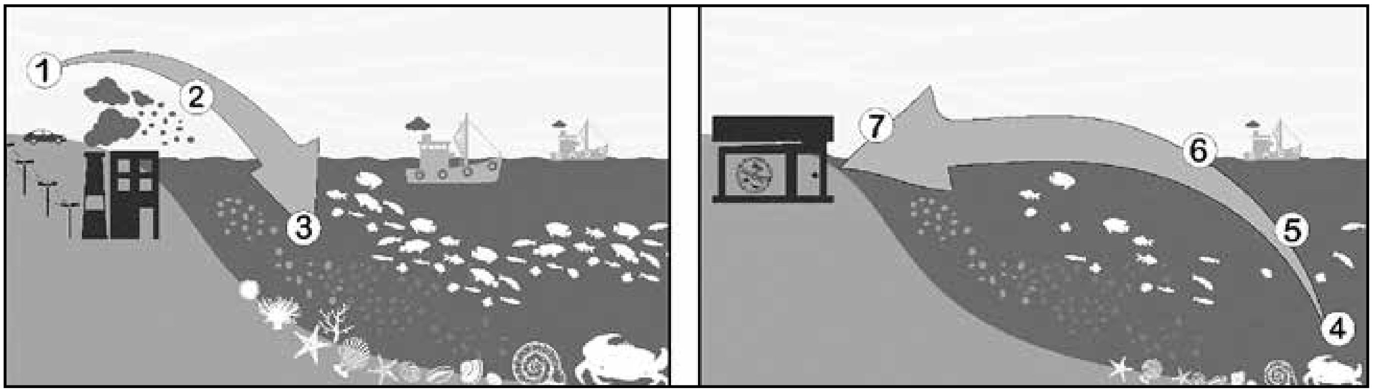
If Mark and Sue's hatchery fails, farmers won't have larvae to grow, restaurants won't have oysters to sell, drivers won't have oysters to transport…

NAME__________________

PERIOD________________

STUDENT **HANDOUT**

LESSON 1 **What Is Ocean Acidification?** *continued*



Images from Samm Newton. bit.ly/2UqdoCP

Ocean Acidification Explained

The Process:

1. Human activities *release* CO_2.
2. The ocean *absorbs* about 25 percent of anthropogenic CO_2.
3. This *changes* ocean chemistry.

An Example:

4. Carbonate, used for shell building, becomes less available. It takes *more energy* to make shells, leading to *fewer* and *smaller* shellfish.
5. Shellfish filter water. Fewer shellfish could lead to *cloudier water*. Cloudy water makes it harder for seagrasses to do photosynthesis. Seagrass beds are important habitat for young fish.
6. Less seagrass could mean *fewer* fish to catch.
7. This could impact humans who rely on fish for food and jobs.

Key Terms:

Ocean Acidification: *the change in ocean chemistry due to increasing amounts of anthropogenic carbon dioxide (CO_2) in the atmosphere.*

Anthropogenic: *human created; coming from humans or their activities.*

NAME________________

TEACHER **ANSWER KEY**

PERIOD______________

STUDENT **HOMEWORK**

LESSON 1 **What Is Ocean Acidification?**

Part 1 Seeing Changes in Invisible Gas

Watch: NASA's "A Year in the Life of Earth's CO_2" (bit.ly/2byrnQC)

1. Describe what happened to carbon dioxide over the course of a year in the simulation. How did it change? Why did it change?

   CO_2 levels cycle seasonally (decrease during northern summer due to net uptake by plants [photosynthesis]; increase during northern winter due to net respiration [decrease in photosynthesis]; daily flashes and pulses visible [day-night photosynthesis cycle]).

   Note: You can see hotspots of CO_2 emissions around population centers, especially in the northern hemisphere. Also, CO_2 levels do not go to zero in the summer (the minimum value on the scale shown is 377 ppm).

Part 2 Interpreting Graphs

Use the three graphs that follow to help answer questions 2–5.

2. What is shown on the y-axis for each graph? What is the range of values on each graph?

   The y-axis shows CO_2 concentrations in parts per million. The first graph ranges from 310 to 417 (410 is an acceptable answer); the second ranges from 200 to 410; and the third from 150 to 410 ppm.

3. What is shown on the x-axis? How does this measure vary between graphs?

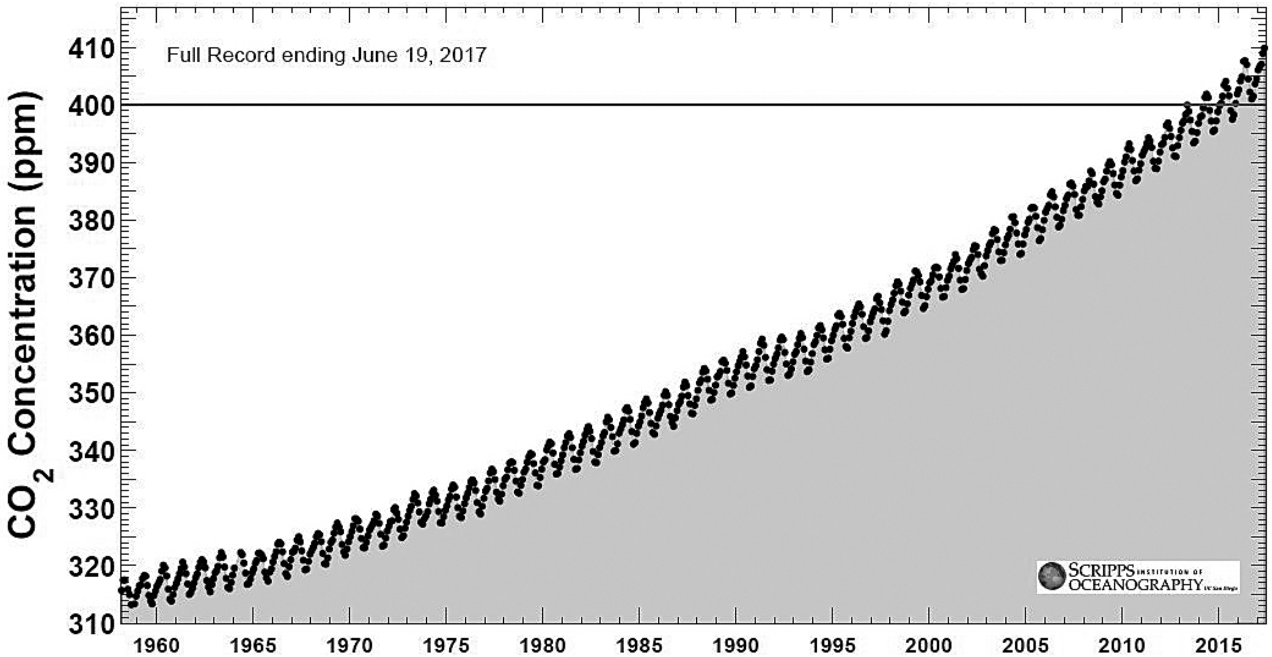
   The x-axis shows time. The first graph is in years, the second in thousands of years ago, and third is named "thousands of years ago" but shows increments of 100,000 years.

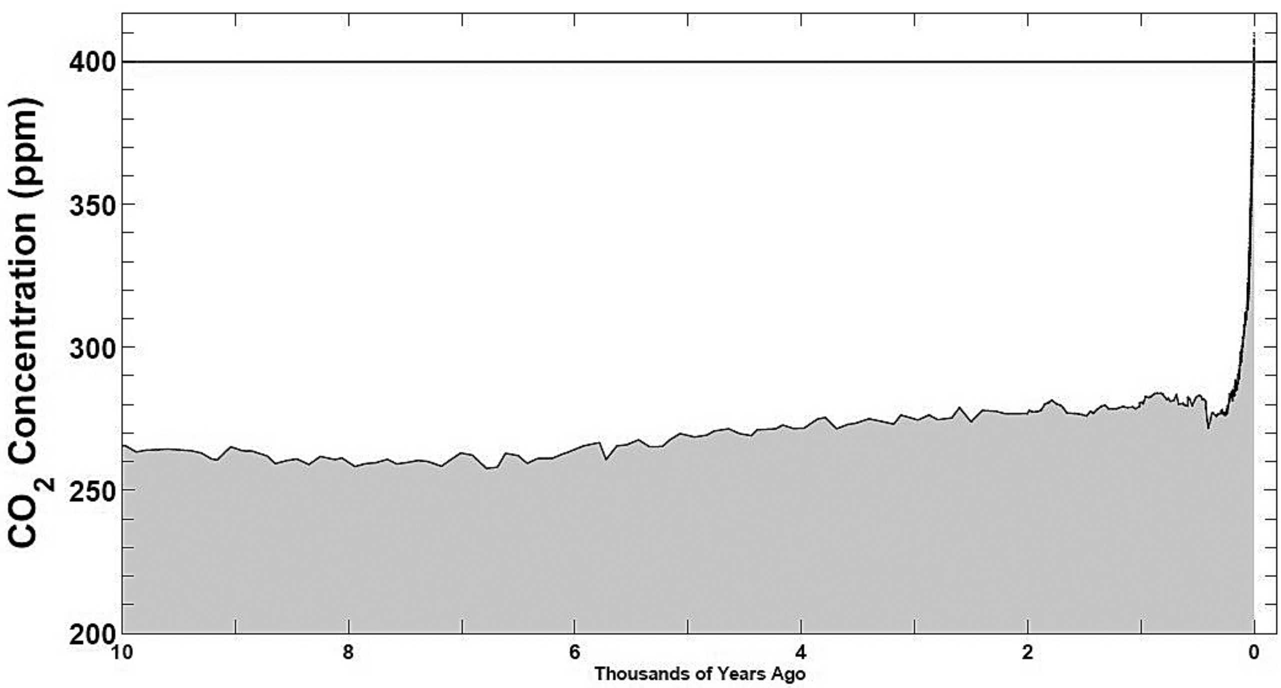
NAME_________________

TEACHER **ANSWER KEY**

PERIOD_______________

STUDENT **HOMEWORK**





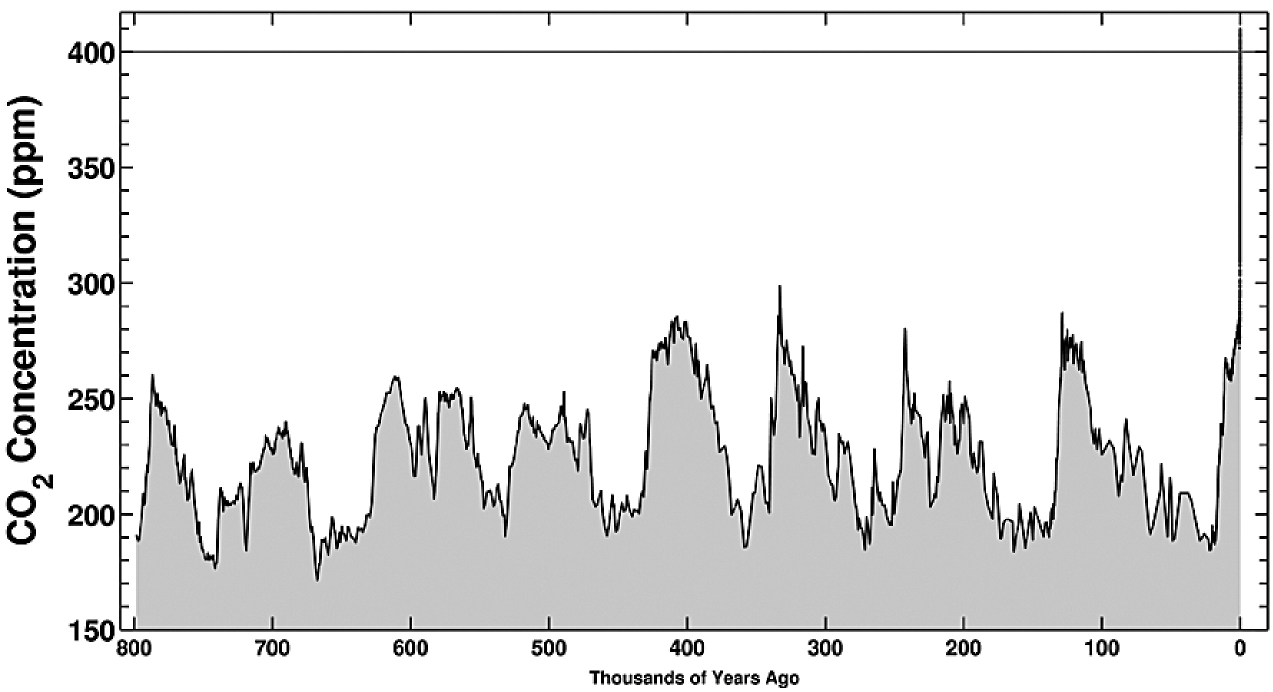
Graphs from Scripps Institution of Oceanography. *bit.ly/1C3b6FA*

NAME__________________

TEACHER **ANSWER KEY**

PERIOD________________

STUDENT **HOMEWORK**



Graphs from Scripps Institution of Oceanography. *bit.ly/1C3b6FA*

NAME________________

TEACHER **ANSWER KEY**

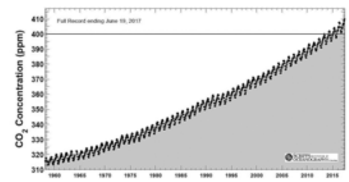
PERIOD______________

STUDENT **HOMEWORK**

LESSON 1 **What Is Ocean Acidification?** *continued*

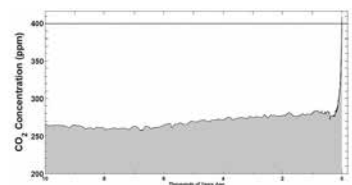
4. Describe what you observe in each graph. Do you see any patterns or trends?

a. Top graph



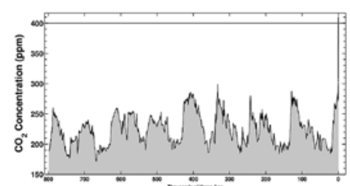
There is an overall increase in CO_2 concentration over the years. The graph looks jagged (saw-toothed). It seems to go up and down every year (this shows the winter increase in CO_2 when plants in the northern hemisphere are less active, and the summer decrease in CO_2 because plants are more active). (Note: Mauna Loa is on Hawaii, and thus in the northern hemisphere.)

b. Middle graph



The CO_2 concentrations look fairly steady over most of the graph, with little ups and downs. There is a sharp decrease about 500 years ago, followed by a very rapid increase (almost straight up on the graph).

c. Bottom graph



There is a lot more variation in this graph, with ups and downs ranging between about 180 and 300ppm. There is a very rapid increase in CO_2 around time 0 from 280 to the present 410 ppm.

5. How does the time scale shown (60 years, 10,000 years, 800,000 years) influence the conclusions you would make about CO_2 in Earth's atmosphere?

Student answers will vary.

The short-term (60-year) time scale gives the impression that CO_2 concentrations have always been rising. Although it documents that CO_2 is increasing, it does not suggest a cause.

The 10,000-year graph (middle) makes the recent increase in CO_2 look like a very unusual situation, suggesting that something is different than it has been for the past 10,000 years.

The 800,000-year graph (bottom) shows that CO_2 concentrations do vary over time; however, the recent increase looks very different from past fluctuations. The current CO_2 concentration is roughly 100 ppm higher than it has been in almost a million years.

NAME________________

PERIOD______________

STUDENT **HOMEWORK**

LESSON 1 **What Is Ocean Acidification?** *continued*

Part 3 Final Synthesis Questions

6. What parts of the simulation and graphs could be used as evidence for natural variation in atmospheric CO_2 levels?

The sawtooth pattern in the 60-year graph shows the interplay of photosynthesis and respiration over the course of the year. The NASA simulation looks like it flashes every day in the tropical rainforests (for example, Amazon and Congo). This is likely the day/night photosynthesis cycle. The 800,000-year graph shows that CO_2 concentrations do change over time and did change way before Homo sapiens evolved, roughly 200,000 years ago.

7. What parts of the simulation and graphs could be used as evidence for human-caused (anthropogenic) variation in atmospheric CO_2 level?

The simulation showed urban areas in North America, China, Europe, etc. with very high CO_2 concentrations. The 10,000-year and 800,000-year graphs show the recent increase in CO_2 to be very different from past changes in CO_2 concentration.

NAME__________________

PERIOD________________

STUDENT **HANDOUT**

LESSON 1 **What Is Ocean Acidification?**

Do Now

What, if anything, have you heard about ocean acidification? What do you want to know more about?

Video Questions Postcard from the Oregon Coast

1. What do they grow at Mark and Sue's hatchery?

2. What happened at the hatchery in 2007?

3. Why does ocean acidification affect baby oysters?

4. How often are conditions currently favorable for shell formation?

5. How might this change in the future?

Post Video Question

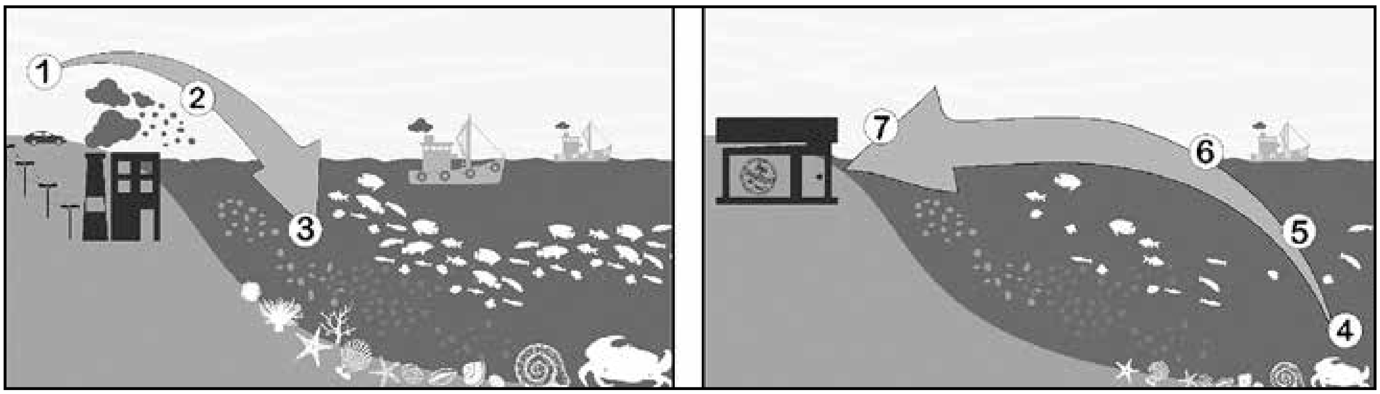
6. Nearly 70 percent of oyster farms along the U.S. west coast rely on Mark and Sue for their baby oysters. What could happen to these farmers, and the restaurants they supply, if Mark and Sue's hatchery cannot cope with ocean acidification?

NAME__________________

PERIOD________________

STUDENT **HANDOUT**

LESSON 1 **What Is Ocean Acidification?** *continued*



Images from Samm Newton. *bit.ly/2UqdoCP*

Ocean Acidification Explained

The Process:

1. Human activities __________________ CO_2.
2. The ocean _________________ about 25 percent of anthropogenic CO_2.
3. This ________________ ocean chemistry.

An Example:

4. Carbonate, used for shell building, becomes less available. It takes __________________ to make shells, leading to ________________________ and ____________________ shellfish.
5. Shellfish filter water. Fewer shellfish could lead to _____________________. Cloudy water makes it harder for seagrasses to do photosynthesis. Seagrass beds are important habitat for young fish.
6. Less seagrass could mean ______________________ fish to catch.
7. This could impact humans who rely on fish for food and jobs.

Key Terms:

Ocean Acidification: ____

____

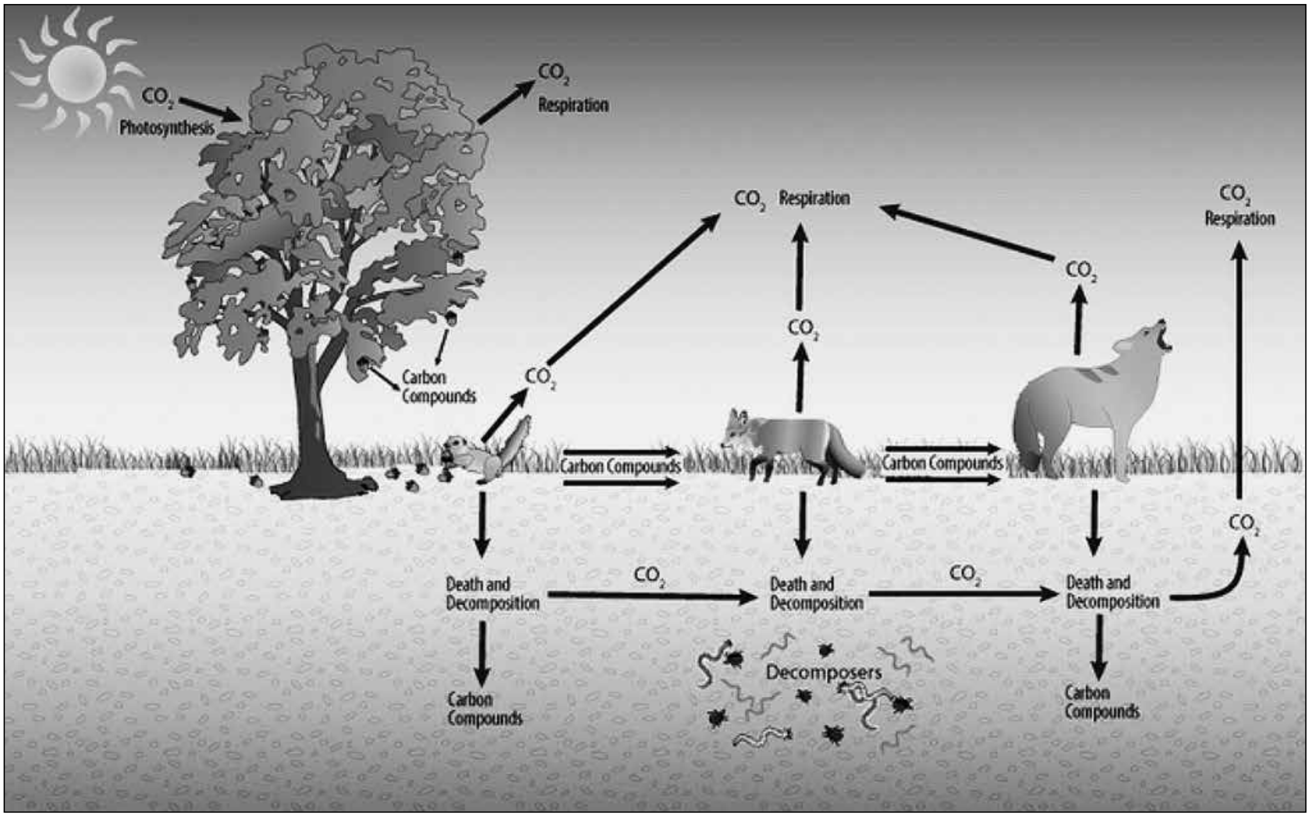
Anthropogenic: ____

NAME________________

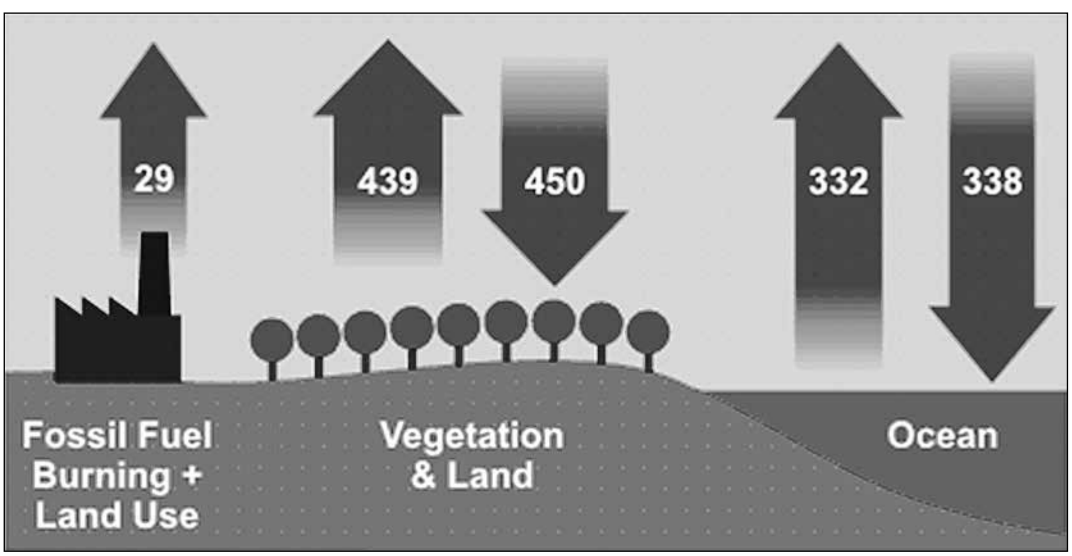
PERIOD______________

STUDENT **HANDOUT**

LESSON 1 **What Is Ocean Acidification?** *continued*



A terrestrial carbon cycle. (Source: Valerie Martin/Earth Labs, TERC. bit.ly/2It3rNo)



Gigatons of Carbon Moving per Year.
(Source: IPCC2004, accessed from Earth Labs Lab 2: bit.ly/2It3rNo)

NAME________________

PERIOD______________

STUDENT **HOMEWORK**

LESSON 1 **What Is Ocean Acidification?**

Part 1 Seeing Changes in Invisible Gas

Watch: NASA's "A Year in the Life of Earth's CO_2" (bit.ly/1ypltC8)

1. Describe what happened to carbon dioxide over the course of a year in the simulation. How did it change? Why did it change?

