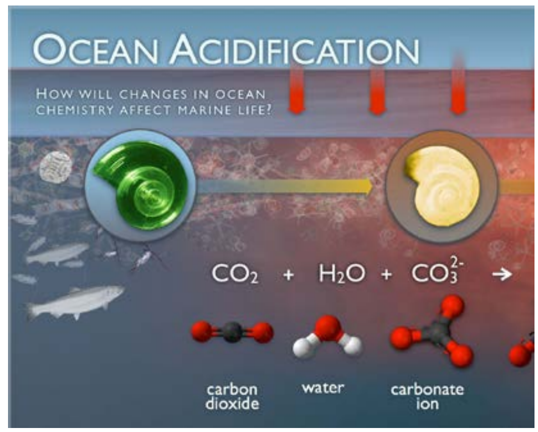
Ocean Acidification

Effects on Organisms & Solving an Environmental Challenge

Overview

Through hands-on investigations and some brief readings, students explore the causes and effects of ocean acidification. They learn that some shell building organisms are and will be negatively impacted by ocean acidification. Additionally, students use ideas of cause and effect as the basis for developing solutions to a real-life problem faced by oyster farmers in one community.



Learning Outcomes

Students will be able to:

- Describe, using evidence from classroom investigations, how pH affects the ability of some marine organisms to build shells.
- Describe, using evidence from readings and observation, direct and indirect effects of ocean acidification on organisms.
- Work in a small group to design a solution for shellfish growers facing ocean acidification.

NGSS and Climate/Ocean Literacy Connections

Disciplinary Core Ideas:

- MS.ESS3.C Human impacts on Earth Systems
- MS.ETS1.B Developing Possible Solutions
- HS.ESS3.D Global Climate Change
- ETS1.B Developing Possible Solutions

Science and Engineering Practice:

- Planning and Carrying out Investigations
- Constructing Explanations
- Designing Solutions

Crosscutting Concepts:

- Cause and Effect
- Stability and Change

Ocean Literacy Principles

- 6.d. Humans affect the ocean in a variety of ways.
- 6.e. Changes in ocean temperature and pH due to human activities can affect the survival of some organisms and impact biological diversity.

Grade Level

Middle School
High School

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Overview

Through hands-on investigations and some brief readings, students explore the causes and effects of ocean acidification. They learn that some shell building organisms are and will be negatively impacted by ocean acidification. Additionally, students use ideas of cause and effect as the basis for developing solutions to a real-life problem faced by oyster farmers in one community.

Session Goals

- Gain an understanding of the meaning and causes of ocean acidification
- Explore the effects of ocean acidification on organisms with exoskeletons and shells— some have difficulty building hard parts, and others' hard parts may dissolve due to ocean acidification
- Apply understanding of the direct effects of ocean acidification to making predictions about cause and effect to other organisms within an ocean food web
- Apply knowledge of daily and seasonal variability in ocean pH and ocean observing systems to propose solutions to real-life problems facing the oyster industry in the Pacific Northwest as a result of ocean acidification.

Materials Needed

For the class:

- PowerPoint presentation and Digital/data projector
- Computer
- Speakers
- Video and animation:
    - http://www.pmel.noaa.gov/co2/story/Ocean+Acidification's+impact+on+oysters+and+other+shellfish
    - http://www.whoi.edu/home/oceanus_images/ries/calcification.html.

For each student:

- Handout: Like Putting Headlights on a Car
- Handout and worksheet: Solving Local Environmental Challenges

For the Ocean Acidification: Effects on Organisms activity
“Break Down” activity
1 complete set of the following for each group of 4-6 students:

- 1 cafeteria tray
- 1 dropper bottle filled with white vinegar labeled “lower pH water”
- 1 petri dish divided into three parts each with a permanent marker (label each section with one of the following: shells/corals, seaweed, jellies)
- damp calcium carbonate powder
- gelatin powder (unflavored Knox Brand found in many grocery stores works well)
- small plastic cup/medicine cup
- 2 spoons
- damp seaweed (dampened with tap water)
- shell and coral samples
- Picture of jellies
- Direction sheet for Break Down Investigation
- Permanent marker

“Build-Up” Activity
1 complete set of the following for each group of 4-6 students:

- 1 cafeteria tray
- Bottle of distilled water
- ¾ cup of limewater in a sealable jar or cup (see preparation instructions below; requires Calcium hydroxide powder and distilled water)
- 3 Straws with a 1 cm diamond-shaped hole cut about two inches from the top
- 1 dropper bottle filled with white vinegar labeled “lower pH water”
- Permanent marker
- 3 6-8 oz. plastic Solo cups with lids (make holes in the lids large enough for a straw to fit through)—label cups 1, 2, and 3

- Direction sheet for and Build Up Investigation
- Build Up Student Sheet
- Litmus paper
- Video animation http://www.whoi.edu/home/oceanus_images/ries/calcification.html.

