Ocean Acidification and Impacts to Dungeness Crab in Monterey Bay National Marine Sanctuary

Grade Level

3rd to 7th grade

Timeframe

2 to 4 hours

Materials

Lesson
• Computer with speakers, projector and screen
• 12-14 sheets of poster paper and markers (or a white board divided into at least 10 sections and white board markers)
• PowerPoint presentation
• Printed and laminated images and signs: see chart on pg. 4
• Nine crab pot representations (size is not important, may use milk crate or similar structure)
• OA in a Cup Experiment materials *see page 9

Scuba
• All primary scuba gear
• Compasses, one for each dive pair
• Slates with attached writing tools, one for each dive pair
• Laminated data capture sheets, one for each dive pair

Classroom
• Classroom with computer and projector, internet access
• Demonstration table
• Pool

Dungeness crab resting on a sandy bottom with a shrimp standing on its back. Photo: Oregon Coast Aquarium

Activity Summary

This lesson introduces students to Monterey Bay National Marine Sanctuary, located off the coast of central California. Students will learn:

- about Dungeness crab and its life cycle;
- how ocean acidification is impacting the marine food web and the commercial fishing industry; and
- daily actions they can take that will reduce the effects of climate change on the marine food web and help to maintain a healthy Dungeness crab population.

Essential Questions

1. What are the stages of the Dungeness crab's life cycle? Why is the Dungeness crab important to the marine food web?
2. What is ocean acidification? How does it impact the Dungeness crab's life cycle? How does ocean acidification affect the marine food web and the commercial fishing industry?

3. What daily actions can be taken to reduce ocean acidification in order to have a healthy marine food web and support the livelihood of the commercial fishing industry?

Learning Objectives

Students will be able to:

- Recognize the stages of the Dungeness crab's life cycle and summarize the role of the Dungeness crab in the marine food web.
- Explain what ocean acidification is and how it affects Dungeness crab at developmental larval stages.
- Summarize the effects of ocean acidification on the Dungeness crab population impacts the marine food web and in turn the commercial fishing industry.
- Infer and implement actions people can take in their daily lives to reduce ocean acidification to support a healthy marine food web and a thriving commercial fishing industry.

Performance Requirements

At the surface students will:

- Streamline gear prior to entry.
- Demonstrate proper descent techniques and awareness of the environment.
- Review hand signals necessary for the dive.

Dungeness crab at the Megalope stage. Small, light orange crab next to a dime to show size relation. Photo: Wesley Luchterhand

Underwater, students will:

- Dive and navigate to multiple areas to locate stations to observe four stages of the Dungeness crab's life cycle.
- Record the necessary information to report observations about each stage of the Dungeness crab's life cycle both in healthy and unhealthy (more acidic) water.

Background Information

Designated in 1992, Monterey Bay National Marine Sanctuary is a federally protected marine area offshore of California's central coast.

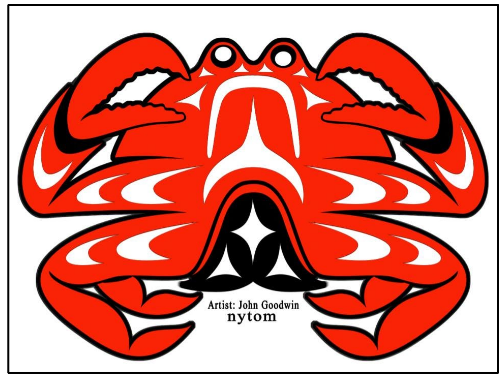
Monterey Bay National Marine Sanctuary contains extensive kelp forests and one of North America's largest underwater canyons. Known as the 'Serengeti of the Sea,' Monterey Bay National Marine Sanctuary is home to 36 species of marine mammals including humpback and blue whales, otters, seals, and sea lions, four turtle species, 180 species of birds, 525 species of fishes, and countless invertebrates. It also has nearly 1,300 reported shipwrecks.

Sustainable tourism and recreation opportunities are limitless: whale watching, diving, boating, surfing, kayaking, fishing, tide pooling, and beach exploration to name a few. And the sanctuary's marine research, monitoring, and conservation activities are just as extensive, with many offering citizen science activities and volunteer engagement.

The research program at Monterey Bay National Marine Sanctuary collaborates with more than 30 research institutions and engages in multiple areas of marine science. The research assesses change in species and habitats, and participates in regional research to better understand the sanctuary ecosystem.

