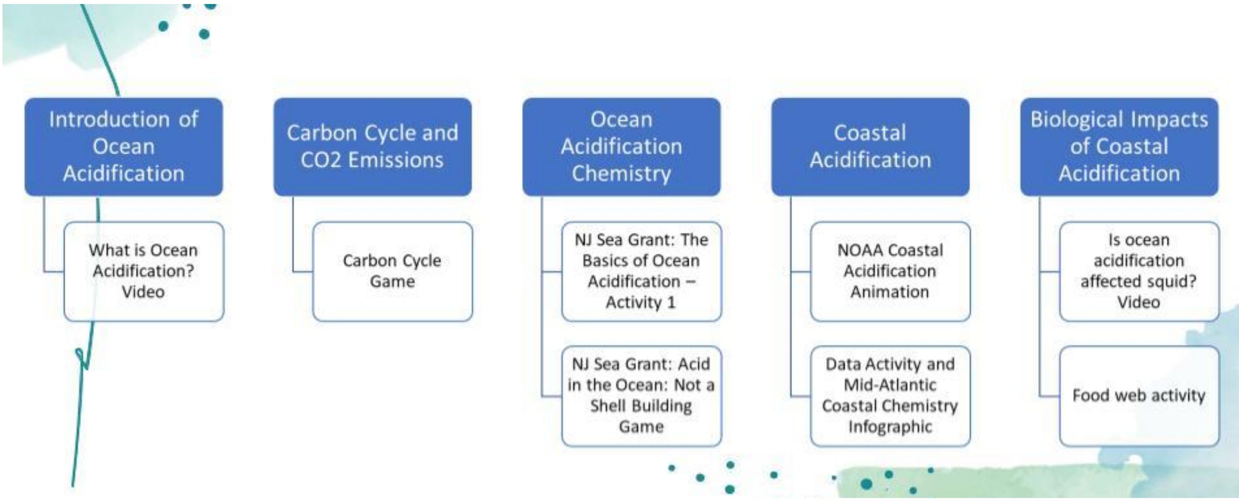
Coastal Acidification in the Classroom

A Module for the Mid-Atlantic

Compiled by the Mid-Atlantic National Estuarine Research Reserve System and the Mid-Atlantic Coastal Acidification Network

Table of Contents

About this Module



The goal of this module is to provide a teaching tool on ocean and coastal acidification specific to the Mid-Atlantic region. In this module, you will find lesson plans that will help students build an understanding of the issues by learning about ocean and estuarine chemistry and the effects of acidifying waters on marine habitats and biota. Lessons within the module have been adapted from organizations like NOAA, SeaGrant, and Project Learning Tree. The ideal age range for these lessons is middle and high school students, however, any of these activities could be modified for younger age ranges.

About MACAN: The Mid-Atlantic Coastal Acidification Network (MACAN) is a nexus of scientists, tribal, federal, and state agency representatives, resource managers, and affected industry partners who seek to coordinate and guide regional observing, research, and modeling of ocean and coastal acidification. MACAN works to develop a better understanding of the processes associated with estuarine, coastal, and ocean acidification, predict the consequences for marine resources, and devise local adaptation strategies that enable communities and industries to better prepare and adapt. MACAN also helps to fulfill the needs of other regional entities where objectives align. Visit MACAN's website for more information: https://midacan.org/

About NERRS: The National Estuarine Research Reserve System is a network of 30 coastal sites designated to protect and study estuarine systems. Established through the Coastal Zone Management Act, the reserves represent a partnership program between NOAA and the coastal states. NOAA provides funding and national guidance, and each site is managed on a daily basis by a lead state agency or university with input from local partners. Visit the NERRS website for more information: https://coast.noaa.gov/nerrs/

Acknowledgements

We consulted Mid-Atlantic school teachers during the making of the module. In 2021 several activities were tested by teachers at the Teachers on the Estuary (TOTE) summer workshops in VA, NJ, and DE. Edits were made based on their feedback and the module was tested again in the summer of 2022. This resource is for formal educators and the involvement of teachers in the creation of this curriculum was imperative to its formation.

The activities in this module were adapted and modified by the 2021 NOAA Hollings Scholar Greta Olsen, marine science graduate student, Anna Caputo, DE NERR education intern Bethany Kline, and the education coordinators from the mid-Atlantic NERRs, Sarah Nuss, Kaitlin Gannon, and Laurel Sullivan.

Background Information for Teachers

This information aims to provide educators with foundational knowledge on the causes and effects of ocean and coastal acidification. It also provides a comparison of coastal acidification and ocean acidification. The sections on ocean chemistry (1b.) and the difference between ocean acidification and coastal acidification (1e.) are recommended in particular.

1. The Carbon Cycle
2. Ocean chemistry & pH
3. Nutrient Pollution & Eutrophication
4. Coastal Acidification vs. Ocean Acidification
5. Biological Impacts
6. Key Terms

1. The Carbon Cycle

Carbon is the fourth most abundant element in the universe and is present in every living thing (as well as most non-living things). Carbon naturally flows between rocks, the ocean, plants, the atmosphere, soil, and fossil fuels through biological and physical processes. Although carbon is always moving between different parts of the Earth and the environment, the carbon cycle maintains a balance over the long term that keeps the temperature of the Earth relatively stable.

Carbon dioxide (CO_2) is a form of carbon that has existed naturally in Earth's atmosphere for millions of years. CO_2 plays an important part in many natural processes and cycles through living things, the soil, the atmosphere, and the oceans. CO_2 concentrations in the atmosphere fluctuate over time but stayed below 300 parts per million until the Industrial Revolution.

In the 1800s, humans rapidly urbanized and industrialized by mining coal, cutting down trees, and burning fossil fuels. Forests and fossil fuels naturally sequester and store carbon, so the consumption of these materials so quickly caused an increase in atmospheric CO_2. In the past, a sudden increase of carbon dioxide in the atmosphere, like a volcanic eruption, would be self-corrected by the carbon cycle. Excess CO_2 in the atmosphere would move to other carbon sinks and the amount of atmospheric CO_2 would return to previous levels. But in modern times, CO_2 is entering the atmosphere too rapidly for the carbon cycle to maintain balance. The threshold of 400 ppm was recently passed (see figure 2) and atmospheric CO_2 concentrations will only continue to increase if humans continue to burn fossil fuels.

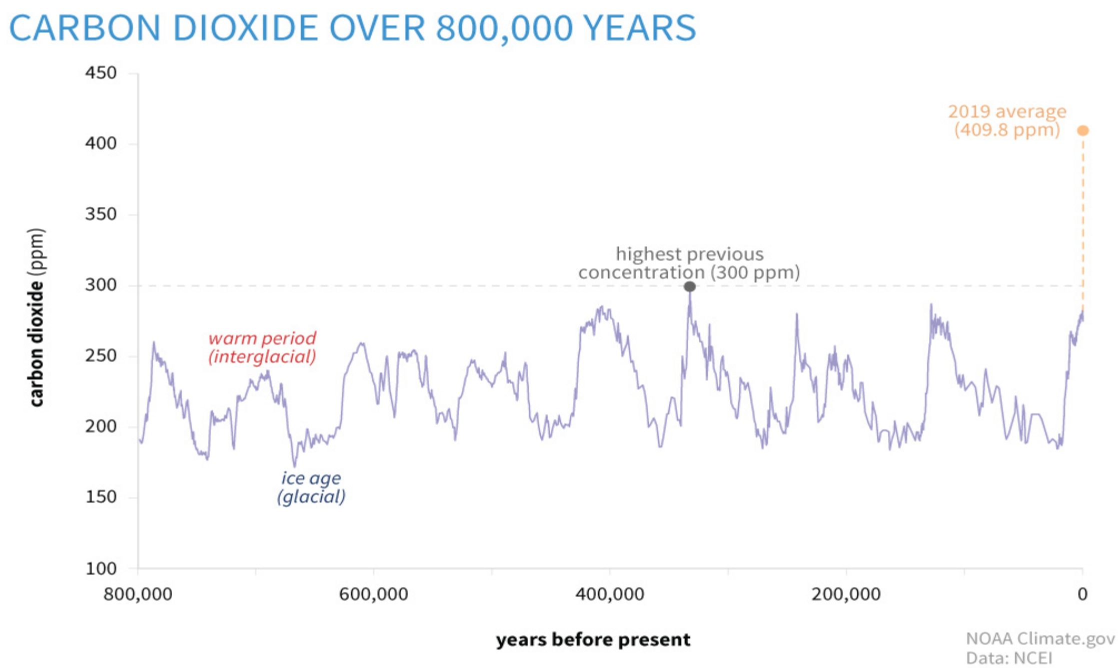


Figure 1:NOAA graph depicting the breakdown of CO2 emissions as compared to carbon sinks.

