Ocean Acidification and Oysters

How will increasing levels of CO_2 affect oysters?

This activity was developed by Mary Stapleton, Jane Wolfson and Asli Sezen-Barrie and funded by the Towson University Center for STEM Excellence and MADE CLEAR.

Email MDLL@towson.edu if you would like a Microsoft Word version of this guide.

This material is based upon work supported by the National Science Foundation under Grant No. 1239758. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

TOWSON UNIVERSITY Center for STEM Excellence

Version 23June21

Table of Contents

Ocean Acidification and Oysters Activity Overview

The *Ocean Acidification and Oysters* activity is designed to provide students an opportunity to consider the driving question *How might increasing levels of CO_2 affect oysters?* Students will build an explanatory model to answer this question using information they learn from engaging in a variety of investigations and activities.

Driving Question: *How might increasing levels of CO_2 affect oysters?*

- Investigative Question 1: *What effect does increasing atmospheric CO_2 have on ocean pH?*
- Investigative Question 2: *How does increasing the amount of CO_2 in the ocean affect an oyster larvae's ability to build shell and survive?*

Connections to Next Generation Science Standards

The *Ocean Acidification and Oysters* activity has been designed in alignment with three-dimensional teaching called for in the Next Generation Science Standards (NGSS). See Appendix A for information on how this activity connects to the NGSS.

***Ocean Acidification and Oysters* Learning Goals:**

- Understand the relationship between increasing CO_2 in the atmosphere (due to burning of fossil fuels by humans) and amount of CO_2 dissolved in Earth's oceans

- Understand pH is a measure of one important water quality characteristic and that changes in ocean pH affect marine ecosystems
- Plan and carry out an investigation to explore relationship between CO_2 and pH of salt water
- Understand the relationship between increasing amounts of CO_2 in oceans and pH levels of the ocean
- Understand that oyster shells are composed of calcium carbonate ($CaCO_3$) and the oysters living in these shells must obtain these minerals from the ocean environment in order to build the shells
- Use a model to predict the effects of decreasing pH on carbonate availability
- Build an explanatory model to answer the driving question *How might increasing levels of CO_2 affect oysters?*

Grade Level and Time to Complete

The *Ocean Acidification and Oysters* activity is designed for middle school and high school. The main investigations are the same for both middle and high school, but the readings and some of the videos are differentiated by grade level.

All of the lessons within the *Ocean Acidification and Oysters* activity will take ~ 250 instructional minutes to complete. Time required may vary depending on your students' prior knowledge and instructional needs. The chart below lists suggested timing for the various parts of the activity.

Engagement - Carbon Cycle - Whaddya Know?	10 minutes
All About Oysters Reading and *Ocean Acidification* Video	20 minutes
Driving Question Introduction	5 minutes
Explanatory Model Construction Round 1	15 minutes
Design investigation: Carbon dioxide and pH	30 minutes
Peer review of investigation design	10 minutes
Conduct investigation	10 minutes
Acids, Bases and Ocean Acidification video and reflection questions (High school only)	10 minutes
Scientific Explanation (C-E-R): Carbon dioxide and pH	15 minutes (or homework)
Explanatory Model Construction Round 2	10 minutes (or homework)
How do Oyster Larvae Form Shells Discussion	5 minutes
Carbonate Model Challenge Introduction	5 minutes
Carbonate Model Challenge Data Collection	15 minutes
Effect of Ocean Acidification on Shell-building Organisms Video and Reflection Questions	10 minutes

Ocean Acidification Causes, Chemistry and Impacts Reading and Reflection Questions	20 minutes
What is Ocean Acidification? Summary Video	5 minutes
Scientific Argument Construction: Which model from Carbonate Model Challenge represented an 'acidified' ocean?	10 minutes
Explanatory Model Construction Round 3	10 minutes
Gallery Walk	20 minutes
Explanatory Model Revision Round 4	10 minutes
What can be done about increasing CO_2 emissions?	5 minutes

Materials and Supplies

Below is a table that lists all the materials and supplies needed for this activity. Please note that some of the items (in red) must be supplied by the teacher, all others supplied by MDLL.

Item	Amount	Supplied by:	Comments	Return Instructions
Student Handouts	1/student	Teacher	MDLL supplies the template, teachers must make their own copies	N/A
Poster Paper	1/student group (3-4 students/ group)	Teacher	Large poster-sized paper or white boards are best, but 11X14 or legal size copy paper can be used.	N/A
Distilled Water	2.5 liters	Teacher	Used to make salt water for pH investigation. Use distilled water, as tap water can affect pH readings.	N/A
Safety goggles/gloves	1/student	Teacher		N/A
Binder and DVD	1	MDLL	Contains DVD w/video and PowerPoint used in lesson.	Return
Magnifying Glasses	10	MDLL	Used by students to examine oyster shells	Return
Oyster shells	16 shells	MDLL	For students to examine and to use in option shell matching exercise	Return rubber-banded together (see Appendix S for codes to assist matching shells)
pH strips	50	MDLL	Max of 4/group (10 groups) provided. An additional 10 provided for teachers to distribute as needed.	Return plastic bags and any UNUSED test strips
pH strip directions and key	10	MDLL	1/group for investigation 1	Return
Beakers	20	MDLL	For Investigation 1 (pH and CO_2). Distribute 2/group	Wash, dry and return
Straws	25	MDLL	Distribute 2 per group. An additional five are provided for teachers to distribute as needed.	Do not return straws or plastic bag.
Salt	1 bag/class set	MDLL	Added to water to model an ocean.	Do not return

Measuring Spoon	1	MDLL	Use to measure salt and water-beads.	Rinse, dry and return
Salt Water bottles (500 ml)	5	MDLL	Used to make and distribute salt water for pH investigation. Each group should use ≤ 200 ml.	Rinse dry and return
Graduated Cylinder (500 ml)	1	MDLL	For Teacher to prep saltwater for Investigation 1 (pH and CO_2)	Return
Tape	1 roll	MDLL	Students can use to label beakers	Return
Black Bowls	10	MDLL	For *Carbonate Model Challenge*	Rinse, dry & return
White Bowls	10	MDLL	For *Carbonate Model Challenge*	Rinse, dry & return
Pop-it Beads	1	MDLL	(10) baggies used in WHITE bowls for Carbonate Model Challenge. Each bag contains: • (10) black beads • (40) white beads • (30) red and black beads attached (10) baggies used in BLACK bowls for Carbonate Model Challenge. Each bag contains: • (35) black beads • (40) white beads • (5) red and black beads attached	Dry, and return. You can return all beads in the "Bead Return Bag"; you don't need to sort them.
Practice Pop-It beads (Green)	1 bags	MDLL	(10) bags that each contain 8 green Pop-it beads that students can use to practice snapping together before engaging in the actual *Carbonate Model Challenge*	Return.
Cups	20	MDLL	2/group, used during *Carbonate Model Challenge* to collect assembled calcium carbonate molecules	Dry and return
Water-beads	1 bag	MDLL	Used to fill 20 bowls for *Carbonate Model Challenge*	Do NOT return
Strainer	1	MDLL	Can use to drain excess water out of bowls of water-beads	Return
Timers	10	MDLL	1/group for *Carbonate Model Challenge*	Return
All About Oysters Middle School Reading	32	MDLL	Light purple laminated handouts	Erase any notes made with dry erase marker and return

All About Oysters High School Reading	32	MDLL	Orange laminated handouts	Erase any notes made with dry erase marker and return
Investigation Design Peer Review Rubric/CER Rubric	32	MDLL	Blue/pink laminated handouts	Erase any notes made with dry erase marker and return
Carbonate Model Challenge Instructions	10	MDLL	1/group; Bright yellow laminated handouts	Erase notes made with dry erase marker and return
Ocean Acidification Causes and Chemistry: Middle School Reading	32	MDLL	Green laminated handouts	Erase any notes made with dry erase marker and return
Ocean Acidification Causes and Chemistry: High School Reading	32	MDLL	White laminated handouts	Erase any notes made with dry erase marker and return
Ocean Acidification Causes and Chemistry: Alternative (lowest level) Reading	32	MDLL	Pink laminated handouts	Erase any notes made with dry erase marker and return
Glossary for Readings	32	MDLL	Pale yellow laminated handouts	Erase any notes made with dry erase marker and return
Video Transcripts	40 total (10/each)	MDLL	Laminated Handouts • Ocean Acidification (red border) • Acids, Bases and OA (optional HS reading, green border) • Effects of OA on Shell-building Organisms (yellow border) • What is OA? (blue border)	Erase any notes made with dry erase marker and return
Post-it Notes	1 pad	MDLL	Up to ~3/student for peer review of explanatory models	Return only unused pads

Dry –erase markers	32 pens	MDLL	1/student to make notes on laminated readings	Return. Throw away markers that do not work.
Erasers	10	MDLL	Used to erase notes made by students on laminated hand-outs	Return

Teacher Background Information

CO2: What it is, what does it do and where we normally find it?

Carbon dioxide, or CO_2, is a gas at room temperature. Along with energy from the sun, CO_2 is used by plants in photosynthesis to produce sugars. Carbon dioxide is released by plants and animals when sugars or carbohydrates are burned or metabolized for energy. Animals use oxygen to expend the energy they obtain from food; the waste product from that metabolism is CO_2. It is the level of CO_2 in your blood that determines your respiration rate, how rapidly you breathe. Exercise leads to rapid rates of breathing because as muscles use energy, they consume oxygen and release CO_2. As CO_2 enters into the blood stream, it causes an increase in the blood's CO_2 concentration; this increase in CO_2 increases the breathing rate. CO_2 is also released when fossil fuels (e.g. coal, oil, natural gas which are the decay products of plants and animals buried during the Carboniferous period), or wood are burned. CO_2 is one form in which carbon (C), an element found in all living organisms and some non-living materials, is found as it cycles on earth (discussed below).

One of the activities included in the *Ocean Acidification and Oysters* lesson involves students designing an investigation in which they need a source of CO_2. When thinking about the environment and climate change, student usually remember that fossil fuels are a source of atmospheric CO_2, but forget that they too produce CO_2. While this is not an important source of atmospheric CO_2, every exhale contains this gas as a result of cellular metabolism. If students don't make this connection on their own, you can ask leading questions to help them remember this 'fact'- that they can be the source of CO_2 for the activity.
Carbon dioxide gas can dissolve in water and when it does so it reacts chemically with water. When mixed with water, carbon dioxide and the water react producing carbonic acid. After the reaction, carbon dioxide is in a different form (it is now held in the carbonic acid) so the concentration of carbon dioxide in the water (if measured as CO_2) hasn't gone up; this allows more carbon dioxide to dissolve in the water. Although that reaction is reversible, this process allows water to absorb a lot of carbon dioxide. About 93% of all the carbon on earth is found in the oceans (in sediments and rocks as well as in living organisms and dissolved in water). How much carbon dioxide can be absorbed by water depends upon several things: salinity, temperature and pressure (deep oceans are at a higher pressure than the surface water). The carbonic acid formed when CO_2 dissolves, dissociates into H^+ and HCO_3^-, hydrogen and bicarbonate. This is described in more detail later.

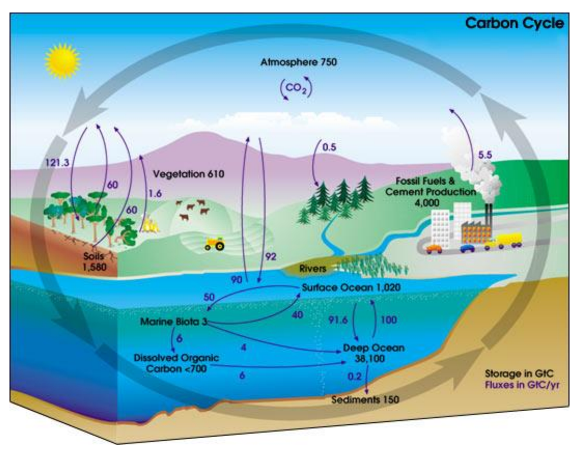


Figure 1: The carbon cycle

Carbon dioxide is constantly being exchanged/cycled among the atmosphere, ocean, and land surface as it is both released and absorbed by microorganisms, water bodies, plants, and animals (see figure 1). Under natural conditions, carbon cycles continually through the earth's natural systems. Emissions and removal of CO_2 by these *natural* processes tend to balance out. Changes to natural processes, such as increasing the amount of CO_2 entering the atmosphere, can greatly affect our natural systems.

Carbon dioxide is naturally present in the atmosphere as part of the earth's carbon cycle; it currently makes up about 0.04% of the air but its concentration was much lower, about 0.028%, when humans developed agricultural systems about 10,000 years ago. The concentration of CO_2 has been steadily increasing since the start of the industrial revolution (~1750). As humans discovered new sources of energy, first coal and then oil (fossil fuels), they developed new technologies to exploit these sources of energy. These new technologies made life for people in societies undergoing transformation much more pleasant in that foods could be cooked more easily, houses warmed, water pumped, travel made much less onerous, etc., but there was an important downside to these improvements; the burning of fossil fuels caused the release of vast amounts of carbon dioxide.

All of the CO_2 being released by the burning of fossil fuels has to go somewhere and it goes either into the atmosphere or the oceans. About 70% of the CO_2 humans are releasing through burning of fuels goes into the atmosphere where it can impact the earth's temperature since CO_2 is a greenhouse gas. For more information about climate change brought about by the increase in atmospheric levels of CO_2 and other greenhouse gases, see the Teachers Background Information (and links within) in the *It's a Gassy World!* MDLL activity (available at www.towson.edu/cse). The remaining 30% dissolves in the earth's waterbodies where it is causing ocean acidification.

Vegetation takes up CO_2 through photosynthesis but natural vegetation is also being impacted by humans. Humans are changing the landscape by reducing the forest cover by harvesting trees for lumber, to make room for residential and industrial development, and clearing land for agriculture. Vegetation does take up CO_2 but as the amount of vegetation cover decreases, the amount that is taken up by plants will also decrease.

The pH scale and what a change in pH means

The pH scale, invented in 1909 by the Danish biochemist S. P. Sørensen, reflects the acidity, neutrality or alkalinity measured in terms of the hydrogen ion concentration. A pH value is a number from 1 to 14, with 7 as the middle (neutral) point. A pH of 7 is neutral, neither acidic nor alkaline. Values below 7 indicate acidity which increases as the number decreases, 0 being the most acidic. Values above 7 indicate alkalinity which increases as the number increases, 14 being the most alkaline. This scale, however, is not a linear scale like a centimeter or inch scale. It is a logarithmic scale in which two adjacent values differ by a factor of 10. For example, a pH of 3 is ten times more acidic than a pH of 4, and 100 times more acidic than a pH of 5. Similarly, a pH of 9 is 10 times more alkaline than a pH of 8, and 100 more alkaline than a pH of 7.

Ocean waters have been becoming more acidic because of the increase in atmospheric CO_2 since the start of the industrial revolution. While the pH of the oceans has not yet dropped below a pH of 7, so they are not 'officially' acidic yet, they have undergone *acidification* (becoming more acidic) as more CO_2 dissolves in water. There has been a 30% increase in the ocean's acidity since the start of the industrial revolution which has had a dramatic impact on the diverse group of organisms that live in the oceans (plankton, shellfish, fish, jellyfish, corals, starfish, etc.). These organisms evolved to thrive at a more basic pH and the recent change in pH impacts them in different ways. Consider what a 30% increase or decrease in your salary might mean to get a sense of how important a change of this magnitude might be!

Biochemical and chemical reactions are impacted by the pH at which are taking place. Certain pH values are optimal for certain reactions. Organisms have evolved to thrive under certain environmental conditions and one of the critical environmental conditions, especially for aquatic and marine organisms is the pH of the water they live in. This is why we find sphagnum moss, pitcher plants and sundew plants only in acid bogs; they thrive under acidic conditions. Most other organisms cannot live in these conditions. One group of organisms that has been severely impacted by ocean acidification are those that must 'create' an external skeleton or shell from the materials dissolved in ocean waters. Organisms such as oysters, clams, corals, etc., make their skeletons/shells from calcium carbonate ($CaCO_3$) and their ability to do this has been severely impacted by acidification.

Calcification and Ocean Acidification Chemistry

The shells of oysters, clams and the skeletons of corals consist of calcium (Ca^{+2}) and carbonate (CO_3^{-2}). Each organism has its own way of 'creating' or synthesizing the mineral calcium carbonate ($CaCO_3$) and depositing it where it needs it to create shell or skeleton and grow, but synthesizing it requires that there be sufficient amounts of Ca^{+2} and carbonate CO_3^{-2} in the water to be able to do so. This is where acidification creates a serious problem for these 'calcifiers' i.e., organisms that create calcium-based shells from dissolved materials.

When carbon dioxide dissolves in water it undergoes a chemical reaction with the water.

$CO_2 + H_20 \leftrightarrow H_2CO_3$	**Carbon dioxide** (CO_2) plus **water** (H_20) combine to make **carbonic acid**, (H_2CO_3)

This reaction is reversible (note the two-sided arrow in the equation above). As mentioned earlier, this reaction doesn't stop here, it continues as follows:

$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+$	**Carbon dioxide** (CO_2) plus **water** (H_20) combine to make **carbonic acid** (H_2CO_3) which dissociates into a **hydrogen** ion (H^+) and what is called a **bicarbonate ion** (HCO_3^-).