Dungeness crabs got their name from the town of Dungeness, Washington, where the commercial fishery for this species began in 1848. These crabs thrive in cold water environments and live in sandy environments like bays, inlets, and estuaries, including seagrass beds and rocky structures.

Dungeness crabs are naturally found in the Pacific Ocean and span three countries: Canada, the United States, and Mexico. Most commonly, we find Dungeness crab populations between the Aleutian Islands in Alaska and Santa Barbara, California, but we occasionally see them as far south as Baja California Sur in Mexico. This means Dungeness crabs are found in the Olympic Coast, Monterey Bay, Cordell Bank, Channel Islands, and Greater Farallones national marine sanctuaries.



Tribal Dungeness crab design. Image: John Goodwin Nytom

Global climate change is increasing sea surface temperatures – this increasing temperature combined with increasing concentrations of atmospheric carbon dioxide are causing the world's ocean to become more acidic (lower pH levels). Ocean chemistry is changing at a rapid pace, and by 2100 it is predicted to drop an additional 0.3 pH units.

A NOAA-funded study has documented that ocean acidification along the U.S. Pacific Northwest coast is impacting the shells and sensory organs of some young Dungeness crab, a prized crustacean that supports the most valuable fishery on the West Coast.

Analysis of samples collected during a NOAA research cruise identified examples of damage to the carapace, or upper shell, of numerous larval Dungeness crabs, as well as the loss of hair-like sensory structures that crabs use to orient themselves to their surroundings. Prior to this research cruise, scientists thought that Dungeness crab were not vulnerable to current levels of ocean acidification. Also, a laboratory study conducted on Dungeness crab larvae by NOAA's Northwest Fisheries Science Center found that their development and survival suffered under pH levels expected in the future.

According to lead author Nina Bednarsek, senior scientist with the Southern California Coastal Water Research Project, this study first demonstrated "that larval crabs were already being affected by ocean acidification in the natural environment" which built "on previous understanding of ocean acidification impacts… pteropods." Discovering the crabs were affected already indicated scientists needed "to pay much more attention to various components of the food chain" to better manage this critical species.

Dungeness crabs are preyed upon by fish, octopus, sea otters, and even larger species of crab, and they eat worms, shrimp, mussels, smaller crabs, clams, and anything else they can find. Dungeness crabs are safe for people to eat and provide for the West Coast's most valuable commercial fishery, valued at more than $220 million annually!

Ocean acidification is one of the largest threats facing Dungeness crabs and the associated commercial fishery. A more acidic ocean environment prevents remineralization of the Dungeness crab's shell, leaving freshly molted crabs especially vulnerable with their soft shells for longer periods of time. This phenomenon could also have impacts on the Dungeness crab fishery, which already stops fishing for the crabs during the molting season between August and early December due to their fragility in their soft-shell state. Management, research, and education programs help contribute to the health, well-being, and knowledge of the species and its habitats.

Vocabulary	
Dungeness Crab	The largest, edible, hard-shelled crab characterized by broad oval carapaces, or outer shell, that are saw-toothed on the front side which can be found from the eastern Aleutian Islands, Alaska to Santa Barbara, California.
Ocean Acidification	A reduction in the pH of the ocean over an extended period of time, caused primarily by uptake of carbon dioxide (CO_2) from the atmosphere.
Larvae	Distinct juvenile forms many animals undergo before metamorphosis into adults.
Carapace	(Upper Shell) A bony case or shield that covers the back of an animal (such as a turtle, crab, or lobster).
Food Web	A network describing the feeding interactions of the species in an area.

Preparation

Before the deck and pool activities, the instructor should prepare the following:

1. Print and laminate the images and set-up all crab pots, including the example one for the deck activity.

2. Set up for Activity A, see both charts: Activity A- Pool Diagram and Activity A- How many copies of the crabs do I make for each crab pot? Chart. Set up the eight crab pots, weighted, with laminated images in the pool and mark the sides; four "blue" side pots and four "yellow" side pots.

*NOTE TO INSTRUCTOR: the "blue" side is the healthy pH level and the "yellow" is the unhealthy pH level. Do not disclose this to the students as they will discuss their observations after the pool activity and hopefully come to this conclusion on their own. Then the instructor can confirm this information for them at the end.