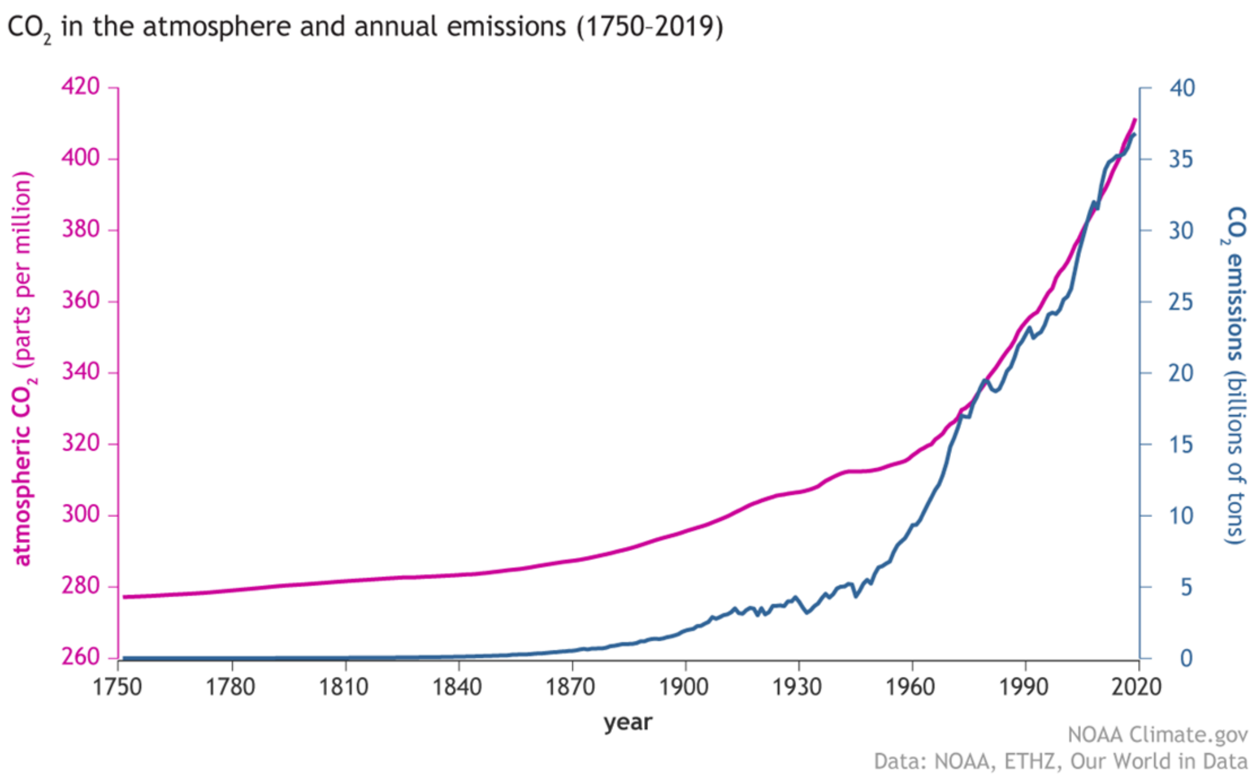


Figure 2: NOAA graph depicting Atmospheric CO2 (pink line) compared to CO2 emissions from burning fossil fuels (dark blue line) .

Around one-quarter of the CO_2 in the atmosphere is absorbed by the ocean, so oceanic CO_2 concentrations have also been increasing over the past 100 years.

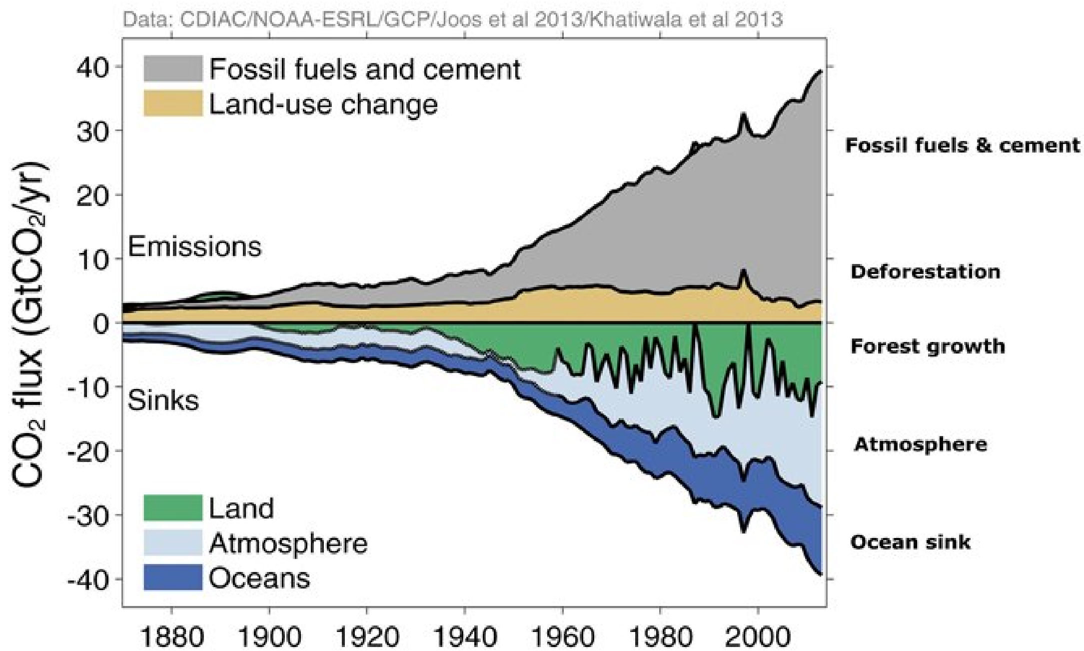


Figure 3: NOAA graph showing the breakdown of CO2 emissions from burning fossil fuels and the making of cement as compared to carbon sinks (places such as forests, wetlands, and the atmosphere that utilize and "store" CO2) .

If students are having trouble understanding how and why carbon moves throughout the Earth, we recommend playing the Carbon Cycle game, which takes students through the carbon cycle as carbon molecules.