The name 'bicarbonate' is historic so don't let that 'bi' confuse you, it is just HCO_3^-!

It is this second reaction that allows the ocean to absorb so much carbon dioxide. Since there isn't a great deal of carbonic acid in the water (it dissociates quickly after being formed) more carbon dioxide can be absorbed. The primary form in which carbon dioxide is found in water is in the form of bicarbonate (HCO_3^-). It is the 'free' i.e. dissociated H^+ ions created by this reaction that are lowering the ocean's pH. Remember that pH is a measure of Hydrogen ion concentration—whenever a CO_2 molecule is dissolved in the ocean (and millions upon millions have been released since the start of the industrial revolution), there is the release of a Hydrogen ion increasing the acidity of the ocean (and decreasing its pH).

Many of those free-floating hydrogen ions just remain that way but some react with dissolved carbonate in water; carbonate is another important ion found in sea water. This reaction is as follows:

$CO_3^{-2} + H^+ \leftrightarrow HCO_3^-$	**Carbonate ion** (CO_3^{-2}) can combine with free **hydrogen ion** (H^+). This creates more **bicarbonate** (HCO_3^-) which *reduces the amount of carbonate in the water, i.e., reducing the amount of carbonate available to make shell.*

How does this ocean chemistry affect organisms?

These chemical reactions have several impacts on organisms that live in the ocean; it can affect their development, their behaviors and/or their habitat. The developmental impacts often occur when the immature stages are just beginning to grow and continue through their mature stages. The organisms that need to create their shells from calcium and carbonate need to have sufficient amounts of calcium and carbonate in the water for them to use them to create shell. Anything that reduces the availability of either of these materials can impact their ability to create shell—and that is what is happening with acidification (explained below). Those organisms that depend on the presence of old shells or healthy coral reefs as part of their habitat are also impacted because these same chemical reactions can lead to reefs and shells dissolving. Scientists have also found that many adult fish cannot tell 'friend' from 'foe' when swimming in acidified waters and so stop fleeing from predators. A fish that doesn't avoid its predators soon becomes another animal's lunch.

Ocean Acidification and Oysters

Oysters have a complicated life cycle (see figure 3). While the oysters we find in the Chesapeake Bay come in different sizes, they start much, much smaller than the smallest oyster you have ever seen. When oysters spawn, release their male and female gametes into the water, the gametes combine creating fertilized eggs. These eggs hatch into microscopic larvae, which cannot feed but grow using the energy stored in the egg. During the first 12 hours of existence, this little larva needs to gather enough calcium and carbonate from the water to create a shell. It has very little time and very little energy. Once it can create shell it can feed and continues to live. Eventually it will become big enough to settle down and become what we recognize as an oyster. It is the fate of the larvae during their first 12 hours that your students are modelling during one activity in this lab. While there are other ways for organisms to build shells, the oyster larvae during their first 12 hours don't have the time or energy needed to use those other methods. They need readily available calcium and carbonate and when carbonate is in short supply because of acidification, they die. If the oyster larvae cannot make shell, we don't get adult oysters.

Figure 3: Oyster Life Cycle

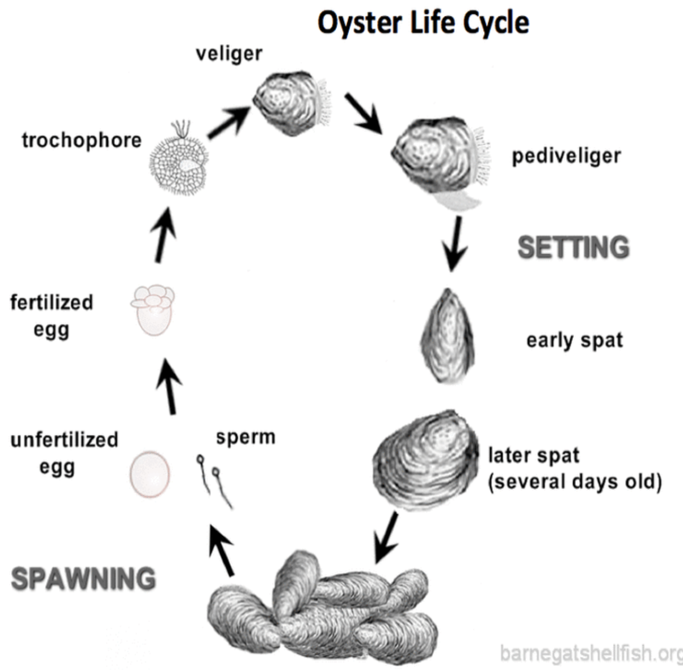
The larval trochophore is the first stage of development—the larval oyster starts this stage unable to feed and needs to develop shell within 12-24 hours. It can only feed and grow once it has a shell.

Oysters remain in the larval veliger stage 2-4 weeks swimming around and being moved by currents.

Development of a foot marks the pediveliger stage, which is a precursor to settling.

Oysters are called 'spat' once they attach to a surface (often the shell of an adult oyster).

The spat grow into adult oysters.



Auburn University School of Fisheries, Aquaculture and Aquatic Sciences. Richard K. Wallace.

A graphic illustration about how the lack of available carbonate ions in the water make it difficult for marine organisms to make a shell can be found in the *Effects of Ocean Acidification on Shell-building Organisms* video from the NC Aquarium although the shell in this illustration is a crab, not a larval oyster. The chemical challenge faced by larval and mature oysters is the same. Without sufficient available carbonate to form its shell and enable it to feed, our larval oyster would just die, which is the basis of the activity called the *Carbonate Model Challenge*.

While acidification impacts oysters at the larval stage, acidification also affects adult oysters. Adult oysters continue to add more shell as they grow (older oysters are larger) but if carbonate is unavailable, the oysters must expend additional energy to add shell. If their energy is going towards building shell that is continually being eroded, it cannot go towards growing larger. Therefore, oysters being stressed by ocean acidification will not be as large as those growing in a healthier environment.

In addition, acidification is destroying old oyster reefs, the perfect habitat for baby oysters. Oysters grow well on old oyster reefs. By settling on a hard substrate such as an old reef, the baby oysters don't have to worry about being covered by sand and other sediments during storms. Ocean acidification is dissolving old shells which are the foundation of the reef.

Ocean acidification is impacting all parts of the oyster life cycle. It is reducing the survival of baby oysters by keeping them from developing the shell they need to feed, grow and survive. It is impacting the ability of adult oysters to grow by dissolving their shells as they are trying to increase the amount of shell as they grow. It is destroying the preferred habitat of oysters, old oyster reef that consists of the shells of earlier generations of oysters.

Ocean Acidification in the Chesapeake Bay

Ocean acidification is happening in oceans throughout the world. For example, dramatic impacts of ocean acidification have been seen in the west coast oyster industry. Producers noticed significant mortality of oyster larvae that threatened their entire industry. Ocean acidification is also occurring in ocean waters on the eastern side of the U.S., including in the Chesapeake Bay, the largest estuary in the United States. While the *chemistry* of acidification is the same in open ocean waters and coastal bays, the sources of CO_2 differ. In open oceans, most of the CO_2 that is affecting the pH of water is from atmospheric CO_2 entering the ocean, as well of upwellings of CO_2 from deep within the ocean. In the Chesapeake Bay, an estuarine system, an additional important source of CO_2 is from the decay processes that result from surges of nutrients from the land into the Bay.

The impact of increasing CO_2 in complex ecosystems like the Chesapeake Bay is influenced by the dynamics of this unique ecosystem. For example, brackish waters found in estuaries are lower in salinity and alkalinity than open ocean environments. As a result, estuaries have less buffering capacity and experience higher swings in pH levels. The results of the interactions of these environmental stressors are often complicated and non-linear, making understanding the overall effects of acidification in the Bay challenging.

Much of the research on the impact of ocean acidification on shell formation in oyster larvae has been done on the Pacific oyster (*Crassostrea gigas*) in open ocean and more research needs to be done on the specific effects of ocean acidification on the Eastern oyster (*Crassostrea virginica*). While the aforementioned complexity of ocean acidification in coastal waters makes forecasting the effects of ocean acidification on eastern oysters challenging, it is clear that the impacts of ocean acidification is a concern in for organisms in Maryland waters, including oysters in the Chesapeake Bay.

You can read more about the impact of ocean acidification on Maryland state waters by accessing the 2015 *Task Force to Study the Impact of Ocean Acidification on State Waters* report. For the purposes of this laboratory activity, students are expected to understand the basic chemistry behind ocean acidification and how that can affect the ability of oysters to produce shells. While students should be aware that ocean acidification in the Bay is complex and affected by additional factors not found in open oceans, they are not necessarily expected to understand these complexities in detail.

Ocean Acidification and Oysters Preparation and Set-up Guide

General Materials

- Student Handout: All students should be provided with a student handout (Appendix B for middle school and Appendix C for high school).
- Explanatory Model Graphic Organizer: Each small group of students (groups of 2-3) should be provided with an "Explanatory Model" graphic organizer page they will work on together. We recommend using poster paper with the basic template, (shown in Appendix D), already drawn. But large copy paper (11X14 or legal size) can also work. Students will be writing/drawing on this page throughout the entire activity. We strongly encourage students to fill out this page in pencil, as they will be revisiting and revising their model throughout the whole activity. We want to encourage the students to makes changes and revise their model as necessary, so you may also want to have extra copies of the "Explanatory Model" graphic organizer available for students if they feel the need to start over.
- The accompanying DVD contains a PowerPoint that has links to the videos needed for this activity. There are also copies saved on the DVD included with this kit if you don't have access to YouTube and/or the internet in school.

Engagement Activities: Carbon Dioxide and Whaddya know? Activities

- Provide each student with a copy of the 'Student Handout' (Appendix B or C).
- Provide each small group with a copy of the 'Explanatory Model' graphic organizer (Appendix D).
- Divide students into 10 small groups
- Provide each group with an oyster shell and a magnifying glass
- (1) Copy of "*All About Oysters*" (Appendix F for middle school and Appendix G for high school)
- (1) dry erase marker/student to makes notes on laminated readings
- Be prepared to show the *Ocean Acidification* video by the Alliance for Climate Education (available on DVD). Transcript available in Appendix H. If you watch online, make sure to stop the video at 1 min, 13 seconds so you don't give away all the answers that students will be working toward throughout the activity.

Investigation 1: What effect does increasing the amount of CO_2 in the ocean have on ocean pH?

<u>Making Salt Water</u>

- You will need to make five bottles (475 mls each) of salt water. Add 1/2 tablespoon salt to each bottle before you plan to teach the activity. The salt water can be made several days in advance.
- In a central location have the five bottles (475 ml each) of salt water available for students. You have enough salt water for each group to use up to ~ 200 ml (plus 375 ml extra).

<u>Student Workstations</u>

You have enough materials for 10 student workstations. Each student workstation should include:

- (4) pH test strips (range 6.00 – 10.00)
- (1) pH test strip instructions
- (2) Beakers
- Straw (~2 per/group, extras can be kept by teacher if students need them)
- Tape for labeling beakers
- Each student should have their copy of the Student Handout (Appendix B or C).
- Each small group should have a copy of the 'Explanatory Model' graphic organizer (Appendix D).

- (1) Copy of Investigation Peer Review Rubric and the CER Rubric per student (Appendix I and J)
- (1) dry erase marker/student to makes notes on laminated readings
- High School Only: Be prepared to show students the video about *Acids, Bases and Ocean Acidification* (transcript in Appendix K) after they complete their investigation and before they write their CER.
- Middle School students will complete their CER directly after completing their investigation- there is no additional video.

Investigation 2: How does increasing the amount of CO_2 in the ocean affect an oyster larva's ability to build shell?

Preparing *Water-beads*

The water-beads need to be hydrated for at least 12 hours (overnight) so must be prepared in advance. To prepare:

- Divide the plastic water-beads evenly into the 20 bowls (just under 1 level tablespoon/bowl). Don't worry if they're not exactly equal, you can move them around after they have expanded.
- Add ~1.5 liters of water to each bowl. You can measure the water out in a beaker, or you can fill the bowl until the water is just under an inch from the top.
- Let soak at least overnight, but no more than a few days. You want each water bead to swell to ~1-1.5 cm.
- Once water-beads reach the appropriate size (~1-1.5 cm), drain any excess water so that you only have hydrated water-beads in bowl, and not extra liquid. We have provided a strainer to assist with this.
- You don't want to leave the water-beads soaking in water once they are the appropriate size, as it makes them more fragile.
- If you make them ahead of time and they shrink due to evaporation, you can always add more water to plump them up.
- Make sure each bowl contains approximately the same amount of water-beads. You can move them around if you have some bowls that are too full and some that are not full enough.
- If you have requested multiple class sets of this activity, you will be reusing the water-beads for every class.
- You can dispose of water-beads in the regular trash. Do NOT put them down the sink, as they will clog the pipes. If you leave the water-beads out, they will eventually dehydrate and shrink to their original size (but it can take weeks). However, we do not recommend saving and rehydrating the water-beads, as they can get moldy.

Preparing Black bowls (represent healthy oceans)

- Add 1 baggie of beads labeled "Black Bowls" to each of the 10 bowls. Each baggie contains:
  - (35) Black Pop Beads: Represent carbonate (CO_3^{-2}) ions
  - (40) White Pop Beads: Represent calcium (Ca^{+2}) ions
  - (5) Black and Red connected Pop Beads: Represent bicarbonate (HCO_3^-) ions (black carbonate plus red hydrogen). Tell students these should not be disconnected.

Preparing White bowls (represent acidified oceans)

- Add 1 baggie of beads labeled "White Bowls" to each of the 10 bowls. Each baggie contains:
  - (10) Black Pop Beads: Represent carbonate (CO_3^{-2}) ions
  - (40) White Pop Beads: Represent calcium (Ca^{+2}) ions
  - (30) Black and Red connected Pop Beads: Represent bicarbonate (HCO_3^-). Ions (black carbonate plus red hydrogen). Tell students these should not be disconnected.

Preparing Student Workstations:

You have enough materials for 10 student workstations. Each student workstation should include:

- (1) white bowl (represents 'acidified ocean' but don't tell students what it represents!)
- (1) black bowl (represents 'healthy ocean' but don't tell students what it represents!)
- (1) 90-second sand timer
- (8) practice pop-it beads (green). These are for students to *practice* snapping together before they begin the actual Challenge. These are *not* part of the Carbonate Model Challenge and do not represent any molecules.
- (2) beakers for students to drop their calcium carbonate molecules (black and white beads they snap together) into as they are completing the Challenge
- (1) laminated *Carbonate Model Challenge* instruction sheet (Appendix L).

List of all *Ocean Acidification and Oysters* Readings/Videos

Middle School

- There are (32) copies of the *All About Oysters* reading (Appendix F).
- Be prepared to show the *Ocean Acidification* introductory video by the Alliance for Climate Education (transcript in Appendix H). **Make sure to stop the video at the 1 min, 13 sec mark**, as the ending of the video will give away the answers that students are working toward throughout the activity.
- Be prepared to show the video about the *Effects of Ocean Acidification on Shell-building Organisms* (2 min, transcript in Appendix M).
- There are (32) copies of the *Ocean Acidification Causes, Chemistry and Impacts* Reading for middle school (Appendix N) students can share. A glossary for this reading can be found in Appendix P.
- Be prepared to show the PBS *What is Ocean Acidification?* summary video (4 min; transcript in Appendix Q).

High School

- There are (32) copies of the *All About Oyster* reading (Appendix G) and students can share.
- Be prepared to show the *Ocean Acidification* introductory video by the Alliance for Climate Education, transcript in Appendix H). **Make sure to stop the video at the 1 min, 13 sec mark**, as the ending of the video will give away the answers that students are working toward throughout the activity.
- Be prepared to show the optional video about *Acids, Bases and Ocean Acidification* (transcript in Appendix K). Most appropriate for higher level chemistry students.
- Be prepared to show the video *Effects of Ocean Acidification on Shell-building Organisms* (2 min, transcript in Appendix M).
- There are (32) copies of the *Ocean Acidification Causes, Chemistry and Impacts* reading for high school (Appendix R) students can share. A glossary for this reading can be found in Appendix P.
- Be prepared to show the PBS *What is Ocean Acidification?* summary video (4 min, transcript in Appendix Q).

Gallery Walk

- Sticky notes (≥ 2 per student)

Ocean Acidification and Oysters Facilitation Guide

Engagement

The engagement activities are used to elicit students' prior knowledge, as well as introduce them to the ideas they will be exploring in this activity. The ideas in the *Engagement* are meant to be review, but if your students are not familiar with these ideas, you may need to spend more time on this part of the activity.