For the Ocean Acidification: Food Web activity

1 complete set of the following reference sheets for each group of 4-6 students:

- Ocean Acidification Food Web and Organism information sheets
- Manilla folder (to contain the reference sheets)

Preparation of Materials

1. **Make copies.**
   - One per student:
     - "Build Up" Student Worksheet
     - Like Putting Headlights on a Car Handout
   - One per group of 4-6 students:
     - "Break Down" Investigation Directions
     - "Build Up" Investigation Directions
     - 1 set of Ocean Acidification Food Web and Organism information sheets
2. Ocean Acidification: Effects on Organisms:
   a. **Prepare limewater.** Limewater is a Calcium hydroxide solution. To make it, dissolve 1/4 tsp Calcium hydroxide powder in 1000 mL of distilled water. Invert the mixing container several times to mix the powder until the water is relatively clear—you may need to dilute further so that water becomes more clear (sometimes it is necessary to dilute by half). To test the prepared limewater, add about an inch of limewater to each of two clear cups. Add a few drops of vinegar to one of the cups. Cover the cups with a lid that has a hole in it for a straw to fit through. Using a straw, blow into each of the cups for about 30 seconds. Then compare the cups side by side. The difference between the cups should be visible, with the plain limewater cup turning cloudy and the cup with added vinegar staying clear. NOTE: If you prepare the limewater more than immediately before you pour it into the cups for the groups to use, you may need to shake the

solution before pouring it into the cups. The Calcium hydroxide can come out of solution.

b. **Prepare gelatin powder.** Scoop into a small sealable container enough gelatin powder for each group of 4-6 to be provided with 1 tablespoon. Dampen the gelatin with water until it is spongy feeling or gelatinous-looking, but not "liquidy". Cover the container so that the gelatin powder does not dry out. Just before class, put about one tablespoon of dampened gelatin powder into a small medicine cup or other small plastic cup for each group.

c. **Place materials on trays.** Place all of the prepared materials on the cafeteria trays for each of the "Break Down" and "Build Up" Investigations. Make sure to leave the dampened seaweed and dampened gelatin powder off the trays until just before class so that they do not dry out.

Session at a Glance

Task	Description	Time (minutes)
A. **Hands-on Activity:** *Ocean acidification effects on organisms*	Through a hands-on investigation and readings, students examine the processes of ocean acidification that are or will directly impact some types of organisms.	40
B. **Solving an Environmental Challenge**: *Ocean acidification & shellfish*	Students read a short article and view a short video describing the effect of ocean acidification on the shellfish industry in the Pacific Northwest. They bring together what they know about the variability of pH in coastal waters to propose a real-world solution to the problem, then compare this to what shellfish growers have done.	40

Session Details

A. Ocean Acidification Hands-on Activity: *Effects on Organisms*

1. **Minute Paper.** Students take two minutes to write down a response to the following prompts:

—What is ocean acidification? Explain as best you can.
—Which organisms do you think might be affected by ocean acidification, and how?

2. **Share a quick definition.** Since the start of the Industrial Revolution, the ocean has gotten about 25% more acidic. This has been caused by excess CO_2 entering the atmosphere and thus more CO_2 being absorbed (taken in) by the ocean. The extra CO_2 comes from the burning of fossil fuels—from cars, trucks, airplanes, factories, making cement, clear cutting forests and other sources. Remind students that atmospheric CO_2 levels have been steadily increasing since the Industrial Revolution.

3. **Review – CO_2 in the ocean.** Remind p students that CO_2 occurs naturally in ocean water, through respiration and absorption. Remind them that some ocean organisms, just like land organisms, use CO_2 for photosynthesis AND that organisms that build shells use the carbon from CO_2 for making calcium carbonate shells.