2. Ocean Chemistry & pH

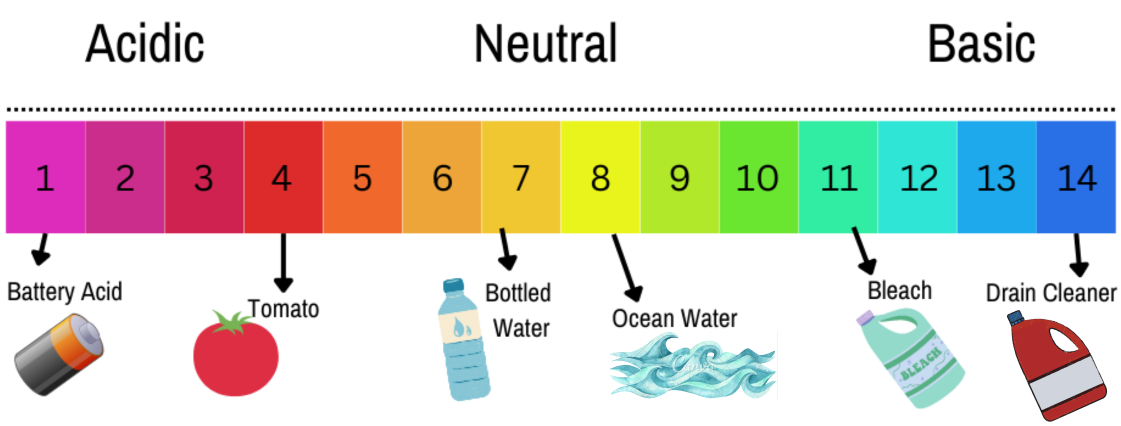
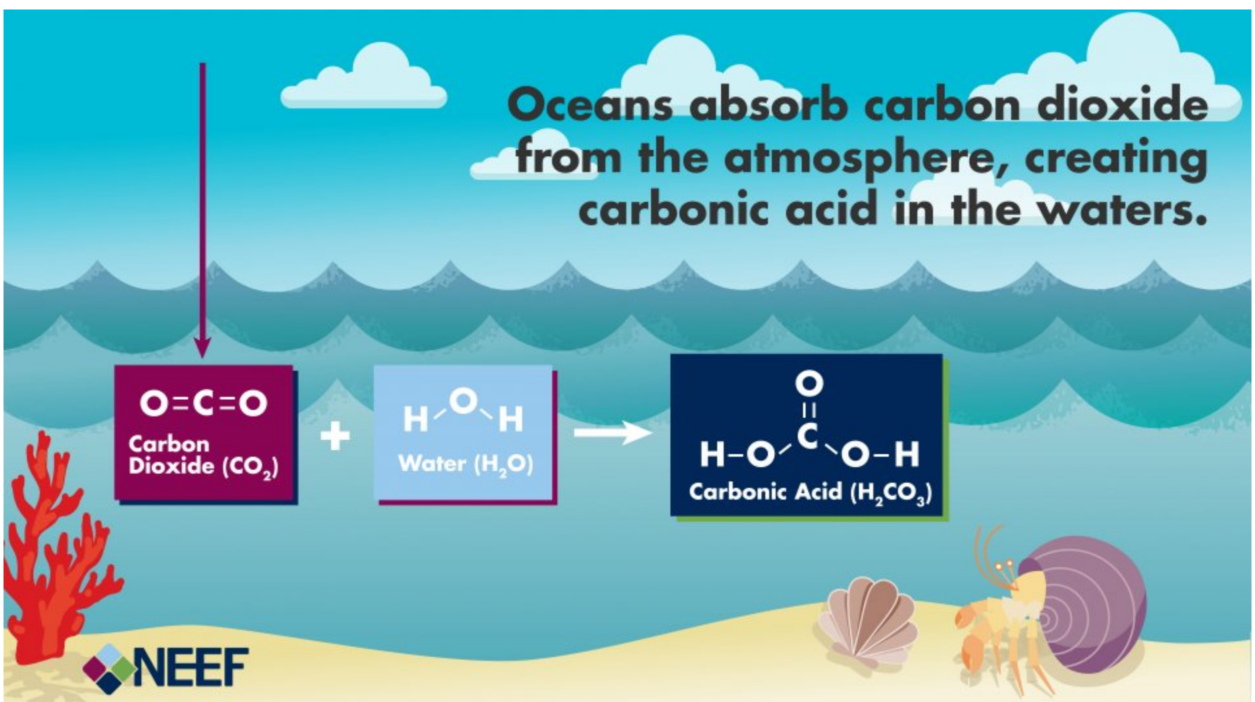


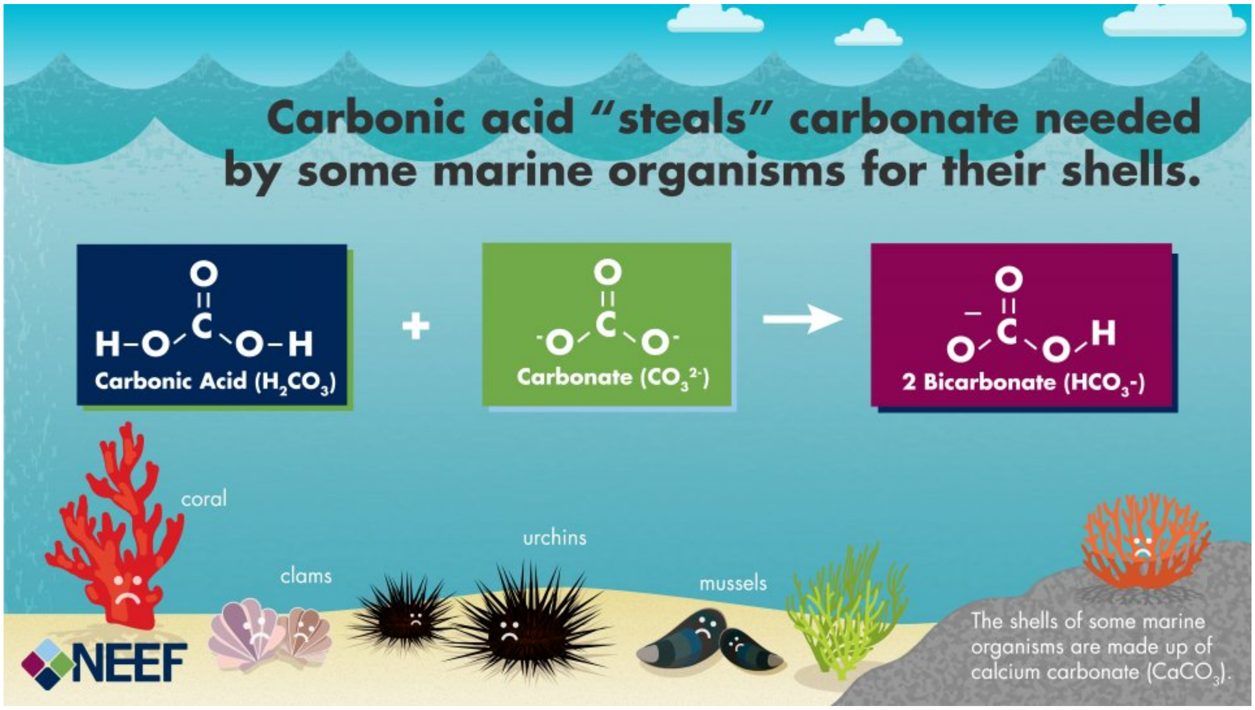
Figure 4: the pH scale. Lower numbers equate to more acidic qualities and higher numbers equate to more basic qualities.

How does the increase in CO2 concentrations affect the ocean?

The pH of a substance depends on the number of hydrogen ions present. The higher the number of hydrogen ions, the higher the "acidity", and the lower the pH of a substance is. Substances with a high pH and a low number of hydrogen ions are called basic on the pH scale. For example, battery acid would have a pH of 0, whereas drain cleaner, which is very basic, would have a pH of 14. In chemistry, basics are called bases and are used to neutralize acids. Distilled water has a neutral pH of 7, whereas saltwater has a more basic pH of around 8. Prior to the Industrial Revolution, the pH of the open ocean was measured to be around 8.2 but is currently measured at 8.1. Although this looks like an insignificant change, it is actually a 25% increase in acidity from the preindustrial era to now, as pH is measured on a logarithmic scale.

When CO2 is dissolved into the water, it reacts with water to form carbonic acid (H_2CO_3). H_2CO_3 then reacts with carbonate (CO_3^{2-}) to form bicarbonate (HCO_3^-). The hydrogen ions released by these reactions lower the pH of the water and cause ocean acidification. As CO2 levels in the atmosphere continue to increase, ocean absorption of CO2 and thus ocean acidification continues to increase.





Figures 5 & 6: Understanding the Science of Ocean and Coastal Acidification | US EPA

3. Nutrient Pollution & Eutrophication

Plants need nitrogen and phosphorus to photosynthesize, but leaching and erosion in the soil can cause nutrient levels to decrease. Farmers and gardeners often use fertilizers containing nitrogen and phosphorus to make up for any lack of nutrients in the soil. Although the intent of these fertilizers is to aid in the growth of plants, the phosphorus and nitrogen often drain away from their original location. Heavy rains can carry the nutrients away from the soil into a nearby stream, and consequently into the watershed the stream is a part of. This causes issues for the larger body of water the watershed drains into.