1. Carbon Dioxide
   - Ask the students *What does carbon dioxide in our atmosphere do for the Earth?* Allow them time to discuss in groups and write their thoughts in their student handout. You might need to point out to your students that symbols in the slide represent carbon dioxide gas.
   - Once students have had time to discuss, you can choose to share some of their ideas as a large group. You want students to know that carbon dioxide is a greenhouse gas, which means it traps heat in our atmosphere and reflects it back to earth, warming it. You can talk about how we need to have some greenhouse gases in order for our atmosphere to be warm enough to support human life and that CO_2 is essential for plant growth. Once they have had a chance to share their own ideas, you can show them the slide that says it is a greenhouse gas and warms the earth.
   - Next, you can ask them *What happened when people started burning fossil fuels for energy?* Students will likely bring up the following ideas:
     - Burning fossil fuels releases carbon dioxide
     - Extra carbon dioxide in the atmosphere traps more heat
     - Our atmosphere has been warming dramatically since the industrial revolution due to the carbon dioxide being released by the increased burning of fossil fuels
   - Next, discuss how the absorption of CO_2 by the ocean is a natural process. You can discuss how carbon dioxide in the ocean is 'good' in that it prevents it from causing the atmosphere to warm. But, because humans have been releasing so much CO_2 into the atmosphere by burning fossil fuels the ocean is now absorbing more CO_2 than ever before. The increase in the amount of CO_2 being absorbed by the ocean is affecting the marine environment and the organisms that live in it. Tell the students they will be exploring these effects throughout this activity. There are several questions in the student handout related to these ideas.

2. Whaddya know?
   - Divide your students into 10 small groups.
   - Provide an oyster shell and a magnifier glass to each group. You can choose to tell your students that it is an oyster shell, or allow them to figure it out on their own.
   - Ask students to make and record observations, inferences and list any questions they have about the object.

- After students have had time to explore the object, discuss their observations and inferences.
- Ask the students how they think oyster grow and produce shells. After they have had a chance to share their ideas, pass out the reading *All About Oysters* (Appendix F for middle school and Appendix G for high school).
- You can use the slides to review the main ideas in the readings.
- Ask students if they have any additional questions about oysters. Make a list of these questions. Some may be answered throughout the activity, and students may choose to research and answer others on their own.
- A fun activity, if you have time, is to give each student (or group of students) only half a shell and challenge them to find the matching half. Encourage students to find their matching shell by comparing their shell to all the others in the class. We have provided an answer key for the teacher of which shells match in Appendix S (look for numbers written on each shell).

3. Show your students the *Ocean Acidification* introductory video by the Alliance for Climate Education (transcript in Appendix H). **Make sure to stop the video at the 1 min, 13 sec mark**, as the ending of the video will give away the answers that students are working toward throughout the activity. Discuss with students that increasing levels of CO_2 in the oceans are affecting marine organisms, including oysters. Tell students they will be exploring how and why this is happening in this lesson's activities. Discuss why decreasing oyster populations might be a concern:

- oysters are an important part of the ecosystem
- oysters filter the water
- oysters and oyster reefs provide habitat for other organisms to live on and around
- other species (including humans) rely on them for food
- oysters are an important component of Maryland's economy and history

Constructing Explanatory Model Round 1

4. Introduce students to the driving question and the investigative questions.
Driving Question: *How might increasing levels of CO_2 affect Oysters?* You don't necessarily need to introduce the following investigative questions yet, but as a reminder, students will engage in several investigations throughout the *Ocean Acidification and Oysters* activity to answer the following questions:

- Investigative Question 1: What effect does increasing the amount of CO_2 in the ocean have on ocean pH?
- Investigative Question 2: How does increasing the amount of CO_2 in the ocean affect oyster larvae's ability to build shell and survive?

5. Explain to the students that they are going to be creating an explanatory or pictorial model of ocean acidification and oysters throughout the lesson and doing it the same way scientists do it. Scientists start such a model by noting what they know and then add new information they

have discovered to their model as they learn more. A scientist's model is going to have lots of words, images, numbers, arrows, circles and other things as the scientists think about what should be in the model and how the parts might be connected. The explanatory model will be revised many, many times before a scientist considers it done. Students often do not like making changes to their models, as they might feel it makes them look 'messy' or suggests they did something 'wrong'. It is helpful to remind students throughout the activity that scientists never start out with a fully formed model and that making changes as more information is learned is the *only* way to develop a good, strong model. Many students struggle with the idea and the act of creating an explanatory model. See Appendix T for more information on explanatory models and how to scaffold your students through the process of creating and using them.

6. Have students begin constructing their explanatory model by using information they learned from considering where carbon dioxide comes from and where it is stored, looking at the oyster shell, reading about oysters. Begin this process by leading a whole class discussion about '*Gotta Have'* ideas they should include in their model. It is important to let students develop this list (with scaffolding from the teacher) and not simply tell them what to include. Students will work cooperatively in 10 small groups (~2-3 students/group). Be sure to encourage all members of the group to actively participate in adding to the model.

Information they may include on their *Gotta-Have* list is below. Note this is not an exhaustive or prescriptive list. Your students may include different or additional ideas. Students should be free to add any prior information they have (it does not have to restricted to only the ideas talked about in class). An important component of building explanatory models is the process of revision. So, if your students include incorrect ideas at this point, or fail to include important ideas, that is okay. They will have several more opportunities to revisit and revise their model.

- CO_2 is released when fossil fuels are burned
- Fossil fuels are used to power factories, cars, airplanes, etc.
- Extra CO_2 in the atmosphere is causing the climate to warm
- The amount of CO_2 present in the atmosphere increases with the amount of fossil fuels burned
- Oceans absorb CO_2 from the atmosphere which is good as it keeps the CO_2 out of the atmosphere where it causes warming, but can also have negative impacts on the oceanic environment
- More atmospheric CO_2 leads to more CO_2 being absorbed by oceans
- Oysters live in the ocean
- Oysters filter water
- Oyster larvae need to build shells to survive
- Building a shell is hard work and takes a lot of energy for oyster larvae
- Oyster larvae need access to calcium and carbonate ions to form calcium carbonate to build their shells and without shells they cannot feed and so they die

Investigation 1: What effect does increasing the amount of CO_2 in the ocean have on ocean pH?

Activity Summary for Teachers: In this activity students will work in small groups to design and conduct an investigation to provide data and evidence to answer the investigative question *What effect does increasing the amount of CO_2 in the ocean have on ocean pH?* The focus in this activity is to allow students an opportunity to engage in the scientific practice of *Planning and Carrying Out Investigations*. Students are supplied with a general list of materials available to them, and the need to design, and then conduct an investigation that will provide the data necessary to answer the investigative question.

Teachers' should serve in the role of facilitator during this activity and support students as they work collaboratively in small groups to come up with their own designs. The *process* of planning the investigation is just as important as the *act* of carrying out the investigation. A good design comes about through trial and error. Therefore, teachers are strongly encouraged to allow the students to come up with their own ideas for how they plan to conduct the investigation. Remember, the goal is to provide your students with an opportunity to work through this challenge themselves. We expect to students to struggle; it is part of the learning process. If/when students struggle, get 'stuck', or miss what might be considered important elements of an investigation, consider using the following prompts to scaffold the experience for them, rather than just telling them what to do.

- Prompts:
  - What question are you trying to answer?
  - Will your investigation give you data to answer your question?
  - Is your investigation a 'fair' test?
  - Is it important that variables (e.g. amount of water) be consistent among trials? Why or why not?
  - What are you doing in your investigation?
  - What are you measuring in your investigation?
  - What data do you expect to collect?
  - How will you know if what you do in your experiment is responsible for an affect or any changes you might see?
  - If you are collecting data, where are you going to record it?
  - Do you have a dependent variable? If so, what is it?
  - Do you have an independent variable? If so, what is it?
  - How many trials will you do?
  - What were the elements of the last investigation we did as a class?

7. Introduce the investigative question: *What effect does increasing the amount of CO_2 in the ocean have on ocean pH?* There are several slides in the PowerPoint that you can use to discuss the following ideas:

- pH is a characteristic of water and levels of pH can affect which organisms can survive in a particular environment

- A basic primer on pH and a slide describing how to use pH test strips
- Sometimes your results fall between two pH values. If that happens you need to pick a middle point as best you can
- The idea that more CO_2 in atmosphere leads to more CO_2 being absorbed by oceans
- These ideas all lead to the investigative question: *What effect does increasing the amount of CO_2 in the ocean have on ocean pH?*

8. Form 10 groups of students.
   - Have each student group brainstorm and design an investigation that will provide data they can use to answer the investigative question *What effect does increasing the amount of CO_2 in the ocean have on ocean pH?*
   - Once they have decided on a design plan, have them write it out in their student handout. Remember, students should be given the opportunity to do this on their own. Teachers can help to scaffold the students, but it is important to allow your students the time and space to tackle this challenge, even if they end up not designing the perfect investigation. You can always discuss after the fact why their investigation may not have yielded reliable results or did not provide the appropriate evidence to address the question. They will also have a chance to receive this feedback during the Peer Review process.

9. Have students engage in a peer review of their investigation plan. Have students swap plans with another group and use the Investigation Design Peer Review Rubric (Appendix I) to help them provide feedback to each other. Remind them that science investigations always benefit from peer review—they make the investigation design stronger.

10. Give students time to discuss and incorporate suggestions from the peer review process into the design of their investigation. There is space in their student handout for them to write their revisions/changes.

Some tips for scaffolding students as they design their own investigations:

- Depending on what you observed during the students' initial protocol writing and review process, you may consider requiring students to check-in with you to receive approval before obtaining materials and conducting their investigation. This check-in can serve as a useful tool to identify groups that may require additional support and/or scaffolding.
- Students might get stuck and not know what to use for carbon dioxide. Instead of just telling them to use the straw to blow into the water, consider asking guiding questions that will help them put together the idea that we exhale carbon dioxide (which they all likely know, but just aren't thinking about) and that that could be a good source of carbon dioxide.
- For groups that may be struggling with the design of their investigation, consider having them talk to another group who is further along in their planning to share ideas.

- One area where you might want to offer a little guidance is with respect to how, and how long to blow into the beakers. Taking multiple breaths over the time works find, no need for this to be one very long exhale. We have found that generally blowing for ~45 seconds is sufficient to see a measurable change in pH. So, if students are suggesting in their designs that they will blow into a beaker for much longer (or much shorter), you can suggest they start with 45 seconds. This saves time, is much easier (you get very out of breath trying to blow for much longer than that) and leads to more consistent results. But, again, let students come up with their own ideas first, then guide them if necessary.
- One issue you might run into is if some students don't get the 'expected' response (that CO_2 in water decreases pH and increases acidity). If it is just a few groups, you can share results as a class so that students see these results as outliers. You would compare this to how scientists work and ask students about the importance of multiple trials and larger sample sizes.

11. Have students conduct their investigation and record their data. Make sure students are wearing appropriate personal proactive equipment (e.g. gloves and goggles).

12. There is an optional short video, *Ocean Acidification Explained*, (3 min 42 sec) that talks about acids, bases and ocean acidification (see Appendix K for transcription) you can show your students. This video is likely most appropriate for high school groups. If you chose not to show this video, you can have them move to the next step without this additional information.

Constructing a scientific Explanation (CER): CO_2 and ocean pH

13. Students will then be asked to construct a scientific explanation that includes a claim, evidence (from their investigation) and reasoning that answers the investigative question *What effect does increasing the amount of CO_2 in the ocean have on ocean pH?* Teachers can use the information from the student's scientific explanations to formatively assess whether students understand that the addition of CO_2 to water decreases the pH (causes the solution to become more acidic). A rubric is provided in Appendix I for assessing the CER. Teachers can choose whether or not to share the rubric with their students.

Constructing Explanatory Model Round 2

14. As a class, discuss and generate a list of *additional Gotta-Have* ideas that the students might include in their explanatory model, based on any new ideas and information students gained with the previous investigation (and optional video). Again, this list should be generated by the students, with guidance and scaffolding from the teacher. This list may include:

- Middle School
    - CO_2 from the atmosphere is absorbed into the ocean.
    - Increasing amounts of CO_2 in the atmosphere will lead to increasing amounts of CO_2 in the water.
    - As CO_2 enters the water, the pH decreases (the water becomes more acidic)

- High School
    - CO_2 from the atmosphere is absorbed into the ocean.
    - Increasing amounts of CO_2 in the atmosphere will lead to increasing amounts of CO_2 in the water.
    - As CO_2 enters the water, the pH decreases (the water becomes more acidic)
    - Information from video about *Acids, Bases and Ocean Acidification*, (transcription in Appendix K) that students might include:
        - When carbon dioxide meets water, it reacts to form carbonic acid
        - The formation of carbonic acid releases two hydrogen ions which increases acidity of water
        - Acidic water can dissolve the calcium carbonate found in exoskeletons of marine organisms.

15. Have students go back to their developing explanatory model and add relevant information from this investigation to their model. Again, be sure to encourage all members of the group to actively participate in adding to the model.

Investigation 2: *Carbonate Model Challenge*

Activity Summary for Teachers: In this activity, students will use models to explore how increasing levels of atmospheric CO_2 can affect the ability of oysters to make calcium carbonate for their shells. As oceans continue to absorb more and more atmospheric carbon dioxide (CO_2), they become more acidic (as evidenced by a decrease in pH). When CO_2 dissolves in the ocean, a series of chemical reactions results in fewer carbonate ions being available in the ocean for the oysters to use to build their shell. Oyster larvae rely on the availability of carbonate ions (and calcium ions) in the water to form their shells. With fewer carbonate ions available, oysters have a more difficult time accessing them and, as a result, have to expend more energy to try and build their shells. If they don't get enough calcium carbonate, oyster larvae cannot make a shell and therefore cannot eat—so they die.

In the *Carbonate Model Challenge*, each student group (10 groups total) is presented with two physical models that allow them to explore how oyster larvae might experience building shells in an acidified ocean and a healthy ocean environment. In the *Carbonate Model Challenge*, students assume the role of oyster larvae and attempt to build shells by creating calcium carbonate molecules. In the *Carbonate Model Challenge*, one bowl represents a healthy ocean and one bowl represents an acidified ocean, but *students don't yet know which is which*. The goal of the activity is for students to use the results of the *Challenge* to figure out which bowl represents a healthy ocean and which bowl represents an acidified ocean).

Within each bowl are soft water-beads meant to represent water. Each bowl also contains hard, plastic "pop-it" beads mixed in with the soft water-filled beads. Black pop-it beads (the color of carbon as coal) represent carbonate ions and white pop-it beads (the color of chalk) represent calcium ions. Red pop-it beads represent hydrogen ions. In the model, all the red beads are bound to black beads, and they represent bicarbonate. It's important for you to tell your students that the bicarbonate molecules should remain attached to each other (they should not pull apart the red/black beads).

For the challenge, one student acts as an oyster larva at each bowl and each oyster larva is tasked with finding and building (connecting) calcium carbonate ions by connecting carbonate ions (black pop-it beads) with calcium ions (white pop-it beads) to form calcium carbonate molecules. Each round lasts 90 seconds. If there are at least three students per group, two students can work at making the calcium carbonate molecules, one for each color bowl, and the third can be the time keeper. At the end of each round, students tally the number of calcium carbonate molecules created in each ocean (Black bowl and White bowl). Using averages from all groups, students will then compare the number of calcium carbonate ions they were able to make in each of the oceans and construct a scientific argument as to which bowl represents the healthy ocean, and which represents an acidified ocean.

After completing this activity, students should understand that 'acidified' oceans (represented in this challenge as the white bowl) have fewer carbonate ions available to bind with calcium, making it more difficult for oysters to build their shells. They should also understand this is because there are more hydrogen ions (red beads) in the acidified ocean, which have already bound to carbonate, making it unavailable for oysters to use. This is why there were many more bicarbonate molecules (black beads attached to red beds) in the acidified 'ocean' (the white bowl). In the 'healthy' ocean (represented by the black bowl in the *Challenge*) the oyster larvae were able to make more calcium carbonate molecules. There were fewer bicarbonate molecules (red and black attached beads), and therefore more carbonate ions (black beads) available. As a result, the oyster larvae were better able to build a shell (by combining calcium and carbonate ions) that is necessary for them to eat and their continued survival.

While students will not know this as they participate in the challenge, teachers will note that the 'healthy' oceans will more carbonate (35 black beads) ions. 'Acidified' oceans have only a fraction of the carbonate ions (10 black beads) beads and will have a higher number of hydrogen ions (red beads) that will be bound to carbonate ions (representing bicarbonate). The number of calcium ions (40) is the same in both the 'healthy' and 'acidified' ocean models.

16. Discuss with students how models are used in the science.
    - Scientists use them to explain and explore phenomena (like the explanatory model they are developing)
    - Scientists use models to make and test predications about phenomena. This is what they will be doing in the next activity, the *Carbonate Model Challenge*.

17. *Carbonate Model Challenge* overview and rules:
    - You have enough materials for up to 10 student workstations.
        - Ideal group size is 3 students. One student is the 'oyster larva' in the ocean represented by the white bowl and one student is the 'oyster larva' in ocean represented by the black bowl, and one student acts as time keeper.