4. **Introduce the exploration question.** Share the Exploration Question: *"What happens to some ocean organisms if the ocean absorbs more CO_2 than they are adapted for?"* Remind students that increasing amounts of CO_2 entering the water decreases the pH of the water, i.e., there is an inverse causal relationship between CO_2 and pH. [**Note:** this evidence comes from the activity *"Ocean Acidification Class Demo – charting the relationship between CO_2 and pH data activity."*)

5. **Introduce two questions to investigate.** Tell students that to help them think about their answer to the broad Exploration Question, they will investigate two smaller questions that focus on forming and maintaining shells. *(1) "Which organisms' parts might break down in water with a lower pH than they are adapted for?"* and *(2) "Can shells form if ocean water has a lower pH than they are adapted for?"*

Break Down Investigation

1. **Introduce "Break Down" investigation to participants.** Pass out trays of materials for "Break Down" investigation to each group. Tell students that they will begin their explorations by following the steps on the direction card for the "Break Down" investigation.
    a. Tell students that they will use calcium carbonate powder to represent shells since this is what shells are made of. Give them a minute to explore and handle the real shells and corals. Tell them that calcium carbonate powder is basically crushed shells.
    b. Tell them they will use gelatin to represent jellies since jellies are made of similar material. Encourage them to feel the gelatin powder and look at the image of a jelly on their tray.

NOTE: This demonstration has been included to represent the phenomenon of the dissolution of carbonate-based shells in lower pH seawater. The reaction that results from mixing $CaCO_3$ *with vinegar is representative of the dissolution process, but not the speed and intensity of what happens to seashells or coral at the pH range predicted by the various models of the effects of climate change on global ocean pH. Further, the dissolution of calcium carbonate powder (versus solid shells) will occur much more rapidly, as the surface area exposed to the acid is greater with powder than shells. Despite these shortcomings, this is an effective model for the dissolution of calcium carbonate shells in acidified oceans.*

2. **If it seems necessary, briefly describe the steps written on the card:**
    a. Spoon a small amount of each of the appropriate materials in each of the labeled areas on the petri dish (seaweed, jellies, shells/corals).
    b. Predict what will happen when "lower pH water" is dropped on each of these materials.
    c. Using the eyedropper, add a few drops of "lower pH water" to each material on your plate.
    d. Note what happens to each material.
    e. Discuss these questions: Are any of the materials unaffected by the lower pH water? If so, which ones? Which materials seem to be most affected by lower pH water?

3. **Students conduct investigation.** Give students a few minutes to conduct the investigation and discuss the questions. Listen in as they share their responses to the discussion questions. They should notice that the calcium carbonate (shells/corals) is the most affected (it bubbles), while the seaweed and gelatin (jellies) remain unaffected.

4. **Discuss results.** Ask, "What types of organisms might be affected by ocean acidification based on your evidence so far? Which organisms might fare well in a more acidic (lower pH) ocean?" [*shelled organisms might have a tough time maintaining their shells, while jellies and seaweeds appear to be unaffected*].

Build Up Investigation

1. **Introduce how marine calcifiers build shells.** Tell students that in a minute they will make predictions about how ocean acidification may impact shell formation. In order to do this, provide them with a bit of information on how marine calcifiers build shells using this animation: http://www.whoi.edu/home/oceanus_images/ries/calcification.html. Stop the animation before the last slide—stop on the one that discusses how hydrogen ions in seawater interfere with shell formation.

2. **Turn & Talk - make predictions.** Ask students, based on what you know about shell formation, how do you think falling ocean pH may impact organisms' abilities to make shells? Give participants a minute to turn and talk to a partner. Remind them to provide reasoning in their prediction. Do not have participants share responses with the class.

3. **Introduce the "Build Up" investigation to participants.** Explain to the class that they will now use containers of limewater as models of the ocean. Limewater is tap water with a lot of calcium dissolved in it (in the form of calcium hydroxide). Tell them that limewater will act as a model of the ocean because:
    a. Ocean water has many different types of substances dissolved in it naturally, such as nitrogen, calcium, sodium, and carbon dioxide. So ocean water is like soup broth that has many ingredients dissolved in it.
    b. Organisms, like corals, snails, and clams, use the calcium and CO_2 in ocean water to form calcium carbonate that makes up their shells, just as they saw in the animation. Calcium carbonate ($CaCO_3$) makes their shells hard. Limewater has a lot of calcium dissolved in it.
    c. CO_2 from respiration (our breath) will be used to add CO_2 to the model ocean water (limewater). When CO_2 is added to the limewater, a chemical reaction will take place

producing calcium carbonate. This means that carbonate is available for combination with the calcium. During the investigation, if $CaCO_3$ forms, the water will turn cloudy due to bits of precipitated $CaCO_3$ floating in the water. Ocean organisms use carbonate (CO_3^{2-}) and calcium dissolved in ocean water to make $CaCO_3$ hard parts.