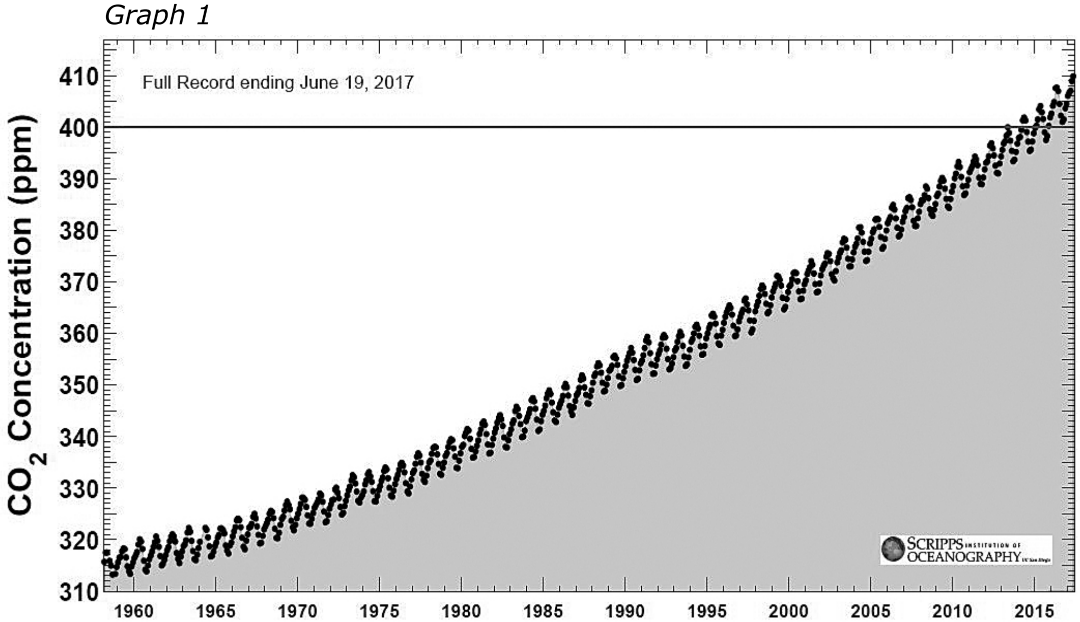
Part 2 Interpreting Graphs

Use the three graphs that follow to help answer questions 2–5.

2. What is shown on the y-axis for each graph? What is the range of values on each graph?

3. What is shown on the x-axis? How does this measure vary between graphs?

Graph 1



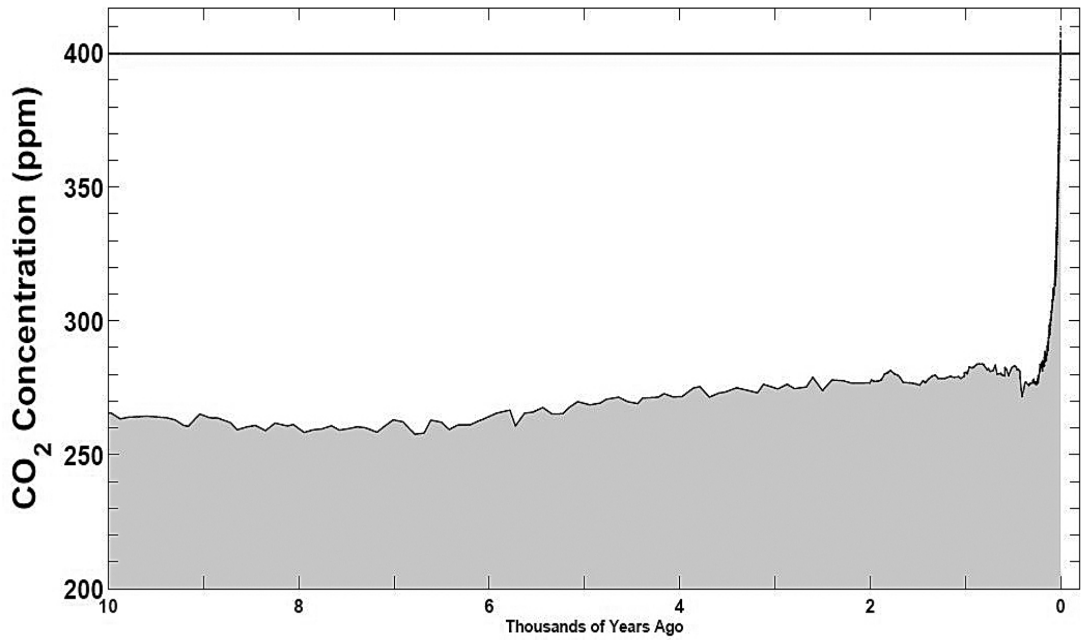
NAME________________

PERIOD______________

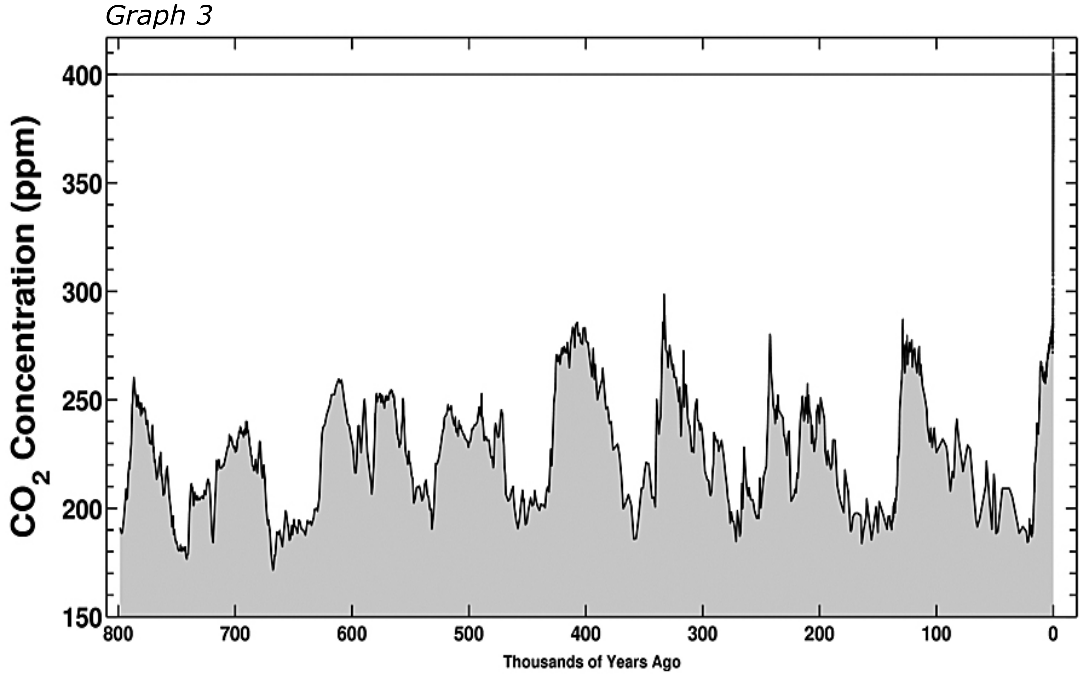
STUDENT **HOMEWORK**

LESSON 1 **What Is Ocean Acidification?** *continued*

Graph 2



Graph 3



Graphs from Scripps Institution of Oceanography, bit.ly/1C3b6FA

NAME________________

PERIOD______________

STUDENT **HOMEWORK**

LESSON 1 **What Is Ocean Acidification?** *continued*

4. Describe what you observe in each graph. Do you see any patterns or trends?

a. Top graph

b. Middle graph

c. Bottom graph

5. How does the time scale shown (60 years, 10,000 years, 800,000 years) influence the conclusions you would make about CO_2 in Earth's atmosphere?

Part 3 Final Synthesis Questions

6. What parts of the simulation and graphs could be used as evidence for natural variation in atmospheric CO_2 levels?

7. What parts of the simulation and graphs could be used as evidence for human-caused (anthropogenic) variation in atmospheric CO_2 level?

LESSON 2

Chemistry of OA (Optional)

OVERVIEW

Lesson 2 is an optional add-on for chemistry classes. Students examine pH in detail. They begin by brainstorming what they already know about pH. Then, the teacher conducts a two-part demonstration: (1) household chemicals are used to show how indicators can estimate pH, then (2) CO_2 from a SodaStream® is added to water. Following this demonstration, the teacher presents a short lecture on acid-base chemistry and introduces part of the chemical equations dealing with OA. Students solidify their understanding of acids and bases using an online simulation. To evaluate their understanding, students are asked to explain *why* the addition of CO_2 lowers the pH of a solution like seawater.

Teacher Note *Substantial changes were made to this lesson after classroom testing of this curriculum. In our experience, students had a superficial understanding of pH and had not yet learned about ions, concentrations, or balancing equations. This meant that at some point the chemistry went over most students' heads. For this version, we added an extra day to allow for an in-depth discussion of pH. Additionally, we have split the chemical reactions of OA into two lessons (Lesson 2 focuses on changes in pH, and Lesson 3 explains how this leads to changes in carbonate ion concentration). This depth is likely not necessary for non-chemistry students. Thus, Lessons 2 and 3 are considered an optional part of this curriculum.*

MATERIALS

- Copies of student handout (one per student)
- Computer, projector, and speakers
- Presentation slides
- Student computers with Internet (Evaluate section)

For CO_2 in water demo:

- Three 300mL Erlenmeyer flasks
- Universal indicator
- Dropper/pipette
- Distilled water
- Vinegar
- Ammonia
- SodaStream®
- Aquarium airline tubing
- Powdered sodium carbonate
- Stirring rod/spoon
- Measuring spoon
- (Optional) aquatic plant

STANDARDS

NGSS: HS-LS2-6; Engaging in Argument from Evidence; ESS2.D; Cause and Effect

CCSS: 9-10.SL.1; 9-10.WHST.10

OLP: 6d, e

OELS: 1b, c; 3b

We tested the curriculum during the fall quarter, and these topics are often taught later in the year. If you teach this module at the end of the year, students may be better prepared.

See Kapsenberg et al. (2015) for more teaching ideas on pH variability.

KEY POINTS

- The pH scale estimates the $[H^+]$ in a solution.
- Adding CO_2 to water decreases the solution's pH, increases the solution's $[H^+]$, and makes it more acidic.
- pH is a logarithmic measurement; small changes in pH represent large changes in $[H^+]$.

ENDURING UNDERSTANDINGS

- Human actions lead to changes in ecosystems.
- Changes in one portion of a system can lead to multiple changes in the rest of the system.

OBJECTIVES

Students will be able to:

- Describe the relationship between pH and $[H^+]$.
- Explain how the addition of CO_2 to seawater lowers the pH.

SETUP

- Make copies of student notebook (one per student).
- Open PowerPoint presentation (bit.ly/2W1CTLl) and preload.
- Gather supplies for CO_2 in Seawater demo (see Supplies List).

MISCONCEPTION ALERT

This lesson likely introduces a misconception about ocean acidification – that the ocean will become acidic. While teaching, we emphasized multiple times that the ocean is not predicted to become acidic; however, on follow-up surveys, a majority of students endorsed this misconception anyway. We found some evidence that directly confronting this misconception following instruction helps students combat this belief. Additionally, the term "ocean acidification" can appear misleading to some because the ocean is basic and will remain so.

See Teaching Notes and Cooley et al. (2012) for more on this misconception: bit.ly/2It4JIe

LESSON PLAN

Engage Brainstorm

1. **Introduce today's lesson.**

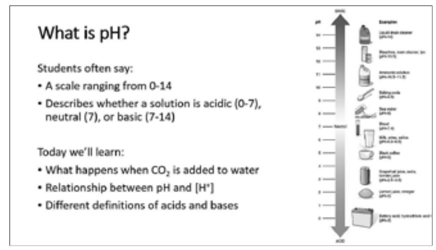
   "Yesterday we introduced ocean acidification. Today and tomorrow we are going to focus on the chemistry of ocean acidification."

2. As a warmup and to gauge prior knowledge, **ask students what they already know about pH.**

   "Today we'll focus on pH. How many of you have heard of pH before? What do you know about pH?"

3. **Show slide summarizing how most students define pH** and previewing what students will learn today.

Students typically say: pH is a scale, it measures whether something is an acid or base. It ranges from 0 to 14; acids have pH<7, bases have pH>7; neutral solutions have pH=7. We've found that very few students have an understanding of what an acid is, beyond this basic definition.



This slide (available at bit.ly/2W1CTLl) does not make reference to the logarithmic nature of the pH scale, because saying the scale was logarithmic seemed to have little meaning for students without exploring the relationship between pH and [H^+] in more detail (see the Evaluate section of this lesson).

Explore Indicators, pH, and CO_2

Demo Part 1 Indicating pH

This demonstration uses household chemicals to help students gain a basic understanding of the pH scale. It offers an opportunity to introduce students to or remind them of indicators and compare their use to other instruments that can be used to measure pH.

1. **Fill an Erlenmeyer flask halfway with distilled water.**

   "I have a flask with distilled water in it. I also have a bottle of universal indicator. Has anyone ever heard of or used an indicator before? What does it do?" (It changes colors, depending on the pH of the solution.)

2. **Project chart showing color range of universal indicator.**

   "Indicators are used to approximate the pH of a solution. Different indicators show different pH ranges, but in general they turn a certain color depending on the pH of a solution. Let's add indicator to our water."

3. **Add indicator and swirl to mix.** Add enough indicator so that the color is clearly visible.

4. **Show students the flask and ask** what the indicator tells us about the pH of the water:

   "Based on our color key, what is the approximate pH of our water?" (7)

This activity is done as a demo to save time but is often done as a student-centered lab. For example, see this lesson from Maria Laws on BetterLesson: bit.ly/2Z27DJR

You could compare indicator and pH probe results and discuss the pros and cons of different scientific technology.

The pH of tap water is usually not 7.0 and varies by location. Thus, we recommend using distilled water for this demo.

"Would our water be considered acidic, basic, or neutral?" *(Neutral)*

"Okay, now let's look at another solution. I have some vinegar here."

5. **Pour vinegar into a flask** until it is about half full.

   "Do you think vinegar is acidic, basic, or neutral?" *(Some students will predict that vinegar is acidic or basic.)*

   "If vinegar is acidic/basic, what color should the indicator turn when we add it?" *(With universal indicator, acids turn red or orange.)*

Universal indicator turns warm colors (yellow, orange, red) when placed in increasingly acidic solutions, and cool colors (blue, dark blue, purple) when placed in increasingly basic solutions.

6. **Add the indicator** [it turns red].

   "Based on our color key, what is the approximate pH of vinegar?" *(Students will say 4. In reality, it is off the charts; the pH of distilled white vinegar is about 2.5.)*

   "Would vinegar be considered acidic, basic, or neutral?" *(Vinegar is acidic, because its pH is below 7.)*

7. **Repeat this line of questioning for at least one base**, such as ammonia.

Don't use bleach as your base. It reacts with the indicator and removes almost all pigment over a few minutes. Also, when mixed with vinegar, it creates chlorine gas.

Demo Part 2 Adding CO_2 to Water

Now that students are generally familiar with pH and indicators, you may move on to the main attraction: adding CO_2 to water.

"All right, let's get back to our flask with water and indicator in it. I also have a SodaStream here. Does anyone know what gas makes soda and carbonated water bubbly?" *(CO_2)*

"What we're going to do is add CO_2 to water. What do you think will happen to the pH?" *(Student answers will vary.)*

If you don't have access to a SodaStream, there are many options to show this concept. *See "Teaching Notes" on page 40 for alternatives.*

8. **Place one end of the aquarium tubing into the water in the flask and connect the other end to the soda stream tube** so that you can direct the CO_2 into the flask.

9. **Press the SodaStream button** for a few seconds, until the solution turns green→yellow→orange. Discuss as a class:

   "What happened when we added CO_2 to water?"

   (It turned orange, which means the solution became an acid. We could say we "acidified" the water.)

   "Do you think we could reverse this reaction? How?"

   (Student ideas may include: add aquatic plants to remove the CO_2 from the water; wait for a while so it offgases, just like a soda going flat; add a base.)

If you have extra aquatic plant around your lab, you can put some in your flask, place it under light, and wait to see what happens. For a complete write-up of a similar lab, see CarboSchool's "Uptake of Carbon Dioxide from Water by Plants": bit.ly/2P3kebu

10. **Transition to showing that bases make solutions less acidic.** We use sodium carbonate because it is used in shellfish hatcheries.

    "We have some soda ash (sodium carbonate) here. It is the same stuff that the oyster hatchery, the one we watched the video about yesterday, uses to adjust their seawater. Let's add a little to our acidified water…"

11. **Add a small scoop of soda ash** (sodium carbonate) to the beaker, and stir. It will turn dark blue/purple.

Careful. A little sodium carbonate goes a long way!

12. **Add more CO_2 from your SodaStream** to this buffered water to acidify it again.

The solution is now partially buff-ered. This time around, it should take longer for the pH to change.

There are multiple labs exploring seawater buffering. See these two resources for ideas: bit.ly/2U8NoH1 (experiments 5 and 6) and bit.ly/2Gcibi8

Explain Acids, Bases, and CO_2 in Seawater

***Teacher Note** This discussion of acid-base chemistry is a new ad-dition to this version of the curriculum*.

1. **Explain dissociation.**

   "In a glass of water, a small portion of water molecules dissociate, or break apart, into hydrogen and hydroxide ions. Let's revisit this glass of water. Why does its pH = 7? Well, we know that water is H_2O. But did you know that roughly 1 in 550 million water molecules dissociates, or splits apart, into charged hydrogen and hydroxide ions?"

(Hsu & Lab-Aids Inc. (2010)

2. **Show slide** with water dissociation equation (bit.ly/2W1CTLl).

   $$H_2O \leftrightarrow H^+ + OH^- \qquad \text{(eq-1)}$$

   "If we were to measure how many hydrogen ions were in 1L of H_2O, we would find $[H^+] = 1x10^{-7}$ mols/L. We would also find that $[OH^-] = 1x10^{-7}$ M."

   "Do you notice anything about our pH and the H^+ concentration?" (The pH is 7 and the concentration is $1x10^{-7}$ M)

3. **Explain "neutral" solutions** (continue on to next slide).

   "One way of defining acids and bases is by comparing the concentrations of hydrogen and hydroxide ions. We just saw that water dissociates and produces equal numbers of hydrogen and hydroxide ions. When concentrations of the two ions are equal, we call this neutral. So, our distilled water sample at pH = 7 is neutral because there are equal concentrations of hydrogen and hydroxide ions.

Without saying so, we've just primed students to think of acids and bases according to the Arrhe-nius theory. This can be a useful starting point when explaining the SodaStream demonstration.

Similarly, if a solution has more hydrogen ions than hydroxide ions, that is if $[H^+] > [OH^-]$, we call it an acid. In contrast, if a solution has fewer hydrogen ions than hydroxide ions, that is, if $[H^+] < [OH^-]$, we call it a base."

4. **Show slide with definitions of acids and bases** (bit.ly/2W1CTLl): acids are H^+ producers, and bases are OH^- producers.

   "Comparing concentrations of hydrogen and hydroxide ions gives us a starting point to talk about acids and bases.

   For example, let's look at vinegar. In our demonstration, was vinegar an acid or a base?" *(It was an acid.)*

   "If vinegar is an acid, what should be written in the two blanks shown?"

   $CH_3COOH \rightarrow$ _______ + _______ (eq-2)

5. **Give students time to come up with an answer.** Ask for student answers.

   "We said that acids produce a proton, so vinegar releases an H^+ and we're left with CH_3COO^-. So:"

   $CH_3COOH \rightarrow CH_3COO^- + H^+$ (eq-2a)

6. **List the steps of ocean acidification.** Now we will connect the dots to answer the question: how does extra CO_2 in the atmosphere lead to ocean acidification?

   $CO_2(g) \leftrightarrow CO_2(aq)$ (eq-3)

   $CO_2(aq) + H_2O \leftrightarrow H_2CO_3$ (eq-4)

   $H_2CO_3 \leftrightarrow$ _______ + _______ (eq-5)

7. **Ask students to fill in the blanks** (in their handout and slide) for equation eq-6 based on the previous conversation.

   $H_2CO_3 \leftrightarrow H^+ + HCO_3^-$ (eq-5a)

8. **Give students time to examine the graph** of CO_2 and pH in their handout. They should work in groups to answer the questions in their notes and discuss the handout questions.

9. **Discuss handout questions as a class** (see Teacher Answer Key).

Equation 3 shows CO_2 gas dissolving in the ocean.