- Each group of students will have:
    - (1) Black bowl which will contain:
        - (35) Black Pop Beads: Represent carbonate (CO_3^{-2}) ions
        - (40) White Pop Beads: Represent calcium (Ca^{+2}) ions
        - (5) Black and Red connected Pop Beads: Represent bicarbonate (HCO_3^-). ions. Remind students these should not be disconnected.
    - (1) White bowl which will contain:
        - (10) Black Pop Beads: Represent carbonate (CO_3^{-2}) ions
        - (40) White Pop Beads: Represent calcium (Ca^{+2}) ions
        - (30) Black and Red connected Pop Beads: Represent bicarbonate (HCO_3^-). ions. Remind students these should not be disconnected.
    - The pop-it beads should be well mixed into the hydrated water-beads in each 'ocean' bowl since they represent dissolved ions.
    - Give each group two bead collection cups (one labeled 'black bowl', one labeled 'white bowl') to collect their calcium carbonate molecules in.
    - Provide each group eight green Pop-it beads they can use to practice connecting two beads together. It can be a challenge to connect the beads (especially if students are wearing gloves) and having students practice increases the quality of data they collect. Just remind students that the green beads are not part of the model and should not be placed in the bowls.

18. Explain the *Carbonate Model Challenge* to the students and have them begin.
    - Each student group counts how many calcium carbonate molecules (one white bead and one black bead) they can make in 90 seconds time. Each group should do the challenge at least twice (this way each person in group gets a turn to be the oyster larva and hunt for ions and the greater number of trials increases the quality of the data collected). If the activity is repeated, the black and white pop it beads that became calcium carbonate molecules need to be separated into their 'ionic' state again and remixed into the model oceans they came from.
        - Sometimes the black and white beads may not fit together easily**. If that happens, tell the students to just place the beads together in the collection beakers without connecting them.** They can still count them later as calcium carbonate molecules, but we don't want them spending too much time trying to get the molecules connected. But we do have them at least *try* to connect the two beads.
        - Have students collect the results of their trials in their own data tables and calculate means if they conducted more than one trial.
        - Remind your students that while this is called the *Carbonate Challenge*, it is a learning experience—that 'they' aren't personally losing or winning depending on how many calcium carbonate molecules they make. Rather, it is the oyster larvae who win or lose and they are demonstrating/modelling what happens to the larvae.
        - Safety: While the water-beads are non-toxic, students should wear appropriate personal protective equipment (e.g. gloves and goggles) while

handling the materials. If students don't wear gloves, consider having them wash their hands with soap and water or use hand sanitizer *before* and *after* handling water-beads.

19. Collect individual results on a class data table and have students calculate the mean number of calcium carbonate ions the class was able to make in each of the two oceans (the black bowl versus the white bowl. You can also have the students calculate the mean number of molecules per second each oyster larva was able to make under the two conditions (healthy ocean versus acidified ocean). Remind your students that the bowls represent two different ocean environments ('healthy' versus 'acidified') and the challenge is for them to figure out which one is which.

20. Have students look for patterns and trends in the data. They may choose to make a graph as a way to visualize the data. Have them write what patterns they see on their student pages. The data will likely show that more $CaCO_3$ molecules were made in black ('healthy') ocean environments. But remember, don't tell the students which bowl is the 'healthy' ocean and which the 'acidified' ocean is; they are meant to figure that out based on their data.

21. Next, students will gather background information through the following videos and readings. (10) laminated copies of transcripts of each video are provided if you feel your students would benefit from being about to read along with the video.

- Middle School
    - Show the video about the *Effects of Ocean Acidification on Shell-building Organisms* (2 min, transcript in Appendix M). Have students answer the questions in their student handout about the video.
    - Have the students read the middle school version of *Ocean Acidification Cause, Chemistry and Impacts (Appendix N)* and answer the reflection questions in their student handout. An alternative (lower level) reading is provided in Appendix O.
    - A glossary for the *Ocean Acidification Causes, Chemistry and Impacts* reading is provided in Appendix P.
    - Show the summary PBS video *What is Ocean Acidification?* summary video (4 min, transcript in Appendix Q).
- High School
    - Show the video about the *Effects of Ocean Acidification on Shell-building Organisms* (2 min, transcript in Appendix M). Have students answer the questions in their student handout about the video.
    - Have the students read the high school version of *"Ocean Acidification Causes, Chemistry and Impacts"* (Appendix R) and answer the reflection questions in their student handout. You have been provided with 32 copies of reading. For lower readers, you might consider providing the Middle School version (Appendix N) or the most simplified 'Alternative' version (Appendix O).

    - A glossary for the *"Ocean Acidification Causes, Chemistry and Impacts"* reading is provided in Appendix P.
    - Show the summary PBS video *What is Ocean Acidification?* (4 min, transcript in Appendix Q).

Construct a Scientific Explanation (CER): acidified versus healthy ocean

22. Have students construct a scientific argument to answer the question *"Which bowl represented the healthy and the acidified ocean?"* They should include evidence and reasoning in their answers.

Constructing Explanatory Model Round 3

23. As a class, discuss and generate a list of additional *Gotta-Have* ideas that the students might include in the explanatory model. Again, this list should be generated by the students, with guidance and scaffolding from the teacher.

24. Have students return to their developing explanatory model and add relevant information from the *Carbonate Model Challenge* and the associated videos and readings. Remind all members of the group to actively participate in adding to the model. Ideas and information they might include:

- Middle School
    - Oysters in 'acidified' oceans can form fewer calcium carbonate molecules as compared to oysters in 'healthy' oceans
    - There were fewer carbonate molecules in the 'acidified' ocean than in the 'healthy' ocean because the extra hydrogen in acidified oceans are binding to carbonate molecules, forming bicarbonate.
    - Because there were fewer carbonate molecules in the 'acidified' ocean, it took more time to search for and find them
    - It takes a lot of energy to build shell in acidified oceans
    - Oyster larvae that grow in more acidic oceans are smaller and less healthy than those that grow in less acidic, healthier oceans.
    - Other issues, in addition to ocean acidification, affect the pH of the Chesapeake Bay including geography, sedimentation, SAV and nutrient run-off.

- High School
    - Oysters in 'acidified' oceans can form fewer calcium carbonate molecules as compared to oysters in 'healthy' oceans
    - There were fewer available carbonate molecules in the 'acidified' ocean than in the 'healthy' ocean because the extra hydrogen in acidified oceans are binding to carbonate molecules, forming bicarbonate.
    - Because there were fewer available carbonate molecules in the 'acidified' ocean, it took more time to search for and find them

- It takes a lot of energy to build shell in acidified oceans
- Oyster larvae that in more acidic oceans aren't able to form shells and die more often than those that grow in less acidic, healthier oceans.
- Other issues, in addition to ocean acidification, affect the pH of the Chesapeake Bay including geography, sedimentation, SAV and nutrient run-off.
- Details about the chemistry of ocean acidification found in the "*Ocean Acidification Causes, Chemistry and Impacts*" reading (Appendix R).

Gallery Walk

25. Sharing and communicating information is an important scientific practice. Have students share and provide and receive feedback on their explanatory models using a Gallery Walk.

- Students should display their models around the room (hang on walls or leave on desks)
- Have students visit at least 2-3 models other than their own. You might consider assigned numbers to each model and then assign students to specific numbers for review. You might also consider having students work in pairs or groups to provide feedback.
- Provide students will stickie notes on which to write their feedback. Students of all ages often struggle to give relevant, useful, and respectful feedback. Consider scaffolding the process by providing the following prompts:
  - I wonder _____________.
  - I like ________________ because _______________.
  - Have you thought about _______________.
  - I would like to see ________.

Constructing Explanatory Model Round 4

26. Provide students time and opportunity to review the feedback they have received from their peers and revise their explanatory model accordingly.

27. Elicit student ideas and thoughts on how humans can address CO_2 emissions, which cause both climate change and ocean acidification. While it is important to address the positive aspects regarding what is being done about climate change, it is also important for students to be able to share their concerns and their fears. Take time to ask your students what they think about the problem. Ask them to consider ways in which humans are addressing the problem. What are scientists doing? What are politicians doing? What are people in other countries doing? What can *they* do?

Evaluation

There are opportunities for formative evaluation throughout the entire activity. These include:

- Listening to and observing student discussions as they design and conduct their investigation and build their explanatory models
- Reviewing student answers on the student handout pages (including responses to reflection questions and scientific argument and explanation construction (C-E-R's)
- Reviewing the explanatory models at all stages of construction
- Listening to and observing students as they give feedback during peer review work

Teachers can use the final versions of student explanatory models as a summative assessment. A rubric for assessing the final model can be found in Appendix T. Answers to student handouts can be found in Appendix V (middle school) and Appendix W (high school). A list of additional resources and links to help with facilitating the lesson can be found in Appendix X.

Appendix A. Connections to Maryland Science Standards

Middle School

Performance Expectations: Students' ability to complete the following performance expectation(s) will be supported by participation in this activity.
MS-LS2-4: Construct an argument supported by empirical evidence that changes to the physical or biological components of an ecosystem affect populations.
MS-ESS3-5: Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century.
MS-PS1-2: Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

Dimension	Code or citation	Matching student task
Disciplinary Core Idea	• LS2.C: ○ Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all of its populations.	Students will investigate how increased atmospheric CO_2 levels can affect ocean pH and the ability of shell-bearing organisms to grow and reproduce Students will explore the connection between increased CO_2 release by humans and survival of shell-bearing organisms.
Disciplinary Core Idea	• ESS3.D ○ Reducing human vulnerability to whatever climate changes do occur depend on the understanding of climate science, engineering capabilities, and other kinds of knowledge, such as understanding human behavior and on applying that knowledge wisely in decisions and activities.	Students will discuss what can be done to limit and/or mitigate the effects of increased CO_2 in the atmosphere.
Disciplinary Core Idea	• PS1.B: Chemical Reactions ○ Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new	During their investigation students will explore the idea that when CO_2 enters the water, it changes the pH of the water.

	substances have different properties from those of the reactants.	In the *Carbonate Model Challenge*, students will explore how ions can be combined to form molecules.
Practice	Developing and using models • Develop and/or revise a to predict and/or describe phenomena • Develop a model to describe unobservable mechanisms.	Students will use a model to explore how the ability of oyster larvae to build shells differs in healthy versus acidified oceans during the *Carbonate Model Challenge.* Students will construct, review and revise an explanatory model to answer the driving question: *How might increasing levels of CO_2 affect oysters?*
Practice	Planning and Carrying out Investigations • Plan an investigation individually and collaboratively and in the design identify independent and dependent variables and controls, what tools are need to do the gathering, how measurements will be recorded, and how many data are need to support a claim. • Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.	Students will design and conduct an investigation to determine the effects of CO_2 on pH levels of salt water. Students will use the results from their investigation to develop an explanatory model to answer the driving question: *How might increasing levels of CO_2 affect oysters?*
Practice	Construct an explanation • Construct an explanation using models or representations. • Construct a scientific explanation based on valid and reliable evidence obtained from sources (including students' own experiments) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future	Students will construct a scientific explanation to answer the investigative question *What effect does increasing the amount of CO_2 in the ocean have on ocean pH?* Students will construct a scientific explanation to answer the driving question *"How might increasing levels of CO_2 affect oysters?"*

Crosscutting Concept	Stability and Change - Students learn that changes in one part of a system might cause large changes in another part, systems in dynamic equilibrium are stable due to a balance for feedback mechanism, and stability might be disturbed by either sudden evets or gradual changes that accumulate over time.	Students will explore how CO_2 is gradually changing the pH of oceans and impacting ocean's biota.
Crosscutting Concept	Cause and Effect - Students will use cause and effect relationships to predict phenomena in natural or designed systems.	Students will explore the empirical evidence that demonstrates a cause and effect relationship between increasing ocean acidity and shell formation in marine organisms as well as the relationship between increasing amounts of CO_2 in the ocean and decreasing ocean pH.
Crosscutting Concept	Systems and System Models - Students can use models to represent systems and their interactions –such as inputs, processes, and outputs- and energy, matter and information flows within systems. - Students learn that models are limited in that they only represent certain aspects of a system under study.	Students will design and use a model to understand the effects of increased CO_2 in the atmosphere on a marine system. Students will discuss how their models are not exact copies of reality and only represent parts of a larger system.

High School

Performance Expectations: Students' ability to complete the following performance expectation(s) will be supported by participation in this activity. **HS-LS2-5:** Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere. **HS-LS2-6:** Evaluate claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organism in stable conditions, but changing conditions may result in new ecosystem. **HS-ESS3-6:** Use a computational representation to illustrate the relationships among Earth systems and how those relationships are being modified by human activity.		
Dimension	Code or citation	Matching student task
Disciplinary Core Idea	• LS2.B: Photosynthesis and cellular respiration are important components of the carbon cycle, in which carbon is exchanged among the biosphere, atmosphere, oceans and geosphere through chemical, physical, geological, and biological processes. • LS2.C: ○ Extreme fluctuations in conditions or the size of any population, however can challenge the functioning of ecosystems in terms of resources and habitat availability. ○ Anthropogenic changes (induced by human activity) in the environment…climate- can disrupt an ecosystem and threaten the survival of some species.	During the engagement activity, students will reflect on the carbon cycle and explore how the oceans act as a carbon sink for increasing levels of atmospheric CO_2. Students will investigate and create an explanatory model for how increased atmospheric CO_2 levels can affect ocean pH and the ability of shell-bearing organisms to grow and reproduce. Students will explore the connection between increased CO_2 release by human activities (such as industry and transportation) and survival of shell-bearing organisms in their explanatory models.
	• ESS3.D: Through computer simulations and other studies, important discoveries are still being made about how the ocean, the atmosphere, and the biosphere interact and are modified in response to	Students explore the complexities facing the Chesapeake Bay in the final reading, which discusses how other inputs such as runoff and sedimentation may be affecting the pH of a large estuary.

	human activities as well as to changes in human activities.	
Disciplinary Core Idea	• PS1.B: Chemical Reactions ○ Chemical processes and properties of materials underlie many important biological and geophysical phenomena. In many situations, a dynamic and condition-dependent balance between a reaction and the reverse reaction determines the number of all types of molecules present.	Students will explore, at a chemical level, what happens when CO_2 enters salt water: $CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow HCO_3^- + H^+$ and $CO_3^{-2} + H^+ \leftrightarrow HCO_3^-$ Students will explore how CO_2 entering the ocean ultimately leads to a decrease in the availability of carbonate for shell-building organisms such as oysters.
Practice	Developing and using models • Develop, revise and/or use a model based on evidence to illustrate and/or predict the relationships between systems or between components of a system.	Students will use a model to explore how the ability of oyster larvae to build shells differs in healthy versus acidified oceans during the *Carbonate Model Challenge.* Students will construct, review and revise an explanatory model to answer the driving question: *How might increasing levels of CO_2 affect oysters?*
Practice	Planning and Carrying out Investigations • Plan an investigation individually and collaboratively to produce data to serve as the basis for evidence as part of building and revising models, supporting explanations for phenomena, or testing solutions to problems. Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled. • Conduct an investigation and/or evaluate and/or revise the experimental design to produce data to serve as the basis for evidence that meet the goals of the investigation.	Students will design and conduct an investigation to determine the effects of CO_2 on pH levels of salt water. Students will use the results from their investigation to develop an explanatory model to answer the driving question: *How might increasing levels of CO_2 affect oysters?*

Practice	Construct an explanation • Construct and revise an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulation, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future.	Students will construct an explanation to answer the question *"How might climate change affect oysters?"*
Crosscutting Concept	Stability and Change	Students will explore how CO_2 is gradually changing the pH of oceans and impacting ocean's biota.
Crosscutting Concept	Cause and Effect	Students will explore the empirical evidence that demonstrates a cause and effect relationship between increasing ocean acidity and shell formation in marine organisms as well as the relationship between increasing amounts of CO_2 in the ocean and decreasing ocean pH.
Crosscutting Concept	Systems and System Models	Students will design and use a model to understand the effects of increased CO_2 in the atmosphere on a marine system. Students will discuss how their models are not exact copies of reality and only represent parts of a larger system.

Appendix B: Middle school student handouts

This page left intentionally blank. Resource begins on next page. Print a copy of this handout for each student.

Carbon Dioxide

1. What does carbon dioxide (CO_2) in our atmosphere do for the earth?

____
____
____
____

2. What happened when people started burning fossil fuels for energy?

____
____
____

3. Does carbon dioxide that is absorbed by the ocean contribute to a warming atmosphere? Why or why not?

____
____
____

4. What are you going to be figuring out in this series of activities?

____
____
____

Whaddya know?

5. Write your observations, inferences and questions you have about the object below.

Observations	Inferences	Questions

6. How does carbon dioxide affect temperatures on earth?

____
____
____
____

7. What is the **driving question** for this activity?

____
____
____
____

Constructing an Explanatory Model

8. Using your Explanatory Model graphic organizer, begin to construct a model to illustrate and explain how burning fossil fuels affects the amount of CO_2 in the environment.

Investigation 1: CO_2 and Ocean pH

9. What is the investigative question you are trying to answer?

____
____
____
____
____

10. What do you predict will happen to the pH of saltwater when CO_2 is added? Why do you think this?

____
____
____
____
____
____
____

11. With members of your group, design an investigation to answer the investigative question. You will have access to the following materials:

- Beakers (up to 2)
- Salt water
- pH strips (up to 4)
- Straw (up to 2)
- Tape (for labeling beakers)

a. Write the protocol for your investigation below. It should contain enough details so someone not in your group could conduct the investigation. It should also contain a place to record any data you plan to collect.

b. Share your investigation design with another group. Use the Peer Review rubric to provide feedback to the other group on their design.

c. Incorporate feedback from the Peer Review process into your investigation design. Record your changes below.

d. Conduct your investigation!