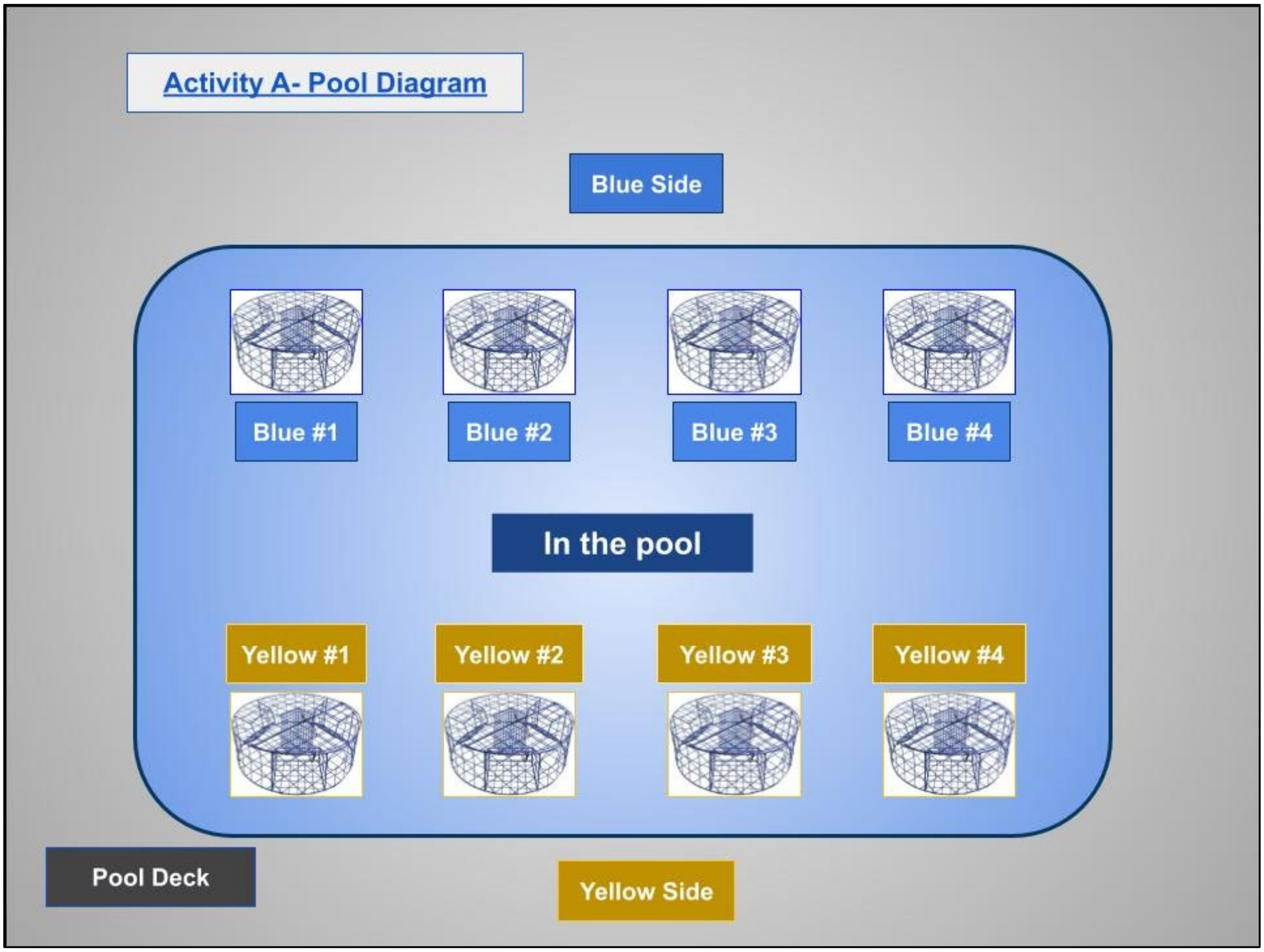
3. Set up the poster paper and markers for the "background knowledge" section and the "observations" after the dive; each poster should be labeled: "blue stage #1, blue stage #2, blue stage #3, blue stage #4, yellow stage #1, yellow stage #2, yellow stage #3, yellow stage #4."