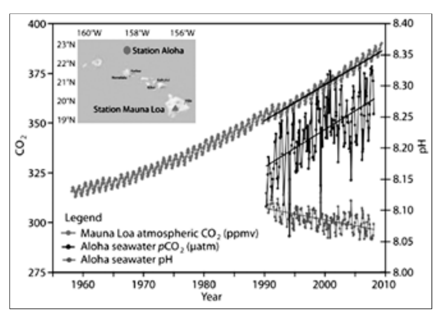


Figure: Changes in carbon dioxide in the atmosphere and ocean, and corresponding changes in ocean pH. (Source: Doney et al. 2009)

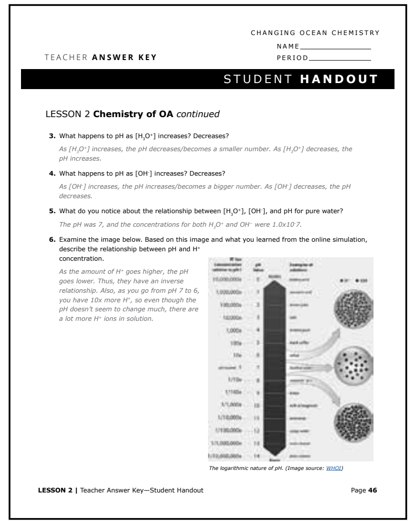
Evaluate Online pH Simulation

Teacher Note *This activity can be done in class or as homework.*

Use PhET's online pH simulation (bit.ly/1U4WWjL) to reinforce the pH lesson and allow students to explore the following question: On a molecular level, what is the difference between acids and bases?

1. Students **watch an introductory video** on Youtube (bit.ly/2D97Dia) that explains the procedure (see teacher/student handout).
2. Students **complete the first two rows of the table in their notes** with data from the demonstration video (coffee and dilute coffee).
3. Students **repeat the procedure for three more chemicals.**
4. Students **answer questions in their notes** to help them make sense of the simulation.

This activity is a slightly modified version of Chris Justus' lesson, available under the "For Teachers" section of PhET's pH Scale simulation: bit.ly/2I8qLRx


CHANGING OCEAN CHEMISTRY

NAME______________

TEACHER **ANSWER KEY** PERIOD______________

STUDENT **HANDOUT**

LESSON 2 **Chemistry of OA** *continued*

3. What happens to pH as $[H_3O^+]$ increases? Decreases?

   As $[H_3O^+]$ increases, the pH decreases/becomes a smaller number. As $[H_3O^+]$ decreases, the pH increases.

4. What happens to pH as $[OH^-]$ increases? Decreases?

   As $[OH^-]$ increases, the pH increases/becomes a bigger number. As $[OH^-]$ decreases, the pH decreases.

5. What do you notice about the relationship between $[H_3O^+]$, $[OH^-]$, and pH for pure water?

   The pH was 7, and the concentrations for both H_3O^+ and OH^- were 1.0x10-7.

6. Examine the image below. Based on this image and what you learned from the online simulation, describe the relationship between pH and H^+ concentration.

   As the amount of H^+ goes higher, the pH goes lower. Thus, they have an inverse relationship. Also, as you go from pH 7 to 6, you have 10x more H^+, so even though the pH doesn't seem to change much, there are a lot more H^+ ions in solution.

The logarithmic nature of pH. (Image source: WHOI)

LESSON 2 | Teacher Answer Key—Student Handout Page **46**

If you cannot access Youtube in your school, use your projector to demonstrate the simulation.

EDUCATOR BACKGROUND

The pH Scale

pH is a concept that is seemingly straightforward and familiar. Most people have some notion of pH as a measure of "acidity." Additionally, the pH of a solution is fairly easy to observe; just ask anyone with a pH test strip or a pool. However, pH is hard to measure accurately and precisely, and interpretation of pH values is complicated (Galster, 1991). There are multiple definitions of acids and bases, multiple pH scales, and pH measurements are sensitive to environmental conditions including temperature, salinity, and pressure. Furthermore, OA happens at the rate of 0.001 pH units/year, while almost all pH measuring instruments measure to 0.1 or 0.01 levels of accuracy, when properly calibrated. Also, the difference between commonly used pH scales is ~0.2, which is within the range of predicted changes in pH due to OA by the year 2100. Additionally, pH can naturally vary over 0.5 units in some marine systems over short time scales (hours to weeks). Thus, without precise measurements, it is difficult to distinguish the small, persistent, long-term trend (OA) from the larger short-term cycles. This does not mean that OA is not happening; it simply means OA is hard to measure.

Thus, while pH is a familiar concept that changes as the ocean absorbs CO_2 and impacts some organisms directly, it might be more accurate to consider pH change as an indicator of larger ocean chemistry changes and possible organism responses, rather than the driver of this change (see Lesson 3 "Educator Background" on page 61 for more information).

TEACHING NOTES

Adding CO_2 to Seawater Demo

The version of the demo included in this lesson is the authors' favorite because it removes several possible factors that might lead students to unintended conclusions. It uses pure CO_2, setup is simple (attach a tube to the SodaStream, add indicator to water), and connections to the students' real lives can be made (soda and other carbonated drinks contain CO_2, which is at least partially responsible for the drinks being acidic). Additionally, this lesson also reverses the reaction (raising the pH by adding a base). Most versions of this demonstration do not include this final step, even though the reversibility of the reaction is a key concept that allows students to make connections to lessons on acid-base chemistry and helps explain the existing natural variation in pH.

For teachers who lack access to a SodaStream, many alternatives exist to show that adding CO_2 to water lowers the pH. All involve a way to observe pH change (indicators are most commonly used, but pH test strips and probes also work) and some way to add CO_2. Variations include:

- Blow through a straw into a beaker containing water and an indicator such as bromothymol blue (Experiment 1, bit.ly/2Z83tQJ).

  The simplicity of this demo is wonderful. The potential confusion here is that many students do not realize that their breath is a mix of multiple gases. While this introduces a great teachable moment, it also requires students to trust that the thing in their breath that is changing the pH is the CO_2 and not one of the other gases. How do students know the O_2 in their breath isn't responsible for the pH change? Additionally, younger students may have a hard time controlling blowing vs. sucking on a straw and could accidentally inhale the indicator solution, which can be toxic. Some write-ups recommend puncturing a hole in the straw to avoid this, but this may not completely remove the possibility of inhalation.

- Add dry ice (solid CO_2) to a beaker with water and indicator (bit.ly/2U6hQ4D).

  This demo has the excitement of bubbling dry ice, and an opportunity to talk about sublimation (going from solid to gas). Complications with this experiment are obtaining dry ice and maintaining lab safety (gas pressure from dry ice can build quickly and cause explosions in closed containers). Dry ice is often available at grocery stores, but it is not always convenient to acquire on the day you need it. Using a SodaStream, in the authors' minds, seems like an easier up-front purchase that allows for demonstrations whenever needed, as opposed to day-of purchasing of materials.

- Use a CO_2 bike pump instead of a SodaStream (bit.ly/2OZTnNn).

These are cheaper and smaller than a SodaStream; however, slightly more work is required to connect the tubing to the pump. If you have the right parts, setup and use seem simple.

- Burn a candle and transfer CO_2 generated to a separate beaker filled with indicator (see Lesson 4, bit.ly/2UNIuU0).

  This makes a great connection between combustion of fossil fuels releasing CO_2 and changing ocean pH. However, the setup is more involved and, like blowing through a straw, it relies on students trusting that combustion releases CO_2 and that this CO_2 is the cause for the pH change. This might be a great extension for students to synthesize several concepts learned throughout this curriculum.

- Mix baking soda and vinegar and capture the CO_2 generated (bit.ly/2lSUa2X).

  This simple setup allows students to quickly and safely generate CO_2 through a reaction they are already familiar with (but may not have previously known that CO_2 is the gas generated in the process). A variation of this method involves using TUMS®.

- Use alternate indicators, pH test strips, or pH probes (see Lesson 5, bit.ly/2Z83tQJ).

  Any indicator in the range of pH 5–9 should work for this demo. In the authors' opinion, universal indicator works better than bromothymol blue because the former includes a wider range of colors, making it easier to show pH changes in both directions; however, universal indicator is slightly less common in school laboratories. You can make an indicator out of red cabbage (page 2, bit.ly/2w1Nwys), although this process can be time intensive and a bit smelly. Additionally, if you have pH probes or test strips in your lab, these work, too. Ultimately, you just need a way to show that the pH changed.

NAME_________________

TEACHER **ANSWER KEY**

PERIOD_______________

STUDENT **HANDOUT**

LESSON 2 **Chemistry of OA**

Demo CO_2 in Water

Describe what happened to the pH of water throughout the demonstration. Try to incorporate the following vocabulary: acidic, basic, carbon dioxide, pH, indicator.

Student answers will vary, but may include:

When we added the indicator to distilled water, it turned green, which told us the pH was around 7. Adding indicator to vinegar turned it red because vinegar is an acid, and adding indicator to ammonia turned it purple because ammonia is a base. We then added carbon dioxide (CO_2) from the SodaStream to our water and it turned yellow, then orange, then red. This means that adding CO_2 made the solution more acidic. Then we added soda ash, and when the teacher stirred the solution it turned dark purple, meaning it became more basic. Then, as we blew in CO_2 from the SodaStream the solution slowly became green, yellow, orange, and red, but it seemed like it took longer this time.

Defining Acids and Bases

There are multiple definitions of acids and bases. Record how we are defining acids and bases below.

Acids
Chemicals that produce hydrogen ions/protons (H^+) in aqueous solutions

Bases
Chemicals that produce hydroxide ions (OH^-) in aqueous solutions

Complete the following equation.

$CH_3COOH \leftrightarrows CH_3COO^- + H^+$

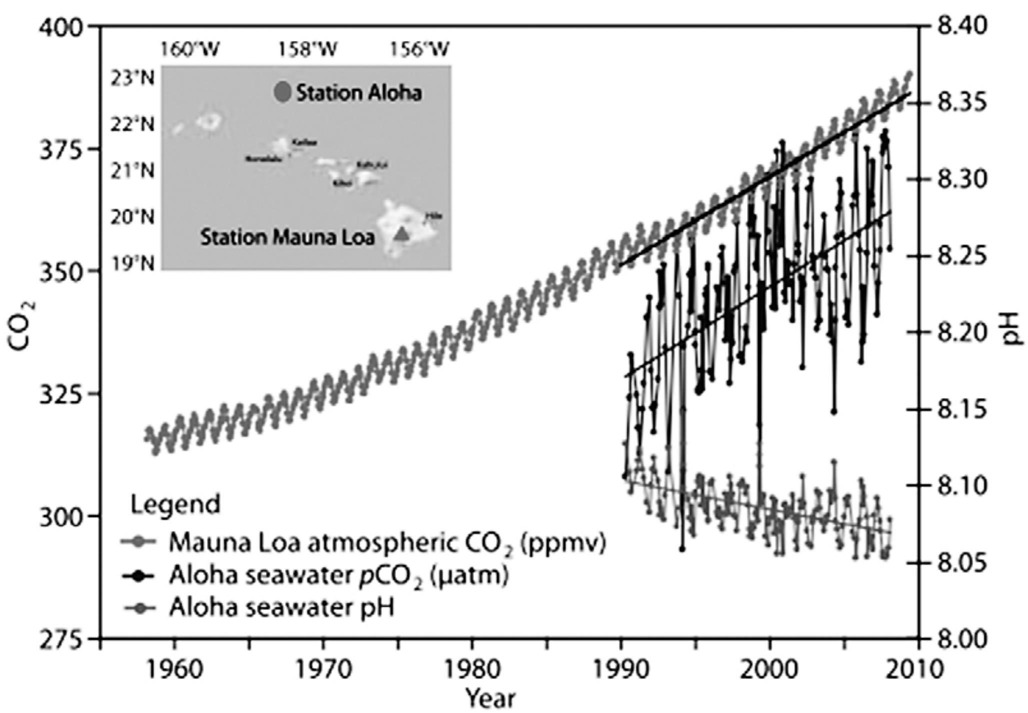
(Vinegar or acetic acid)

LESSON 2 **Chemistry of OA** *continued*

How does extra CO_2 in the atmosphere lead to ocean acidification?

Chemical Equations	**Describe in words what the equation says**
1. CO_2 (g) ↔ CO_2 (aq)	*carbon dioxide goes into seawater*
2. $CO_2 + H_2O$ ↔ H_2CO_3 (H_2CO_3 is carbonic acid)	*carbon dioxide and water react to form carbonic acid*
3. H_2CO_3 ↔ $HCO_3^- + H^+$ (HCO_3^- is bicarbonate)	*carbonic acid breaks apart into a hydrogen ion and a bicarbonate ion*

Using the graph below, discuss the following questions with your partner:



Note: The legend lists the lines in order, from top to bottom. Atmospheric CO_2 is the top line, seawater pCO_2 is in the middle, and seawater pH is the bottom line. (Source: Doney et al. 2009)

NAME________________

PERIOD______________

STUDENT **HANDOUT**

LESSON 2 **Chemistry of OA** *continued*

1. In what ways does this graph connect to the equations above?

   The equations showed that when you add CO_2 to water, a hydrogen ion is released, making it more acidic. The graph shows that CO_2 in the ocean and atmosphere is going up, and that the pH of the ocean is going down. In other words, it is acidifying, or becoming more acidic.

2. How does the SodaStream demo connect with this graph and the equations?

   The SodaStream added CO_2 to the water, making it more acidic. It helps show that as the ocean CO_2 goes up, the ocean pH goes down.

3. Look at the pH values on the graph. Is seawater currently acidic, neutral, or basic?

   The ocean is above pH 7.0, so it is basic.

4. Scientists predict an average ocean pH of 7.8–7.9 by 2100. Will the ocean be acidic then?

   No, the ocean will still be basic because the pH will still be above pH = 7.0.

5. Considering your answers to #3-4, why do you think we call it ocean acidification?

   Beginner: *The word "acidification" refers to lowering the ocean's pH by any amount. Using this name is similar to how people say it is "warming" when the air temperature goes from -20°C to 0°C, even though they still would be happy wearing a warm coat and hat!*

   Intermediate: *Ocean acidification refers to the process of lowering the ocean's pH (that is, increasing the concentration of hydrogen ions) by dissolving additional carbon dioxide in seawater from the atmosphere, or by other chemical additions caused by either natural processes or human activity. The word "acidification" refers to lowering pH from any starting point to any end point on the pH scale. This term is used in many other scientific areas (including medicine and food science) to refer to the addition of an acid to a solution, regardless of the solution's pH value. For example, even though seawater's pH is greater than 7.0 (and therefore considered "basic" in terms of the pH scale), increasing atmospheric CO_2 levels are still increasing the ocean's acidity and lowering its pH. In comparison, this language is similar to the words we use when we talk about temperature. If the air temperature moves from -20°C to 0°C (-4°F to 32°F), it is still cold, but we call it "warming." – J. Orr, C. L. Sabine, R. Key*

   **Answers from WHOI's OA FAQ page, bit.ly/2It4JIe: Why call it ocean acidification, when the ocean is not acidic?*

LESSON 2 **Chemistry of OA** *continued*

Online Activity On the molecular level, what is the difference between acids and bases?

Procedure:

1. Watch this video to orient you to this lesson: bit.ly/2D97Dia
2. Access the simulation by going to bit.ly/1U4WWjL
3. You'll begin by working in the Micro section. Double click on the Micro tab.

As shown in the video, you will follow these steps:

4. Choose one chemical (coffee, for example).
5. Write down the pH, the [H_3O^+], and the [OH^-] in your data table.

   Remember: [brackets] means "concentration."
6. With a calculator, multiply those numbers together. Write down your answer in the last column.
7. Make a dilute solution by adding water until the container is full. Repeat steps 5 and 6.
8. Repeat this process for three more chemicals and their dilutions.

   You must pick at least one acid and at least one base.
9. Finally, in the ninth row in your table… Repeat steps 1–4 for pure water.

   To get pure water, drain the solution (click on the blue handle on the bottom left of the solution), then add water (click on the blue handle next to the water label).

After you have completed steps 4–9 for a total of 4 chemicals (coffee plus 3 additional ones), answer the questions below:

1. Describe the difference between an acid and a base on the molecular level.

   Answers will vary: for example, acids have a [H^+]>$1.0x10^{-7}$, while bases have a [H^+]<$1.0x10^{-7}$. Acids have more hydrogen ions, while bases have more hydroxide ions.
2. What was the product of [H_3O^+] x [OH^-]?

   It was always $1.0x10^{-14}$.

LESSON 2 **Chemistry of OA** *continued*

3. What happens to pH as $[H_3O^+]$ increases? Decreases?

As $[H_3O^+]$ increases, the pH decreases/becomes a smaller number. As $[H_3O^+]$ decreases, the pH increases.

4. What happens to pH as $[OH^-]$ increases? Decreases?

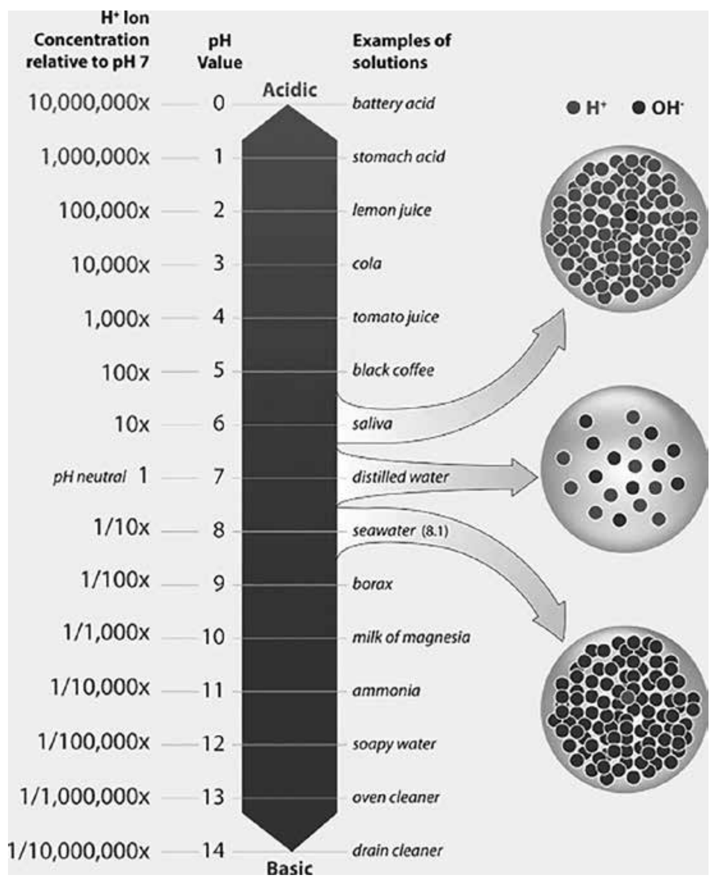
As $[OH^-]$ increases, the pH increases/becomes a bigger number. As $[OH^-]$ decreases, the pH decreases.

5. What do you notice about the relationship between $[H_3O^+]$, $[OH^-]$, and pH for pure water?

The pH was 7, and the concentrations for both H_3O^+ and OH^- were 1.0×10^{-7}.

6. Examine the image below. Based on this image and what you learned from the online simulation, describe the relationship between pH and H^+ concentration.

As the amount of H^+ goes higher, the pH goes lower. Thus, they have an inverse relationship. Also, as you go from pH 7 to 6, you have 10x more H^+, so even though the pH doesn't seem to change much, there are a lot more H^+ ions in solution.



The logarithmic nature of pH. (Image source: WHOI)

NAME_______________

TEACHER **ANSWER KEY**

PERIOD_______________

STUDENT **HANDOUT**

LESSON 2 **Chemistry of OA** *continued*

Chemical	pH	H_3O^+ Count	OH^- Count	Product of $[H_3O^+] \times [OH^-]$
Coffee	*5.00*	*$1.0x10^{-5}$*	*$1.0x10^{-9}$*	*$1.0x10^{-14}$*
Dilute coffee	*5.37*	*$4.2x10^{-6}$*	*$2.4x10^{-9}$*	*$1.0x10^{-14}$*
Battery acid	*1.00*	*$1.0x10^{-1}$*	*$1.0x10^{-13}$*	*$1.0x10^{-14}$*
Dilute battery acid	*1.38*	*$4.2x10^{-2}$*	*$2.4x10^{-13}$*	*$1.0x10^{-14}$*
Vomit	*2.00*	*$1.0x10^{-2}$*	*$1.0x10^{-12}$*	*$1.0x10^{-14}$*
Dilute vomit	*2.38*	*$4.2x10^{-3}$*	*$2.4x10^{-12}$*	*$1.0x10^{-14}$*
Soda pop	*2.50*	*$3.2x10^{-3}$*	*$3.2x10^{-12}$*	*$1.0x10^{-14}$*
Dilute soda pop	*2.88*	*$1.3x10^{-3}$*	*$7.6x10^{-12}$*	*$1.0x10^{-14}$*
Orange juice	*3.50*	*$3.2x10^{-4}$*	*$3.2x10^{-11}$*	*$1.0x10^{-14}$*
Dilute orange juice	*3.88*	*$1.3x10^{-4}$*	*$7.6x10^{-11}$*	*$1.0x10^{-14}$*
Chicken soup	*5.80*	*$1.6x10^{-6}$*	*$6.3x10^{-9}$*	*$1.0x10^{-14}$*
Dilute chicken soup	*6.14*	*$7.2x10^{-7}$*	*$1.4x10^{-8}$*	*$1.0x10^{-14}$*
Milk	*6.50*	*$3.2x10^{-7}$*	*$3.2x10^{-8}$*	*$1.0x10^{-14}$*
Dilute milk	*6.72*	*$1.9x10^{-7}$*	*$5.3x10^{-8}$*	*$1.0x10^{-14}$*
Spit	*7.40*	*$4.0x10^{-8}$*	*$2.5x10^{-7}$*	*$1.0x10^{-14}$*
Dilute spit	*7.21*	*$6.1x10^{-8}$*	*$1.6x10^{-7}$*	*$1.0x10^{-14}$*
Blood	*7.40*	*$4.0x10^{-8}$*	*$2.5x10^{-7}$*	*$1.0x10^{-14}$*
Dilute blood	*7.21*	*$6.1x10^{-8}$*	*$1.6x10^{-7}$*	*$1.0x10^{-14}$*
Hand soap	*10.00*	*$1.0x10^{-10}$*	*$1.0x10^{-4}$*	*$1.0x10^{-14}$*
Dilute hand soap	*9.62*	*$2.4x10^{-10}$*	*$4.2x10^{-5}$*	*$1.0x10^{-14}$*
Drain cleaner	*13.00*	*$1.0x10^{-13}$*	*$1.0x10^{-1}$*	*$1.0x10^{-14}$*
Dilute drain cleaner	*12.62*	*$2.4x10^{-13}$*	*$4.2x10^{-2}$*	*$1.0x10^{-14}$*
Pure water	*7.00*	*$1.0x10^{-7}$*	*$1.0x10^{-7}$*	*$1.0x10^{-14}$*

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STUDENT **HANDOUT**

LESSON 2 **Chemistry of OA**

Demo CO_2 in Water

Describe what happened to the pH of water throughout the demonstration. Try to incorporate the following vocabulary: acidic, basic, carbon dioxide, pH, indicator.

Defining Acids and Bases

There are multiple definitions of acids and bases. Record how we are defining acids and bases below.

Acids

Bases

Complete the following equation.