12. Use data from your investigation and what you know about pH to write a scientific explanation below to answer the question *What effect does increasing the amount of CO_2 in the ocean have on ocean pH?* Make sure to include evidence and reasoning to support your claims.

Claim (answers the question):	
Evidence (from your investigation):	Reasoning (scientific ideas that connect your evidence to your claim, explains why the evidence is important)

Constructing an Explanatory Model

13. Add information to your explanatory model to illustrate and explain how increasing atmospheric CO_2 affects ocean pH. Remember, you are constructing this explanatory model to address the driving question "*How might increasing levels of CO_2 affect oysters?*"

The Carbonate Model Challenge

14. What investigative question are you trying to answer in the *Carbonate Model Challenge*?

____

____

____

15. What does each object represent in the Carbonate Model?

Object in Carbonate Model Challenge	**What object represents in model**
Water-beads	
Black beads	
White beads	
Red beads	
Black bowl	
White bowl	
Black and White beads connected together	
Black and Red beads connected together	

16. Conduct the *Carbonate Model Challenge* using instructions on laminated sheets.

17. Fill in the information below using the class data set.

	Ocean	
	Black bowl	White bowl
Class average number of calcium carbonate molecules made in 90 seconds		

18. Examine the class data for patterns and trends. Make a graph if it helps you to visualize patterns. Write down any patterns and trends you detect below.

____

____

____

____

____

____

19. Watch the video "*Effect of Ocean Acidification on Shell-building Organisms*" and answer the following questions. Your teacher will provide a written transcription of the video for you to refer to when answering the questions.

a. What two chemical reactions take place when CO_2 is absorbed into the ocean?

____
____
____
____
____
____

b. What two types of ions do oysters need to form shells?

____
____
____
____
____
____

c. When CO_2 enters the ocean and undergoes chemical reactions, it produces lots of hydrogen ions. All these extra hydrogen ions make the ocean water more acidic (decreasing its pH). What happens to many of these extra hydrogen ions?

____
____
____
____
____
____

d. What happens to oysters if there are too many hydrogen ions in the ocean?

____
____
____
____
____
____
____
____
____

20. Read *“Ocean Acidification Causes, Chemistry and Impacts”* and answer the following reflection questions.

a. How does carbon dioxide affect the pH of the ocean?

____
____
____
____
____
____
____
____
____
____

b. How do oysters build their shells?

____
____
____
____
____
____

c. Why do oysters have trouble building their shells in oceans that are becoming more acidic?

____
____
____
____
____
____
____

d. What other issues, besides ocean acidification, are facing oysters in the Chesapeake Bay?

____
____
____
____
____
____

21. Make a claim, and support it with evidence and reasoning, for the question *"Which bowl represents a healthy ocean and which bowl represents a more acidic ocean?".*

Claim (answers the question):	
Evidence (from your investigation):	Reasoning (scientific ideas that connect your evidence to your claim, explains why the evidence is important)

Constructing an Explanatory Model

22. Go back to your Explanatory Model graphic organizer and add information you learned from the *Carbonate Model Challenge*, video and reading to illustrate and explain the how increasing the amount of CO_2 in the ocean affects an oyster larva's ability to build shell. Remember, you are constructing this explanatory model to address the driving question "*How might increasing levels of CO_2 affect oysters?*".

23. Participate in a Gallery Walk to give and receive feedback on your explanatory models.

24. Use feedback and comments you received on your explanatory model during the Gallery Walk to revise and improve your model.

25. What can be done to address the issue of increasing atmospheric CO_2?

____
____
____
____
____

Appendix C: High school student handouts

This page left intentionally blank. Resource begins on next page. Print a copy of this handout for each student.

Carbon Cycle

1. What does carbon dioxide (CO_2) in our atmosphere do for the earth?

____
____
____

2. What happened when people started burning fossil fuels for energy?

____
____
____

3. Does carbon dioxide that is absorbed by the ocean contribute to a warming atmosphere? Why or why not?

____
____
____

4. What are you going to be figuring out in this series of activities?

____
____
____

Whaddya Know?

5. Write your observations, inferences and questions you have about the object below.

Observations	Inferences	Questions

6. How does carbon dioxide affect temperatures on earth?

7. What is the driving question for this activity?

Constructing an Explanatory Model

8. Using your Explanatory Model graphic organizer, begin to construct a model to illustrate and explain how burning fossil fuels affects the amount of CO_2 in the environment.

Investigation1: CO_2 and Ocean pH

9. What is the investigative question you are trying to answer?

10. What do you predict will happen to the pH of the saltwater when CO_2 is added?

11. With your group, design an investigation to answer the question *What effect does increasing atmospheric CO_2 have on ocean pH?* You will have access to the following materials:

- Beakers
- Salt water
- (4) pH strips
- Straw
- Tape (for labeling)

a. Write the protocol for your investigation below. It should contain enough details so someone not in your group could conduct the investigation. It should also contain a place to write your data.

b. Share your investigation design with another group. Use the Peer Review rubric to provide feedback to the other group on their design.

c. Incorporate feedback from the Peer Review process into your investigation design. Record your changes below.

d. Conduct your investigation!

12. Watch the *Acids, Bases and Ocean Acidification* Video.

13. Use data from your investigation and any readings or videos you watched to write a scientific explanation below to answer the question *What effect does increasing atmospheric CO_2 have on ocean pH?* Make sure to include evidence and reasoning to support your claims.

Claim (answers the question):

Evidence (from your investigation):	Reasoning (scientific ideas that connect your evidence to your claim, explains why the evidence is important)

Constructing an Explanatory Model

14. Add information to your explanatory model to illustrate and explain how increasing atmospheric CO_2 affects ocean pH.

The Carbonate Model Challenge

15. What investigative question are you trying to answer in the *Carbonate Model Challenge*?

____
____
____

16. What does each object represent in the Carbonate Model?

Object in Carbonate Model Challenge	**What object represents in model**
Water-beads	
Black beads	
White beads	
Red beads	
Black bowl	
White bowl	
Black and White beads connected together	
Black and Red beads connected together	

17. Conduct the *Carbonate Model Challenge* using instructions on laminated sheets.

18. Fill in the information below using the class data set.

	Ocean	
	Black bowl	White bowl
Class average number of calcium carbonate molecules made in 90 seconds		

19. Examine the class data for patterns and trends. Make a graph if it helps you to visualize patterns. Write down any patterns and trends you detect below.

____
____
____
____
____
____
____

20. Watch the video "*Effect of Ocean Acidification on Shell-building Organisms*" and answer the following questions. Your teacher will provide a written transcription of the video for you to refer to when answering the questions.

a. What two chemical reactions take place when CO_2 is absorbed into the ocean?

____
____
____
____
____
____

b. What two types of ions do oysters need to form shells?

____
____
____
____

c. When CO_2 enters the ocean and undergoes chemical reactions, it produces lots of hydrogen ions. All these extra hydrogen ions make the ocean water more acidic (by decreasing the pH). What happens to many of these extra hydrogen ions?

____
____
____
____
____
____

d. What happens to oysters if there are too many hydrogen ions in the ocean?

____
____
____
____
____
____
____

21. Read *Ocean Acidification Causes, Chemistry and Impacts"* and answer the following reflection questions.

a. What is causing the increase in carbon dioxide in the air and the ocean since the start of the industrial revolution?

____
____
____

b. How would you respond if someone asked you if oceans were considered acidic or basic?

____
____
____
____
____
____

c. Why do oyster larvae have difficulty building shells in oceans that are more acidic?

____
____
____
____
____
____
____

d. In the example given in the reading, describe how each of the following could affect the pH of the Bay?

Scenario	Effect on the pH of the Bay
Algal bloom	
Algal blooms blocking SAV access to sunlight	
Massive algal bloom die-off	

22. Make a claim, and support it with evidence and reasoning, for the question *"Which bowl represents a healthy ocean and which bowl represents a more acidic ocean?".*

Claim (answers the question):	
Evidence (from your investigation):	Reasoning (scientific ideas that connect your evidence to your claim, explains why the evidence is important)

Constructing an Explanatory Model

23. Go back to your Explanatory Model graphic organizer and add information you learned from the Carbonate Model Challenge, videos and readings to explain the how increasing the amount of CO_2 in the ocean affects an oyster larva's ability to build shell. Remember, you are constructing this explanatory model to address the driving question "*How might increasing levels of CO_2 affect oysters?*".

24. Participate in a Gallery Walk to give and receive feedback on your explanatory models.

25. Use feedback and comments you received on your explanatory model during the Gallery Walk to revise and improve your model.

26. What can be done to address the issue of increasing atmospheric CO_2?

____
____
____
____
____
____
____
____

Appendix D: Explanatory Model graphic organizer template

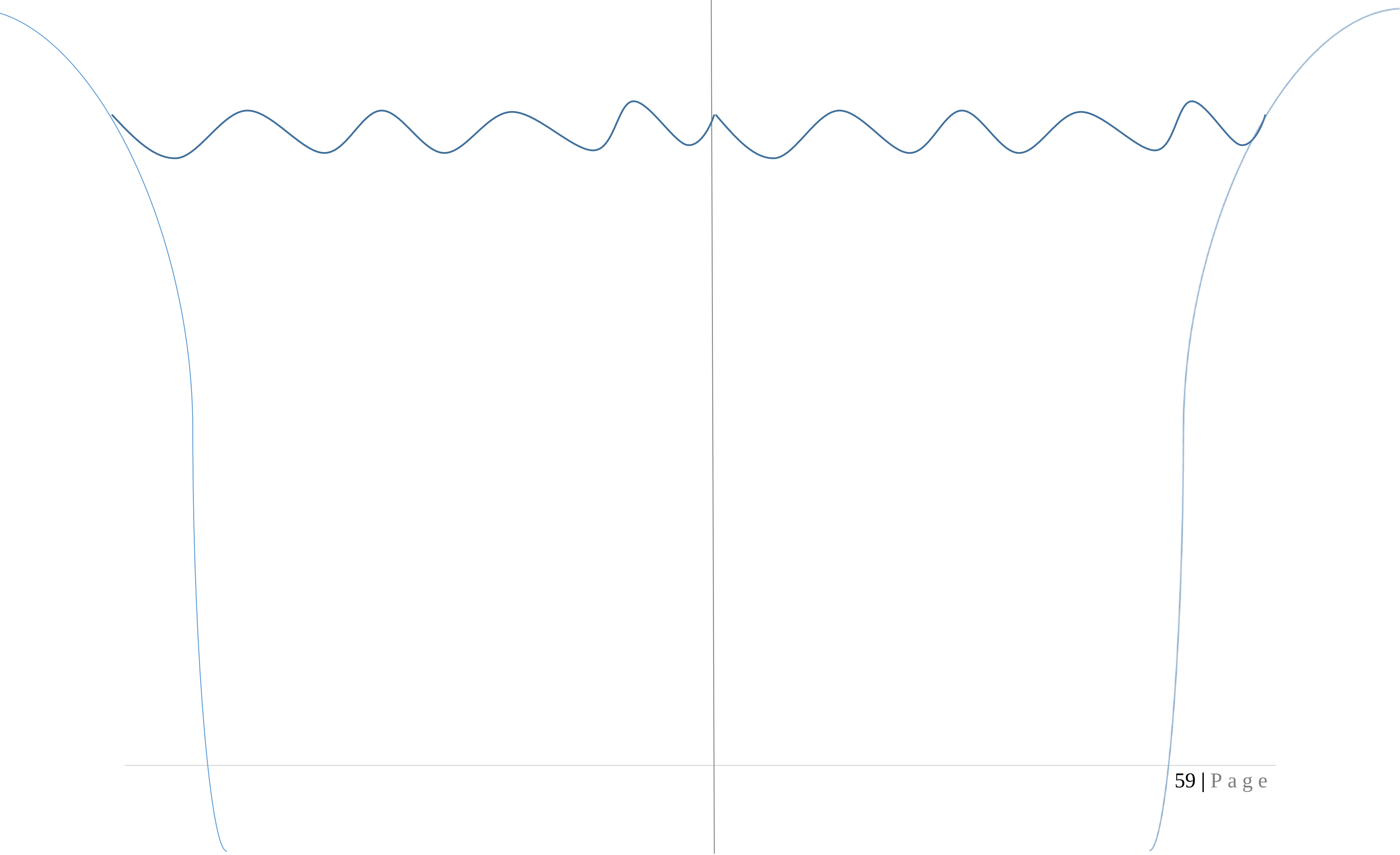
This page left intentionally blank. Resource begins on next page. Ideally, students would create their explanatory models on large poster papers. If you do not have large paper available, you can print a copy of this graphic organizer (11X14 or legal size works best). You need one graphic organizer for **each small group of** students. You may want to make extra copies for groups who may need a clean copy as they work to revise their explanatory model.

Explanatory Model

How might increasing levels of CO_2 affect oysters?

Atmosphere with Less CO_2

Atmosphere with More CO_2



Appendix E. *All About Oysters* reading (below grade-level)

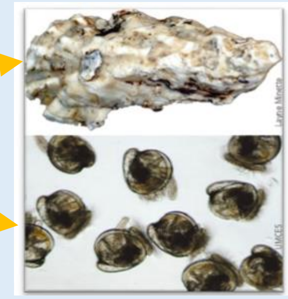
This page left intentionally blank. Resource begins on next page. (32) laminated copies of this reading are provided with the MDLL kit.

Oyster Larvae:

Unlike humans, baby oysters don't look anything like their parents. Scientists call a baby oyster a "larva" or "larvae" when talking about more than one. Oyster larvae are too small to be seen with the naked eye (scientists must use microscopes to see at them).

Adult

Oyster Larvae



Eastern Oyster
http://necan.org/sites/default/easter-oyster-aslt-and-larvae.png

Oyster Shells

Oyster larvae don't have shells right away! One of first things a larval oyster needs to do after it hatches is to begin to grow its shell. Oysters can't eat without their shell. To build their shells, oysters need:

- calcium ions (Ca^{+2})
- carbonate ions (CO_3^{-2})

Oysters combine these two materials together into a calcium carbonate molecule ($CaCO_3$) to make their shell. And building a shell takes a lot of energy! If oysters aren't able to get all the materials they need to build their shell quickly and easily, they will die and not grow to be a healthy adult oyster.

Oysters Clean the Chesapeake Bay

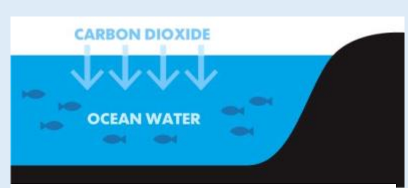
Oysters help keep the Chesapeake Bay water clean and healthy by filtering sediment (soil and other small particles) out of the water. Oysters also provide food and habitat for other organisms in the ecosystem.

Photo credit: Steve Vilnit

Tanks without (left) and with (right) oysters.

How does Carbon Dioxide affect oysters?

You learned that humans are putting more and more carbon dioxide into our atmosphere and some of that carbon dioxide is going into our oceans. Today, you are going to explore how and why this carbon dioxide is affecting oysters that live in the ocean.

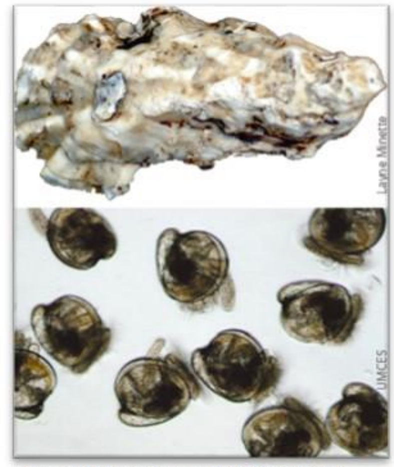


https://www.usatoday.com/story/weather/2016/02/24/co2-emissions-change-ocean-chemistry/80864904/

Appendix F. *All About Oysters* reading (Middle School)

This page left intentionally blank. Resource begins on next page. (32) laminated copies of this reading are provided with the MDLL kit.

All About Oysters!



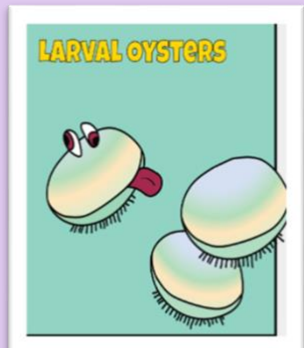
Eastern oyster adult (top) and larvae (bottom, magnified).
http://necan.org/sites/default/files/eastern-oyster-adult-and-larvae.png

Oyster Spawning

Unlike humans, baby oysters don't look anything like their parents.

Scientists call a baby oyster a "larva" or "larvae" when talking about more than one. When oysters reproduce, it is called spawning. After spawning, fertilized eggs begin cell division and become oyster larvae.