4. Set up the computer/projector for the PowerPoint.

5. Set up the needed tools for the dive pairs; compasses and dive slates with attached writing tools.

6. Set up for Activity C – see page 9 for "OA in a Cup" Activity Guide

Activity A: How many copies of the crabs do I make for each crab pot? Chart	
BLUE SIDE	**YELLOW SIDE** Roughly 1/6 of the count for the blue side pots. Hopefully students will discover this ratio in their observations and group discussion.
Crab Pot #1 printable: print six copies Crab Pot #2 printable: print six copies Crab Pot #3 printable: print six copies Crab Pot #4 printable: 4-A, 4-B, 4-C and 4-D- print four copies of 4-A print two copies of 4-B print two copies of 4-C print two copies of 4-D	Crab Pot #1 printable: print one copy Crab Pot #2 printable: print one copy Crab Pot #3 printable: print one copy Crab Pot #4 printable: 4-A, 4-B, 4-C and 4-D- print one copy of 4-A print one copy of 4-C print one copy of 4-D



Procedure

1. Instructor uses the PowerPoint to introduce the students to Monterey Bay National Marine Sanctuary and how ocean acidification is a threat to the Dungeness crab.

2. "Let's see what you already know." Instructor asks students the essential questions from slide #4 to assess background knowledge: Record answers on Background Knowledge poster.

- A. What is a Dungeness crab? What are the stages of the Dungeness crab's life cycle? What is a marine food web? Why is the Dungeness crab important to the marine food web?
- B. What is ocean acidification? How do you think it impacts the Dungeness crab's life cycle? How does ocean acidification affect the marine food web? What is the commercial fishing industry? How does ocean acidification affect the commercial fishing industry?
- C. What actions can be taken to reduce climate change impacts in order to have a healthy marine food web and commercial fishing industry?

Activity A - on the pool deck

- Prior to pool entry, the instructor sets up an example crab pot (crab pot #9).

3. The instructor divides students into pairs such that each pair has a Diver A and a Diver B.

4. The instructor explains that the use of the crab pot is not the true way scientists observe the stages of the Dungeness crab's life cycle, but the crab pots are being used so the students can become familiar with the equipment that fishers use to catch adult Dungeness crabs to sell at the fish market. The instructor explains that each crab pot represents a different stage in the crab's development to adulthood. Instructor tells the students that their task is to record observations about each stage and come up with a list of characteristics to define each developmental stage.

5. First, the instructor shows the students how to use the compass to navigate to the position of the first crab pot. Allow each pair enough time to practice so each diver gets a couple of turns to use the compass and feels comfortable with how it works.

6. Then, the instructor demonstrates how to make an observation of the crab's developmental stage of the crab pot and record the data on the data collection worksheet on the dive slate such that the instructor models how to count the number of crabs recording the number on the dive slate, drawing what the crabs look like in the box on the dive slate worksheet and recording the color, etc... Each pair gets a chance to practice and learn how to use the dive slate.

<u>Activity B</u> - in the pool

- Students will practice dive skills while meeting diving performance requirements and national marine sanctuary learning objectives.
- Students will work in groups of two to complete the learning objectives.
- Students will use pre-arranged hand signals to communicate underwater.
- Students will use a compass to navigate underwater.
- Students will observe and record data on a dive slate underwater.

7. The instructor explains that each pair will dive on both sides of the pool: the "blue" side and the "yellow" side. The instructor explains that each side of the pool represents different kinds of water that the Dungeness crabs could live in. Each side of the pool has four crab pots, and each crab pot displays a different stage of the crab's development from larval to adult stages. On the blue side: Diver A navigates with the compass and Diver B records observations on the dive slate. On the yellow side: Diver B navigates with the compass and Diver A records observations on the dive slate.

8. Then the pairs switch sides of the pool so that each dive pair gets a turn to dive both the "blue" side and the "yellow" side of the pool.

9. After the dive, the instructor allows time for each pair to record their observations on the posters; eight poster papers- "blue stage #1, blue stage #2, blue stage #3, blue stage #4, yellow stage #1, yellow stage #2, yellow stage #3, yellow stage #4". (Discussion will come later.)

<u>Activity C</u>: pool deck, OA in a Cup experiment

10. The instructor does the OA in a Cup experiment. Have students help with each step of the experiment. See page 9 for complete activity guide.