CH_3COOH ⇆ _______________ + _______________

(Vinegar or acetic acid)

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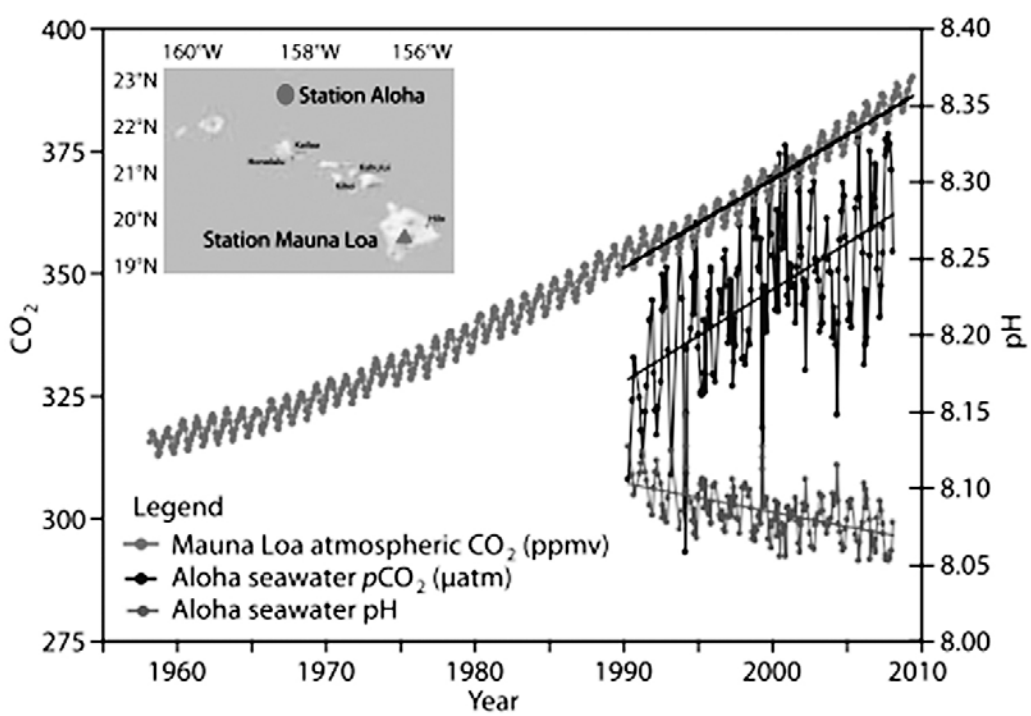
STUDENT **HANDOUT**

LESSON 2 **Chemistry of OA** *continued*

How does extra CO_2 in the atmosphere lead to ocean acidification?

Chemical Equations	**Describe in words what the equation says**
1. CO_2 (g) ⇔ CO_2 (aq)	
2. $CO_2 + H_2O$ ⇔ H_2CO_3 (H_2CO_3 is carbonic acid)	
3. H_2CO_3 ⇔ _______ + _______ (HCO_3^- is bicarbonate)	

Using the graph below, discuss the following questions with your partner:



Note: The legend lists the lines in order, from top to bottom. Atmospheric CO_2 is the top line, seawater pCO_2 is in the middle, and seawater pH is the bottom line. (Source: Doney et al. 2009)

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STUDENT **HANDOUT**

LESSON 2 **Chemistry of OA** *continued*

1. In what ways does this graph connect to the equations above?

2. How does the SodaStream demo connect with this graph and the equations?

3. Look at the pH values on the graph. Is seawater currently acidic, neutral, or basic?

4. Scientists predict an average ocean pH of 7.8–7.9 by 2100. Will the ocean be acidic then?

5. Considering your answers to #3–4, why do you think we call it ocean acidification?

NAME__________________

PERIOD________________

STUDENT **HANDOUT**

LESSON 2 **Chemistry of OA** *continued*

Online Activity On the molecular level, what is the difference between acids and bases?

Procedure:

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3. You'll begin by working in the Micro section. Double click on the Micro tab.

As shown in the video, you will follow these steps:

4. Choose one chemical (coffee, for example).
5. Write down the pH, the [H_3O^+], and the [OH^-] in your data table.

   Remember: [brackets] means "concentration."
6. With a calculator, multiply those numbers together. Write down your answer in the last column.
7. Make a dilute solution by adding water until the container is full. Repeat steps 5 and 6.
8. Repeat this process for three more chemicals and their dilutions.

   You must pick at least one acid and at least one base.
9. Finally, in the ninth row in your table… Repeat steps 1–4 for pure water.

   To get pure water, drain the solution (click on the blue handle on the bottom left of the solution), then add water (click on the blue handle next to the water label).

After you have completed steps 4–9 for a total of 4 chemicals (coffee plus 3 additional ones), answer the questions below:

1. Describe the difference between an acid and a base on the molecular level.

2. What is the product of [H_3O^+] x [OH^-]?

NAME__________________

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STUDENT **HANDOUT**

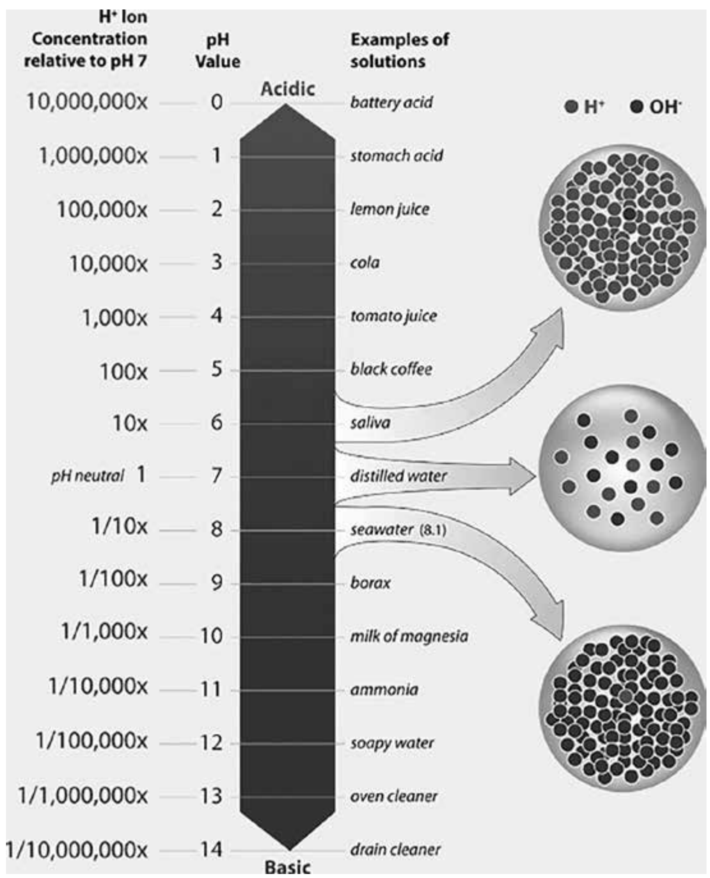
LESSON 2 **Chemistry of OA** *continued*

3. What happens to pH as [H_3O^+] increases? Decreases?

4. What happens to pH as [OH^-] increases? Decreases?

5. What do you notice about the relationship between [H_3O^+], [OH^-], and pH for pure water?

6. Examine the image below. Based on this image and what you learned from the online simulation, describe the relationship between pH and H^+ concentration.



The logarithmic nature of pH. (Image source: WHOI)

NAME__________________

PERIOD________________

STUDENT **HANDOUT**

LESSON 2 **Chemistry of OA** *continued*

Chemical	**pH**	**H_3O^+ Count**	**OH^- Count**	**Product of $[H_3O^+]$ x $[OH^-]$**
Coffee				
Dilute coffee				
Pure water				

LESSON 3

OA Chemistry Continued (Optional)

OVERVIEW

Lesson 3 expands student understanding of the chemistry of OA by focusing on other changes to ocean chemistry that result from the addition of CO_2. It begins with a demonstration that challenges students to explain what they see using information from the previous day's lesson: floating candles are lit in a closed aquarium, and students watch as the pH of the surface layer of an indicator solution changes. Following the demo, the teacher provides a short lecture on two topics: (1) carbonate concentration also decreases when CO_2 is added to seawater, and (2) summer upwelling exacerbates OA along the U.S. west coast. Students then synthesize their learning as they work with water quality data from Whiskey Creek Shellfish Hatchery.

MATERIALS

- Copies of student handout (one per student)
- Computer, projector, and speakers
- Presentation slides
- Student computers with Internet (evaluate section)

For candle demo:

- Universal indicator
- Distilled water
- Two clear salad bowls/aquaria
- Lighter/matches
- Floating candles

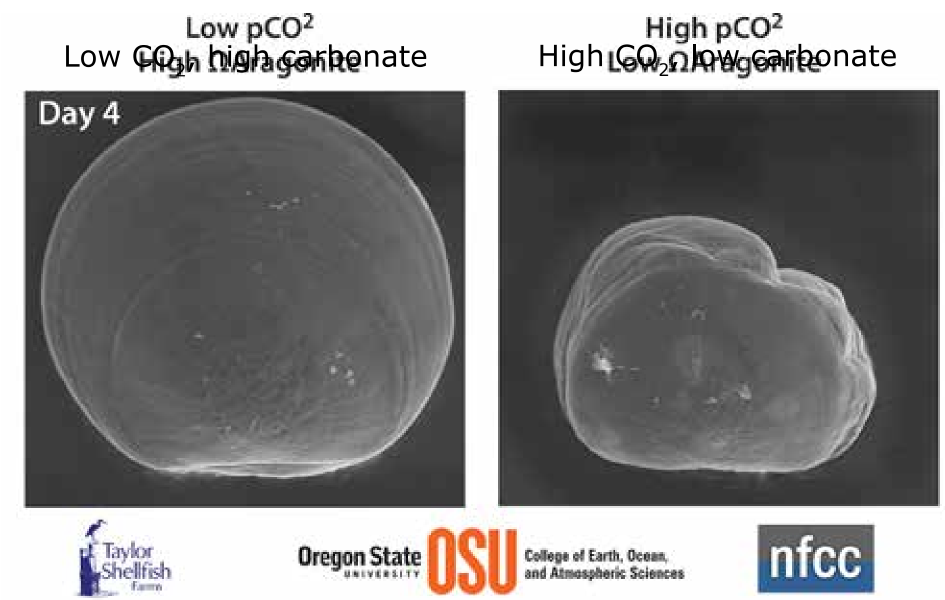
STANDARDS

NGSS: HS-LS2-6; Engaging in Argument from Evidence; Cause and Effect

CCSS: 9-10.SL.1; 9-10.WHST.10

OLP: 6d, e

OELS: 1b, c; 3b



Pacific oyster larvae, four days post-fertilization, from the same spawn, raised by the Taylor Shellfish Hatchery in natural waters of Dabob Bay, WA. Shell development is impaired under more acidified conditions (high CO_2, low carbonate). (Image source: Brunner/Waldbusser)

KEY POINTS

- Adding CO_2 to seawater causes multiple changes in chemistry, resulting in a decrease of both pH and carbonate ion concentration ($[CO_3^{2-}]$).
- Some organisms are impacted by the change in pH while others are impacted by the decreased $[CO_3^{2-}]$.
- The pH and $[CO_3^{2-}]$ vary over time due to natural processes like photosynthesis, respiration, and upwelling.
- Human actions are causing a long-term shift in pH and $[CO_3^{2-}]$; this shift occurs in addition to preexisting natural variation.

ENDURING UNDERSTANDINGS

- Human actions lead to changes in ecosystems.
- Changes in one portion of a system can lead to multiple changes in the rest of the system.

OBJECTIVES

Students will be able to:

- Describe how adding CO_2 to seawater changes ocean chemistry (lowers pH and carbonate ion concentration).
- Explain how natural processes (photosynthesis, respiration, upwelling) influence local water chemistry.
- Explain patterns in water quality data collected at Whiskey Creek Shellfish Hatchery.

SETUP

- Make copies of student handout (one per student).
- Open PowerPoint presentation (bit.ly/2W1CTLl).
- Obtain supplies for demonstration.

LESSON PLAN

Engage/Explore: Candles floating in indicator

This demo uses candles floating on water with an indicator solution in a closed container to simulate OA from fossil fuel combustion. Students are asked to connect what they observe in this model to OA.

Procedure

1. **Place a clear salad bowl** on top of a white background (such as a paper towel). Fill the bowl about half full with distilled water.
2. **Add several drops of universal indicator** to the bowl. Make sure the water is visibly green in color.
3. **Place two to four floating candles** on top of the solution. Light the candles and cover the bowl with another salad bowl. Take note of the color of the water at the start of the experiment.

Figure 1 - *Floating candles setup (BIOACID).*

4. **Observe the color change** of the water at the air/water interface (upper few millimeters of the water; see Figure 1).
5. After watching the demo, **students draw and annotate** their notes (see Teacher Answer Key).
6. **Discuss what students wrote/drew/saw** as a class.

This activity is modified from BIOACID's Experiment 2. See writeup for additional notes: bit.ly/2U8NoH1

While this is presented as a demo, the change on the surface of the indicator is subtle. You could use a document camera to project the air-water interface. For an alternative version that can be done at students' desks without fire, see the Exploratorium's Ocean Acidification in a Cup*: bit.ly/2UhBWZP*

The original write-up uses three bowls: room temperature, ice water, and a control where the candles are not lit. This would be a nice addition if you plan to go into detail on the relationship between temperature and gas exchange.

Slightly offset the top bowl to have the candles burn longer.

Explain Lecture on Carbonate and Upwelling

This approach is similar to Aquarium of the Bay's Lesson 2: bit.ly/2I9bf7L

Changes in Carbonate

1. **Project Table 1** (included in slides, bit.ly/2W1CTLl).

Table 1 - Carbonate Species

Name	Chemical Formula
Carbonic Acid	H_2CO_3
Bicarbonate	HCO_3-
Carbonate	CO_3^{2-}

2. **Ask students to compare** the different molecules. In their notes, write down what they notice. *(The number of hydrogen atoms; the charges.)*

3. **Review the steps to OA** previously discussed. Project the equations (see slides) and have students fill in blanks in their notes:

The equation numbering matches Lesson 2.

$CO_2(g) \leftrightarrow CO_2(aq)$ (eq-3)
$CO_2 (aq) + H_2O \leftrightarrow$ ________ (eq-4)
$H_2CO_3 \leftrightarrow$ ________ $+ HCO_3^-$ (eq-5c)

"Why does adding CO_2 to water make it more acidic/decrease the pH?" *(CO_2 reacts and releases extra H^+ into the solution)*

"Where do you see that in these equations?" *(In the last equation, the product is H^+, which means it is created. We saw yesterday that increasing the [H^+] decreases the pH.)*

4. **Introduce one final reaction** between carbonate and H^+ (see slides).

"Some of the H^+ that is created reacts with carbonate, which is naturally occurring in seawater, according to the following reaction:"

$H^+ + CO_3^{2-} \leftrightarrow HCO_3^-$ (eq-6)

"What does this equation suggest happens to the [CO_3^{2-}]?"
(It decreases, meaning there are fewer carbonate ions around.)

KEY POINT: Adding CO_2 to seawater lowers the pH *and* decreases the carbonate concentration, among other changes. Both changes potentially impact marine organisms.

Upwelling

5. Introduce upwelling.

"The U.S. west coast is known as an ocean acidification hotspot. We are one of the first places, in addition to the polar oceans, that will experience the impacts of OA. The reason we are so vulnerable is because of something called upwelling."

"Has anyone heard of upwelling? What is it?" (Upwelling is a process where deep, cold water rises to the surface.)

Channel Islands National Park/ Marine Sanctuary's Lesson 2 includes an upwelling demo: bit.ly/2UNIuU0

Definition from NOAA: bit.ly/2I6Fv3n

6. Explain upwelling.

"During the summer months in the Pacific Northwest, winds blow from the north. When they do, this causes deep ocean water to rise to the surface."

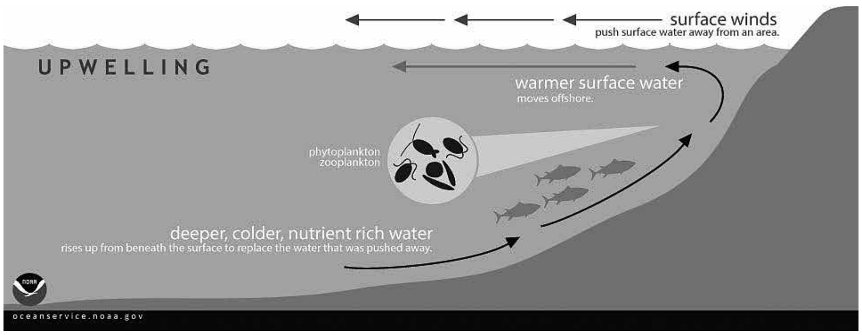


***Figure 2** - Upwelling. A simplified example of upwelling along the west coast of North America (NOAA).*

In the summer, our winds typically blow from north to south, but because the earth is spinning, the Coriolis effect and Ekman transport cause the surface water to move 45 degrees to the right of where the wind comes from. This means our surface water moves west, away from the coast (see NOAA's explanation at bit.ly/2U7nK5p).

7. Draw a t-chart with surface ocean at left and deep ocean at right.

8. Students brainstorm differences between deep and surface ocean.

"In what ways do you think deep ocean water might be different from water on the ocean's surface?" (Student responses will vary. See Table 2 for some differences.)

Table 2 - Comparison between surface and deep ocean.

Surface ocean	Deep ocean
• In contact with atmosphere (gases can be exchanged)	• No contact with atmosphere (gases are trapped)
• Sunlight (so photosynthesis can remove CO_2 from the water)	• No sunlight (without photosynthesis, CO_2 builds up)
• Low nutrients (plants/phyto-plankton use them)	• High nutrients (they're released when organisms respire and decay)

9. **Explain differences** between deep and surface ocean:

"In many ways, the surface ocean and deep ocean could be considered two separate parts of the ocean. In the deep ocean it is dark and cold. The water is separated from the surface. But organisms die and sink, and living creatures in the deep continue to respire. This combination makes it so that the deep upwelled water is rich in nutrients (bits of digested organisms) and high in CO_2 (a respiration waste product). These nutrients fuel growth, but the extra CO_2 also lowers the pH and carbonate ion concentrations in the water, making it harder for some organisms to survive."

Elaborate What's happening to Whiskey Creek Shellfish Hatchery's water?

This is a modification of an activity by Hilary Palevsky, University of Washington: bit.ly/2GgsGBn

1. **Introduce the data exploration activity** by reading the introduction on the student handout.

2. **Students work through the activity** in their notes.

The questions walk them through how photosynthesis and respiration influence CO_2 concentrations and pH over the course of a day. Then, students work with graphs of data from the hatchery to apply these understandings. Some students will likely struggle with application and interpretation in this section. Use the Teacher Answer Key to help answer questions and guide discussion.

Some of our students suggested that changes in human activity cause the pattern seen in the Whiskey Creek data. They thought we might emit more CO_2 at night when we light our homes. While CO_2 emissions vary on a daily cycle by level of urbanization, they are generally higher during the daytime in urban areas (Ueyama & Ando 2016).

Evaluate Challenge Question

1. **Students answer the question** below as a final check-and-synthesis question. You could use this as an exit ticket.

"We have seen that ocean acidification is a small decrease in pH per year. If ocean acidification is a smaller change than what naturally happens over the course of days, weeks, and months, why do you think scientists are so concerned about ocean acidification?" (While OA results in only a small change in overall pH each year, it is a persistent decrease over time. Natural variation will continue to occur, but OA and carbonate ion concentrations mean pH will get lower and lower during those natural events.)

This question is meant to get students to realize that, while the graphs show a drop in omega and pH during upwelling, OA caused these values to drop to below where they had been in prior years. In essence, OA means these low pH/low carbonate days ("bad days" for larval oysters) are becoming more frequent and more extreme.

Teacher Note *We found it helpful to compare this situation to variations in temperature. There is a natural range in temperature where you live (say, 30–80°F). The temperature equivalent of OA would mean that this range slowly decreases, so it might be 25–75°F, then 20–70°F, and eventually 0–50°F. There is still variation, but the low temperatures are much lower than they used to be. If you cannot adapt to colder temperatures, you may struggle to survive.*

EDUCATOR BACKGROUND

Carbonate Chemistry

There are three major inorganic forms of dissolved carbon dioxide in seawater: free aqueous carbon dioxide [CO_2 (aq)], bicarbonate [HCO_3^-], and carbonate [CO_3^{2-}] (Zeebe, 2012). These chemical variants are known collectively as dissolved inorganic carbon. When gaseous CO_2 is absorbed by the ocean, the concentration of dissolved CO_2 in seawater (pCO_2) increases. This dissolved carbon dioxide reacts with water molecules and undergoes a series of near-instantaneous, reversible equilibrium reactions:

$$CO_2(g) \leftrightarrow CO_2(aq)$$

$$CO_2(aq) + H_2O \leftrightarrow H_2CO_3$$

$$H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

$$H^+ + CO_3^{2-} \leftrightarrow HCO_3^-$$

Under today's oceanic conditions, bicarbonate (HCO_3^-) is favored, and when bicarbonate is formed through the dissociation of the carbonic acid (H_2CO_3), a hydrogen ion (H^+) is released. Since pH = $-\log[H^+]$, adding CO_2 to seawater increases the [H^+], which can be described as "making it more acidic" or "decreasing the pH." However, the final equation above is typically written in the opposite direction, which unintentionally suggests that carbonate is formed under typical oceanic conditions. The following chemical reaction helps clarify the net changes in the carbonate system:

$$CO_2 + H_2O + CO_3^{2-} \rightarrow 2HCO_3^-$$

By combining information from the first four equations into the net chemical reaction, we see that the overall result of the ocean absorbing CO_2 from the atmosphere is an increase in the pCO_2, [H^+], [CO_2 (aq)], [H_2CO_3], and [HCO_3^-] and a decrease in pH and [CO_3^{2-}].

Carbonate Saturation State

An additional concept of importance to marine calcifying organisms, or those that build shells or hard parts out of calcium carbonate, is the carbonate saturation state (Ω, "omega"), which is defined as:

$$\Omega = [Ca^{2+}]\,[CO_3^{2-}] / K^*_{sp}$$

Carbonate saturation state is the product of the calcium ion concentration times the carbonate ion concentration divided by the apparent solubility constant (K^*_{sp}). Carbonate saturation states >1 indicate conditions in which solid calcium carbonate is thermodynamically favored, while carbonate saturation states <1 indicate thermodynamically unfavorable conditions for solid calcium carbonate. In other words, at $\Omega>1$, shell formation is favored, and at $\Omega<1$, shell formation is not favored (instead, dissolution is favored). This does not, however, say anything about the rate of reaction, and therefore, does not mean that shells immediately and completely dissolve when $\Omega<1$.

A Complicated Experiment

Ultimately, it is worth keeping in mind that OA represents what could be considered a complicated experiment. As science teachers, we begin by teaching our students to design experiments so that only one variable changes. With OA, when CO_2 is added to seawater, carbon dioxide enters the carbonate system and at least six additional variables change at the same time. Thus, if a researcher were to try to simulate future ocean conditions by adding CO_2 to seawater, it would be difficult without careful controls of seawater chemistry to know whether an organism that responds to a change was responding to the increase in CO_2, decrease in pH, decrease in Ω, or one of the other chemical changes that co-occurred when CO_2 was absorbed. Additionally, depending on the conditions of the seawater (temperature, salinity, pressure, total alkalinity, etc.) being tested, the amount of change in the carbonate system per unit of CO_2 added would differ. This reality makes the scientific study of OA complicated and, in the mind of the authors, much more exciting. It also, however, makes it difficult to reach conclusions about cause and effect when pH or pCO_2 are manipulated without controlling for and reporting other aspects of the carbonate system.