Oyster Larvae



http://www.squidtoons.com/about.html

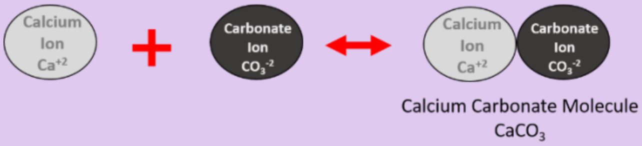
Oyster larvae are too small to be seen with the naked eye (scientists must use microscopes to see at them). At their biggest, oyster larvae are no bigger than the width of a human hair. And oyster larvae don't have shells right away! They start to develop their shells during the first 12-24 hours of their life. But it takes a long time to build a big, heavy shell like the ones you find on a beach.

About two weeks after a larva starts to grow it develops a tiny appendage (body-part) called a foot. It's not an actual foot like humans have, but this foot-like body part helps the tiny larvae crawl along the water bottom looking for a good, hard, place to attach itself. They often attach to the shells of adult oysters and become a part of big giant piles of oysters called oyster reefs.

An underwater oyster reef. Image used by permission from Maryland Department of Natural Resources.

Once an oyster larva attaches to something hard (after about two weeks of floating around in the water), we call it 'spat' or a juvenile oyster. And once spat attaches itself somewhere, it never moves again! Adult oysters spend their whole lives in the same exact place.

Oyster Shells



One of first things a larval oyster needs to do after it hatches is to begin to grow its shell since it can't eat until it has a shell. The shell also protects the oyster from predators. To build their shells, oysters need to absorb two types of materials from the water. They need to absorb calcium ions (Ca^{+2}) and they need to absorb carbonate ions (CO_3^{-2}). Oysters combine these two materials together into calcium carbonate ($CaCO_3$) to make their shell. And building a shell takes a lot of energy! If oysters aren't able to get all the materials they need to build their shell quickly and easily, they will die and not grow to be a healthy adult oyster.


Soft body of oysters found inside the shell.

The Inside of an Oyster

Most people only think of the hard, outer shell when they think of an oyster. But the actual oyster lives inside its shell. Oysters have very soft bodies. They don't have eyes, but they have a mouth. Oysters feed themselves by drawing water in over their gills and trapping plankton (microscopic organisms floating in the water). The gills move the trapped plankton to their mouth, to be eaten. Chesapeake Bay oysters can usually grow to be between 3-5 inches long within 2-3 years.


Photo credit: Steve Vilnit
Tanks without (left) and with (right) oysters.

Oysters Clean the Chesapeake Bay

The picture to the left shows a tank without oysters on the left and a tank with oysters on the right. Which one is cleaner? Oysters help keep the Chesapeake Bay water clean and healthy by filtering sediment (soil and other small particles) out of the water. Oysters also provide food and habitat for other organisms in the ecosystem.

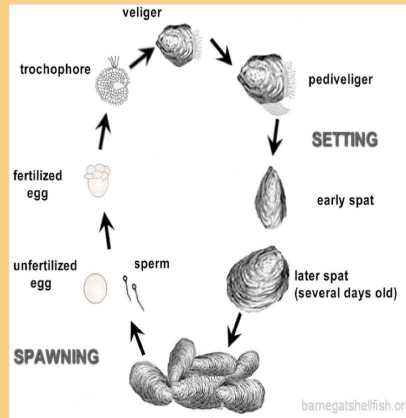
Oysters are being affected by increasing amounts of CO_2 that is being absorbed into the oceans. In this activity, you're going to explore how and why oysters are being affected.

Appendix G. *All About Oysters* Reading (High School)

This page left intentionally blank. Resource begins on next page. (32) laminated copies of this reading are provided with the MDLL kit.

All About Oysters

Figure 1. Oyster Life cycle



Richard K. Wallace. Auburn University School of Fisheries, Aquaculture & Aquatic Sciences

Oysters and many other marine invertebrate species have a very complicated life cycle when compared to humans (Figure 1). The developing oysters pass through various stages from the time the eggs are fertilized until the time there is anything that looks like an oyster someone might eat. Eastern oysters, those naturally found in the Chesapeake Bay, can live up to 20 years!

Oyster Spawning: Oysters being their life cycle through a process called spawning during which the oysters in an area all release their gametes (either eggs or sperm). Fertilization occurs in the water (the eggs float around and the sperm swim) and fertilization is random (an oyster does not choose its mate). An individual adult oyster can be male or female and their sex changes as they age. They start as male and become female when they get larger. For this system of fertilization to work, all the oysters in an area need to release their gametes at the same time. They coordinate by responding to environmental clues including increases in temperature, changes in salinity and a large quantity of high quality food. Once one oyster releases his sperm into the water it triggers the other oysters to release their eggs and sperm resulting in mass fertilization. The fertilized eggs start to develop and the developing oysters start their life floating around in the water as part of the plankton.

An underwater oyster reef. Image used by permission from Maryland Department of Natural Resources.

Planktonic Stages: While we usually think of oysters as living on the bottom of the Bay, they start life in the plankton floating around in the water moving from place to place along with the currents. About 12 hours after fertilization, the developing oyster enters a state known as a trochophore—this is a critical, non-feeding stage that lasts only an additional 12-24 hours. If all goes well (and it doesn't always), the trochophore will be able to gather the materials it needs from the water to develop a small shell and start to be able to feed. At this stage, it is called a veliger and it still very, very small and not visible to the eye without a microscope. After growing for another 2 weeks, the veliger develops a small appendage called a foot (although you would not recognize it as a foot) which helps it find a place to settle and grow. Once this 'pediveliger' settles onto a hard surface it is called spat and starts to look like a tiny oyster but it is only ¼ mm in size. Once it settles it does not move again.

Oyster Shells: The oyster shell that we find in nature started being developed by the larval oyster soon after fertilization. The shell performs many functions; it protects the oyster from predators and it enables the oyster to feed. To make it, oysters need to obtain two types materials from the water they are living in, calcium (Ca^{+2}) and carbonate (CO_3^{-2}). Building shell requires energy. If there is not enough of either of the building materials in the water the oysters either don't grow successfully, if this problem occurs once they have settled, or don't grow at all, if it occurs while they are larvae (remember they cannot eat without a shell).

Inside of an Oyster: Oyster are very soft and considered delicacies in many places including Maryland. Oysters pull water into and expel it from inside their shells through siphons. The water provides food particles that they oyster traps and eats. The water also provides oxygen to the oyster. Waste is also expelled into the water.

Tanks without (left) and with (right) oysters.

Oysters in the Chesapeake Bay: Oysters help keep the Chesapeake Bay water clean and healthy by filtering sediment (soil and other small particles) out of the water as it feeds. This picture shows a tank without oysters on the left and a tank with oysters on the right. In addition to filtering water, oysters form reefs (huge piles of oyster shells) that are an important part of the ecosystem in the Atlantic and Gulf coasts. Oyster reefs provide habitat for many other marine organisms, including tunicates, fish, crab, worms, mussels, bryozoans, and barnacles. Oysters are being affected by increasing amounts of CO_2 that is being absorbed into the oceans. In this activity, you're going to explore how and why oysters are being affected.

Appendix H. *Ocean Acidification* video by Alliance for Climate Education

Available on DVD and online https://www.youtube.com/watch?v=6SMWGV-DBnk

Please note if you are watching online, it's important to STOP the video at 1 min 13 seconds, otherwise you will be providing students with answers that should be working toward throughout the rest of the activity.

This page left intentionally blank. Resource begins on next page. (10) laminated copies of this reading are provided with the MDLL kit.

Ocean Acidification Video Transcript

By now you've heard that the way we're living is filling up our atmosphere with CO_2. As a result, the planet's warming. Heat waves and floods are more likely to be extreme and people's lives will get tougher. And the more we learn about climate change, the more risks we uncover. Since we started burning fossil fuels, the ocean has absorbed about half of all the co_2 we humans have put out. That's why it's called the planet's biggest carbon sink. Now this is good, because it's kept a lot of CO_2 out of the atmosphere. But as the ocean warms, it takes up less and less CO_2. And with all that CO_2 in the sea, scientists are shedding light on, well, an ocean of problems.

Ready for the first big problem? Some sea creatures like clams, oyster and coral, their shells and skeletons are getting weaker. Okay, you got bigger problems than easy to crack clams? Maybe not, if you're among the 1 in seven people who get most of their protein from seafood. Or if you understand how unstable the world would be with a billion more hungry people.

Accessed online https://youtu.be/6SMWGV-DBnk

Appendix I. Investigation Design Peer Review rubric

This page left intentionally blank. Resource begins on next page. (32) laminated copies of this rubric are supplied in the MDLL kit.

Investigation Design Peer Review Rubric

Scientists depend on peer review to help them design their investigations. The more input you get into the design of your investigation, the better it will be. Help your classmates create a better investigation by providing feedback using this rubric.

	0	1	2
MATERIALS	The plan does **not** include details on how to use the materials to specifically respond to the scientific question.	The plan contains only **partial** details on how to use the materials to specifically respond to the scientific question.	The plan contains **full** details on how to use the materials to specifically respond to the scientific question.
Feedback to my friends for improvement:			
PROCEDURES	There are **no** procedures in the plan or and/or the plan does not address the scientific question.	The plan includes **one or two** aspects of the procedures for the investigation such as: • number of trials • roles of investigators • steps of investigation • control for investigation And the procedures are written to specifically address the scientific question.	The plan includes **most** aspects of the procedures for the investigation such as: • number of trials • roles of investigators • steps of investigation • control for investigation And the procedures are written to specifically address the scientific question.
Feedback to my friends for improvement:			
DATA RECORDING	The plan does **not** include how the data will be recorded or the data will **not** respond to the scientific question.	The plan includes recording **incomplete** data by using a tool such as creating a data table which will **inadequately** address to the scientific question.	The plan includes recording **all** data by using a tool such as creating a data table that will address the scientific question
Feedback to my friends for improvement:			

Appendix J. Rubric for Scientific Explanation/Argument using C-E-R framework

This page left intentionally blank. Resource begins on next page. (32) laminated copies of this rubric are supplied in the MDLL kit.

Claim-Evidence-Reasoning Rubric

C-E-R Element	Zero (0)	Early (1pt)	Emerging (2pts)	Sophisticated (3pts)
1) Claim	Does not make a claim that responds to the question.	The claim responds to the question, but is an inaccurate claim.	Makes an accurate but incomplete claim in response to the question.	Makes an accurate and complete claim in response to the question.
2a) Evidence Use of data	No evidence is provided.	The evidence contains **some** of the appropriate data from an observation.	The evidence contains **most** of the appropriate data from an observation.	The evidence contains **all** the appropriate data from an observation.
2b) Evidence Interpretation of data	Does not interpret any evidence.	Interprets only some data accurately.	Interprets **most** of the data accurately.	Interprets **all** of the data accurately.
3a) Reasoning General Statement	Does not provide any reasoning.	Answers why or how the evidence supports claim with **no relevant** scientific principles (disciplinary core ideas).	Answers why or how the evidence supports claim with **insufficient use of relevant** scientific principles (disciplinary core ideas).	Answers why or how the evidence supports claim with **sufficient use of relevant** scientific principles (disciplinary core ideas).
3b) Reasoning Use of pieces of evidence	Uses no evidence or relevant big ideas accurately to explain the relationship between claim and evidence.	Uses **some** piece(s) of evidence and relevant disciplinary core ideas accurately to explain the relationship between claim and evidence.	Uses **most** pieces of evidence and relevant disciplinary core ideas accurately to explain the relationship between claim and evidence.	Uses **all** pieces of evidence and relevant disciplinary core ideas to accurately to explain the relationship between claim and evidence.
4a) Persuasion Complete sentences	**No** sentences are complete**.**	**Only few** sentences are complete.	**Most** sentences are complete.	**All** sentences are complete.
4b) Persuasion Grammatical Choices	**Most** of CER contains many grammatical errors.	CER contains **some** grammatical errors.	CER contains **few** grammatical errors.	CER contains **minimal** grammatical errors.

Rubric developed and adapted from material at http://slider.gatech.edu/student-edition.

Appendix K: *Acids, Bases and Ocean Acidification* video transcript

Link to Video https://youtu.be/QH0HAyxqdoY

This is an optional video you may choose to use with high school students. It is most appropriate for students who are taking, or have taken, a chemistry course.

This page left intentionally blank. Resource begins on next page. (10) laminated copies of this reading are provided with the MDLL kit.

Acids, Bases and Ocean Acidification **Video Transcript** (optional)

So, first we will explain the definitions of acids and bases. The definition of an acid is an ionic compound that breaks apart in water, creating a hydrogen ion. A base is also an ionic compound that breaks apart in water. But bases remove hydrogen ions, sometimes also creating a hydroxide ion.

When an acid and a base react, they form two things, a water and a salt. Remember that when we say salt in chemistry we're not talk in about table salt necessarily, we're talking about any ionic compound, which could include table salt. For example, let's combine hydrochloric acid, an acid obviously. And sodium hydroxide (NaOH), a base. We are adding the sodium hydroxide slowly into the acid and we've used indicator to determine when they neutralize. As a result, we got water and table salt, or sodium chloride. We then boiled off the water to see the salt.

When talking about chemical reactions, there is a really big topic that comes up: equilibrium. Equilibrium can be explained as when a forward reaction happens at the same rate as the reverse reaction, making the products and the reactants stop changing. All reactions eventually reach equilibrium, the only exception is if the system isn't closed. If the system is open, it's possible the reaction will never reach equilibrium, since compounds can leave the system and come into the system.

In 1884 La Chatelier's principal was proposed. La Chatelier's principle is what happens in a system when it is taken out of equilibrium. There are three ways to take a system out of equilibrium, changing the temperature, pressure or concentration of the compounds. When you take a system out of equilibrium, it tries to get back to equilibrium since that is the desired state.

Let's say you add more of the reactants. At first the equilibrium moves to the left. But what the system will do is it will start reacting with the reactants and creating products until it is balanced out again. If you increase the pressure, the system will react in a way that creates less molecules, and therefore lowering the pressure of the system. If you decrease the temperature, the system will heat itself up to regain equilibrium.

Huge unnatural amounts of carbon dioxide are emitted into the atmosphere by cars, factories and other man-made fuels burning sources. This fairly recent and sudden mass release of carbon into the atmosphere is negatively affecting sea life. The carbon dioxide finds it's way from the atmosphere into the ocean. When the carbon dioxide meets the water, it reacts and forms carbonic acid.

Each molecule of carbonic acid then releases two hydrogen ions, which increases the acidity of the water and in turn, dissolves the calcium carbonate of shells and exoskeletons of sea creatures. Zooplankton have very thin exoskeletons and the increased acidity of the ocean threatens to react with the calcium carbonate in their shells. Zooplankton are the base of the oceanic food chain, and without them the food chain would collapse, affecting the vast majority of marine species.

Link to Video https://youtu.be/QH0HAyxqdoY

Appendix L: *Carbonate Model Challenge* Instructions

This page left intentionally blank. Resource begins on next page. (10) laminated copies 1/group) are provided with the MDLL kit for students to use when completing the *Carbonate Model Challenge*.

Carbonate Model Challenge

How does increasing the amount of CO_2 in the ocean affect oyster larvae's ability to build shell?

In the *Carbonate Model Challenge* you are taking on the role of a baby oyster (an oyster larva). Your goal is to make as many calcium carbonate molecules as you can in 90 seconds. Remember, oyster larvae need to build their shells (using calcium carbonate molecules) before they can begin feeding. If they can't build their shells, they won't be able to eat and they won't survive. You will be using data from the *Carbonate Model Challenge* to make a claim about which color bowl represents a healthy ocean and which represents an acidified ocean.