11. Students observe the changes in the cups and discuss what they think is happening.

12. Instructor uses slides 9 to 13 to explain what happens during ocean acidification and how it changes the water chemistry in the ocean (include an explanation of upwelling). Instructor shows the video on slide 11 to the students about how the more acidic water affects the early developmental stages of the Dungeness crab. The instructor will show students the video on slide 13 to learn how about crabbers.

13. Instructor asks students what will happen to the crab population if the early developmental stages are affected? What will happen to the marine food web? Discuss in small groups. Then discuss as a whole group.

14. Students take time to think about the observations they made of the "blue" side and the "yellow" side. Discuss differences in small groups, and then discuss as a whole group.

Ocean acidification effects on a pteropod. Image: David Liittschwager/National Geographic Stock

15. Instructor asks the students which side of the pool has a healthy pH level and which side has an unhealthy pH level? How do they know? Discuss in small groups. Then discuss as a whole group.

Discussion Questions and Wrap-up:

- Upon completion of the pool mission assess student understanding.

16. Instructor asks students based on what they've learned today about ocean acidification, the Dungeness crab life cycle and the marine food web, what will happen if the ocean continues to become more acidic? What will happen to marine life? What will happen to the crabbing industry? Discuss in small groups, and then discuss as a whole group.

17. Instructor asks the students what actions they can take in their daily lives to reduce the carbon emissions into the atmosphere in order to reduce the effects of climate change? (Refer back to slides #9 to #14 if students struggle.)

18. The instructor helps the students to log the information from the dive into their Ocean Guardian Dive Club passports.

Education Standards	
Dive Industry Standards	PADI Aqua Mission: Navigation Specialist SSI: Navigation Ranger NAUI Junior Scuba Diver or Passport

Education Standards	
Ocean Literacy Principles	2. The ocean is the largest reservoir of rapidly cycling carbon on Earth. Many organisms use carbon dissolved in the ocean to form shells, other skeletal parts, and coral reefs. (D) 6. 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. (B) 7. Over the last 50 years, use of ocean resources has increased significantly; the future sustainability of ocean resources depends on our understanding of those resources and their potential. (C)
Climate Literacy Principles	3. Changes in climate conditions can affect the health and function of ecosystems and the survival of entire species. The distribution patterns of fossils show evidence of gradual as well as abrupt extinctions related to climate change in the past. (C)

For More Information

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Additional Resources

Climate Change and Ocean Acidification, Monterey Bay Sentinel site

https://sanctuaries.noaa.gov/science/sentinel-site-program/monterey-bay/climate-change-ocean-acidification.html

Informative One-Pager about Dungeness Crab

https://nmssanctuaries.blob.core.windows.net/sanctuaries-prod/media/archive/education/voicesofthebay/pdfs/dungenesscrab.pdf

Monterey Bay National Marine Sanctuary Overview

https://montereybay.noaa.gov/intro/welcome.html

Monterey Bay National Marine Sanctuary Sentinel site

https://sanctuaries.noaa.gov/science/sentinel-site-program/monterey-bay/

National Marine Sanctuary Foundation site about Monterey Bay

https://marinesanctuary.org/sanctuary/monterey-bay/

NOAA Research News article "Dungeness crab larvae already showing effects of coastal acidification."

https://research.noaa.gov/article/ArtMID/587/ArticleID/2581/Dungeness-crab-showing-impact-of-coastal-acidification

NOAA Resource Collection: Ocean Acidification

https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification

NOAA’s Office of National Marine Sanctuaries

This site contains information on each of the sites in the National Marine Sanctuary System. https://sanctuaries.noaa.gov

Ocean Acidification Online Toolkit: Dungeness Crab

The toolkit includes: fact sheet; infographic; PowerPoint slideshow with script; reference list; resource list; public domain video B-roll; and public domain images.

https://sanctuaries.noaa.gov/education/crab-toolkit.html

Ocean acidification to hit West Coast Dungeness crab fishery, new assessment shows

https://www.washington.edu/news/2017/01/12/ocean-acidification-to-hit-west-coast-dungeness-crab-fishery-new-assessment-shows/

Oregon Dept of Fish and Wildlife: Life of a Dungeness Crab

https://www.dfw.state.or.us/mrp/shellfish/crab/lifehistory.asp

Sea Wonder: Dungeness crab information.

https://marinesanctuary.org/blog/sea-wonder-dungeness-crab/

What is Ocean Acidification

https://oceanservice.noaa.gov/facts/acidification.html

Ocean Acidification in a Cup: Complete Activity Guide

Change the atmosphere to change the water below.