4. **Do "Build Up" investigation with participants.** To each group, pass out the tray of materials for the "Build Up" investigation, including the directions sheet and the "Build Up" Student Sheet. Point out that in this investigation, they will be looking at the effects of ocean acidification on organisms' shell-building capabilities. They will be comparing the availability of $CaCO_3$ for shell building in waters of differing pHs. If it seems necessary, briefly describe the steps written on the card:
    a. Note three cups on the sheet of paper labeled, 1, 2 and 3 and a line reading higher pH at one end and lower pH at the other end. Each cup contains limewater. Line the cups up from 1 to 3, with #1 closest to the higher pH end of the line, cup #2 in the middle of the line, and cup #3 at the lower pH end of the line.
    b. Drop 10 drops of vinegar into cup #2.
    c. Drop 20 drops of vinegar into cup #3.
    d. Using litmus paper, measure the pH in each cup to confirm placement on the pH line.
    e. Cover each of the cups with a lid.
    f. When CO_2 mixes with Calcium in water, sometimes calcium carbonate is formed. ***Predict what will happen*** when you add CO_2 to each cup by breathing into them through a straw. This will mimic CO_2 naturally being absorbed by ocean water. You will be able to tell if calcium carbonate forms in the cups because the cup will become cloudy from the white calcium carbonate.
    g. Unwrap the straws; insert one straw through the lids into each of the three cups of limewater. Do not drink the water. Give each of the cups to different people.
    h. At the same time, have each person holding a cup use their straw to blow air into the solution in the cup. Air bubbles should be apparent in the solution. Have each person blow for the same amount of time—about 30-45 seconds.
    i. Record observations of each of the cups and answer the wrap-up question: Which of the cups of water seems to have more calcium carbonate available for organisms to use to build shells? What is your evidence?

5. **Whole group discussion.** Once students have completed the activity and their worksheets, bring them back together as a class and ask for groups to report out what they observed.
   a. Students should notice that the higher pH water gets cloudy because more white precipitate forms. Remind students that this cloudiness is calcium carbonate – the compound ocean organisms use to build their shells. However, the lower pH water is less cloudy because less white precipitate forms.
   b. Ask, "Which of the waters appear to have more calcium carbonate available for building shells? How do you know?" [*The higher pH water seems to have more calcium carbonate available because it is cloudier than the lower pH water, therefore it could be easier for organisms to make shells in water with higher pH.*]
   c. Ask, "How is shell building connected to atmospheric CO_2 concentrations?" [*As atmospheric CO_2 increases, ocean pH decreases. So, when atmospheric CO_2 levels are higher, ocean organisms will most likely have a harder time building shells because there is less available carbonate in the ocean water when the pH is lower.*]

6. **Review models in science.** Tell students that the two investigations used models to represent the ocean. Ask students to think about the ways in which these models are accurate for investigating the questions regarding effects of a more acidic ocean on ocean organisms, and then ask them to think about the ways they are inaccurate. Call on a few volunteers to discuss their ideas. Encourage students to build on each other's ideas by asking questions like, "What do others think about that idea?" or "Does anyone have anything to add to that idea?"

Accurate: *The models use some of the substances dissolved in ocean water, including calcium and CO_2; the gelatin and the calcium carbonate are essentially the same materials the actual organisms we're modeling are made of.*

Inaccurate: *The models are much smaller than the actual ocean; the CO_2 entering the ocean is not really from blowing into it, but is absorbed from the atmosphere; the low pH water is likely a lot more acidic than ocean water will ever actually be, but we have made it more acidic to speed up the process so that it can be seen in a short amount of time. In addition, there are other feedbacks and processes occurring in organisms than just the calcium carbonate/carbon dioxide relationship and therefore this model is not a complete picture of what is happening in the ocean to marine organisms with ocean acidification.*

More information about effects of Ocean Acidification: Food Webs

1. **Getting more evidence about organisms affected by ocean acidification**. Tell students that they will continue to gather evidence about the effects of ocean acidification. Pass out the set of 8 Ocean Acidification Food Web and Organism information sheets to each table group of participants. Ask table groups to divide up the 8 sheets between themselves. Then give students a few minutes to peruse whatever interests them.