1. Assign roles for the *Carbonate Model Challenge*.

Ocean	**Trial # 1**		**Trial # 2**		**Average**
	Name of student in assigned role	# Calcium carbonate molecules	Name of student in assigned role	# Calcium carbonate molecules	Avg # Calcium Carbonate Molecules
Black bowl					
White bowl					
Timekeeper					

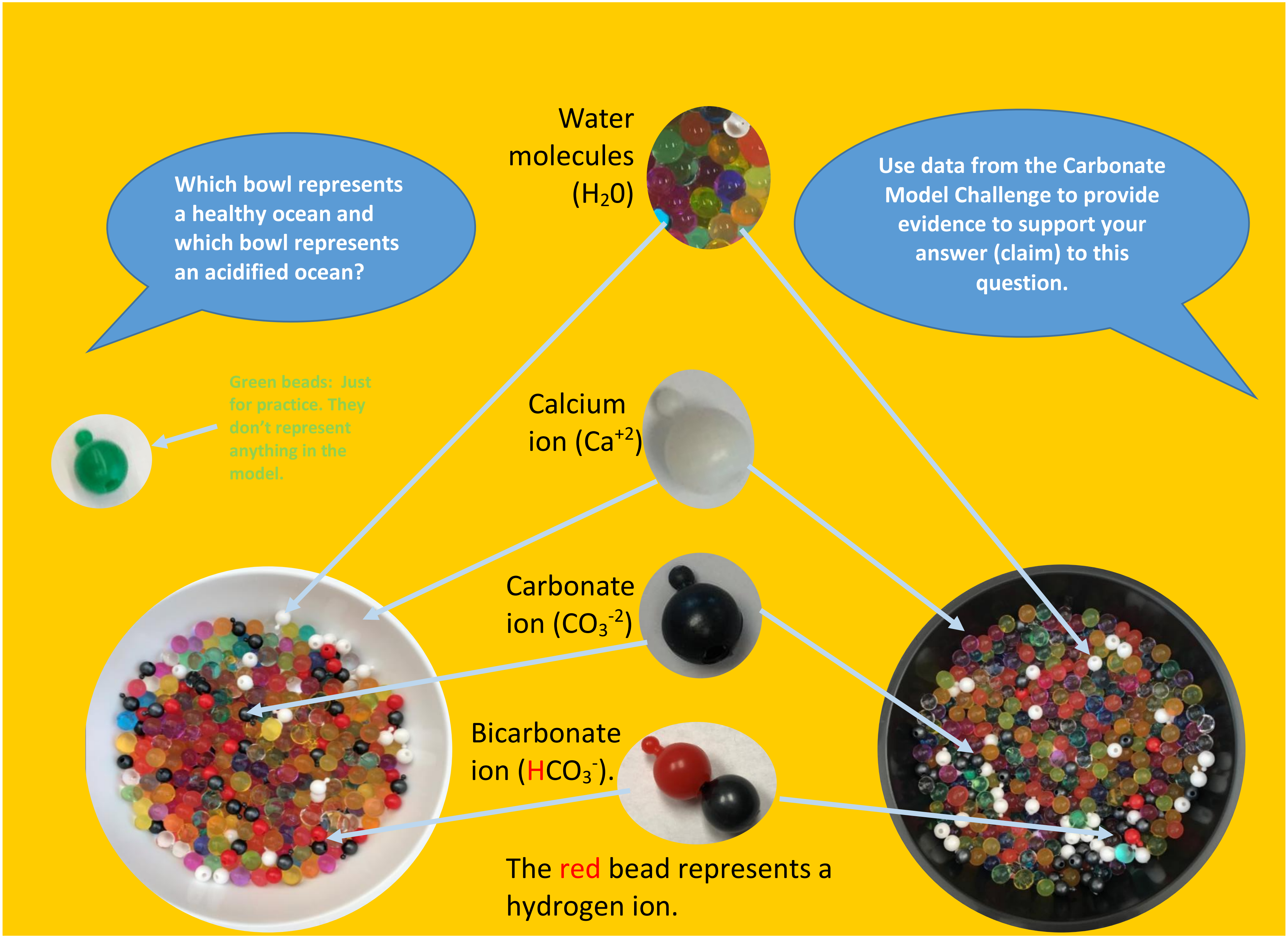
2. Have time keeper start the 90 second timer. Each 'Oyster Larva' needs to put together as many calcium carbonate molecules as they can in that time. Remember, you goals is to make as many calcium carbonate molecules as you can in 90 seconds. **And you cannot use the carbonates (black beads) that are already attached to a hydrogen ion (red bead).**

3. Each group should complete at least two trials. Switch roles so everyone has a chance to be an oyster. Record the total number of calcium carbonate molecules made in the table above.

4. When you're done, add your data to the class data set.

Rules and Tips:

- If you can't snap the black and white beads together easily, just drop them both into the collection beaker.
- You CANNOT use the carbonate (black beads) that are part of the bicarbonate molecules (red and black beads already attached). Do not take red and black beads apart!
- Remember to disassociate (take apart) the calcium carbonate molecules (black and white beads) and mix well in between trials.
- Be sure and return to each color bowl *only* those beads which originally came out of it.


Which bowl represents a healthy ocean and which bowl represents an acidified ocean?
Water molecules (H_20)
Use data from the Carbonate Model Challenge to provide evidence to support your answer (claim) to this question.
Green beads: Just for practice. They don't represent anything in the model.
Calcium ion (Ca^{+2})
Carbonate ion (CO_3^{-2})
Bicarbonate ion (HCO_3^{-}).
The red bead represents a hydrogen ion.

Appendix M: *Effects of Ocean Acidification on Shell-building Organisms* video transcript

Video Link: https://youtu.be/kxPwbhFeZSw

This page left intentionally blank. Resource begins on next page. (10) laminated copies of this reading are provided with the MDLL kit.

Effects of Ocean Acidification on Shell-building Organisms Video Transcript

Ocean acidification is caused by carbon dioxide emissions. It threatens the health of our oceans and the animals in it. Let's start by looking at the formation of shells in animals. The shells of animals, like crabs, are formed primarily of calcium carbonate. Calcium carbonate is formed when calcium ions bind with carbonate molecules.

Ocean acidification begins with CO_2 emissions. Most CO_2 is produced when fossil fuels are burned for industrial and automotive purposes. Once in the air, CO_2 is absorbed into the ocean through wave action.

Once absorbed into the ocean, CO_2 combines with water to form carbonic acid. Carbonic acid breaks down easily into bicarbonate molecules and hydrogen ions. Calcium and bicarbonate cannot bind together to form shells. Carbonate, that usually forms shells, binds more easily with the hydrogen ions. This makes them unable to form shells.

Let's review. In a normal ocean, calcium carbonate is taken from the water and combined with calcium to form the shells of many animals. In an acidic ocean, abundant hydrogen ions bind with carbonate and prevent shell formation. Animals, like these crabs and those that depend on them for food may eventually disappear if they cannot easily form their shells.

Video Link: https://youtu.be/kxPwbhFeZSw

Appendix N. *Ocean Acidification Causes, Chemistry and Impacts* reading (Middle School)

This page left intentionally blank. Resource begins on next page. (32) laminated copies of this are provided in the MDLL kit.

Ocean Acidification Causes, Chemistry and Impacts Reading

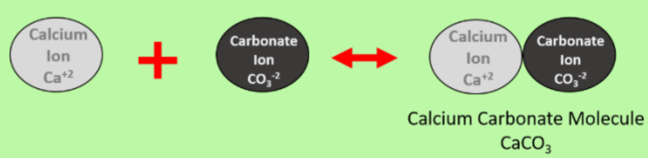
Increasing levels of carbon dioxide

The industrial era began about 250 years ago when machines were invented that could use **fossil fuels** such as oil and coal. Burning fossil fuels releases **carbon dioxide** (CO_2) as a gas. The carbon dioxide released goes either into the oceans (30%) where it chemically interacts with water molecules or the atmosphere (70% of it). The burning of fossil fuels by humans has resulted in more carbon dioxide in the atmosphere now than at any time in the past 15 million years and it is having an impact on our climate and natural systems. Only recently have scientists realized the critical effects that the 30% of the carbon dioxide that dissolves in seawater is having on marine systems. The 70% of the fossil fuel released carbon dioxide that goes into the atmosphere has been studied for much longer and is known to impact global climate by raising global temperature.

Impact of Carbon Dioxide in the Ocean: Ocean Acidification

The ability of the ocean to absorb carbon dioxide takes some of the carbon dioxide out of the atmosphere—if it didn't go into the ocean there would be even more in the atmosphere leading to even more global warming. But the carbon dioxide that is being absorbed into the ocean is affecting organism that live in the water by causing **ocean acidification**. Ocean acidification occurs when dissolved carbon dioxide reacts with the water in the ocean. This reaction produces a lot of **hydrogen ions** (H^+). These extra hydrogen ions decrease the **pH** of the ocean which affects the organisms that live in the oceans in a variety of ways.

How does ocean acidification affect oysters?



Oyster shells are made of calcium carbonate ($CaCO_3$). **Carbonate** (CO_3^{-2}) is a type of ion that is important to all organisms that live in the oceans, especially those that have shells. Baby oysters, called oyster **larvae,** combine **calcium** (Ca^+) and carbonate (CO_3^{-2}) to form calcium carbonate ($CaCO_3$) to make their shells. The oyster larvae need a shell to be able to eat. Acidified oceans are oceans that have absorbed a lot of carbon dioxide and have lots of hydrogen ions in them which makes harder for oyster larvae to get the carbonate they need to make their shells. This is because the extra hydrogen ions produced when carbon dioxide reacts with water bind to the carbonate ions that are in the water, forming a molecule called bicarbonate (HCO_3^-). When this happens, there are not enough carbonate left for the larvae to use to make their shells since the carbonate is already bound to hydrogen. If oyster larvae cannot build their shells, they won't be able to feed themselves and they will die. In some situations, the extra hydrogen ions can attack the calcium carbonate in existing shells of marine organisms, both living and dead, making them start to breakdown.

What about oysters in the Chesapeake Bay?

Up until now, we've been focusing on acidification of ocean waters. However, acidification is also a problem in the Chesapeake Bay, one of the world's largest estuarine systems an home to the Eastern oyster (*Crassostrea virginica*). An estuary is an area where fresh water from streams mix with salty water from the ocean and the *chemistry* of acidification is the same in Chesapeake Bay as in the open oceans. As we've been discussing, one of the main sources of increased CO_2 in open oceans is from atmospheric carbon dioxide entering the ocean. However, in the Chesapeake Bay, a second important source of CO_2 is from the decay processes that result from surges of nutrients from the land into the Bay. When excess nutrients, like fertilizer, animal waste and sewage enter the bay, it leads to some organisms growing and others dying, processes that affect levels of CO_2 and therefore water pH levels. Oysters in the Chesapeake Bay are being affected by acidification but there are also other issues that are affecting them. These issues include over-harvesting, disease and loss of good habitat. Oysters play a critical role in Bay's ecosystem. They filter water and provide food and habitat for other organisms. In addition, they are an important to Maryland's economy. As we work to restore oyster populations, it is important to consider all the factors that affect their survival, including the effects of acidification.

Appendix O: *Ocean Acidification Causes, Chemistry and Impacts* Reading (alternative version for lower level readers)

This page left intentionally blank. Resource begins on next page. (32) laminated copies of this are provided in the MDLL kit.

Acidification Causes, Chemistry and Impacts Reading

Too much carbon dioxide!

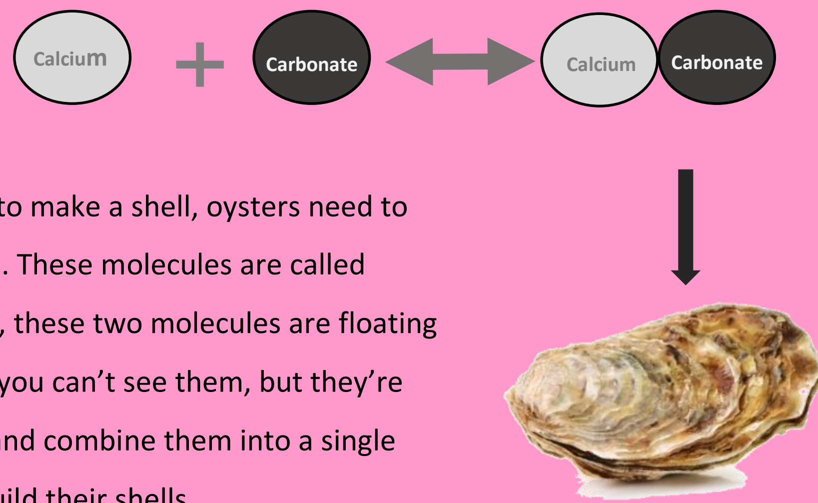
About 250 years, people began burning a lot more oil, gas and coal to provide energy for factories and cars. When oil and coal are burned, they release a gas into the air. This gas is called carbon dioxide. We sometimes use "CO_2" to represent the words 'carbon dioxide'. You can't see or smell carbon dioxide, but it is an important part of our atmosphere (the air around us). Carbon dioxide helps to keep the earth warm enough so we can live here. But, too much carbon dioxide is making the Earth become too warm.

The extra carbon dioxide we are producing goes both into the air and into the oceans. It's ok for some carbon dioxide to go into the oceans, but too much carbon dioxide in the oceans is a problem. This is because when the carbon dioxide gas gets into the water, the carbon dioxide reacts with the water and becomes a new chemical. This change is called a chemical reaction. The chemical reactions that happen when carbon dioxide reacts with water causes 'ocean acidification'.

What is ocean acidification?

You've probably heard the word 'acid' before. It might make you think of something that is very dangerous. And acids can be dangerous. But they're also useful. For example, you have acids in your stomach that help you to digest the food you eat. What we mean by 'ocean acidification' is that oceans are becoming more acidic than they normally are. This is because of the extra carbon dioxide being absorbed into the water and reacting with it. This doesn't mean that oceans are so acidic that it is dangerous for people to touch the water. But, this tiny change in how acidic the ocean is can be dangerous for the animals and plants that live in the ocean. Especially animals that need to make shells, like oysters.

How do oysters build their shells?



Shells, including snail shells, crab shells and oyster shells are made by the animals that live inside of them! And to make a shell, oysters need to have two types of chemicals, or molecules. These molecules are called calcium and carbonate. In healthy oceans, these two molecules are floating around in the ocean. They're so tiny that you can't see them, but they're there! Oysters find these two molecules and combine them into a single molecule we call 'calcium carbonate' to build their shells.

How does ocean acidification affect the ability of oysters to build their shells?

Because baby oysters aren't born with any shells, the very first thing they need to do is build their shells by finding, and combining, calcium and carbonate chemicals. But, the process of ocean acidification, what happens when CO_2 reacts with water, makes it very hard for baby oysters to find enough of one of these chemicals, the carbonate chemical, to make their shells. Since there's not enough carbonate for the baby oysters, they can't build their shells. If they can't build their shells, they can't feed themselves and they die.

What can be done about ocean acidification?

Scientists are learning more and more about how too much carbon dioxide is affecting oysters, and other plants and animals that live in the ocean. Understanding what is happening in our environment is the first step to figuring out how everybody, including you, can help solve the problem. One thing scientists have figured out is that if we burned less oil and gas and coal, there would be less carbon dioxide in the air. And less carbon dioxide in the air would mean less carbon dioxide going into our oceans. This would help the oysters and all the other organisms that live in the ocean.

Appendix P. Glossary for *Ocean Acidification Causes, Chemistry and Impacts* reading for middle and high school

This page left intentionally blank. Resource begins on next page. (32) laminated copies of this glossary are supplied in the MDLL kit.

Glossary

acid – chemical substances that can neutralize bases, can dissolve some metals, have a pH below 7. They release hydrogen (H^+) ions in aquatic solutions

acidic – characterized by having more acid-like characteristics, having the properties of an acid, something becoming acidic is gaining more acid-like characteristics.

algal blooms – a rapid increase in the density of algae in bodies of water, blooms can be so dense they can be seen from space and block sunlight. Often indicators of an influx of nutrients into the water

base – chemical substance that can neutralize an acid and can be slippery to the touch, has a pH above 7. Bases release OH^- (hydroxyl) ions in aquatic solutions. Also referred to as alkaline.

bicarbonate (HCO_3^-) – An ion formed when carbon dioxide dissolves in water, bicarbonate is a breakdown product of carbonic acid (H_2CO_3). Bicarbonate is often found in natural buffering systems, i.e., systems that maintain a constant pH such as blood. Commonly used kitchen material, baking soda is sodium bicarbonate.

calcium (Ca^{+2}) – A chemical element that provides structural integrity to bones and shells when combined with other materials. Limestone rock contains lots of calcium as do bones and teeth.

calcifiers – Organisms that create calcium-based shells from dissolved and carbonate in the water.

carbon dioxide (CO_2) – a colorless gas that is a naturally occurring atmospheric gas. The concentration of carbon dioxide in the atmosphere has been rising. It is released when carbon based materials are oxidized, i.e., burned. The burning of fossil fuels is responsible for the increase in atmospheric carbon dioxide. It is also released during human respiration.

carbonate (CO_3^{-2}) – a chemical compound derived from carbonic acid or carbon dioxide. Marine organisms such as oysters and clams combine it with calcium to form shell. It is an important constituent of limestone.

carbonate chemistry – the chemical reactions that occur as carbon dioxide dissolves in water and reacts with it chemically. It consists of a series of reactions that will reach an equilibrium, a stopping point, depending on the concentration of carbon dioxide. As the amount of carbon dioxide increases, the reactions result in the release of H^+ making the water more acidic. At lower concentrations of carbon dioxide, the reactions result in lower levels of dissolved H^+ leading to less acidic conditions.

carbonic acid (H_2CO_3) – an acid formed when carbon dioxide dissolves in water. It is part of carbonate chemistry. When formed it readily dissociates into a bicarbonate ion and a hydrogen ion.

dead zones – areas of water lacking oxygen in which nothing can live and animals entering the zone suffocate. These can occur after an algal bloom because after the algae use up all the nutrients in the water they die, and the bacteria that then consume the algae use up all the oxygen in the water, leaving none for any organisms.

equilibrium – a point when opposing forces are balanced. When neither side is moving; in a tug-of-war when both sides are pulling and neither side is winning, the system is in equilibrium.

estuary – a special habitat found where fresh water flows into salt water. These areas are very rich ecologically and are home to many species. They are very nutrient rich and productive areas. The Chesapeake Bay is an estuary.

fossil fuels – types of fuels, sources of energy, derived from long dead plants and animals which were compressed and transformed over millions of years into fuels. Coal, oil, natural gas and their products, i.e., propane and gasoline, etc., are all forms of fossil fuels.

hydrogen ions – ionized hydrogen of the form H^+, found in aqueous solutions of all acids. Water (H_2O) is composed of a hydrogen ion (H^+) and a hydroxyl ion (OH^-).

larvae – an immature form of some organisms, especially organisms in which the immature forms appear very different looking than the adult forms. Baby butterflies or caterpillars, are called larvae as are baby oysters. The singular form of larvae is larva.

nitrogen – one of the chemical elements that is found in all living things. It is a major constituent of proteins and amino acids and a critical nutrient for plant growth. Farmers usually apply some source of nitrogen to their fields before planting. Common sources include manure, compost, or commercial chemical fertilizers.

ocean acidification – any drop in the ocean's pH indicates that the waters are becoming more acidic. The process is called ocean acidification. Since organisms are adapted to live at a fairly narrow pH range such changes can have major impacts on marine life.

pH – a measurement of acidity and alkalinity that runs from 0-14. Acidic materials have a pH below 7 and alkaline or basic materials have a pH above 7, 7 itself is neutral. Soap is alkaline, lemons are acidic and pure water is neutral.

pH scale – a scale that goes from 0 -14 that reflects the number of hydrogen ions in a solution. Very low numbers indicated a large number on hydrogen ions and an acidic solution whereas a high number reflects a very low number of hydrogen ions and a more basic solution. Lemon juice is very acidic and has a pH of 2 whereas oven cleaner has a pH of 13 and is very basic.

phosphorus – along this nitrogen, this is a critical element for growing plants and living organisms. It plays a critical role in energy transformation and heredity. Farmers also apply it to their fields but at lower amounts than nitrogen.

runoff – the movement of materials carried in water and the water itself from land to water. Pollution, nutrients, sediments can all be carried in rainwater into larger water systems such as bays, streams, oceans, etc. If farmers apply more fertilizer to a field than their crops can absorb or if fields are very rich in nutrients, rainwater flowing over those fields can wash the nutrients off the fields and into waterways. The flow of nutrients into the water is called nutrient runoff.

sedimentation – soils consist of particles of material that are called sediments. When these are picked up in rainwater and carried into streams or other water bodies they fall out of the moving rain water or settle when its speed changes (when it hits the new, larger, waterbody). The pieces of sediment are then deposited over the bottom of the receiving water and the process through which this happens is called sedimentation.

submerged aquatic vegetation – plants that grow under water are called SAV or submerged aquatic vegetation. They play an important role in the water systems that have them. They are sources of food for organisms as well as habitats for organisms to living within. They are very important to the ecology of the Chesapeake Bay and damaged or destroyed by storms and high levels of sedimentation.