When nutrient runoff from a neighboring field, garden, or lawn spreads into a body of water, it can cause problems for that ecosystem. These nutrients promote a spike in growth for that body of water and algae and other plants will grow rapidly. This excess growth begins to cover the surface of the water, prohibiting sunlight from reaching the plants and animals under the surface. Additionally, bacteria will use more of the dissolved oxygen in the water to eat the algae and plants, leaving less for the other plants and animals. This causes animals, such as fish, to suffocate. Algal growth and related low oxygen conditions brought on by increased nutrients in water is known as eutrophication and can alter a whole ecosystem.

4. Coastal Acidification vs. Ocean Acidification

As discussed above in detail, increased amounts of CO2 in the atmosphere cause a decrease in ocean pH in a process known as ocean acidification. Although a common misconception, the open ocean is not acidic but does continue to become more acidic with each passing decade. In open ocean waters, increased CO2 is the primary driver of ocean acidification.

Coastal acidification has been used less commonly and refers more specifically to pH changes in coastal waters. In addition to the acidification caused by excess CO2, local factors such as nutrient runoff, upwelling, and hypoxia can cause further acidification in coastal waters. Coastal acidification can encompass all of these coastal factors but occurs uniquely in each coastal area depending on the stressors there. Eutrophication in particular can cause additional coastal acidification. As excess algal blooms die, their decomposing tissue releases CO2 into the water and increases acidity. Coastal areas that see large amounts of freshwater and sediment inputs, which are naturally more acidic, may also see increased acidity.

Besides acidification, other local stressors such as toxins, marine debris, overfishing, and shoreline changes can compound and create a unique set of problems for the individual organisms and ecosystems in each coastal and estuarine area. Fish already become stressed in low oxygen level environments and with rising temperatures, but the addition of acidification compounds these effects. Minimizing local stressors can help the organisms in a specific area be more resilient in the face of acidification

5. Biological Impacts

One of the largest effects of ocean acidification is the decrease in calcium carbonate solubility. More CO_2 and a lower pH reduces the concentration of carbonate ions in ocean water. Carbonate is one of the ions that make up calcium carbonate, which is a mineral used by many marine plants and animals to build their shells and skeletons. Less carbonate means less calcium carbonate which makes it more difficult for these animals to build their shells. Unlike finfish that can move to less stressful environments, adult oysters are unable to move to areas with better water quality.

A growing number of studies have demonstrated the effects of ocean acidification on marine organisms. These include the reduced survival of larval marine species, impaired development of invertebrates, and excessive CO_2 levels in the blood of some fish that can greatly reduce their growth and fertility. Similar fish do not always react similarly to acidification, so it can be hard for researchers to make assumptions about groups of fish species. Based on research so far, it seems freshly hatched fish are most vulnerable to acidification while most adult and juvenile fish are likely to survive.

Some species, like algae and seagrass, take in CO_2 as part of photosynthesis and are more likely to thrive in high CO_2 conditions. Research is being conducted to determine if seagrass can help to mitigate coastal acidification with the potential for the use of seagrass to lessen acidic conditions, but research is still preliminary.

6. Key Terms

Coastal Acidification - all of the processes that lead to acidification in coastal and estuary areas including, but certainly not limited to ocean acidification

Eutrophication - an increase of plant growth in a body of water due to excessive nutrients in the water, often due to runoff, that causes low oxygen conditions and animal die-off

Ocean acidification - the process of the ocean becoming more acidic due to absorption of increased CO2 emissions

pH - stands for the power of hydrogen. It's the measure of hydrogen ions in water. More hydrogen ions correlate to a lower pH or more acidic conditions. $pH = -\log[H+]$

Upwelling - when cold waters from the deeper parts of the ocean rise and replace surface waters. Deep waters often bring with them a high nutrient level and low pH

Additional Resources

The Mid-Atlantic Coastal Acidification Network has many resources and news stories related to coastal acidification in the Mid-Atlantic region
Virginia Sea Grant site talking about the biological impacts of acidification in the Chesapeake Bay
The EPA's guide to understanding ocean acidification

Section I. Introduction to Ocean Acidification

In the context of climate change, ocean acidification is sometimes referred to as "the other CO2 problem." Waters are becoming more acidic as carbon is released into the atmosphere from burning fossil fuels like coal, oil, and gas. Have your class watch this video on Ocean Acidification by The Alliance for Climate Education as an introduction to the issue that will be covered over the course of this module.

What is Ocean Acidification?

Topic: Acidification introduction

Objective: Students will explore the concept of Ocean Acidification and demonstrate how CO2 causes water to become more acidic.

Standards:

NGSS: 5-ESS3-1, HS-PS1-2, MS-LS2-1

Virginia Science Standards: 6.1, 6.9, CH.1, CH.5, ES.1, ES.10

Approximate time: 10-15 minutes (plus prep time for the pH indicator)

Materials:

- A red cabbage
- A reusable or paper straw
- Cups
- Water
- A pH meter or pH test strips

Set up:

This is a quick introductory experiment on acidification. Beforehand, finely chop half of the red cabbage. The finer you can chop it the more color you'll get. Place the cabbage in a heat-safe bowl. Boil water in a kettle and pour it over the cabbage until it is covered. Let it sit for at least 15 minutes. The longer you let it sit, the better. Collect the cabbage water by straining it into another container. This is your pH indicator.

Activity:

Pour regular water into cups until they're each about ¼ full. Add a few drops of the pH indicator into each glass until the water turns a deep purple. Have students measure the pH of the water and record it on a sheet of paper. Tell students that the water will represent the ocean and that their breath will represent anthropogenic CO2, that is, excess carbon in the atmosphere from burning fossil fuels. Make sure to mention that the pH of the ocean (around 8) is less acidic than the water that you will be using (around 7). Next, have students use a straw to blow air into the water until there is a change in color. This may take a few minutes to occur depending on how much liquid is in the cups and how dark the water is to start. Have students measure the new pH and record it. Have the students experiment with how acidic they can make the water.

Section II. The Carbon Cycle and CO2 Emissions

This activity will require students to be aware that carbon comes in different forms, that carbon can be stored in different places on Earth, known as carbon sinks, and that carbon can move from sink to sink in the carbon cycle.

Carbon can easily form bonds with other chemical compounds, which is one of the reasons the element is so abundant. It can dissolve in water, form chains of atoms to create sugars, and form solid materials like coal and limestone. Carbon in living things can be released through respiration, consumed as food, or transformed into fossil fuels over millions of years. In the atmosphere, carbon exists mainly as carbon dioxide. Carbon dioxide is called a greenhouse gas because it can trap some of the sun's heat in the atmosphere. Without carbon dioxide's natural ability to trap heat in the atmosphere, life as we know it could not exist.

Carbon on Earth is found in four different types of carbon sinks: the **atmosphere**, soil and rocks (the **lithosphere**), water (the **hydrosphere**), and living organisms (the **biosphere**). The activities of living organisms, volcanoes, weather and many other processes can cause carbon atoms to move from one place to another. This pattern of movement is called the carbon cycle.

The Carbon Journey
Topic: The Carbon Cycle, Climate Change, CO2 emissions
Objective: Students will be able to articulate the basics of the global carbon cycle.
Standards:

NGSS**:** MS-ESS3-5, HS-ESS2-6
Virginia State Standards: LS.1, LS.5, LS.9, ES.1, ES.6, ES.10, ES.11

Approximate time: 25-30 minutes
Materials:

- 7 Dice
- 7 Station Signs
- 7 Station Movement Directions for Before Human Interference
- 7 Station Movement Directions for After Human Interference
- Data record sheets for each student
- Pony beads, regular (8/0) size, in various colors one for each station in the game
- Bowls to hold the pony beads for each station
- String knotted at one end so that a bead won't slip off;, about 12 inches long

Set up:
Cut string for each student in your class. This will be where students put their pony beads. Create stations around the room for each carbon sink: Atmosphere, Plants, Animals, Soil, Ocean, Deep Ocean, and Fossil Fuels. Make sure each station is labeled so students can find it. Each station should have a "before human interference" station movement direction sheet, a pair of six-sided dice, and a bowl with different colored beads. Each color bead represents a different carbon sink. Set aside the station movement directions for "after human interference." You will need them for round two when you replace all of the movement directions.