2. **Students share findings in table groups.** After students have had a few minutes to look through the information sheets, ask them to share their findings with others in their table group. Give students about 5 minutes to share anything they found interesting or surprising.

3. **Whole group share out.** After a few minutes, ask the whole class, *"Based on the available evidence, what can you say about direct and indirect effects of ocean acidification on organisms?"*

Encourage everyone to participate in the discussion and to build on each other's ideas by asking questions like, *"What do others think about that idea?"* or *"Does anyone have anything to add to that idea?"* If no one points out the information on plankton, you might share that many plankton build parts from calcium carbonate, and plankton are the base of most ocean food webs. Students should also mention that most organisms within the marine food web will be at least indirectly affected by ocean acidification due to effects on many organisms at the base of the food web.

4. **Revisit minute papers.** Have students draw a line under their first ideas on the minute paper. Then have them record their current thinking under the line, making sure to include evidence.

5. **Small groups write key concepts; class consensus recorded on chart.** Have table groups complete the following sentence starters and then call on volunteers to share their ideas. Record ideas on the board and come to a class consensus about the wording of the ideas to add to the class chart.
    - Ocean acidification is caused by_____________________. [*Answers may vary and include an increase in atmospheric CO_2, production of carbonic acid out of water and CO_2, increase in hydrogen ions, decrease in pH, or increase in acidity*]
    - The effects of ocean acidification include_________________. [*Answers may vary and include dissolution of oyster and/or mussel shells and other calcifying organisms,*

disruption of food webs, economic challenges for communities that rely on marine resources, etc].

Note to Instructor: *Students often have additional questions about ocean acidification. If students want more information, please share the following link: http://www.whoi.edu/ocean-acidification/. Students may also wish to revisit the animation: http://www.whoi.edu/home/oceanus_images/ries/calcification.html.*

B. Solving an Environmental Challenge: *Ocean Acidification*

In this section, students will read a short article and view a short video as an introduction to some of the adverse effects of ocean acidification on oyster larvae and the resulting challenges facing the shellfish industry in the Pacific Northwest. After reading background information provided on the handout, the first page of the NOAA article, and the first part of the PBS video on ocean acidification, students will work together to bring in what else they know about the variability of ocean pH to propose a solution for the problems facing oyster growers in the Pacific Northwest. *NOTE: The second page of the NOAA article and the last part of the video explain some of the solutions that oyster growers came up with. For this reason, only have students read and view the first part of the article and video.*

1. **Background on the effects of ocean acidification and oysters**. Have students read the background section of the *Solving Local Environmental Challenges* handout, then the first page of the short NOAA article on IOOS titled *Like putting headlights on a car,* which describes some of the challenges faced by the shellfish industry and how ocean observing systems are involved in the solution. While reading, ask students to create a written list of the challenges faced by the shellfish industry. Link to article: http://www.noaa.gov/features/01_economic/pacificoysters.html

2. **Gather more information from a video.** Tell students that the video you are about to watch will provide additional information on the effects of ocean acidification on oysters. As they watch, they should add to their list of challenges. Watch the first part of the PBS report titled "Ocean Acidification's impact on oysters and other shellfish: Acidifying Waters Corrode Northwest

Shellfish." Pause the video at 3:20 after Bill Dewey of Taylor Shellfish describes the effect of ocean acidification on oyster larvae. (You will resume the video at the end of the activity).
http://www.pmel.noaa.gov/co2/story/Ocean+Acidification's+impact+on+oysters+and+other+shellfish

3. **Designing a solution to the problem facing oyster growers (group work)**: Tell students they will work together in small groups to come up with strategies for how the shellfish industry can overcome the effect of ocean acidification (OA) on oyster larvae. Provide the following prompt to set the stage for the challenge:

"Imagine you are an oyster grower in the Pacific Northwest, with many families, employees, restaurants and seafood distributors that depend on you for oysters and livelihood. In order to maintain production of healthy oyster larvae, you need to pump fresh ocean water into your hatchery daily until they reach a size when they are less vulnerable to changing environmental conditions (approximately 2 weeks). However, if you pump ocean water into your hatchery that is too low in pH, millions of oyster larvae might die and shellfish growers will be left without oyster seed."