Seawater Chemistry Varies Naturally

In temperate coastal marine ecosystems, there can be large variations in seawater conditions over short time scales (hours to weeks). While there are several factors that contribute to fluctuations in coastal ecosystems, two processes are of primary importance in coastal ecosystems in the Pacific Northwest: net community metabolism (or the balance between photosynthesis and respiration) and seasonal upwelling.

The amount of natural variation in pH is not constant across the ocean (see Figure 3). Temperate kelp forests (such as those off the U.S. west coast) have larger variation; tropical coral reefs (for example, French Polynesia) are relatively stable throughout the year; and polar oceans show large variations during summer (peak productivity) and small variations in winter (when productivity decreases) (Kapsenberg et al., 2015).

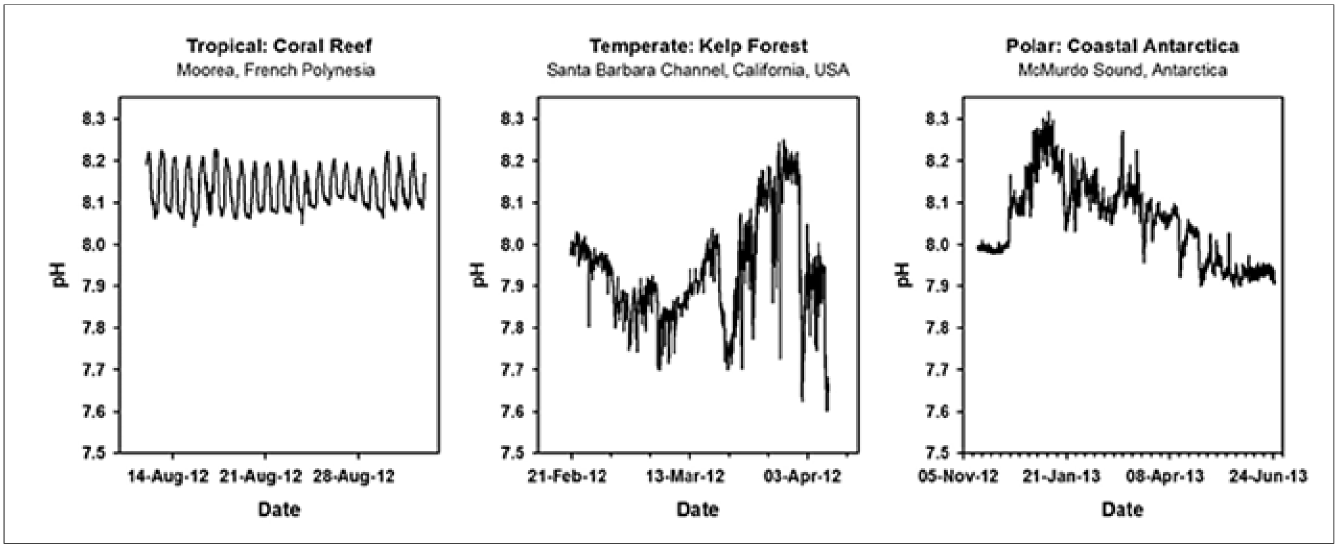


Figure 3 *- pH variation by ecosystem. (Kapsenberg et al. 2015)*

Net Community Metabolism

Net community metabolism describes the balance between photosynthesis and respiration. Photosynthesis and respiration are processes with opposite effects, with respect to carbon dioxide. Photosynthesis removes CO_2 from seawater, while respiration adds CO_2 to seawater:

Photosynthesis (simplified): $CO_2 + H_2O \rightarrow CH_2O + O_2$

Respiration (simplified): $CH_2O + O_2 \rightarrow CO_2 + H_2O$

Photosynthesis, however, occurs only during the daytime, while respiration is continuous. Additionally, photosynthesis occurs only in the upper 50–200m where sunlight is sufficient to fuel the process, while respiration occurs throughout the ocean. Measurements of water chemistry in areas with large populations of primary producers show pH level fluctuations of 0.3–0.5 pH units over the course of a day (Kapsenberg et al., 2015), rising as photosynthesis removes CO_2 during daylight hours and falling overnight as respiration continues releasing CO_2 back into the environment.

Upwelling

Upwelling also contributes to seasonal changes in water conditions. In the Pacific Northwest, summer winds blow from the north, deflecting surface waters offshore. Cold, nutrient-rich, deep water comes up from the depths to replace the displaced surface water. This upwelled water has naturally elevated carbon dioxide levels because the water that upwells in Oregon has been below the surface for roughly 50 years (Feely et al., 2008). While the deeper waters were away from the surface, where photosynthesis occurs, respiration continued, adding CO_2 to the water.

Additionally, upwelling often triggers summer algal blooms. These blooms reduce CO_2 levels in the short term, creating temporary relief from decreased pH and Ω levels, but once the blooms die, the organisms sink to the bottom and decompose, thus elevating CO_2 levels at depth.

TEACHING NOTES

Whiskey Creek Shellfish Hatchery Data

Data from Whiskey Creek Shellfish Hatchery in 2009 helps put the chemistry of OA into context. Students can see how pH and Ω ("omega") co-vary, the pattern between larval success and Ω, and the impacts of photosynthesis and respiration on local water conditions over short timescales. Less intuitive is why small changes in ocean chemistry (ocean acidification) would matter, given the context of widely varying oceanic conditions over shorter time scales (seasonal upwelling and net community metabolism). The key idea is that of changing baselines: while organisms in coastal ecosystems may be used to living in highly varying environments, OA adds a consistent downward trajectory to pH and Ω values. This longer-term trend could cause organisms to experience extreme conditions more often, beyond the conditions to which they've adapted. Additional impacts will be addressed in Lesson 4.

Misconceptions to Avoid in this Lesson

MISCONCEPTION | **Ocean Acidification Kills Oysters by Dissolving Their Shells**

Students could conclude that the decreased pH dissolved larval oyster shells, killing larval oysters. In reality, the situation is a bit more complicated. Larval oysters rely on egg energy reserves when building their first shell. There is essentially a six-hour window in which larvae need to create their shells. If they are unable to do so, they die. With OA, the decrease in saturation state causes larvae to expend more of their initial energy reserves in the shell building phase. Some larvae do not complete their shell within the allotted time and perish. Those that do within the six-hour time window finish with lower energy reserves, impacting subsequent growth and development. Thus, for larval oysters, OA creates an energy bottleneck; it usually does not directly dissolve their shells (personal communication with Dr. B. Hales and Dr. G. Waldbusser).

NAME________________

TEACHER **ANSWER KEY**

PERIOD______________

STUDENT **HANDOUT**

LESSON 3 **Chemistry of OA** *continued*

Demo Floating Candles

1. Explain with pictures and words what happened in this demo. In what ways does it show ocean acidification? In what ways is it different from ocean acidification? (Explanations should include these key words: combustion [burning], CO_2, absorb, reaction, pH.)

Student answers will vary, but may include:

We placed candles on top of water with indicator in it. We then lit the candles and closed the top. When candles burn, they release CO_2, and the lid helps create a buildup of CO_2 inside the container. This is similar to how humans burn fossil fuels, and as we do, CO_2 is released and builds up in the atmosphere. A few days ago, we saw graphs of CO_2 increasing over time. As the CO_2 builds up, some of it is absorbed into the water because of diffusion (molecules move from high to low concentration). When CO_2 goes into the water, a chemical reaction happens, and eventually the surface of the water-indicator solution starts to change colors. This color change shows that a reaction has occurred and that the pH is dropping (the solution is becoming more acidic). This is similar to ocean acidification because the CO_2 we put into the atmosphere from burning fossil fuels is absorbed by the ocean, and the ocean is also becoming more acidic (although it is a base and will remain a base in the future).

This demonstration is a bit different from ocean acidification because of the speed (this happens way faster), scale (a bowl of water versus the entire globe/ocean), and source (candle vs fossil fuels and other activities). It is also different because the ocean is saltwater but we used distilled water, and our demo was pretty simple, whereas the ocean is complex, with mixing, winds, animals, etc.

NAME__________________

PERIOD________________

STUDENT **HANDOUT**

LESSON 3 **Chemistry of OA** *continued*

Ocean Acidification Chemical Reactions

Name	Chemical Formula
Carbonic Acid	H_2CO_3
Bicarbonate	HCO_3^-
Carbonate	CO_3^{2-}

2. Compare the molecules in the table above. What do you notice?

I notice that they all have CO_3, but they have between 0 and 2 hydrogen atoms and different charges.

3. Fill in the blanks below:

$$CO_2\ (g) \leftrightarrow CO_2\ (aq)$$

$$CO_2\ (aq) + H_2O \leftrightarrow H_2CO_3$$

$$H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

There's another reaction that happens due to ocean acidification:

$$H^+ + CO_3^{2-} \rightarrow HCO_3^-$$

4. What does this suggest happens to the $[CO_3^{2-}]$?

The last reaction suggests the amount of CO_3^{2-} goes down as you add carbon dioxide to the water because the carbonate reacts with hydrogen ions.

NAME__________________

TEACHER **ANSWER KEY**

PERIOD________________

STUDENT **HANDOUT**

LESSON 3 **Chemistry of OA** *continued*

What is happening to Whiskey Creek Shellfish Hatchery's water?

We have introduced several concepts over the past few days. Each of these influences the water chemistry. We are now going to use real water-quality data that was collected at Mark and Sue's shellfish hatchery (named Whiskey Creek) in 2009, to figure out why ocean acidification was blamed for the die-offs.

5. In the table below, summarize what we've learned about ocean acidification by circling the word that describes how each measure changes as a result of OA.

Measure	How it changes
$[H^+]$ "hydrogen ion concentration"	*Increase* or Decrease?
pH	Increase or *Decrease*?
$[CO_3^{2-}]$ "carbonate ion concentration"	Increase or *Decrease*?

The equation below shows a simplified formula for photosynthesis:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

"carbon dioxide + water forms glucose (sugar) + oxygen"

6. Based on the equation above, would photosynthesis by aquatic plants cause the concentration of carbon dioxide in the water to increase, or decrease? Explain.

Photosynthesis would decrease the amount of CO_2 in water because it is a reactant, on the left side of the equation, which means it gets used up in the reaction. Plants are taking in CO_2 to make sugar, removing it from the water.

7. What would this change in $[CO_2]$ do to the water's pH? Explain.

We saw in the demo that adding CO_2 lowers pH, making water more acidic. Photosynthesis does the reverse—removes CO_2—which would make the pH increase. In other words, the water should become more basic because of photosynthesis.

8. During what time of day would you expect plant and phytoplankton photosynthesis to influence the $[CO_2]$ and pH of seawater? *Hint: When does photosynthesis occur?*

I would expect CO_2 to go down during the day because that's when plants photosynthesize because there is sunlight.

NAME_______________

TEACHER **ANSWER KEY**

PERIOD_______________

STUDENT **HANDOUT**

LESSON 3 **Chemistry of OA** *continued*

The equation below shows a simplified formula for respiration:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

"glucose (sugar) + oxygen forms carbon dioxide + water"

9. Based on the equation above, would respiration cause the [CO_2] to increase, or decrease? Explain.

Respiration would cause the CO_2 concentration to increase. CO_2 is a product, on the right side, which means the process creates CO_2.

10. What would this change in [CO_2] do to the water's pH? Explain. *Hint: think about the SodaStream demo.*

We saw in the demo that adding CO_2 lowers the pH, making water more acidic.

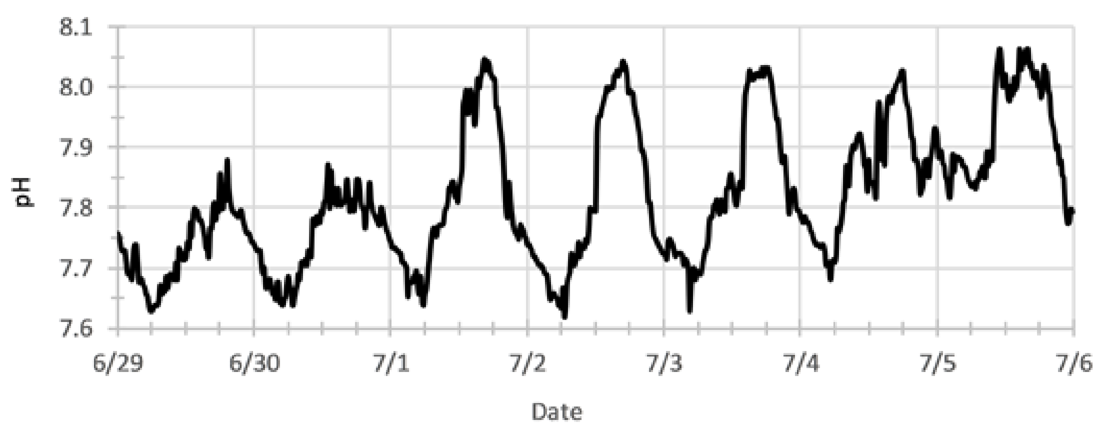
11. What types of organisms carry out respiration?

All living organisms (plants, animals, and many single-celled organisms) respire.

12. During what time of day does respiration occur?

Respiration happens all day long both during the day and at night.

The graph below shows pH at Whiskey Creek Shellfish Hatchery over the course of one week in July 2009. Use the graph to answer the questions that follow:



13. What patterns/trends do you notice in this data?

I notice that there is an up and down pattern, and that the overall pH values seem to be increasing over time.

LESSON 3 **Chemistry of OA** *continued*

14. At what time of day is pH the lowest?

It looks like pH is the lowest around 6 a.m. every day.

15. At what time of day is pH the highest?

It looks like pH is the highest around 3 to 6 p.m. every day.

16. What might explain these daily changes in pH?

Photosynthesis and respiration could be responsible, at least in part. It looks like pH goes up during the day, because photosynthesis removes CO_2 from the water. At night, when plants aren't photosynthesizing but are still respiring, respiration could cause the pH to drop until morning, when the sun comes out and photosynthesis begins again.

17. Larvae oysters generally do better when pH is higher. What time of day would you recommend the hatchery take water out of the bay to fill its tanks?

I would recommend they take water out in the late afternoon, 3 to 6 p.m. This is when the pH is at its highest, because the plants in the water have been removing CO_2 all day long. The worst time of day to fill their tanks with water from the bay would be in the morning around 6 a.m., because the pH is the lowest it will be for the day at that time.

Note *Whiskey Creek Shellfish Hatchery used to fill their tanks in the morning. After collaborating with researchers at Oregon State University, they realized this was hurting their larvae. They changed their practice and started filling up their tanks in the afternoon.*

NAME_________________

TEACHER **ANSWER KEY**

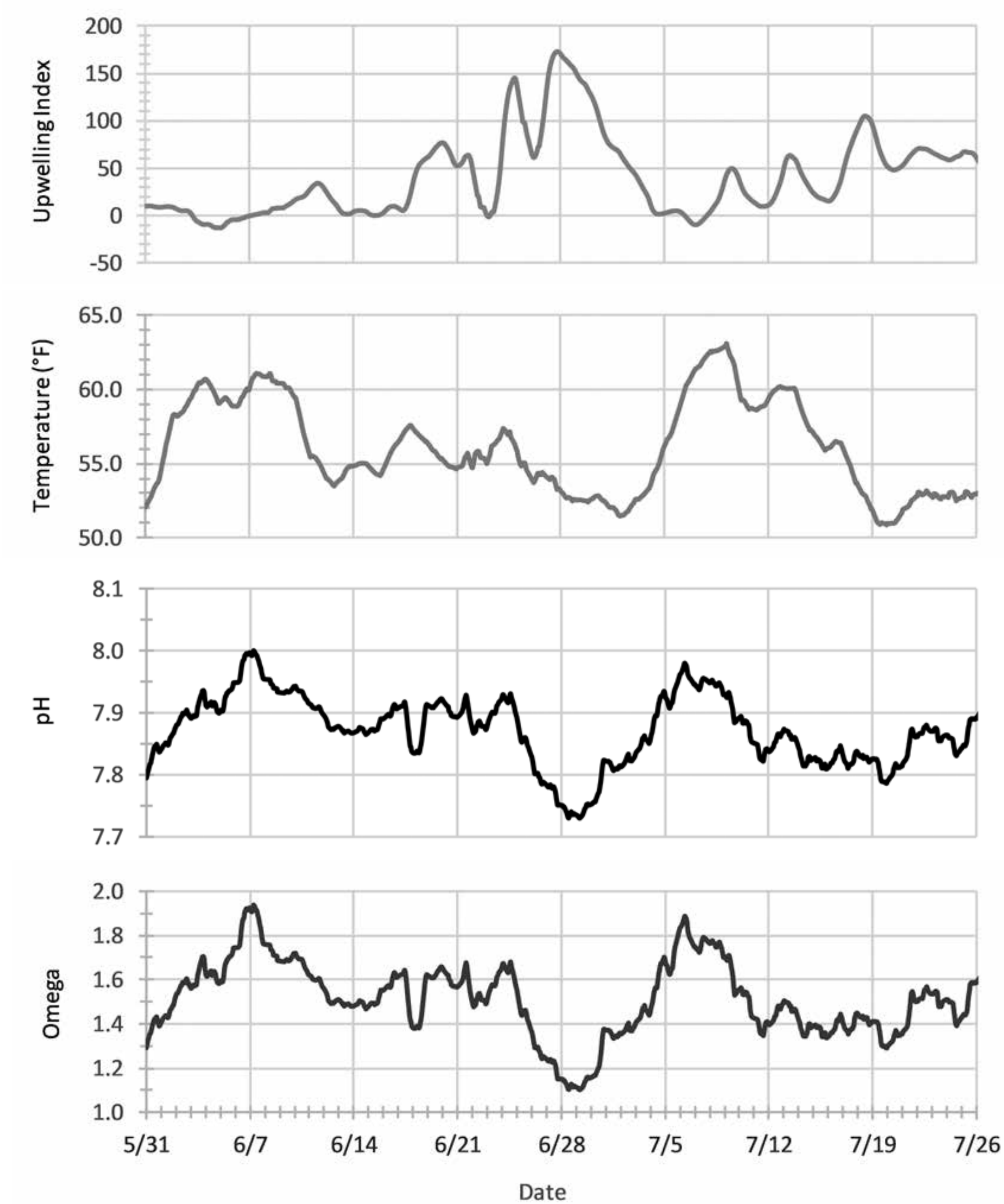
PERIOD_______________

STUDENT **HANDOUT**

LESSON 3 **Chemistry of OA** *continued*

The graphs below show Whiskey Creek Shellfish Hatchery water quality data from summer 2009.

Note *Upwelling index is a measure of the strength of upwelling. More positive numbers reflect stronger upwelling. Omega is a measure related to the amount of carbonate in the water. Larger numbers mean it is easier (less energy is required) for organisms to build shells. When omega is below 1.6, oyster larvae die.*



NAME__________________

PERIOD________________

STUDENT **HANDOUT**

LESSON 3 **Chemistry of OA** *continued*

Use the graphs on the previous page to answer the questions that follow.

18. Based on the upwelling index graph, when was the strongest upwelling event in 2009?

The peak of upwelling was around 6/28, but the upwelling values are high from 6/23 to 7/4.

19. Explain the relationship between upwelling and water temperature.

While the relationship isn't really obvious in the graph, it looks like when upwelling is high, the water temperature is colder. This makes sense, because upwelling brings up cold water from deep in the ocean.

20. Explain the relationship between upwelling and pH.

It also looks like when upwelling is high, pH is lower or the water is more acidic. This might be because there is no photosynthesis in the deep ocean where there is no sunlight, but there is respiration and decomposition. So, CO_2 *is being added to the water in the deep ocean but not being taken out, which would make the water more acidic.*

21. Larval oysters die when omega is below 1.6. For roughly how much of the summer was omega below 1.6?

Most of the summer! It looks likes omega is above 1.6 for only a few weeks. In other words, omega is below 1.6 for the majority of the summer, which is why so many larval oysters died.

22. Why do you think scientists concluded that ocean acidification was causing the oysters to die? Wouldn't it make more sense to conclude that upwelling caused the deaths?
(Hint: Upwelling occurs in Oregon every summer.)

I think the scientists concluded ocean acidification was to blame because upwelling is a natural event that happens every summer. The upwelling by itself shouldn't be causing larval oysters to die, because they have always had to live with upwelling. The scientists blamed ocean acidification because it is a long-term decrease in pH and carbonate ion concentration. Over time, the ocean became low enough that the larval oysters could no longer handle the upwelling conditions. In other words, upwelling lowers the pH and $[CO_3^{2-}]$ *every summer, but ocean acidification made the pH and* $[CO_3^{2-}]$ *levels even lower than what the larval oysters can tolerate.*

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STUDENT **HANDOUT**

LESSON 3 **Chemistry of OA** *continued*

Demo Floating Candles

1. Explain with pictures and words what happened in this demo. In what ways does it show ocean acidification? In what ways is it different from OA? *(Explanations should include these key words: combustion [burning], CO_2, absorb, reaction, pH.)*

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STUDENT **HANDOUT**

LESSON 3 **Chemistry of OA** *continued*

Ocean Acidification Chemical Reactions

Name	Chemical Formula
Carbonic Acid	H_2CO_3
Bicarbonate	HCO_3^-
Carbonate	CO_3^{2-}

2. Compare the molecules in the table above. What do you notice?

3. Fill in the blanks below:

$$CO_2\ (g) \leftrightarrow CO_2\ (aq)$$

$$CO_2\ (aq) + H_2O \leftrightarrow \_\_\_\_\_\_\_\_$$

$$H_2CO_3 \leftrightarrow \_\_\_\_\_\_\_\_ + HCO_3^-$$

There's another reaction that happens due to ocean acidification:

$$H^+ + CO_3^{2-} \rightarrow \_\_\_\_\_\_\_\_$$

4.What does this suggest happens to the $[CO_3^{2-}]$?

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STUDENT **HANDOUT**

LESSON 3 **Chemistry of OA** *continued*

What is happening to Whiskey Creek Shellfish Hatchery's water?

We have introduced several concepts over the past few days. Each of these influences the water chemistry. We are now going to use real water-quality data that was collected at Mark and Sue's shellfish hatchery (named Whiskey Creek) in 2009, to figure out why ocean acidification was blamed for the die-offs.

5. In the table below, summarize what we've learned by circling the word that describes how each measure changes as a result of OA.

Measure	How it changes
$[H^+]$ "hydrogen ion concentration"	Increase or Decrease?
pH	Increase or Decrease?
$[CO_3^{2-}]$ "carbonate ion concentration"	Increase or Decrease?

The equation below shows a simplified formula for photosynthesis:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

"carbon dioxide + water forms glucose (sugar) + oxygen"

6. Based on the equation above, would photosynthesis by aquatic plants cause the concentration of carbon dioxide in the water to increase, or decrease? Explain.