Activity: This activity is a way to compare the carbon cycle before the industrial revolution with the carbon cycle after humans began burning large quantities of fossil fuels. This is a great way to communicate important ideas about climate science and the carbon cycle.

1. Round 1: Each player starts the game at a pre-assigned station (divide students equally amongst the four stations). They should have a sting and a date sheet to record where they travel. Have the students tie a large knot onto one end of the string and write the name of their starting station on the sheet of paper.
2. Tell the students that they will represent carbon atoms in the carbon cycle. They will travel around the Earth following the journey of a carbon atom in the pre-industrial world – before we began burning lots of fossil fuels.
3. When the game starts each student places one bead from their station on their string.
4. Each student rolls the dice at their station and checks the movement direction to find out where to go next. If the direction indicates that they stay in the same spot, the student then goes to the back of the line for that station and waits to roll again. While they are waiting to roll the dice, they should take another bead from the station and put it on their string, and write down their station on their datasheet.
5. Each time the player moves to another station, they do the same thing: Take a bead, roll the dice, move to the next station (or go to the end of the line and repeat), and record the name of the next station on the datasheet.
6. Have the students move from station to station 6 times to fill part 1 of their datasheet. This is the end of round one.
7. Ask the students what color beads they have on their string and what happened to them during their trip. Did they see any patterns? For instance, did they stay at any place more than once? Did anyone go back and forth between two stations (for example, biosphere and atmosphere)?
8. Round 2: replace all of the movement instructions with the "after human interference" instructions.
9. Have the students tie another knot in their string to separate round one beads from round 2 beads.
10. Repeat 10 times to fill up part 2 of their datasheet.

11. Ask the students to go back to their seats. Discuss what happened. Ask the students again, what they observed. Did they observe anything different from round 1? Were there any carbon sinks that students go stuck at this round?

Printouts/ worksheets:

- For the template and further instructions go to this pdf

Credits: This activity was adapted from the *Incredible Carbon Journey* game from NOAA and modified by Jennifer Ceven, Grade 6 Science Teacher

Section III. Ocean Acidification Chemistry

There are 2 activities in this section. One will explore how burning fossil fuels (combustion) causes oceans to acidify. The other activity will go more in-depth about how this will affect marine organisms that utilize calcium carbonate.

In the previous section, students learned how carbon forms different bonds and cycles through different sinks. One of the ways that carbon moves from one sink to another is when humans burn fossil fuels. Burning coal, oil, and gas breaks the bonds that hold carbon atoms together inside those fuels, and carbon is released into the atmosphere. The ocean absorbs about a quarter of the CO2 we release into the atmosphere every year, so as atmospheric CO2 levels increase, so do the levels in the ocean. Initially, many scientists focused on the benefits of the ocean as a carbon sink as it is removing this greenhouse gas from the atmosphere. However, decades of ocean observations now show that there is also a downside: the CO2 absorbed by the ocean is changing the chemistry of seawater.

As the ocean absorbs increasing amounts of CO2 from the atmosphere, chemical reactions take place that decrease the pH of the ocean. This lowering of pH makes ocean water more acidic. The ocean's pH has lowered by .1 pH units since the Industrial Revolution. This may not seem like much, but pH is measured on a logarithmic scale, which means a .1 difference in pH indicates the ocean has become 30% more acidic. With CO2 continuing to sink into the ocean at extreme rates, scientists predict that the ocean could become 150% more acidic by 2100.

Standards:

NGSS: MS-PS1-2, MS-LS2-1, MS-ESS3-5, HS-PS1-2, HS-LS2-6, HS-ESS2-2, HS-ESS3-5, HS-ESS3-6

VA State Science Standards: PS.1, PS.3, CH.1, CH.5, ES.1, ES.10, ES.11

Combustion and Ocean Acidification Experiment

Topic: Chemistry, pH, Ocean Acidification

Objective: In this lesson, students will be able to:

1. Show students how CO2 is created by combustion in our atmosphere, and then diffuses into the ocean, changing the pH and making the ocean more acidic.
2. Use the scientific method to hypothesize, test, record, and make conclusions about the effects of decreasing acidity on marine organisms that use calcium carbonate to build their skeletal structures.

Materials:

- Dilute Bromothymol blue (BTB)

*Note that BTB is a chemical and can be harmful if used improperly

- Two test tubes with stoppers. Make sure to use tubes made of glass or a plastic that will not melt when held up to a flame
- Candle (preferably non-scented tea lights)
- Match or some other device to light the candle

Set up:

Students will perform a simple lab to observe how humans create CO2 by combustion and how easily CO2 is absorbed by water. In this activity, the burning (or combustion) of the candle represents the burning of fossil fuels, the air in the combustion test tube represents the Earth's atmosphere, and the water represents the ocean. The pouring of water into the combustion test tube represents how wind, waves, and ocean currents physically move seawater, which allows CO2 to dissolve into it. The Bromothymol blue (BTB) helps students to better visualize the change. Please remind students this lab is a visualization to help them better understand ocean acidification; this lab creates super-fast reactions in relation to time and on a much, much, much smaller scale than in Earth's actual atmosphere and ocean.

Combustion is the process of burning organic material in the presence of oxygen to produce heat energy, CO2, and water. Examples of some organic materials include wood, paper, and fossil fuels (natural gas, oil, or coal). These organic materials, and other organic materials that combust, all consist of carbon and hydrogen. They may also include oxygen and some other elements. When the organic material is burned in a complete reaction, the carbon is released in the form of CO2. About 25-40% of the CO2 from the burning of fuels is dissolved in water and will affect the pH of the water, which is creating havoc in oceans.

Activity:

Briefly introduce your students to the topic of combustion and how this creates CO_2. Then have students research ocean acidification and how an excess of CO_2 in our atmosphere from combustion or the burning of fossil fuels (coal, gas, oil), is being dissolved into the ocean and changing the ocean's pH. Based on their research, have them make a hypothesis on what will happen during the experiment.

Bromothymol blue (BTB) indicates changes in pH and the presence of CO_2. This activity uses BTB to indicate if we have captured CO_2 gas from our combustion experiment and how the CO_2 gas changed the pH of the water.

1. Label your two test tubes "*air*" and "*combustion.*"
2. Pour approximately 5mL of dilute BTB into the test tube labeled "*air*." Then cap the test tube and shake it for approximately 10 seconds. Observe the BTB solution. Do you notice any color change?

3. Set the "*air*" test tube aside and record your observations in your lab notebook.
4. Light the candle
5. Uncap the test tube labeled "*combustion*" and hold it upside down above the flame for 10 seconds.
6. While the test tube is still upside down, cap it.
7. Once capped, the "combustion" test tube may be inverted. Then uncap the BTB solution.
8. Carefully uncap the "*combustion"* test tube and replace the cap with your thumb. Roll your thumb to create a very small opening and quickly pour approximately 5mL of dilute BTB solution into the test tube.
9. Recap the "combustion" test tube and shake for approximately 10 seconds.
10. Compare the BTB in the test tube labeled "air" to the BTB in the test tube labeled "combustion." Record your observations in your lab notebook.

Follow-up Questions:

Please answer these questions in your lab book:

1. Which gas was captured in the "combustion" test tube?
2. Why did combustion change the water's pH?
3. What does a change from blue to yellow in the bromothymol blue and water solution indicate in relation to the pH?
4. List four (4) activities that humans do that combust fossil fuels.
5. How can you relate this experiment to CO2 in our atmosphere and ocean acidification? What does the test tube represent? What do the air and water symbolize? What does the burning of the candle represent? How does pouring the water into the combustion test tube relate to ocean currents and waves?
6. How might humans reduce the amount of CO2 that enters the ocean?