4. **Small groups discuss strategies.** Given this challenge, have students work together in small groups to come up with a strategy to overcome some of the problems associated with ocean acidification. The following prompts are on their Solving Local Environmental Challenges worksheet and are meant to help build evidence for possible solutions.

Note to educator: *Let students know that they will be calling on previous content and making new connections regarding daily and seasonal patterns in dissolved oxygen,* CO_2*, and pH.*

1) What do you know about the daily variability of oxygen and carbon dioxide? [*Carbon dioxide and oxygen go up and down and are inversely related. Due to photosynthesis, oxygen is higher during daylight hours and carbon dioxide is lower. The opposite occurs at night due to respiration*].
2) How is this variability in oxygen and carbon dioxide related to pH? [*pH changes as a function of carbon dioxide concentrations*]. When is pH low? [*At night or times when respiration is greater than photosynthesis*]. When is it high? [*During the day when photosynthesis is greater than respiration*]. Can you use this to your advantage when collecting water to raise oysters? [*Collect water at times when carbon dioxide is lowest, for example most likely during the afternoon*].

3) What do you know about the seasonal fluctuation of ocean pH? Is this pattern predictable? [*Ocean pH varies predictably and inversely with carbon dioxide throughout the year. pH is generally higher in summer when carbon dioxide concentrations are the lowest (due to drawdown from photosynthesis). pH is lowest in the winter when there is less photosynthesis and respiration has increased the dissolved carbon dioxide concentrations*].
4) Could this information help with timing the collection of water for growing oysters? [*Collecting water later in the season (summer) is most likely better than winter*].
5) What technologies are available to monitor ocean chemistry and water quality? [*Sensors have been developed that can measure salinity, dissolved oxygen, pH, carbon dioxide, temperature, and chlorophyll (i.e., phytoplankton) concentrations - and other parameters. These sensors can be on handheld instruments, or automated instruments deployed on pilings, buoys, and gliders that provide real-time data via satellite, cellular or telemetry data streams. Remote sensing from satellite or aircraft can be used to determine ocean temperature, salinity, chlorophyll, or other features.*]. How would you use these? [*These technologies can be used to measure real-time ocean conditions and also predict changes in chemistry and water quality. These data can then be used in real-time to make informed decisions*].
6) Is there anything else you know about the seasonal fluctuation of ocean pH? Are you familiar with any other oceanographic processes that bring low pH water to the surface? How could this information be helpful? [*Students may also mention the effect of upwelling, where low pH water from the deep ocean is brought to the surface when upwelling-favorable winds occur. Hatcheries on the coast should not collect water during periods of upwelling if they intend to use this water for growing oysters*].

5. **Small groups record solutions**. Once they have discussed these questions, have them write down their solution. Encourage them to use drawings or illustrations to provide a more detailed description.

6. **Small groups share with other small groups**. When the small groups are done with their discussions and have written down their solutions, have them share with another small group and compare their strategies for dealing with the effect of low pH ocean water on oyster larvae and the oyster industry. Encourage them to push each other to provide evidence for their proposed solutions.

7. **Comparing Solutions**: Have students read the second page of the NOAA article and finish the PBS report video on ocean acidification. Have them make note of the following and discuss these questions within their small group:
    1) What are some of the solutions that oyster growers implemented to deal with low pH waters in the Pacific Northwest? Were these similar to the solutions your group proposed?
    2) What ocean observing technologies were used to assist in the solution described in the NOAA article?
    3) This exercise has focused on oysters in the Pacific Northwest. Based on your own ideas and the PBS video, what other coastal industries are potentially affected by ocean acidification?

7. **Lead whole group discussion to summarize**. Encourage students to share their reactions to the activity and to compare and contrast their solutions to what the oyster growers implemented.

8. **Turn & Talk: add ideas to class chart.** Have students turn and talk to the person next to them and discuss if there are additional ideas or key concepts about ocean acidification we should add to the class chart. Record on class chart as volunteers share their ideas.

9. **Exit ticket - students record Muddiest Point.** Ask students to write down questions they still have about ocean acidification, especially noting any idea that is the most confusing (muddy) for them. Collect these responses at the end of class to discuss during the next class period.