7. What would this change in $[CO_2]$ do to the water's pH? Explain.

8. During what time of day would you expect plant and phytoplankton photosynthesis to influence the $[CO_2]$ and pH of seawater? *Hint: When does photosynthesis occur?*

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STUDENT **HANDOUT**

LESSON 3 **Chemistry of OA** *continued*

The equation below shows a simplified formula for respiration:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

"glucose (sugar) + oxygen forms carbon dioxide + water"

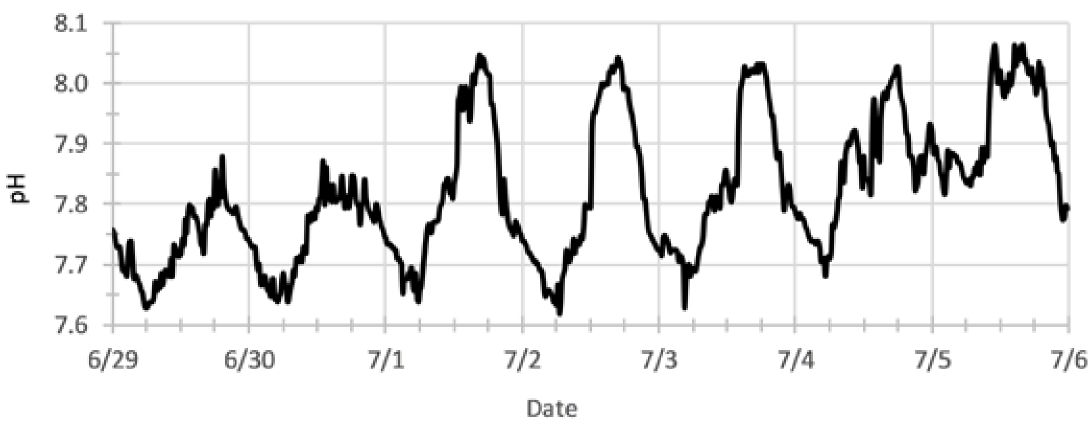
9. Based on the equation above, would respiration cause the [CO_2] to increase, or decrease? Explain.

10. What would this change in [CO_2] do to the water's pH? Explain. *Hint: think about the SodaStream demo.*

11. What types of organisms carry out respiration?

12. During what time of day does respiration occur?

The graph below shows pH at Whiskey Creek Shellfish Hatchery over the course of one week in July 2009. Use the graph to answer the questions that follow:



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STUDENT **HANDOUT**

LESSON 3 **Chemistry of OA** *continued*

13. What patterns/trends do you notice in this data?

14. At what time of day is pH the lowest?

15. At what time of day is pH the highest?

16. What might explain these daily changes in pH?

17. Larvae oysters generally do better when pH is higher. What time of day would you recommend the hatchery take water out of the bay to fill its tanks?

NAME________________

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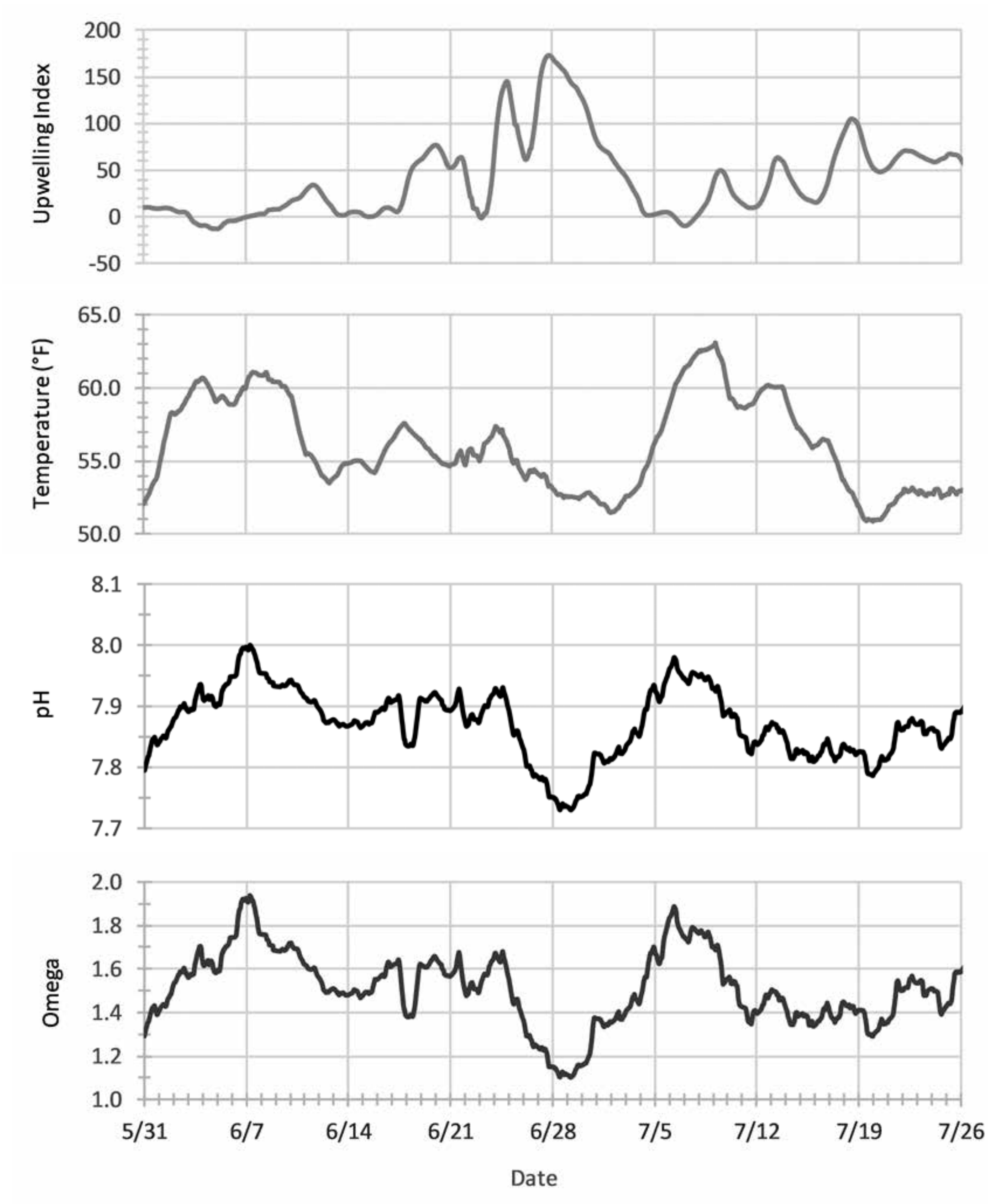
STUDENT **HANDOUT**

LESSON 3 **Chemistry of OA** *continued*

The graphs below show Whiskey Creek Shellfish Hatchery water quality data from summer 2009.

Note *Upwelling index is a measure of the strength of upwelling. More positive numbers reflects stronger upwelling. Omega is a measure related to the amount of carbonate in the water. Larger numbers means it is easier (less energy is required) for organisms to build shells. When omega is below 1.6, oyster larvae die.*



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STUDENT **HANDOUT**

LESSON 3 **Chemistry of OA** *continued*

Use the graphs on the previous page to answer the questions that follow.

18. Based on the upwelling index graph, when was the strongest upwelling event in 2009?

19. Explain the relationship between upwelling and water temperature.

20. Explain the relationship between upwelling and pH.

21. Larval oysters die when omega is below 1.6. For roughly how much of the summer was omega below 1.6?

22. Why do you think scientists concluded that ocean acidification was causing the oysters to die? Wouldn't it make more sense to conclude that upwelling caused the deaths? (Hint: Upwelling occurs in Oregon every summer.)

LESSON 4

What Are the Impacts of OA?

OVERVIEW

In this lesson, students conduct online research to explore how ocean acidification (OA) could impact marine ecosystems and the humans who rely on them. It seeks to avoid the overtly dire tone and misconceptions that often accompany OA lessons, including notions that "all shells will dissolve" and "the oceans will be inhospitable." Instead, students are responsible for finding out what it might mean and teaching each other about the possible impacts on ecosystems and people.

This lesson begins with a formative probe to uncover existing student beliefs on the impacts of OA. Then, students watch a four-minute video of scientists, shellfish hatchery workers, and marine resource managers describing what we know and don't know about the impacts of OA. Next, students explore additional possible impacts through independent research and present their findings to their classmates the next day. The lesson finishes with a synthesis of what the students learned.

Teacher Note *Online student research is a new addition to this latest edition of this module. In prior iterations, we found that students did not develop the broad understanding of what OA might mean for ecosystems. We'd love to hear your feedback (brian.erickson@oregonstate.edu) on this new approach to teaching the impacts of OA!*

MATERIALS

- Copies of student handout (one per student)
- Computer, projector, and speakers
- Presentation slides and videos
- Computers with Internet connection for student research

STANDARDS

NGSS: HS-LS2-6; Engaging in Argument from Evidence

CCSS: 9-10.RST.2; 9-10.SL.1; 9-10.WHST.10

OLP: 6b, d, e

OELS: 1b, c; 3b

A prior version of this curriculum had students build an Oregon marine food web (modified from the Channel Islands OA curriculum, bit.ly/2UNIuU0), then use four research-based scenarios for a short but structured discussion of possible impacts of OA. Additional information on these activities can be found in Brian's thesis: bit.ly/2Z5yTXX

KEY POINTS

- There will be some winners and losers of ocean acidification (some organisms will benefit, while others will face negative consequences).
- Calcifiers, such as corals, shellfish, and some plankton, are especially vulnerable.
- Ocean acidification could have major impacts on marine ecosystems and the humans who rely on them for food, income, and well-being.

ENDURING UNDERSTANDINGS

- Marine ecosystems, and the humans who rely on them, are interconnected.
- Human actions lead to changes in ecosystems.
- Changes in one portion of a system can lead to multiple changes in the rest of the system.

OBJECTIVES

Students will be able to:

- Describe some ways ocean acidification could impact organisms, food webs, and humans.
- Communicate research findings to classmates.

SETUP

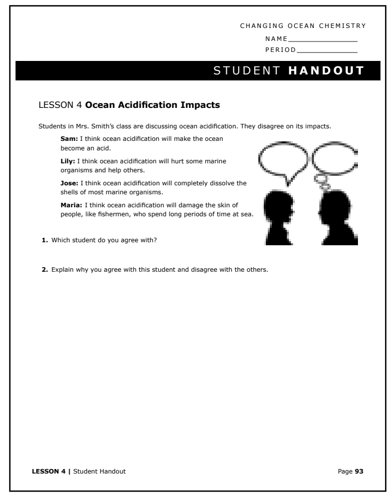
- Make copies of student handouts (one per student).
- Open PowerPoint presentation and pre-load video (both available at bit.ly/2W1CTLl).
- Reserve laptop cart/computer lab space for student research.

LESSON PLAN

Formative Probe

Use the formative probe to uncover students' prior understandings about the impacts of OA before presenting information on the topic. This is not meant to see who knows the "right answer." Instead, this probe helps you better plan future instruction by identifying what students currently think.

This formative probe was inspired by Teaching for Conceptual Understanding in Science *(Konicek-Moran and Keeley, 2015) and the* Uncovering Student Ideas in Science *series. The probe was created in response to persistent alternative conceptions uncovered in our research project. It has not been classroom tested.*


CHANGING OCEAN CHEMISTRY
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STUDENT **HANDOUT**

LESSON 4 **Ocean Acidification Impacts**

Students in Mrs. Smith's class are discussing ocean acidification. They disagree on its impacts.

Sam: I think ocean acidification will make the ocean become an acid.

Lily: I think ocean acidification will hurt some marine organisms and help others.

Jose: I think ocean acidification will completely dissolve the shells of most marine organisms.

Maria: I think ocean acidification will damage the skin of people, like fishermen, who spend long periods of time at sea.

1. Which student do you agree with?

2. Explain why you agree with this student and disagree with the others.

LESSON 4 | Student Handout Page **93**

1. **Give students two minutes to write** a response to the probe in their handout.

   Students in Mrs. Smith's class are discussing ocean acidification. They disagree on its impacts.

   Sam: I think ocean acidification will make the ocean become an acid.

   Lily: I think ocean acidification will hurt some marine organisms and help others.

   Jose: I think ocean acidification will completely dissolve the shells of most marine organisms.

   Maria: I think ocean acidification will damage the skin of people, like fishermen, who spend long periods of time at sea.

   Which student do you agree with? Explain why you agree with this student and disagree with the others.

2. **Students discuss their ideas with a partner** or small group, then as a class.

   During this discussion, the teacher should listen to understand what students know and what has led them to this current belief. The discussion should be between students, not between student and teacher.

   Explanation The best answer is Lily's. While many discussions of OA focus on dissolution of shells of marine organisms, OA is predicted to impact entire ecosystems and food webs. This means that many organisms, especially those that use carbonate for shells and skeletons, will be negatively affected; however, some organisms will likely benefit from OA due to loss of predators, decreased competition, resistance to OA, etc.

The other three students' responses reinforce commonly held misconceptions about OA. Sam's idea that OA means the ocean will become an acid (below pH=7) is misguided because even though the ocean is becoming more acidic than it was (it is "acidifying"), it is predicted to reach an average pH of only 7.8, which is still basic, by 2100. Jose's response builds off of the common conception that "acids dissolve things." Furthermore, Jose's response echoes the heavy emphasis on dissolution found in reports of OA. While some organisms are vulnerable to dissolution due to OA (for example, pteropods), many organisms have ways to protect their shells from dissolution and can actively repair corroded shell. Therefore, while OA will impact shell formation and calcification, it does not mean that all shells will dissolve (and by extension, it does not mean there will be no more seashells). Maria's response is also based on the notion that "acids burn." While the change in ocean chemistry due to OA will have impacts on ecosystems and people, skin damage is not one of the predicted impacts.

Ecosystem Impacts Video

1. **Show Ecosystem Impacts video** (3:30, available at bit.ly/2W1CTLl). Students answer questions in their notes.
2. **Discuss the viewing questions** (see Teacher Answer Key).

Students in our study were reluctant to share how it felt to hear scientists say they didn't know what the impacts of OA would be. In their written notes, some students expressed fear/worry, while others asked why it took researchers so long to figure this out. These responses inspired the synthesis questions at the end of this lesson.

Interconnections between Humans and the Ocean

1. **Students brainstorm** ways in which humans and marine ecosystems are interconnected.

   Highlight both our dependence on the ocean and ways in which we change the ocean.

"In what ways do humans rely on the ocean?" *(Food, minerals, climate, transportation, shipping, recreation, well-being.)*

"Does the ocean rely on humans for anything?" *(Many students will say no, the ocean doesn't need humans. A few in each class may say the ocean relies on humans to avoid polluting/overharvesting.)*

Framing a conversation about climate or ocean change with a focus on values, such as inter-connections, can be an effective way to help individuals think about what is at stake and what can be done about an issue (Bales et al., 2015).

Researching Impacts of Ocean Acidification

Each student (or group of students) will be responsible for researching how OA is predicted to impact a different marine organism. After conducting Internet research and recording their findings on the student research handout or in their notebooks, students present their findings to small groups using a jigsaw activity.

For teachers without Internet/ classroom computers, you could print the Seattle Times *Sea Change Creatures page (bit.ly/2X5Splh) or the Smithsonian OA site (s.si.edu/2P1FhuX), give it to students and have them jigsaw their reading.*

See the student handout for a list of possible organisms.

1. **Introduce the research activity:**

   "Today we want to try to answer the question: 'What are the possible impacts of ocean acidification?' To do so, each of you is going to research how ocean acidification is predicted to impact a specific organism. Our goal is to create a list of different possibilities for what it could mean for marine organisms and for people."

2. **Direct students to look at their handout.** Tell students:

   "You will research the potential impacts of ocean acidification on an organism of your choosing. You will be responsible for presenting your findings to your classmates in small groups. Our goal is to gain a broad understanding of the range of impacts ocean acidification might have."

3. **Allow students to research** and prepare their presentation for the rest of the class period.

   A few recommendations:

   - Have students sign up for organisms, to ensure that a variety of organisms are being researched. You could do this in a number of ways, including on the board, online, or on a sheet of paper that gets passed around.
   - Make sure at least one student researches the possible benefits to photosynthesizers, like seagrass and diatoms.
   - Students will be responsible for presenting their findings to classmates in one or two minutes. The presentation will be a summary of what they learned:
     - What organism did they look at?
     - How might it be impacted by OA?
     - What impact would this have on other creatures and/or humans?

Some websites, such as CO_2 Science, bit.ly/2UNo65A, may seem legitimate to students but are actually climate/ocean change denial sites. If students use this site, the teacher could lead a discussion about reliable vs. unreliable websites and information.

Presentations: What Are the Impacts?

Instead of one set of all-class presentations, we recommend a modified jigsaw approach. Students will give quick presentations in small groups, then rotate to new groups and repeat. This approach allows students to practice presenting information in a low-stakes environment and exposes them to multiple and varying predicted effects of OA.

1. **Introduce the focus** of today's class:

   "Today, we'll be learning from each other's research on the impacts of ocean acidification. Our goal is to better understand what ocean acidification means for the ocean and for people."

2. **Pass out the student handout**, Learning about Ocean Acidification's Impacts.

3. **Model how students should take notes** during presentations. Since we've already talked about the Pacific oyster, use it as an example for how to fill out the table. You could prompt students to help you fill in the first row in their handout.

   Predicted impacts: *(Students should be able to explain that some larval oysters will die.)*

If you have a document camera, you could fill out the first row based on what students tell you about the impacts of ocean acidification on oysters.

4. **Show slide of four-day-old larval oysters** (available at bit.ly/2W1CTLl).

   "This slide shows baby oysters that are four days old. The oyster on the left was grown in normal conditions while the one on the right was grown in water simulating ocean acidification."

   "What do you notice when you compare the two oysters?" *(The oyster on the right, grown in "bad" or acidified water, is smaller and deformed.)*

   "How will this impact ecosystems and humans?" *(Fewer and smaller oysters could mean: less habitat for other organisms, less food for other organisms that eat oysters, and murkier water as oysters filter the water. Hatchery owners might make less money or go out of business; oyster farmers might have a harder time finding seed (baby oysters), making them less productive; restaurants might not have as many oysters to sell or might have to charge more for them…)*

   After giving this example of how to fill out the table, begin student presentations.

Not all oysters die from OA. Research at Whiskey Creek Shellfish Hatchery has shown that larval oysters that don't die can still be affected.

5. **Describe the overall progression:**

   "You will be divided into small groups of four to six. You will have 10 minutes to share your findings with each other. As you listen, take notes in your handout. When the time is up, you will rotate to a new group and repeat the process."

Summary: The Big Picture

1. After two or three rounds of presentations, **students work in groups to summarize what they learned.** Use the following questions:

   "Could ocean acidification benefit any organisms?" *(Likely yes. Some plants might do better with extra CO_2. Some organisms may benefit from population changes in their predators and competitors.)*

   "Could ocean acidification hurt any organisms?" *(Absolutely. A range of organisms may be harmed, and the impacts go beyond shell dissolution.)*

   "How would you answer our research question, "what are the possible impacts of ocean acidification?"" *(Student answers will vary.)*

2. **Ask students to share with the class** what they discussed in groups.

3. **Compare class discussion to slide outlining the key points** about the predicted impacts of OA.

4. This may be a good time to revisit the ideas brought up in the video at the start of this lesson. **You could have students discuss:**

   "Based on what you learned about the predicted impacts of ocean acidification, what do you think the scientists in the video meant when they said, 'We don't know what the impacts of ocean acidification will be?'" *(The scientists were likely explaining that ecosystems are complex, and it is hard to predict all the outcomes. It is also hard to translate lab experiments into the real world.)*

In other words, we know a lot, but we are unsure how the possible changes will interact and how bad the impacts will be.

5. **Highlight that tomorrow we will focus on what we can do** about OA. It is important to acknowledge that this lesson on the impacts of OA may have been dispiriting.

"While the last two days have likely been a little depressing, as we discussed quite a few mostly negative impacts to organisms and people, tomorrow we'll be discussing possible solutions and what we and others can do about ocean acidification."

EDUCATOR BACKGROUND

There are thousands of papers, meta-analyses (papers that synthesize findings from many papers on the same subject), and white papers (non-peer-reviewed documents, usually written by government agencies or nonprofits) focused on the possible impacts of OA. Most of the experiments described in the literature are short-term (days to weeks) laboratory experiments where organisms are exposed to elevated CO_2/low pH conditions. Not surprisingly, results vary, depending on the organism used, the organism's developmental life-history stage, experimental conditions, and research methods. Early experiments often exposed organisms to extreme conditions well beyond what would be expected in the coming decades or century (Browman, 2016). When these studies showed negative impacts, results were extrapolated to suggest that OA was an impending ocean calamity. As research continues, studies are showing mixed results. Since 2016, there has been a concerted effort to publish all study results, including those showing little to no impact, to help round out our collective understanding (Browman, 2016).

While it is easy to get lost in the research literature, some generalizations are clear:

- There will be winners and losers. Calcifiers (organisms that build calcium carbonate skeletons and hard parts) and organisms that are less able to regulate internal body chemistry will likely be more severely impacted by OA (Kroeker et al., 2013). In contrast, it seems that some macroalgae, phytoplankton, and seagrasses may actually benefit from increases in CO_2 concentrations (Feely et al., 2012). However, this benefit will likely depend on availability of other limiting nutrients and will vary by species.
- Ocean acidification has differing impacts on different life stages. Experiments in Pacific Northwest hatcheries helped show that some life stages (for example, young larvae) are extremely susceptible to carbonate chemistry, while other life stages (adults) seem largely resistant to these chemical changes. While larval stages of some organisms do appear susceptible to OA, in other instances with different organisms, larvae show no response to acidification. This is equally true for adults.
- Ocean acidification has impacts beyond calcification and shell building. Other documented responses include changes in: growth, reproduction, survival, energy use, predator detection, hearing, and other behavioral changes.

- It is difficult to study the effects of OA in the field and within ecosystems (in contrast to single-organism laboratory studies). Currently, in instances where field measurements exist, data sets are often too short to allow for conclusions on whether significant changes are occurring over time. Even if changes are observed, it will be hard to determine whether they are due to OA or some other environmental change or stressor (for example, temperature, nutrients, and human use).
- Ocean acidification is not happening in isolation. While scientists study OA, the oceans are also warming, decreasing in oxygen, rising, and being polluted, and some species are being overharvested. These multiple problems can have effects that intersect, building on each other or partially canceling out effects.
- The impacts of co-occurring stressors (for example, increasing temperatures and OA) are contentious and difficult to accurately study. For example, some studies suggest that OA accelerates coral bleaching, a phenomenon primarily related to seawater temperature, while other studies suggest there is no impact of elevated CO_2 on bleaching events, at least down to pH 7.5 (Cooley et al., 2012).
- Short-term (days to weeks) studies are largely unable to comment on longer-scale (decades) changes because they provide little to no insight on whether organisms will be able to acclimate (get used to changes in ocean chemistry), adapt (undergo genetic changes due to natural selection allowing them to survive under new conditions), or go extinct. There is some evidence that, depending on the context, organisms could respond in one or more of these ways (acclimation, adaptation, extinction) (Cooley et al., 2012).