Printouts/ worksheets:

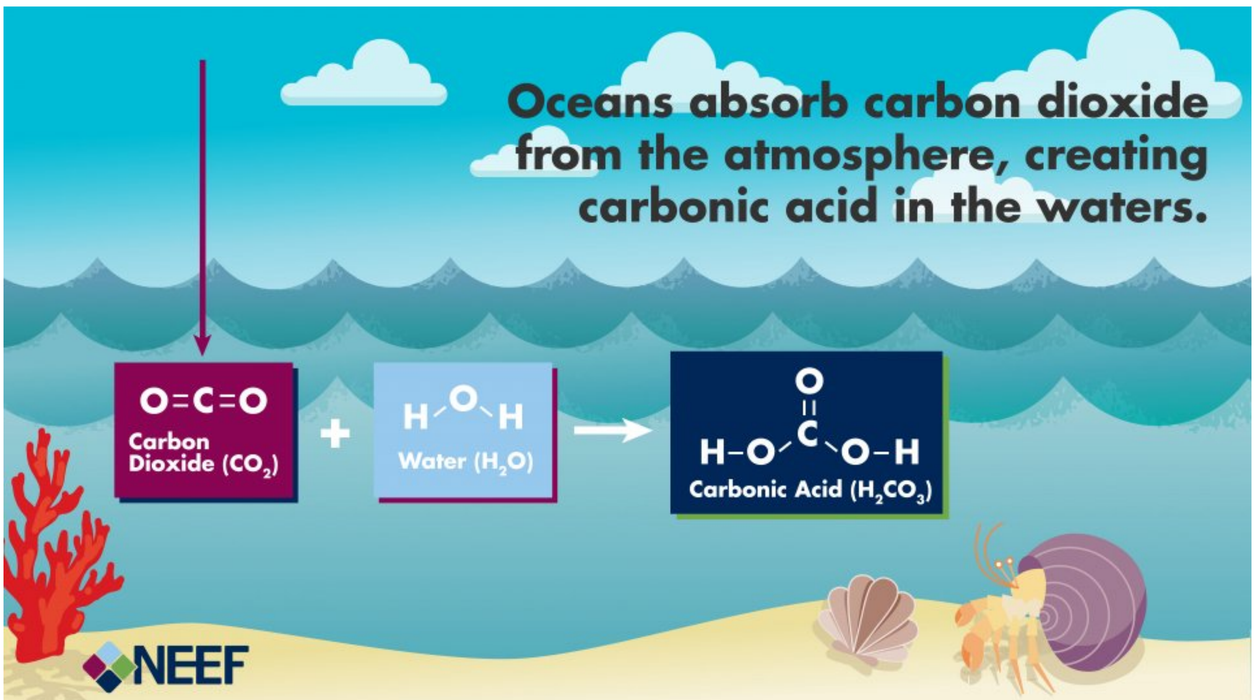
A lab worksheet for students can be found here.

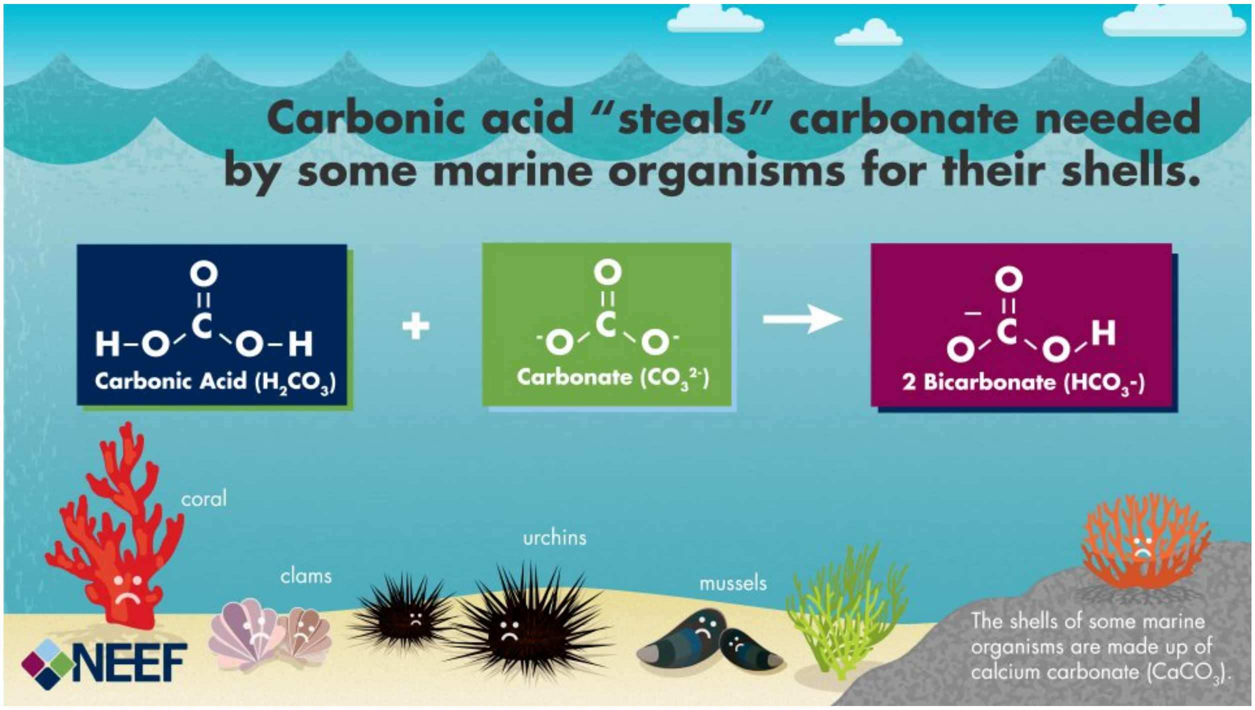
Credits: This activity was adapted from *The Basics of Ocean Acidification* lesson from the NJ Sea Grant Consortium.

Acid in the Ocean: Not a Shell (Building) Game

Topic: Impacts of increased ocean acidity on marine animals
Objective: In this lesson, students will explore how excess CO2 in our atmosphere diffuses into the ocean, changes the chemistry of seawater, and how that hinders the ability of some marine organisms to build their skeletal structures by constructing simple a model out of Legos.

Background: We know that the pH in the ocean is decreasing and becoming more acidic as the ocean absorbs increasingly higher levels of CO2 from the atmosphere. Water changes pH as it gains or loses hydrogen ions (H+). As CO2 is absorbed by the ocean, it creates carbonic acid (H_2CO_3). Carbonic acid further breaks down and forms bicarbonate ions (HCO3) and hydrogen (H+) ions. An increase in hydrogen (H+) ions increases the ocean's acidity, decreasing pH.





Understanding the Science of Ocean and Coastal Acidification | US EPA

Hydrogen ions (H+) also combine with carbonate ions (CO_3) dissolved in seawater to form bicarbonate ions (HCO_3) that are not useful to organisms. Carbonate ions bond eagerly with hydrogen ions in water; carbonate will even leave calcium behind to bond with hydrogen ions. More hydrogen ions in the ocean interfere with shell or skeleton formation because they reduce the amount of carbonate available for organisms that need calcium and carbonate to bond to grow their shells and skeletons.

Materials

- 3 colors of Legos (12 yellow, 12 blue, 8 red per bag)
    - Use Duplo Legos if you want bigger blocks
- Small opaque reusable bags (one for each small group)
- A stopwatch or timer
- Student worksheets

Setup:

To set the stage for your students, explain that in the ocean many organisms build shells or skeletons made up of calcium carbonate which is available in seawater. Ask students if they can name some animals that have shells. If possible, show the students a few seashells (clams, scallops, snails) and/or pieces of coral or pictures of seashells and/or corals. Ask students to brainstorm how these animals are important to oceans and to humans. Be sure that students know that these organisms are an important food source for other ocean organisms and also can provide a source of food and income for humans.