Create a carbon dioxide-rich atmosphere in a cup and watch how it changes the water beneath it. This model of ocean–atmosphere interaction shows how carbon dioxide gas diffuses into water, causing the water to become more acidic. Ocean acidification is a change that can have big consequences.

Tools and Materials

- Safety goggles
- An acid-base indicator, such as Bromothymol Blue or purple cabbage juice indicator, that is diluted with water: 10 ml Bromothymol Blue (0.04% aqueous) to 1 liter of water (see the Teaching Tips section below for alternatives)
- Two clear 10 oz plastic cups (the tall ones)
- Paper cups—3 oz size (you'll only use one in the experiment, but keep a few extras at hand just in case)
- Masking tape
- Plain white paper
- Permanent marker
- Baking soda
- White vinegar
- Two Petri dishes—to use as lids on the plastic cups
- Graduated cylinder (or measuring spoons)
- Gram scale (or measuring spoons)

Assembly

1. First things first: put on your safety goggles.
2. Pour 40–50 ml of acid-base indicator into each of the two clear plastic cups. One cup will be your control.
3. Add 2 g (about half a tsp) of baking soda to the paper cup.
4. Tape the paper cup inside one of the clear plastic cups containing the acid-base indicator so that the top of the paper cup is about 1 cm below the top of the clear cup. Make sure the bottom of

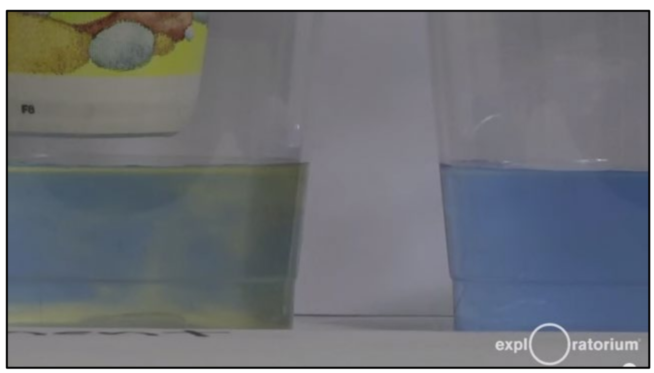
the paper cup is not touching the surface of the liquid in the plastic cup—you don't want it to get wet!

5. Place both clear plastic cups onto a sheet of white paper and arrange another piece of white paper behind the cups as a backdrop—this makes it easier to see the change.
6. Add 6 ml (a little more that 1 tsp) of white vinegar to the paper cup holding the baking soda. Be very careful not to spill any vinegar into the acid-base indicator. Immediately place a Petri dish over the top of each plastic cup.

To Do and Notice

Move your eye to the surface level of the acid-base indicator and observe the liquid's surface. What do you see? Where is the color change taking place?
After a few minutes have passed, you should notice a distinct color change at the surface of the liquid. As you continue to observe the cup, the liquid in other parts of the cup will also begin to change color.

What's Going On?



This activity illustrates how the diffusion of a gas into a liquid can cause ocean acidification. It also models part of the short-term carbon cycle—specifically the interaction between our atmosphere and the ocean's surface.

Human activities, such as burning fossil fuels and changes in land use, have increased the amount of carbon dioxide (CO_2) in the atmosphere from 540 gigatons of carbon (Gt C) in pre-industrial times to 800 Gt C now. Because the CO_2 amounts in the atmosphere are greater than they have been in 800,000 years, the carbon cycle is not in balance. As a result, from 1860 to 2009, the oceans absorbed an additional 150 Gt C from the atmosphere.

Mixing vinegar and baking soda together in the paper cup creates carbon dioxide gas (CO_2). The CO_2 gas then diffuses into the liquid below. When CO_2 gas diffuses into water, the result is carbonic acid (H_2CO_3) —the following chemical reaction takes place: CO_2 (aq) + H_2O —> H_2CO_3.

Carbonic acid dissociates into H^+ and HCO_3^-. The increase in H^+ causes the solution to become more acidic.