TEACHING NOTES

This lesson makes an explicit choice to avoid an overtly ominous tone when discussing the possible effects of OA. Instead of listing all the possible impacts or confusing students with lists of conflicting findings, this lesson has students explore some of the many possible responses to OA. It introduces some uncertainty to show students that there are still unknowns. The overall message is that marine ecosystems consist of many interconnected pieces. Students consider how changes to one organism could impact other organisms in the ecosystem and the people who rely on the ocean. Extinction is not the only possible response to ecosystem change; it is, however, an intuitive response for many students. The intent is that students walk away from this lesson understanding that it appears that OA will create largely negative changes in marine ecosystems; we just don't know exactly what these changes will be or what they will mean for humans.

Misconceptions to Avoid in this Lesson

MISCONCEPTION | **The ocean will become inhospitable to all life**

MISCONCEPTION | **All shelled organisms will dissolve**

MISCONCEPTION | **All organisms will be negatively impacted by ocean acidification**

MISCONCEPTION | **Ocean acidification does not impact humans**

The traditional approach to teaching about the impacts of OA has students place shells into acid and watch them dissolve. This is often paired with a discussion of how pteropods show evidence of dissolution in laboratory and field settings. Occasionally, decreased coral calcification is also mentioned. The Educator Background section (above) suggests this is an overly simplistic presentation of the research. Our hope is that by introducing students to the Whiskey Creek story in Lesson 1, and by having them conduct research on and share findings about a variety of organisms in this lesson, they will realize that OA is an environmental problem with wide-ranging but still uncertain impacts. We avoid using fear-based messaging because of the psychological research suggesting fear is an effective motivator in only very specific circumstances where specific actions can be taken by the listener to avoid a threat. For more ideas on how to talk about ocean and climate change, see Bales et al. (2015).

NAME__________________

TEACHER **ANSWER KEY**

PERIOD________________

STUDENT **HANDOUT**

LESSON 4 **Ocean Acidification Impacts**

Students in Mrs. Smith's class are discussing ocean acidification. They disagree on its impacts.

Sam: I think ocean acidification will make the ocean become an acid.

Lily: I think ocean acidification will hurt some marine organisms and help others.

Jose: I think ocean acidification will completely dissolve the shells of most marine organisms.

Maria: I think ocean acidification will damage the skin of people, like fishermen, who spend long periods of time at sea.

1. Which student do you agree with? _______________

2. Explain why you agree with this student and disagree with the others.

   Student responses will vary. See Lesson Plan for additional notes.

NAME__________________

PERIOD________________

STUDENT **HANDOUT**

LESSON 4 **Ocean Acidification Impacts** *continued*

Video Questions

3. What does Mark mean when he says it is going to be a "timing issue"?

Mark means that ocean acidification will impact species that are trying to reproduce when the water is most acidic. He refers to bad water, meaning low pH and low carbonate ion concentration. If oysters are reproducing (spawning) when the water is more acidic, the larvae will die because the conditions cause them to use up all their energy before they can feed. In the Pacific Northwest, waters are currently most acidic during the summer, due to upwelling. For other organisms that reproduce at other times of year when the water isn't as bad—there isn't ocean acidification AND upwelling but rather only ocean acidification—these organisms will probably be okay, at least for now. Mark insinuates that this period of "bad water" may expand with time.

4. How does it feel to hear scientists say, "We don't know what the impact will be for ecosystems"? What does this make you think about and/or wonder?

Student answers will vary. Listen carefully to the different emotional responses that students have to this type of messaging, and pay attention to what they think it means for scientists to talk about uncertainty and "not knowing."

NAME__________________

PERIOD________________

STUDENT **HANDOUT**

LESSON 4 **Ocean Acidification Impacts**

Students in Mrs. Smith's class are discussing ocean acidification. They disagree on its impacts.

Sam: I think ocean acidification will make the ocean become an acid.

Lily: I think ocean acidification will hurt some marine organisms and help others.

Jose: I think ocean acidification will completely dissolve the shells of most marine organisms.

Maria: I think ocean acidification will damage the skin of people, like fishermen, who spend long periods of time at sea.

1. Which student do you agree with?

2. Explain why you agree with this student and disagree with the others.

NAME________________

PERIOD______________

STUDENT **HANDOUT**

LESSON 4 **Ocean Acidification Impacts** *continued*

Video Questions

3. What does Mark mean when he says it is going to be a "timing issue"?

4. How does it feel to hear scientists say, "We don't know what the impact will be for ecosystems"? What does this make you think about and/or wonder?

NAME__________________

PERIOD________________

STUDENT **HANDOUT**

LESSON 4 **Ocean Acidification Impacts** *continued*

Ocean Acidification Explained

Step 1: Choose an organism you want to research

My organism: ____________________________

Your first step is to pick an organism that you want to research. There is more known about some creatures than others. The *Seattle Times* has a website (bit.ly/2X5Splh) that provides a starting point for many creatures:

- Brittlestars
- Clams
- Clownfish (Nemo)
- Corals
- Blue crab
- Red king crab
- Damselfish
- Jellyfish
- Krill
- Mussels
- Oysters
- Pteropods
- Seagrass
- Sea urchins
- Walleye pollock
- Walrus

There are many other organisms for which researchers have looked at the possible impacts of ocean acidification. Some of these may be more challenging to research. They include:

- Blue-green algae (cyanobacteria)
- Coccolithophores
- Copepods
- Coralline algae
- Diatoms
- Dungeness crab
- Foraminifera
- Other fish (such as herring)
- Pink shrimp
- Salmon
- Squid
- Starfish
- Whales

NAME________________

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STUDENT **HANDOUT**

LESSON 4 **Ocean Acidification Impacts** *continued*

Step 2: Research your organism

Use at least two or three websites in your research. Record the websites below and the key information you gathered from them in the table on the next page.

Source 1: Organization (who runs the website?)

Website URL:

Author (if available):

Why do you trust this source?

Source 2: Organization (who runs the website?)

Website URL:

Author (if available):

Why do you trust this source?

Source 3: Organization (who runs the website?)

Website URL:

Author (if available):

Why do you trust this source?

Source 4: Organization (who runs the website?)

Website URL:

Author (if available):

Why do you trust this source?

NAME________________

PERIOD______________

STUDENT **HANDOUT**

LESSON 4 **Ocean Acidification Impacts** *continued*

Which organism are you researching? (Describe/draw it)	How will this organism be affected by ocean acidification?
How could this impact other organisms in the food web?	How could this impact people?

Step 3: Present your findings

You will present your findings to several small groups of classmates. Be ready to give a one- to two-minute presentation on what you learned, focusing on the four key points in the table above.

NAME__________________

PERIOD________________

STUDENT **HANDOUT**

LESSON 4 **Ocean Acidification Impacts** *continued*

Learning About Ocean Acidification's Impacts

Today you will learn from your classmates about the potential consequences of ocean acidification. Take notes in the table below (or separately in your notes).

Organism	Predicted impacts	How will this impact ecosystems and humans?
Oysters		

NAME__________________

PERIOD________________

STUDENT **HANDOUT**

LESSON 4 **Ocean Acidification Impacts** *continued*

Organism	Predicted impacts	How will this impact ecosystems and humans?

LESSON 5

What Can We Do about OA?

OVERVIEW

This lesson aims to leave students with a sense of hope. Students are reminded that carbon dioxide emissions from human activities are the primary cause of OA. After brainstorming possible actions to reduce CO_2 emissions and identify barriers to these actions, students are introduced to an analysis performed by researchers that looks at how much of an impact various household changes could have on total U.S. energy use, and thus on CO_2 emissions. This discussion leads into an analysis of the impacts of individual vs. collective action, and then into the final Call to Action project.

MATERIALS

- Copies of student handout (one per student)
- Computer, projector, and speakers
- Presentation slides and videos
- CO_2 reduction actions cards
- Student computers with Internet (Evaluate section)

STANDARDS

NGSS: HS-ESS3-4; Engaging in Argument from Evidence

CCSS: 9-10.SL.1; 9-10.WHST.10

OLP: 6g

OELS: 1b, c; 5d

KEY POINTS

- There are ways to reduce future damage to ecosystems from ocean acidification.
- Even if people know what actions could reduce CO_2 emissions, there are many barriers to taking action.
- Some actions have larger impacts on reducing CO_2 emissions than others, and thus have greater potential to reduce ocean acidification.

ENDURING UNDERSTANDINGS

- Marine ecosystems, and the humans who rely on them, are interconnected.
- Individual and collective actions are needed to effectively manage resources for all.

OBJECTIVES

Students will be able to:

- Identify potential solutions to ocean acidification.
- Discuss the impact and feasibility of various actions to reduce OA.

SETUP

- Make copies of student handout (one per student).
- Open PowerPoint presentation and preload video (both available at bit.ly/2W1CTLl).
- Prepare CO_2 Reduction Action Cards: Print enough copies of CO_2 action cards (one page each, see lesson materials) for each group to have a set. Cut out a set of action cards for each group of students. Use a paper clip to hold each set together. Laminate cards for long-term use.

LESSON PLAN

Engage Solutions Video

Procedure

1. **Present slide** (bit.ly/2W1CTLl) **summarizing key ideas** covered previously.

   "Today we're going to think about solutions to ocean acidification, things that people like you can do to reduce ocean acidification. I wanted to start with a short video clip."

If you did not use Lessons 2 and 3, you may need to modify the key ideas on this slide.

2. **Show the two-minute video** "L5_Solutions," discussing the future of OA.

For longer videos on solutions, see bit.ly/2WfazFn or bit.ly/2K-u4P5h

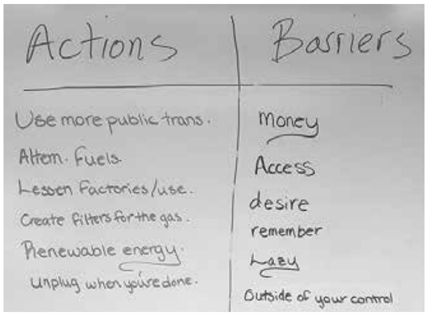
3. **Present slide introducing three main ways to address** OA: dealing with the cause, buying time (seagrass restoration, sewage/runoff reduction), and learning more about the problem. This lesson focuses on dealing with the main cause, anthropogenic CO_2.

Explore Cutting CO_2 Emissions

Brainstorming Actions and Barriers

1. **Students take two minutes to brainstorm actions** that could be taken to reduce CO_2 emissions in the U.S. and things that might prevent people from taking these actions.
2. **Make a T-chart** on the board. The left side should read "Actions" while the right side reads "Barriers."
3. **Students verbally share actions to reduce CO_2 emissions.** Write these ideas under the Actions heading.
4. **Students share possible barriers to action.** Record answers under the Barriers heading.

   "You've just listed several actions that could be taken to reduce CO_2 emissions and thus reduce ocean acidification, since we said anthropogenic CO_2 was the main cause of the problem. You've also come up with numerous explanations for why people, even people who care and want to do something, might not take action."



Sample T-chart

Explain Maximizing Impact

"Now we are going to go beyond just thinking of possible actions and move toward being strategic about prioritizing which actions to take. It's not very common to talk about the impact of different CO_2 reduction actions. Usually we talk about what would be easy, or inexpensive, or what's in our control; we don't often talk about how much CO_2 is removed or prevented by actions."

Commit and Toss

In this activity, students write an anonymous answer on a piece of paper, then toss it to maintain anonymity. Answers are then read aloud.

This commit-and-toss activity was added to increase student discussion.

1. Tell students to **take out a blank piece of paper.** Ask them not to put their name on it! They are going to write an honest answer on the paper.
2. Students answer the following question on a piece of paper: "*What is the most effective thing you could do to conserve energy? (Write ONE action.)"*
3. **Write "Most Effective Actions..." on the board** while students answer the prompt.
4. When finished, **students crumple their answer** into a ball and toss it around the room (not at someone).
5. After brief chaos, each student **grabs a paper ball** from the floor.
6. **Students read answers aloud.** Record the answers on the board (use tally marks for answers that are listed multiple times).
7. **Introduce card sort activity** (see slides).

   "Back in 2008, a research study was published that reviewed possible actions American households could take. The study came up with a list of nine low-cost actions that would have the largest impact. We are going to explore some of the ideas from this paper. We are trying to think about how we can get the most bang for our buck; or, in other words, how we can be sure that the actions we are taking make a difference."
8. **Explain card sort activity directions** (see slides).

   "Each group will get a stack of cards. Each card lists an action you could take to reduce household CO_2 emissions. With your

Tossing balls of paper will not be appropriate in all classrooms. You could have students "toss" their ball into a basket. Once you have collected all answers, shake the basket and have each student pull one answer out.

The data used in this activity come from Gardner & Stern (2008).

group, organize the cards from the most effective to least effective actions to reduce energy use (in other words, from most to least energy saved)."

9. Student groups **complete their initial card sort** for three to five minutes.

10. **Show data on household energy use** (see slides).

"Now that you have an initial guess, I wanted to show you some data about how households use energy."

11. **Based on the new information, students adjust their cards** for one to two minutes.

12. **Reveal answers** ranked by relative impact of the different household actions (see Table 3 and slides).

13. **Discuss as a class.** Possible discussion points include:

"How does your list compare to the order of actions the researchers found?" (Student answers will vary.)

"Were you surprised by anything from this activity?" (Answers will vary. Many students are surprised by the high impact of driving.)

"Turn off lights" and "watch less TV" are energy-saving actions that are commonly mentioned but have limited impact on energy use. These actions were initially included as cards to make the point that they were commonly thought of but are very low impact. We found that students remembered these actions but not that they had limited impact. To focus students on high-impact actions, we removed these two actions from the card deck.

Table 3 - Energy-saving actions rankings.

Ordered list of impacts of various household actions on energy use. Data from Gardner & Stern (2008).

Action	Energy Saved (%)
1. Buy a more fuel-efficient vehicle	13.5
2. Adjust your driving habits	8.3
3. Insulate your attic	7.0
4. Install a more efficient heater/AC unit	5.1
5. Maintain your vehicle	5.1
6. Carpool to school with one other person	4.2
7. Replace 85% of incandescent lightbulbs with LEDs	4.0
8. Replace old windows with high-efficiency ones	3.7
9. Use less heat/air conditioning	3.4
10. Wash clothes in cold water	1.2
11. Install a more efficient washing machine	1.1
12. Line-dry clothes five months of the year	1.1

"Do you notice anything about the actions at the top vs. those at the bottom of this list?" (Answers will vary. Many top actions deal with efficiency; bottom actions are daily habits/behaviors.)

"How many of the actions listed involve one-time improvements, and how many involve an ongoing choice in how much/how intensely an item is used?" (Efficiency - 6; Daily Choice - 6)

For example, buying a fuel-efficient vehicle is a choice that will lead to large savings every time the car is used. In contrast, washing with cold water, line-drying clothes, turning out lights, etc. are choices that have to be made on an ongoing basis.

Elaborate The Short List

1. **Pass out the Short List Infographic.**

   "While it is helpful to have an ordered list, for me this is still a bit overwhelming. Also, many of the actions seem expensive. What low-cost actions lead to the biggest reduction in CO_2? Look at the infographic. Notice that the main section shows low-cost actions that could be done now, while the bottom shows more-expensive actions with big impacts on emissions."

2. **Students discuss the following questions** with one of their neighbors, then as a class:

   "What do you think about the actions listed in this table? How many seem doable?" (Answers will vary. Younger students often mention that their parents make driving decisions, not them.)

   "Do you think they would have an impact on ocean acidification? Why or why not?" (Answers will vary. Many students say "Every bit helps," while others talk about how little their actions matter compared to total emissions.)

   "What's missing from this list that you expected to see?" (Answers will vary, but energy generation and policy measures were not included in this household-focused activity.)

You could have students calculate the impact of a family, county, and state taking one of these actions, to show the impact of one versus many participants.

Installing solar panels doesn't appear on the list because it is high cost, and this analysis was focused on saving energy, not generating it. Similarly, commonly listed actions like turning off the lights were not included because they are considered low-impact.

3. **Present slides on the impact of planting trees** versus changing light bulbs.

   A Note on Planting Trees: *This estimate is based on several assumptions that might not hold for your area. Instead of getting lost in the specifics, focus on the main idea: many of the actions we typically think of as environmentally friendly may not make as much of a difference as we think. For example, while trees do remove CO_2 from the atmosphere for photosynthesis, the impact of planting one young tree is likely not as great as students expect. Estimates of CO_2 absorption by trees vary. One estimate suggests a young conifer removes 10 lbs*

The idea that small actions will lead to larger pro-environmental actions is known as "spillover." For a recent meta-analysis of spillover research, see Maki et al. (2019)

of CO_2/year per tree planted and kept alive, over an average lifespan of 30 years. In contrast, changing one 43-watt incandescent bulb to a 9-watt LED saves about 66 lbs of CO_2/year (EPA, 2017).

Evaluate Personalizing the Message

Have students calculate their own carbon footprint and look through the various actions they could take to reduce their impact (this could be done as homework if you are running short on class time). The following activity primes students for the final project.

1. **Students go to Berkeley's Cool Climate Calculator** (bit.ly/2Dc2aH8).
2. **Students answer the questions** about their home energy use. After completing the questions, they will be presented with a list of possible actions they could take to reduce their footprint.
3. **Students record their CO_2 footprint** and identify the area where they generate the most CO_2.
4. **Students choose three actions** they'd be most likely to take, explain why they chose those actions, and consider how challenging it will be for them to make these changes.

Several curricula recommend a carbon footprint activity.

We recommend Berkeley's Cool Climate Calculator because it allows students to easily analyze different possible actions and adjust the assumptions to show the relative impact of various actions more clearly.

Cards: Actions to Reduce Household Energy Use

Use less heat/air conditioning (Set heat to 68°F during the day and 65°F at night instead of 72°F; set AC to 78°F instead of 73°F.)	**Replace 85% of incandescent lightbulbs with LEDs**
Adjust your driving habits (60 mph on highway; avoid sudden stops/ acceleration; combine errands.)	**Replace old windows with high-efficiency ones**
Buy a more fuel-efficient vehicle (Use a car that gets 30 mpg instead of 20 mpg.)	**Wash clothes in cold water**
Insulate your attic	**Install a more efficient washing machine**
Maintain your vehicle (Get frequent tune-ups, including air filter changes; use correct tire pressure)	**Line-dry clothes five months of the year**
Install a more efficient heater and AC unit	**Carpool to work/school with one other person**

EDUCATOR BACKGROUND

With changing water chemistry already impacting the U.S. west coast shellfish industry (Barton et al., 2015) and field samples revealing severe dissolution in pteropods in the California Current System (Manno et al., 2017), the notion that OA is a future problem that will begin to show impacts in 50 to 100 years appears outdated, at least in OA hotspots like the Pacific Northwest.

Discussing Solutions to Inspire Action

Upon hearing about OA for the first time, many students will likely ask or wonder, "Is there anything that can be done about it?" Some research suggests that when individuals hear of an environmental problem, but do not hear of any solutions, they fill in the gap and conclude that there is little that can be done to address the problem (Bales et al., 2015). Similarly, theories of psychological coping behavior suggest that for individuals to take action to fix a problem (called problem-focused coping), they must think there is a problem and that there is something they can do to fix it (Lazarus and Folkman, 1984; Witte, 1994). In contrast, if they don't think they can control the threat, they will respond with emotion-focused coping strategies, which seek to reduce one's feelings through responses such as denying, ignoring, or dismissing the threat. This final day of the module argues that there are things that students can do to reduce OA. The challenge is to present solutions that seem within a high-school student's control while also encouraging collective actions that could lead to broader impacts.

The primary cause of OA is anthropogenic carbon dioxide emissions. Thus, solutions to OA, meaning actions that could be taken to reduce OA, should focus on reducing anthropogenic CO_2 emissions and/or removing CO_2 from the ocean/atmosphere. Many students have already heard of ways to reduce human CO_2 emissions. When they are reminded that anthropogenic CO_2 is the primary cause of OA, students are able to brainstorm possible actions. Many of these actions, however, are either outside of their immediate control (for example, regulating industry, increasing government funding) or they are low-impact actions that would do little to decreases the amount of anthropogenic CO_2 emitted (such as planting one tree). Research suggests that the public does not know which actions would best reduce their home energy use (Attari et al., 2010; Gardner & Stern, 2008). Thus, in order to attain meaningful reductions in energy use and fossil fuel consumption, individuals need better awareness of the payoffs of different actions, not just that actions would reduce energy/fossil fuel consumption.

The question, then, switches from "What could be done to reduce anthropogenic CO_2 emissions" to "What are the most effective actions we could take to reduce our CO_2 emissions?" While national policy efforts and technological advancements would certainly help reduce anthropogenic CO_2 emissions, these often take decades to fully implement. Research from the field of conservation psychology has identified household actions that could be taken today, many at little or no cost, that could reduce household energy consumption by up to 30 percent, or 11 percent of total U.S. energy consumption (Dietz et al., 2009; Stern et al., 2010).

Seagrass Restoration as Possible Mitigation

In addition to increasing energy efficiency and decreasing consumption, other actions are being discussed that could be taken to remove CO_2 from the ocean and atmosphere. One idea that holds promise but still requires testing is that of seagrass and kelp restoration (see *Oregon Field Guide's* eight-minute video, "A Greener Future for Oysters?" bit.ly/2Ku4P5h). We know that photosynthesizers like seagrass and kelp take in CO_2 during the day. In theory, these organisms could help reduce the amount of CO_2 in the ocean through an increase in photosynthetic biomass. This could potentially improve local water chemistry in seasonal to multi-year timescales (Cooley et al., 2012). This idea is similar, but not identical, to the notion of Blue Carbon, which seeks to capture carbon in plants. Both ideas hinge on a few key factors. For example, would the daytime decrease in CO_2 be more beneficial than the likely increase in daily variation (areas with vegetation see greater daily cycles in pH/CO_2 than comparable areas without substantial vegetation)? Are there other limiting nutrients that would restrict growth? How do plant life cycles impact restoration benefits? If a plant dies in the same season it was planted/created, the net CO_2 removal would be zero. Thus, longer-living plants, like some seagrasses and kelps, seem to have potential to help with local water chemistry, but these results are tentative (Smith, 2016).

Ocean Buffering with Chemicals

When discussing ways to reduce the impacts of OA, the notion that the ocean could be buffered through the addition of chemicals is sometimes raised. This idea makes some intuitive sense: the ocean is naturally buffered over hundreds of thousands of years, through a balance of volcanism and weathering, and shellfish hatcheries can improve pH conditions by buffering seawater with soda ash (sodium carbonate). Unfortunately, it would take vast amounts of calcium carbonate (limestone) to buffer the global ocean. In fact, the amount of limestone required to buffer global ocean pH annually is more than 30x the limestone currently mined by humans (Cooley et al., 2012). This increased level of mining is likely unachievable and would certainly involve substantial carbon dioxide emissions of its own.

Reducing Additional Environmental Stressors

Another area of potential for OA mitigation is to address other co-stressors (pollution, deoxygenation, temperature increases, etc.). In some locations, runoff from sewers and farms adds excess nutrients to waterways, including estuaries. These nutrients cause eutrophication, or excessive growth of aquatic plants due to nutrient enrichment. The initial result is to stimulate phytoplankton and algal growth, which temporarily reduces CO_2 levels; however, these blooms die within a few weeks. When they die, the organisms sink and decompose. This decomposition releases CO_2 into the water and reduces O_2 levels. When blooms occur in shallow waters, acidification and hypoxia can be considerable. Thus, in places where runoff is substantial, tackling runoff and eutrophication can improve local water quality and reduce OA.