Explain that a decrease in organisms in the ocean impacts food webs, decreases biodiversity, reduces the health of the ocean, and can even result in the loss of jobs and income for people. Coral reefs are a great example since they are simultaneously important habitats and essential to ocean health. Explain how these organisms take in calcium and carbonate dissolved in seawater and combine them to make calcium carbonate, which forms their shell and/or skeleton. In a healthy ocean, organisms can form and grow their shell fairly easily, extracting all the calcium and carbonate they need from seawater. However, the amount of carbonate in the ocean is decreasing because humans are releasing excess CO_2 into our atmosphere.

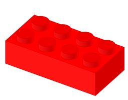
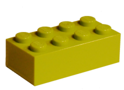
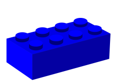
Activity

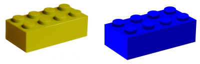
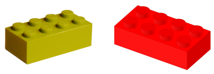
To further understand the chemistry of ocean acidification and its effect on organisms that need calcium carbonate to build shells and skeletons, students will play a game using Lego blocks (or other interlocking blocks). Each different color Lego block used in the game represents chemicals found in the ocean which support the growth of animals that build shells and skeletons. The game goes through different scenarios which will demonstrate to players the impact ocean acidification will have on many species of animals in the ocean.

Students will play three (3) rounds:

1. The first round is based on pre-industrial ocean water conditions
2. The second is based on current seawater conditions,
3. The third is based on future predicted ocean water conditions.

In this activity each color Lego is a different ion or bond. You can assign any Lego color to a chemical as long as they are consistent across groups. For the purposes of this set of instructions, we will use the following colors:

Lego	Ion/ molecule
	H+ (Hydrogen) *amount determines pH of seawater
	CO_3 (Carbonate)
	Ca+ (Calcium)

	$CaCO_3$ (Calcium Carbonate)
	HCO_3^- (Bicarbonate)

**Access the student worksheet here*

Basic rules:

- The more hydrogen ions are present in the water, the more acidic ocean water becomes.
- The carbonate ions (yellow Legos) are very attracted to and bond eagerly with the hydrogen ions (red Legos)
- The carbonate ions (yellow Legos) will not bond with calcium (blue Legos) when there are hydrogen ions (red Legos) available to bond with
- When the carbonate ions (yellow legos) connect or bond with hydrogen ions (red Legos) they form bicarbonate, which is not useful for many forms of sea life.
- The blue Legos (dissolved calcium ions) are left on their own.

While playing the game, students will see what happens when excess hydrogen enters the ocean (ocean acidification).

Students will have one minute to reach into the bag and take just one Lego out at a time. Players may not look into the bag to choose Legos. As Legos are taken out, players must combine yellow Legos, representing carbonate ions (Co_3), to the blue Legos representing calcium (Ca+), as fast as possible to form a calcium carbonate which is used by organisms to build shells or skeleton. If a red (H+) Lego and yellow (Co_3) Lego are chosen, you must combine the red (H+) and yellow (Co_3) to form bicarbonates (HCo_3). If possible, students must connect the Legos to form calcium carbonates or bicarbonates before choosing another Lego out of the bag. If two of the same colors are chosen, players must set them aside and wait to connect them to the correct color on the next grab.

Example- If a player pulls out 2 yellow Legos but not any blue or red blocks, that player must set the yellow blocks aside and wait until blue or red blocks are grabbed.

As yellow and blue Legos are connected, each set should be connected together into one large structure, just as an animal building a shell would do. When a red Lego, representing a hydrogen ion, is pulled out of the bag, it must be connected to any yellow carbonate Lego that is not already paired with blue calcium Lego. This forms bicarbonate that is not useful for shell or skeleton building, and players must set it aside. Carbonates are much more strongly attracted to hydrogen ions. Therefore a yellow carbonate block must connect to a red hydrogen block if a red block is available. Players are not to have any red blocks unconnected unless a yellow block has not yet been pulled out of the bag. Blue calcium blocks **never** connect to red hydrogen blocks. After one (1) minute, players should count how many blue and yellow Lego pairs they were able to connect, and have the students record their results. Be sure players only count the pairs of yellow and blue.

Round One

1. Disconnect and place 12 yellow, 12 blue, and 2 red Legos in a bag. The amount of red Legos (representing hydrogen ions) in this round reflects the amount of hydrogen found in seawater before industrial times.
2. Set the timer for 1 minute.
3. Have players reach into the bag and grab one (1) Lego at a time. They may not look in the bag to choose their blocks. If a blue and a yellow block are picked, they need to be connected to represent calcium carbonate.

   Note: If a red and a yellow block are picked, those need to be connected to represent bicarbonate. Red and blue blocks never connect and neither do two (2) blocks of the same color.
4. If blocks are picked out of the bag that cannot connect, such as two blocks of the same color, or red and blue, players must set them aside until another red, blue, or yellow block is picked out of the bag that can connect together.

   Note: Anytime a red block is pulled out of the bag, it must be connected to a yellow block to form bicarbonate. A blue block can be connected to a yellow block only when no red blocks have been selected out of the bag. All sets of yellow and blue Legos, representing calcium carbonate, should be connected to represent the formation of one animal shell, such as a shell, or a coral. Any red and yellow blocks that were connected represent bicarbonates, and cannot be used by an animal.
5. Put aside any unconnected blue blocks.
6. Students should quantify how many pairs of calcium carbonate they formed and record the number. This represents the growth in their animal.
7. After completing this round, students should be directed to disconnect all the blocks and place them back into the bag to prepare for Round 2.

Round Two

1. Place 12 yellow, 12 blue, and 3 red Legos in a bag. The amount of red Legos represent the amount of hydrogen found in seawater in 2018. This represents the increase in ocean acidity since pre-industrial times. This increase in acidity is caused by an increase in carbon dioxide absorbed by the ocean from the burning of fossil fuels (coal, oil, gas.) When the ocean absorbs excess carbon dioxide chemical changes increase the amount of hydrogen in the ocean, increasing ocean acidity.

2. Repeat the game following the steps listed above. Students should count and record the pairs of yellow and blue blocks, or calcium carbonate they formed and compare results to their results from the first round. Students might see a small difference in the amount of calcium carbonate formed. In today's ocean, some sea animals do have a slightly more difficult time finding carbonate to form with calcium but most species are able to still do so.
3. After completing this round, students should be directed to disconnect all the blocks and place them back into the bag to prepare for Round 3.

Round Three

1. With a continued rise of carbon dioxide released in the atmosphere, it is predicted that the ocean will become nearly 150% more acidic by the end of the century. This will cause more hydrogen to be released into the ocean. For round three, keep 12 blue and 12 yellow Legos. Place a total of 6 red Legos in the bag.
2. Again, time students for 1 minute. Remember, yellow carbonate blocks are much more attracted to the hydrogen red blocks; therefore red blocks always connect over blue blocks! If players have a free yellow block and then choose a red and blue block, the red block must be connected to the yellow block, and not the blue calcium block. Players may set the blue block aside until the next two blocks are grabbed out of the bag.
3. Remember to have students record their data.

The End of the Game

Have students look at each chart they completed from the three rounds of play and compare the results. As a class or group, share and compare results. Students should notice a small difference between rounds 1 and 2, and a larger difference between rounds 1 and 3 and 2 and 3. Review the chemistry and have students explain how excess carbon dioxide released in our atmosphere is the root cause of ocean acidification.

Credits: This activity was adapted from *The Basics of Ocean Acidification* lessons from the NJ Sea Grant Consortium.

Handouts: Student worksheet for the small groups can be found here

Section IV. Coastal Acidification

This section explores the sources of CO2 in coastal waters. These habitats are more vulnerable to acidification because there are additional sources of carbon in coastal waters. Have your class go through this interactive coastal acidification site by NOAA. You can do this all together or assign students to do this individually.