Carbonic acid is a weak acid. Even so, the presence of this acid affects the pH of the solution. Thus, after a short time, the pH indicator at the surface changes color—from blue to yellow if you're using Bromothymol Blue or from purple to pale pink if you're using cabbage juice indicator. This color change indicates a pH change caused by the diffusion of CO_2 gas into the liquid.

Outside of your paper cup—on a much larger scale—atmospheric CO_2 diffuses into the oceans.[1] Oceans are the primary regulator of atmospheric CO_2. They have absorbed half of all the CO_2 from anthropogenic sources produced between 1800–1994 and one-third of the anthropogenic carbon produced between 1980–2000.[2] The CO_2 taken up by the oceans reduces oceanic pH through a series of chemical reactions. The first of these is the reaction you've just observed: the creation of carbonic acid via the diffusion of CO_2 gas into water.[2]

The pH of the oceans was close to 8.2 in pre-industrial times. In 2005, it was approximately 8.1.[3] While the pH of the ocean is still basic, it is more acidic than it used to be. Since the pH scale is logarithmic, this means that the oceans are 30% more acidic now than they were in pre-industrial times.

Going Further

Diffusion goes both ways—from the atmosphere into the liquid and from the liquid into the atmosphere. This experiment shows passive diffusion: the CO_2 gas diffuses into the liquid. What experiment might you try in order to show that diffusion also goes the other way—from the liquid back into the atmosphere?

In March 2015, the global monthly average of the atmospheric concentration of CO_2 was around 400 parts per million (ppm)—or 0.04%. It is a small amount, but it is increasing by more than 2 ppm every year due to the combustion of fossil fuels—oil, gasoline, natural gas, coal—and land use changes, such as deforestation.

Increases in the concentration of atmospheric CO_2 have led to increases in the concentration of CO_2 and other carbon-containing molecules in seawater. The CO_2 added to seawater reacts with the water molecules to form carbonic acid in a process known as ocean acidification. The oceans are absorbing about 25% of the CO_2 we release into the atmosphere each year. Additionally, as more CO_2 gas enters the atmosphere, the atmosphere gets warmer, causing global temperatures to rise.

Ocean acidification is expected to impact ocean species to varying degrees. Photosynthetic algae and seagrasses may benefit from higher CO_2 conditions in the ocean, as they require CO_2 to live (just like plants on land). On the other hand, studies have shown that a more acidic ocean environment has a dramatic effect on some calcifying species, including oysters, shellfish, clams, sea urchins, shallow water corals, deep sea corals, and calcareous plankton. When shelled organisms are at risk, the entire food web may also be at risk.

Teaching Tips

Prior to trying Ocean Acidification in a Cup, learners should be familiar with acid-base indicators and know that baking soda and vinegar create CO_2 gas when mixed. This lesson dovetails with prior lessons on surface interactions and diffusion.

Making your use cabbage juice indicator

If Bromothymol Blue indicator is hard to come by, or if you'd prefer not to use this chemical in your classroom, you can use cabbage juice indicator instead. It's easy to make: just take a quarter head of purple cabbage, place it in a blender with water to cover, and blend until you get a uniform puree. Strain the resulting mixture—the purple liquid you're left with is your cabbage juice indicator. Dilute it with some water and proceed with the experiment, using it instead of Bromothymol Blue. You will need to experiment with the ratio of water to cabbage juice to see what dilution gives you good results. Unlike Bromothymol Blue, cabbage juice indicator turns pink, not yellow, in the presence of an acid.

Resources

"Ocean Acidification in a Cup: Complete Activity Guide" copied from
https://www.khanacademy.org/partner-content/exploratorium-ddp/exploratorium-chemistry/ocean-acidification/a/ocean-acidification-in-a-cup-complete-activity-guide

Thanks to Chris Sabine of NOAA's Pacific Marine Environmental Lab for his expertise.

Thanks to Jim Butler of University of California at Berkeley for his expertise.

References:

- Dr. Jürgen Schieber (Indiana University, Geology 1425 course notes): Chapter 8: The Importance of Carbon for Climate Regulation
- Mathez, E. A. (2009). *Climate Change: The Science of Global Warming and Our Energy Future*. Columbia University Press, New York.
- NOAA Ocean Acidification Program: What is Ocean Acidification (OA)?
- NOAA PMEL Carbon Program: What is Ocean Acidification?