TEACHING NOTES

Most teaching resources on OA do not fully engage students in thinking about solutions to the problem. Of the few that do address solutions, many ask students to brainstorm ways to reduce emissions for five to 10 minutes at the end of a lesson, and occasionally they are told to use a carbon footprint calculator to see how much they could reduce. In contrast, this curriculum attempts to encourage students to think more critically about actions to reduce CO_2 emissions. It tries to have students evaluate the impact of various actions and consider what might prevent people from taking action (it isn't just about whether someone "cares" about the problem). The Call to Action project allows students to try to persuade whomever they think should do more to take action on OA, while simultaneously cementing their own understanding.

NAME________________

TEACHER **ANSWER KEY**

PERIOD______________

STUDENT **HANDOUT**

LESSON 5 **Household Actions to Address OA**

Reducing the Problem

Brainstorm responses to the following questions:

1. What actions could be taken to reduce CO_2 emissions in the U.S.?

Answers will vary, but often include: walk more/drive less, use public transportation, use and generate clean energy, pass laws, turn off lights, and raise awareness.

2. What might prevent someone from taking one or more of the actions you listed?

Answers will vary, but may include: too hard, too expensive, laziness, outside of their control, not their choice, and they don't care.

Card Sort Activity Reflection

1. How does your list compare to the order of actions the researchers found?

Answers will vary. Many students overestimate the impact of familiar actions, such as hanging clothes to dry and washing clothes in cold water, and they underestimate the impact of driving behaviors, increasing efficiency (cars and lights), and weatherization (insulation and windows).

2. Were you surprised by anything from this activity?

Answers will vary. Students tend to be surprised by how large an impact driving has on their energy use.

3. Do you notice anything about the actions at the top vs. bottom of this list?

Answers will vary. Many top actions deal with efficiency; bottom actions are daily habits/behaviors.

4. How many of the actions listed involve one-time improvements to the efficiency of an energy-using appliance, and how many involve an ongoing choice as to how much/how intensely an item is used?

Efficiency - 6; Daily Choice - 6

LESSON 5 **Household Actions to Address OA** *continued*

What Is Your **Carbon Footprint?**

Go to the Cool Climate Calculator (bit.ly/2Dc2aH8). After completing the questions, you will be presented with a list of actions that could help reduce your carbon footprint.

5. What was your CO_2 footprint?

Answers will vary.

6. Look at the graph of your results. What part of your lifestyle generates the most CO_2 emissions?

Answers will vary.

7. Look through the list of possible actions to reduce your carbon footprint (clicking on the title reveals more details). Of the actions listed, what three actions would you be most likely to take? Explain why you chose these actions, and describe how challenging you think it would be for you to make these changes.

Answers will vary. Look for reflection in terms of what would make actions easier/harder to take.

NAME________________

PERIOD______________

STUDENT **HANDOUT**

LESSON 5 **Household Actions to Address OA**

Reducing the Problem

Brainstorm responses to the following questions:

1. What actions could be taken to reduce CO_2 emissions in the U.S.?

2. What might prevent someone from taking one or more of the actions you listed?

Card Sort Activity Reflection

1. How does your list compare to the order of actions the researchers found?

2. Were you surprised by anything from this activity?

3. Do you notice anything about the actions at the top vs. bottom of this list?

4. How many of the actions listed involve one-time improvements to the efficiency of an energy-using appliance, and how many involve an ongoing choice as to how much/how intensely an item is used?

NAME________________

PERIOD______________

STUDENT **HANDOUT**

LESSON 5 **Household Actions to Address OA** *continued*

What Is Your **Carbon Footprint?**

Go to the Cool Climate Calculator (bit.ly/2Dc2aH8). After completing the questions, you will be presented with a long list of actions that could help reduce your carbon footprint.

5. What was your CO_2 footprint?

6. Look at the graph of your results. What part of your lifestyle generates the most CO_2 emissions?

7. Look through the list of possible actions to reduce your carbon footprint (clicking on the title reveals more details). Of the actions listed, what three actions would you be most likely to take? Explain why you chose these actions, and describe how challenging you think it would be for you to make these changes.

NAME_______________

PERIOD_____________

STUDENT **HANDOUT**

10 actions could cut family energy use by up to 50%

Adjusting your driving habits can cut total energy use 18%

Adjust your driving style
Reducing sudden stops and quick acceleration, and cutting highway speeds from 70 mph to 60 mph saves gas; can cut total energy use 5.6%

Maintain your car
Getting frequent tune-ups, changing the air filter, and keeping your tires properly inflated saves gas; can cut total energy use 5.1%

Carpool to school / work
Carpooling saves gas; can cut total energy use 4.2%

Combine errands to reduce trips
Doing multiple errands in the same trip, instead of going home after each errand, saves gas; can cut total energy use 2.7%

Making in-home adjustments can cut total energy use 9%

Switch lights to LEDs
Replacing at least 85% of the incandescent lightbulbs in your home with LEDs saves electricity; can cut total energy use 4.0%

Adjust your in-home temperature
Turning heat down from 72°F to 68°F during the day and 65°F at night, and turning AC up from 73°F to 78°F can cut total energy use 3.4%

Wash & rinse clothes in cold water
Washing clothes in cold water, instead of hot, reduces energy used to heat water; can cut total energy use 1.2%

Hang clothes to dry
Hanging clothes to dry for 5 months a year, instead of using a dryer, saves energy; can cut total energy use 1.1%

Two higher-cost actions could cut total energy use 23%

Get a more efficient car
Replacing your vehicle with one that gets 30+ mpg can cut total energy use 13.5%

Upgrade home insulation
Caulking, weather-stripping, and insulating your home can cut total energy use 9.5%

Modified from: Gardner, G.T. & Stern, P.C., 2008. The Short List: the most effective actions U.S. households can take to curb climate change. Environment, 50(5), 12-26.

FINAL PROJECT

A Call to Action

OVERVIEW

This final project was added to the curriculum to help students process what they've learned and attempt to influence those who they think should be taking action. Some of our students felt that "everyone" should be taking action, while others thought people with money, power, and knowledge should be the ones leading the way. This project allows students to determine who they feel should be doing more and try to convince these people to act. We've included a few thoughts that might help you structure a final Call to Action project.

Possible way to introduce the project:

> *"To reduce OA and its impacts, action will be needed by many different individuals, groups, and governments. Your task for this final project is to create something that will convince others to take action. You get to choose whom you target, what action(s) you try to get them to take, and how you try to convince them. In addition to letting you try your hand at persuading others, this final project is also designed so you can showcase what you learned/know about OA."*

You might create a handout for students to explain the important components of their project. Main features could include:

> **Target audience:** Who are you trying to persuade to take action? Why did you choose them? (You might try to convince someone in government, such as a Congressperson or the president, because you think they have the most power to change things. You might target your friends and family because you know them. You might target your classmates or

STANDARDS

NGSS: HS-ESS3-4, HS-LS2-7; Constructing Explanations and Designing Solutions; Engaging in Argument from Evidence

CCSS: 9-10.SL.1; 9-10.WHST.10

OLP: 6g

OELS: 1b, c; 5d

This final project could be a great way to connect with an English classroom to work on crafting persuasive messages/arguments.

It might also be worthwhile to have students show that they looked into what their audience is already doing, especially if they are writing to government officials.

school, your sports team, or someone else entirely. But you have to explain who you are trying to persuade and why.)

Method: You can be as creative as you want in your means of persuasion. Ideas include: letter, op-ed piece for a newspaper, flyer, public service announcement, video, grassroots action campaign, speech, etc.

Argument: Make a persuasive argument that shows that you understand ocean acidification.

Overcoming barriers: Demonstrate that you thought about what barriers might prevent your audience from taking action, and explain how you tried to get around these barriers.

Recommended grading criteria for the project include: current and accurate information on OA, clear ask/call to action, action justified with evidence, messaging appropriate to audience, and neatness/ attractiveness of product.

APPENDIX

Changing Ocean Chemistry

MATERIALS LIST

The following list summarizes materials needed for the curriculum. It is a repeat of the list found at the start of each lesson.

Teacher Note *a computer, projector, and speakers, as well as student handouts, are needed for every lesson.*

Lesson 1

- No additional materials needed

Lesson 2

- Three 300mL Erlenmeyer flasks
- Universal indicator
- Dropper/pipette (for adding indicator to solution)
- Distilled water (tap water okay)
- Vinegar
- Ammonia
- SodaStream®
- Aquarium airline tubing (about 1–2 feet)
- Powdered sodium carbonate (soda ash)
- Stirring rod/spoon
- Measuring spoon (to scoop soda ash)
- (Optional) aquatic plant

If you do not have universal indicator, bromothymol blue and cabbage juice also work but have a more limited pH range. See Lesson 2 Educator Background.

Lesson 3

- Universal indicator
- Floating candles
- Lighter/matches
- Two clear salad bowls/aquaria
- Distilled water
- Computers with Internet access for student homework

Lesson 4

- Computers with Internet access for student research

Lesson 5

- CO_2 reduction cards
- Computers with Internet access for student research

Make enough card sets to have one per group of two to four students. Paperclips and envelopes will help with organizing and keeping card sets together. Laminate the CO_2 reduction action cards to extend their life.

ONLINE RESOURCES

Links are listed in the order they appear in the text. All URLs were last accessed on April 12, 2019.

Introduction

B. Erickson and T. Crews, *Changing Ocean Chemistry* (this curriculum): bit.ly/2VAmcm4

Climate Interpreter (website): bit.ly/2v1OoCC

Lesson 1

Greenpeace, Postcard from the Oregon Coast (video): bit.ly/2IePbc7

Oregon State University, Alternative Lesson 1 (video): bit.ly/2VCr6Pu

Earth Labs, Lab 2: Carbon on the Move (lab activity): bit.ly/2v3m8j0

M. Laws, Cruising Through the Carbon Cycle (lesson plan): bit.ly/2UhDgeR

University of Otago, Oceans of Tomorrow Lesson 2a (educational resource, PDF): bit.ly/2Ua7elb

V. Martin, SERC, A terrestrial carbon cycle (illustration): bit.ly/2HLzJm6

IPCC 2004, accessed from Earth Labs Lab 2 (lab activity): bit.ly/2VGoIXV

Skeptical Science, Does breathing contribute to CO_2 buildup in the atmosphere? (website): bit.ly/2IgRoUp

NASA, A Year in the Life of Earth's CO_2 (video): bit.ly/2UQR58t

Scripps Institution of Oceanography, The Keeling Curve (interactive graph): bit.ly/1C3b6FA

S. Newton (website): bit.ly/2Gm6QeD

Lesson 2

J. Orr, C. L. Sabine, and R. Key, accessed Cooley et al. (2012). The name "ocean acidification" (website): bit.ly/2Kwnzkz

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Oregon State University SMILE Program, Ocean Acidification: From a Geological and Chemical Perspective (lesson plan, PDF): bit.ly/2D5xasv

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Lesson 3

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Aquarium of the Bay, HS Chemistry Teacher Resource Guide, Lesson 2 (teacher resource guide, PDF): bit.ly/2UTsyjh

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NOAA, What is Upwelling? (web page): bit.ly/2VHaiqm

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Lesson 4

B. Erickson, Effects of Teaching Household Actions to Address Ocean Acidification on Student Knowledge and Attitudes (thesis): bit.ly/2Z5yTXX

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C. Welch, Creatures Behaving Strangely (web page): bit.ly/2X5Splh

Lesson 5

Oregon State University, Lesson 5 Solutions to Ocean Acidification (video): bit.ly/2P6ZMqb

CoolClimate Network, Household Calculator (interactive website): bit.ly/2Dc2aH8

Oregon Field Guide, A Greener Future for Oysters? (video): bit.ly/2Ku4P5h

Oregon State University, Alternative Solutions (video): bit.ly/2WfazFn

STANDARDS FOR EACH LESSON

Lesson 1
NGSS: HS-LS2-6; Engaging in Argument from Evidence; ESS2.D
CCSS: 9-10.SL.1; 9-10.WHST.10
OLP: 6b, d, e
OELS: 1b, c; 3b

Lesson 2
NGSS: HS-LS2-6; Engaging in Argument from Evidence; ESS2.D; Cause and Effect
CCSS: 9-10.SL.1; 9-10.WHST.10
OLP: 6d, e
OELS: 1b, c; 3b

Lesson 3
NGSS: HS-LS2-6; Engaging in Argument from Evidence; Cause and Effect
CCSS: 9-10.SL.1; 9-10.WHST.10
OLP: 6d, e
OELS: 1b, c; 3b

Lesson 4
NGSS: HS-LS2-6; Engaging in Argument from Evidence
CCSS: 9-10.RST.2; 9-10.SL.1; 9-10.WHST.10
OLP: 6b, d, e
OELS: 1b, c; 3b

Lesson 5
NGSS: HS-ESS3-4; Engaging in Argument from Evidence
CCSS: 9-10.SL.1; 9-10.WHST.10
OLP: 6g
OELS: 1b, c; 5d

Project
NGSS: HS-ESS3-4, HS-LS2-7; Constructing Explanations and Designing Solutions; Engaging in Argument from Evidence
CCSS: 9-10.SL.1; 9-10.WHST.10
OLP: 6g
OELS: 1b, c; 5d

LITERACY PRINCIPLES AND STANDARDS ADDRESSED

Next-Generation Science Standards

Performance Expectations

HS-ESS3

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

HS-LS2

Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.

HS-LS2

Design, evaluate, and refine a solution for reducing the impacts of human activities on the environment and biodiversity.

Science and Engineering Practices

Constructing Explanations and Designing Solutions

- Design, evaluate, and refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and tradeoff considerations. (HS-LS2-7), (HS-ESS3-4)

Engaging in Argument from Evidence

- Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. (HS-LS2-6)
- Construct an oral and written argument or counterarguments based on data and evidence. (HS-ESS2-7)

Disciplinary Core Ideas

ESS2.D: Weather and Climate

- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. (HS-ESS2-6)

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS2-8), (HS-LS4-6)

Common Core Standards

9-10.RST.2

Determine the central ideas or conclusions of a text; trace the text's explanations or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

9-10.SL.1

Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 9–10 topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.

9-10.WHST.10

Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline specific-tasks, purposes, and audiences.

Ocean Literacy Principles

6. **The ocean and humans are inextricably interconnected.**

   B. The ocean provides food, medicines, and mineral and energy resources. It supports jobs and national economies, serves as a highway for transportation of goods and people, and plays a role in national security.

   D. Humans affect the ocean in a variety of ways. Laws, regulations, and resource management affect what is taken out and put into the ocean. Human development and activity lead to pollution (point source, nonpoint source, and noise pollution) changes to ocean chemistry (ocean acidification), and physical modifications (changes to beaches, shores, and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

   E. Changes in ocean temperature and pH due to human activities can affect the survival of some organisms and impact biological diversity (coral bleaching due to increased temperature and inhibition of shell formation due to ocean acidification).

   G. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Oregon Environmental Literacy Strands

1. **Systems thinking.** Students study systems and issues holistically, striving to understand the relationships and interactions between each system's parts. They use the knowledge gained to assess the effects of human choices on economic, ecological, and social systems, and to optimize outcomes for all three systems.

   B. Habits of systems thinking. Understand the habits of systems thinking, and identify opportunities to apply them.

   - Recognize the impact of time delays on cause-and-effect relationships.
   - Consider short- and long-term consequences of actions.
   - Notice how system elements change over time, generating patterns and trends.
   - Identify where unintended consequences emerge.

   C. Strategic responsibilities of systems thinking. Apply the habits and techniques of systems thinking to decision-making.

   - Explain how human action or inaction affects the systems in which we live.
   - Consider the effects of human choices on economic, ecological, and social systems.

3. **Interconnectedness of people and the environment.** Students understand the interdependence of humans and the environment, and appreciate the interconnectedness of environmental quality and human well-being.

   B. Interrelationships between the environment and human activities. Analyze how environmental changes affect human systems; how human activities and systems change the environment; and the connection between environmental quality and human well-being.

   - Analyze how environmental changes affect political, social, cultural, economic, and health systems.
   - Analyze how human activities and systems change Earth's physical systems (atmosphere, ocean, climate, soil, landforms) and living systems (such as ecosystems, biodiversity, and carrying capacity).

5. **Investigate, plan, and create a sustainable future.** Students apply civic action skills that are essential to healthy, sustainable environments and communities.

   D. Demonstrate effective decision-making and citizen action. Analyze options, plan actions, evaluate outcomes, and reach evidence-based conclusions.

Evaluate the need for action:

- Decide whether action is warranted, based on available evidence about the issue and proposed solutions; the scale of the concern; the legal, social, economic, and ecological consequences; and alternatives to citizen action.
- Identify options for citizen action, including consumer choices; resource use choices; writing letters to the editor; drafting legislation, ordinances, or policies; environmental stewardship projects; and communicating with decision-makers.
- Speculate on the probable effects of specific actions and the likelihood that they will resolve the problem.
- Decide whether to take personal action, based on their own values, skills, resources, and commitments.

READINGS

Reading The Case of the Dying Oysters

NOTE *This reading is a modified, edited version of paragraphs from the following three articles: Geiling (2015); Gilles (2013); and Grossman (2011).*

The sun chips away at the clouds on a quickly warming May morning. On the estuary's muddy banks, people dressed in knee-high rubber boots dig in the dark sludge for clams, while throughout the bay other aquatic farmers dredge for their prize: oysters.

Oysters have been grown commercially on the west coast since the mid- to late-1800s, thriving in the shallow, cool estuaries along the Pacific Coast. By the 1890s, oystermen were pulling 200,000 bushels a year out of the Puget Sound. But the boom was followed by bust, as over-harvesting and declining water quality devastated the native population of Olympia oysters (*Ostrea lurida*). In the 1920s, as a way of saving their industry, the west coast oyster growers began importing Pacific oysters (*Crassostrea gigas*) from Japan. The Pacific oysters thrived, and oyster farmers began growing the species in large numbers.

But unlike the native Olympia oyster, the Pacific oyster was never able to reproduce quite as successfully in the wild – so in the 1970s, the shellfish industry began installing hatcheries along the Pacific Coast, in order to supply oyster farmers with the larvae needed to sustain their businesses. In 1978, the Whiskey Creek Shellfish Hatchery set up shop next to Netarts Bay, five miles southwest of Tillamook, Oregon. A family-run business, it now supplies Pacific oyster larvae to 70 percent of the west coast's oyster farms stretching from Canada to South America.

In 2007, Pacific oyster larvae at Whiskey Creek started dying en masse… At first, the only thing anyone knew was that something was horribly wrong.

"We had three or four months when we had zero production. We'd never seen anything like it," says Mark Wiegardt, who owns a small oyster farm on the bay's south end and whose wife, Sue Cudd, has owned and operated Whiskey Creek since 1997.

"We had two awful years in a row," said Alan Barton, Production Manager at Whiskey Creek. "And this is a small business, so that's almost the end."

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Challenge Reading The Case of the Dying Oysters

NOTE *This challenge reading is a modified version of Barton et al. (2015).*

Shellfish have been harvested in the Pacific Northwest for thousands of years, and commercial oyster farming has been an important cultural and economic part of coastal communities in the Northwest since the late 1800s. Today, shellfish farming supports more than $270 million in economic activity and more than 3,000 family-wage jobs in rural areas throughout the region. Although shellfish farms can be found throughout Oregon, Washington, Alaska, California, and Hawaii, most of the oysters harvested in the Pacific Northwest are produced in Washington. Large farms in Willapa Bay and southern Puget Sound make up the majority of the industry and have existed in these areas for several generations.

Shellfish species farmed in the Pacific Northwest include Manila clams (*Venerupis philippinarum*), geoduck clams (*Panopea generosa*), mussels (*Mytilus trossulus* and *M. galloprovincialis*), and several species of oysters. Although Kumamoto oysters (*Crassostrea sikamea*), eastern oysters (*Crassostrea virginica*), and the native Olympia oyster (*Ostrea conchaphila*) represent important niche markets, the Pacific oyster (*Crassostrea gigas*) is the predominant species farmed in the region, comprising more than 80 percent of the industry's total annual shellfish production by live weight.

Pacific oysters from Japan were first brought to the United States in the early 20th century, and naturalized populations became established in portions of Puget Sound and in Willapa Bay. Natural recruitment of seed oysters from these spawning populations helped support the industry for several decades, supplementing the supply of imported seed from Japan. In the 1970s, the cost of importing seed became prohibitively expensive, and it became clear that growers could not rely solely on inconsistent natural spawning events to support their burgeoning industry (Dumbauld et al., 2011; Gordon and Blanton, 2001).

By the late 1970s, successful commercial hatcheries were established in the Pacific Northwest and began supplying billions of "eyed" (setting size) larvae to growers each year. The three major commercial hatcheries that currently supply larvae to the west coast shellfish industry are Whiskey Creek Shellfish Hatchery (Netarts Bay, OR), Taylor Shellfish Hatchery (Dabob Bay, WA), and

Coast Seafoods Hatchery (Quilcene Bay, WA). These hatcheries combine with smaller hatcheries in Washington and Hawaii to produce 40–60 billion eyed larvae each year, and their 30 years of consistent production has helped build today's $270 million per year shellfish industry.

High levels of larval mortality at the Whiskey Creek Shellfish Hatchery began in July 2007 and persisted to the end of the growing season in October. Some month-to-month variability in hatchery production is normal, but the magnitude and duration of the 2007 mortality events were unprecedented in the hatchery's 30-year history… Overall production at Whiskey Creek in 2008 was approximately 2.5 billion eyed larvae, about 25 percent of a normal season's production. Whiskey Creek is the primary supplier of larvae to many independent growers throughout the Pacific Northwest, and the shortage of larvae from the hatchery, combined with several consecutive years of poor natural recruitment of larvae from spawning populations in Willapa Bay generated concern among growers across the entire west coast shellfish industry (Dumbauld et al., 2011).

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Reading Questions The Case of the Dying Oysters

What problem occurred at Whiskey Creek Shellfish Hatchery from 2007 to 2009?

In a separate interview about the dying oysters, Mark Wiegardt said, "if [we] go out of business [we're] taking a bunch of people with [us]." What did he mean by this?

What might be wrong at Whiskey Creek? On the left side of the table below, write three to five possible causes for the hatchery's problems. Then, on the right side of the table, list one way you could test each idea to see whether it is correct.

Possible Causes	Possible Tests

Teacher Key: Reading Questions – The Case of the Dying Oysters

What problem occurred at Whiskey Creek Shellfish Hatchery from 2007 to 2009?

A large number of oysters mysteriously started to die. The hatchery was able to produce only 25 percent of its normal amount of larval oysters.

In a separate interview about the dying oysters, Mark Wiegardt said, "if [we] go out of business [we're] taking a bunch of people with [us]." What did he mean by this?

Mark meant that many other businesses rely on the hatchery to provide them with oyster seed. Without seed, oyster farms don't have young oysters to raise, which would impact those farmers as well as restaurants who buy oysters from farms, grocery stores, etc.

What might be wrong at Whiskey Creek? On the left side of the table below, write three to five possible causes for the hatchery's problems. Then, on the right side of the table, list one way you could test each idea to see whether it is correct.

Possible Causes	Possible Tests

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