Seasonal pH Data Breakdown

Topic: Coastal acidification, working with data, water chemistry, reading graphs

Objective: After the completion of this activity students will:

1. learn about different factors that contribute to coastal acidification
2. identify the pH changes characteristic to factors
3. be able to read a graph and connect trends to causes of acidification

Standards:

VA State Science Standards: LS.1, LS.8, LS.9, CH.1, CH.5, ES.1, ES. 10, ES.11

Materials:

- Worksheet with graph
- Access to the infographic (online or print-out)

Activity:

This activity can be completed as a group, with the images shown to the class on a projector and questions discussed as a group, or completed individually as a worksheet activity.

Discuss the infographic with your students and the sources of acidification in coastal waters. Then, have them take a look at the worksheet. The following is the teacher guide to the student worksheet. Answers to the questions are in blue:

There are many factors that can influence the pH of coastal waters. One area of the coast can have multiple influences on the water quality at any given time. Read the "What's driving the changes to the Mid-Atlantic's coastal chemistry" infographics to learn more about factors influencing acidity, or review the list below before starting this worksheet.

Factors that can affect ocean acidity:

CO_2 absorption: CO_2 in the atmosphere is absorbed by surface waters

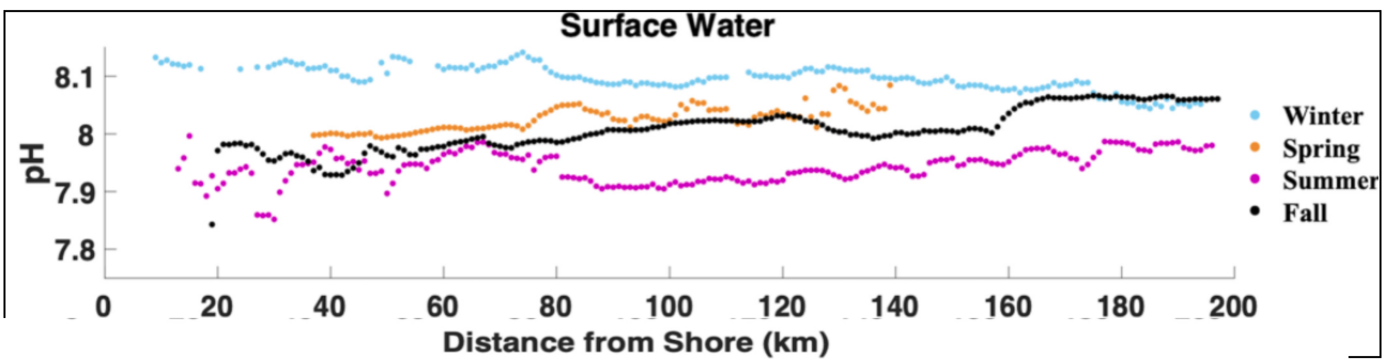
Upwelling: When deep ocean water rises to the surface, bringing cold, nutrient-rich water to the surface. Upwelling events can occur anytime but are common in summer months in the mid-Atlantic

Freshwater inputs: Freshwater from streams and rivers is more acidic than ocean waters. Freshwater can also carry additional sediments or nutrients to coastal waters
Biological removal of CO_2: plants take in and use CO_2 to photosynthesize
Eutrophication: Excess nutrients in coastal waters can increase algae growth. When algal blooms die and decompose, more CO_2 is released into the water

Recall that CO_2 in ocean water will decrease the pH of the water, or increase acidity. Which factors listed above could increase the acidity of water? Which will decrease the acidity?
CO_2 absorption, upwelling, freshwater inputs, and eutrophication can all cause an increase in acidity. Biological removal of CO2 can decrease the acidity.

Think about each factor that can affect ocean acidity. Which will be relatively consistent throughout the year? Which may change throughout the year?
CO_2 absorption will be relatively consistent. Other factors may be seasonal or even change daily. pH drops at night with no photosynthesis. Upwelling events are short and may last less than a day.

pH trends in New Jersey coastal waters
Below is a graph of surface water pH off the coast of New Jersey. This data was measured in 2018 & 2019 by an autonomous glider deployed by researchers at Rutgers University.



What variable is measured on the y-axis? What variable is measured on the x-axis? What are the units?
Y-axis is pH (recall that a lower pH correlates to more acidity) and x-axis is the distance each measurement was taken from shore in kilometers.

What range of pH do you see on the graph?
About 7.8 to 8.15

What trends in pH can you observe about the seasons or about the distance from shore?
Winter pH seems pretty linear with a slight decline further from shore. The spring pH increases slightly, then becomes more variable around 120km. Summer pH is variable close to the shore (0 to 50km), then increases steadily as it gets closer to the ocean. pH in the Fall is more viable closer to the shore and increases the further out it goes.

What season typically has the lowest pH?
Summer

Why might this be?
Freshwater inputs and eutrophication could cause a lower pH.

Which season typically has the highest pH?
Winter

Why might this be?
Less freshwater inputs and eutrophication (less precipitation in the winter), there could be more biological removal of CO_2.

What other trends do you notice in the graph? What ideas do you have to explain them?
pH varies a lot in the summer closer to the shore- may be related to more factors changing pH when you are closer to the shore that smooth out further from the shore
Lowest pH occurs quite close to shore in the summer and fall - likely due to freshwater inputs

Note: For high school chemistry students with knowledge of buffer solutions- explain that freshwater has a low capacity to buffer, so water close to the coast with lots of freshwater inputs may have a wide range of pH levels due to a lowered buffering ability.

Wrap-up: Now knowing some of the causes and trends of changing pH, ask students to think about the effects of pH. How might organisms be affected by the pH changes throughout the seasons? How might they need to adapt to the changes? Summarize that there are many factors that contribute to changing pH, often at the same time, so it can be hard to determine which acidification factors are most important. Emphasize that the impacts of CO2 absorption by ocean water will continue to grow as a leading factor of ocean acidification

Section V. Biological Impacts

In this section, you will dive deeper into biological impacts, learning about how organisms are impacted by coastal acidification. As in the introduction to this section, have your students watch this video on what decreasing pH does to squid and the food web.

Ocean Acidification and Food Webs
Topic: Biological impacts of acidification
Objective: At the end of this activity students will be able to:

1. Provide examples of marine organisms that will be impacted by decreasing ocean pH.
2. Identify how these impacts will affect the ocean web.

Standards:

NGSS -NGSS MS-ESS3.C; HS-ESS3.D
VA State Science Standards: 6.1, 6.9, LS.1, LS.7, LS.8, LS.9, CH.1, CH.5, ES.1, ES.10

Materials:

- 1 complete set of Ocean Acidification Food Web
- Organism information sheets for each group

Activity:
This activity will allow students to learn and discuss various disruptions to the ocean food web caused by acidifying water.

1. Break up students into groups of 4-6.
2. 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?
3. Review CO2 in the ocean- Since the start of the Industrial Revolution, the ocean has gotten about 25% more acidic. This has been caused by excess CO2 entering the atmosphere and thus more CO2 being absorbed (taken in) by the ocean. The extra CO2 comes from the burning of fossil fuels like coal, oil, and gas. Remind students that CO2 occurs naturally in ocean water, through respiration and absorption. Remind them that some ocean organisms, just like land organisms, use CO2 for photosynthesis AND that organisms that build shells use the carbon from CO2 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 CO2 than they are adapted for?*"
Remind students that in the previous activities, they learned that increasing amounts of CO2 entering the water decreases the pH of the water (i.e., there is an inverse causal relationship between CO2 and pH).

5. Share more evidence about organisms affected by ocean acidification. Pass out the set of 8 Ocean Acidification Food Web and Organism information sheets to each table group of students. Ask table groups to divide up the 8 sheets between themselves. Then give students a few minutes to pursue whatever interests them.
6. 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.
7. Whole group share out- After a few minutes, ask the whole class this question:
   "Based on the available evidence, what can you say about direct and indirect effects of ocean acidification on organisms?"
   Remember to use the discussion map to encourage everyone to participate in the discussion. 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?" 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 its effects on many organisms at the base of the food web.
8. 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.

Printouts/ worksheets:

You can find the handouts for this activity here.
Minute paper worksheet can be found here.

Credits: This activity is adapted from the Lawrence Hall of Science ACLIPSE Course, session 10.

Additional Resources:
http://www.whoi.edu/ocean-acidification/