Appendix Q. *What is Ocean Acidification?* summary PBS video transcript

Video Link: https://mpt.pbslearningmedia.org/resource/nvls-sci-acidification/what-is-ocean-acidification/#.WepH_CiGO71

This page left intentionally blank. Resource begins on next page. (10) laminated copies of this reading are provided with the MDLL kit.

What is Ocean Acidification? Video Transcript

Samples taken around the globe over the last 40 years reveal that ocean acidity is increasing by about 5% every decade. Why is this happening? It turns out the driving force of ocean acidity is the same thing that is responsible for global warming. When we burn fossil fuels they release carbon dioxide gas, or CO_2 into the atmosphere. Much of that CO_2 blankets the planet and raises the global temperature. But about a quarter of that gas is absorbed into the oceans.

At first scientists thought this was beneficial, since the more CO_2that goes into the ocean means less in our atmosphere, reducing the warming effect. Oceanographers knew for years that carbon dioxide from the atmosphere was being absorbed into the oceans. And everyone thought, *"Oh perfect, this a service that the ocean is performing for us. Storing the gas that we're releasing. It's a pollutant. It's a product of our activities."* so everybody thought this is awesome. But scientists soon realized that this service comes at a cost. The extra carbon dioxide absorbed by the ocean is dramatically changing the water's chemistry.

We're dissolving 30 million metric tons of carbon dioxide into the surface of the ocean each and every day, and that is what's driving down the pH or increasing the acidity.

This is how it works. When carbon dioxide dissolves into the ocean, it reacts with water, H_2O, to form a weak acid called carbonic acid.

This almost immediately breaks apart, releasing hydrogen ions. Those are hydrogen atoms stripped of their electrons. This is what increases the water's acidity and it can have a devastating effect on marine life, like oysters.

Healthy baby oysters are busy building their shells. They pull the ingredients they need from the surrounding water, including calcium and a substance called carbonate, combining them into a tough matrix, calcium carbonate. But when too much carbon dioxide gets into the mix, the resulting acid can radically alter one crucial ingredient, carbonate.

There's plenty of calcium in the ocean. The carbonate is kind of what we call the "limiting ingredient". There's not a lot of carbonate. When acidity rises and there are lots more hydrogen ions floating around, they react with carbonate, taking away this essential molecule. Instead of carbonate being all over the place, they're few and far between.

So what happens is, physiologically, it's much more difficult to make shell. Without enough carbonate in the water, the baby oysters simply can't build their shells and as a result they die.

It's not just oysters that need carbonate to survive. The changing chemistry of the ocean threatens all kinds of shelled creatures. Scientists now face an urgent challenge. To understand what this will mean for life in the sea. Along with the oysters, how many other species will struggle to survive?

Video Link: https://mpt.pbslearningmedia.org/resource/nvls-sci-acidification/what-is-ocean-acidification/#.WepH_CiGO71

Appendix R: *Ocean Acidification Causes, Chemistry and Impacts* Reading (High School)

This page left intentionally blank. Resource begins on next page. (32) laminated copies of this reading are supplied with the MDLL kit.

Ocean Acidification Causes, Chemistry and Impacts **Reading**

Increasing levels of carbon dioxide

The industrial era began about 250 years ago when machines were invented that could use **fossil fuels** such as oil and coal. The use of these new technologies led to increased extraction and use of fossil fuels. Burning fossil fuels releases **carbon dioxide** (CO_2) as a gas. The carbon dioxide released goes either into the oceans (30%) where it chemically interacts with water molecules or the atmosphere (70% of it). The burning of fossil fuels by humans has resulted in more carbon dioxide in the atmosphere now than at any time in the past 15 million years and it is having an impact on our climate and natural systems. Only recently have scientists realized the critical effects that the 30% of the carbon dioxide that dissolves in seawater is having on marine systems. In contrast, scientists have studied the impacts on global climate of the 70% of carbon dioxide that goes into the atmosphere for much longer.

Impact of Carbon Dioxide in the Ocean: Ocean Acidification

Scientists are finding that all that carbon dioxide that is being absorbed into the ocean is having an important effect on the organisms that live in the oceans. In the last 200 years, oceans have become 30% more acidic because of the chemical reactions that occur when carbon dioxide dissolves in ocean water**.** This reaction (described in Figures 1 and 2) produces a lot of hydrogen ions (H^+). These extra hydrogen ions (H^+) decrease the **pH** of the ocean which affects the organisms that live in the oceans in a variety of ways. The result of these reactions which lower the ocean's pH is called ***ocean acidification.*** Ocean acidification refers to the *process* by which oceans are becoming increasingly acidic. It is important to understand that while oceans are becoming more acidic, ocean waters aren't actually an **acid**. To understand why they're not an acid, we need to explore how acidity and pH are related.

Acidity and pH

Acidification, pH and the availability of hydrogen ions **(H^+)** are all interconnected. Something is becoming acidic when it is gaining more hydrogen ions than it previously had. Remember, that pH is a measure of hydrogen ion concentration. So, if ocean water is experiencing an increased concentration of hydrogen ions, the pH of the ocean is decreasing. The lower the pH, the more acidic the solution.

The pH scale was invented in 1909 by a Danish biochemist and it reflects the acidity, neutrality or alkalinity (another term for basic) measured in terms of the hydrogen ion concentration. A pH value is a number from 1 to 14, with 7 as the middle (neutral) point. A pH of 7 is neutral, neither acidic nor alkaline (basic). Values below 7 indicate acidity which increases as the number decreases, and 0 is the most acidic. Values above 7 indicate alkalinity which increases as the number increases, and 14 is the most alkaline (basic). The pH scale, however, is not a linear scale like a centimeter or inch scale; it is a logarithmic scale in which two adjacent values differ by a factor of 10. For example, a pH of 3 is ten times more acidic than a pH of 4, and 100 times more acidic than a pH of 5. Because the pH scale is not a linear scale, small differences mean a lot!

So far, the pH of the ocean has dropped from 8.2 to 8.1 which doesn't sound like a lot, but remember, this is a logarithmic scale, not a linear scale, so this small increase means a lot more hydrogen ions. A drop from 8.2 to 8.1 represents a 30% increase in hydrogen ion concentration. According to the Smithsonian Institute in Washington D.C., if we continue to add carbon dioxide at current rates, ocean water pH may drop another 120% by the end of this century, to 7.8 or 7.7, creating an ocean more acidic than any seen for the past 20 million years or more.

The Impact of Ocean Acidification on Marine Organisms

Many of the impacts, especially those on corals and shelled organisms such as oysters, clams and crabs occur because the carbon dioxide in the ocean is having an important impact on the ocean's **carbonate chemistry**. The carbonate chemistry of the ocean is important to all marine organisms since it is responsible for regulating the ocean's pH, but it is especially important for organisms, such as shellfish and corals, that build their shells or skeletons with carbonate.

The Carbonate Chemistry of Ocean Acidification

When water (H_2O) and carbon dioxide (CO_2) mix, they combine to form **carbonic acid** (H_2CO_3) (see Eq 1). When carbonic acid is formed, it almost immediately breaks down to bicarbonate (HCO_3^-) and a hydrogen ions (H^+) (see Eq 2). One of the molecules that the released hydrogen ions (H^+) bind to in the ocean is the **carbonate** molecule (CO_3^{-2}) (see Eq 3). Carbonate is a relatively common ion present in all

Eq 1: $CO_2 + H_2O \leftrightarrow H_2CO_3$

Eq 2: $H_2CO_3 \leftrightarrow HCO_3^- + H^+$

Eq 3: $CO_3^{-2} + H^+ \leftrightarrow HCO_3^-$

Figure 1. Carbonate chemistry equations.

ocean water and is used by marine **calcifiers** for shell formation. Once carbonate binds to hydrogen, we call it **bicarbonate** (HCO_3^-) and it is no longer readily available for shell building organisms to absorb from the water and use to synthesize shell.

Why Ocean Acidity Matters to Oysters

Oysters need to combine **calcium** (Ca^+) and carbonate (CO_3^{-2}) into calcium carbonate ($CaCO_3$) to make their shells. In acidified oceans that have absorbed a lot of carbon dioxide, it can be harder for day-old oyster **larvae** to get the carbonate they need to make shell. Much of the hydrogen (H^+), released as carbonic acid (H_2CO_3) dissociates, binds to the carbonate in the water. Both calcium and hydrogen can bond with carbonate, but the hydrogen has a greater attraction to carbonate than calcium. If there are not enough carbonate ions available for oyster larvae to use to build their shells, they won't be able to feed and they will die (remember, baby oysters need to create a shell to feed after they hatch). When there are too many hydrogen ions around and not enough carbonate molecules for them to bond with, the hydrogen ions can even begin breaking down existing calcium carbonate molecules apart, dissolving shells that already exist.

A summary of the ocean acidification process and its impact on the availability of carbonate and abundance of hydrogen ions is presented in Figure 2 to the right. The chemical reactions outlined are in **equilibrium** but *where* in the gradient from more to less acidic they are at any one point depends on the carbon dioxide concentration in the atmosphere.

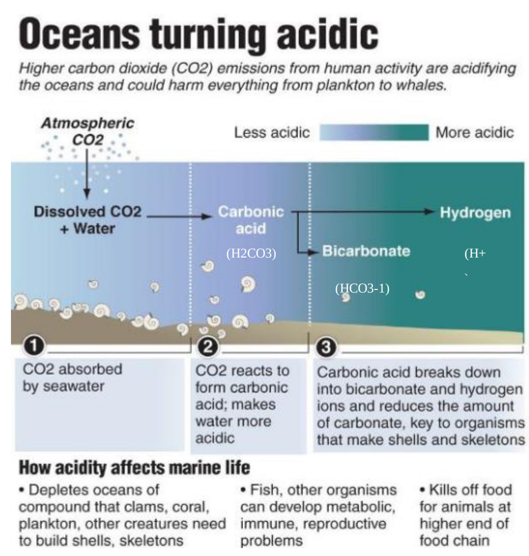


Figure 2. Ocean Acidification.
Image used by permission from Maryland Department of Natural Resources.

Acidification in the Chesapeake Bay

Up until now, we've been focusing on acidification of ocean waters. However, acidification is also a problem in the Chesapeake Bay, one of the world's largest estuarine systems and home to the Eastern oyster (*Crassostrea virginica*). An estuary is an area where fresh water from streams mixes with salty water from the ocean and the *chemistry* of acidification is the same in the Chesapeake Bay as in the open oceans. As we've been discussing, the main sources of increased CO_2 in open oceans is from atmospheric carbon dioxide entering the ocean. However, in the Chesapeake Bay, there is a second important source of CO_2. CO_2 in the Bay also comes from the decay processes that result from surges of nutrients from the land into the Bay. When excess nutrients, like fertilizer, animal waste and sewage enter the bay, it leads to some organisms growing and others dying. These processes affect levels of CO_2 and therefore water pH levels. In addition, the Bay's unique and complex ecosystem is affected by many other factors that impact how it responds to increasing levels of carbon dioxide, regardless of the source. These factors include the geography of the Bay, **sedimentation** and **submerged aquatic vegetation** (SAV). These other issues can increase or decrease the pH and, in some cases, can do both!

Ocean Acidification in the Chesapeake Bay: It's Complicated

Oysters in the Chesapeake Bay are being affected by acidification but there are also other issues that are affecting them. The impact of sedimentation, nutrient runoff, SAV and the geography of the Bay are complex and complicated. Read the example below and consider how each impact might affect the pH of the Bay.

The runoff from farms surrounding the Bay and homes with fertilized lawns, and leaky sewer systems are responsible for increased levels of nutrients in the Bay, mostly **Nitrogen** (N) and **Phosphorous** (P). These two chemical nutrients are normally limiting factors for the growth of algae in the Bay. Excess nutrients from run-off can lead to huge **algal blooms** in the Bay. As algae grow, they consume carbon dioxide in the water in the presence of sunlight. **How would algal blooms *initially* affect pH of the Bay?**

If the algal blooms become dense enough to block sunlight from reaching submerged aquatic vegetation (SAV), they can keep sunlight from reaching the SAV for photosynthesis. **How would this affect pH of the Bay?**

Massive algal blooms are short lived since eventually the algae use up all the available nutrients—this leads to a massive die-off of algae. As the algae die and sink to the bottom of the Bay, they are decomposed by bacteria. The bacteria take up the oxygen in the water (through the process of respiration) as they decompose the algae leading to **dead zones**, but the bacterial respiration also releases carbon dioxide. **How would the decomposition of algae by bacteria affect the pH of the Bay?**

Appendix S. Optional shell-matching activity answer sheet

A fun activity for students is to try to find the matching half to their oyster shells after they have completed the "Whaddya know" activity where they examine and ask questions about oyster shells. Each class set of oysters we send out consists of 16 complete oyster shells. Each oyster shell, or bivalve, has two halves, or two valves. Each valve is either a 'right valve' or a 'left valve'.

In this activity, have students move around the classroom and try to find their matching shell. It can take a while, but eventually most students are able to find the shell that fits with their own.

Below is a list of codes that you can use to assist students if they are struggling or if you are not sure which shells are pairs. But, remember, try and let the students find their matching shells through trial and error.

Matching Shells
OA1, OA75.1
OA2, OA76
OA3, OA77
OA4, OA78
OA5, OA79
OA6, OA80
OA7, OA41
OA8, OA42
OA9, OA43
OA10 ,OA44
OA75,OA76
OA77,OA100
OA78,OA101
OA79,OA102
OA80, OA103
OA81, OA104

Matching Shells
OA11, OA45
OA12, OA46
OA13, OA47
OA14, OA48
OA15, OA49
OA16, OA50
OA17, OA51
OA18, OA52
OA19, OA53
OA20, OA54
OA82,OA105
OA83,OA106
OA84,OA107
OA85,OA108
OA86,OA109
OA87,OA110

Matching Shells
OA21, OA55
OA22, OA56
OA23, OA57
OA24, OA58
OA25, OA59
OA26, OA60
OA27, OA61
OA28, OA62
OA29, OA63
OA30, OA64
OA88,OA111
OA89,OA112
OA90,OA113
OA91,OA114
OA92,OA115
OA93,OA116

Matching Shells
OA31, OA65
OA32, OA66
OA33, OA67
OA34, OA68
OA35, OA69
OA36, OA70
OA37, OA71
OA38, OA72
OA39, OA73
OA40, OA74
OA94,OA117
OA95,OA118
OA96, OA119
OA97,OA120
OA98,OA121
OA99, OA122

Appendix T. Using and Creating Explanatory Models in Your Classroom

Developing and using models is an integral part of scientific inquiry and has been identified as one of the eight central scientific and engineering practices that K-12 students should engage in as part of the Next Generation Science Standards. While physical models are often used in K-12 classrooms, engaging students in using models to predict and explain is less common. As a result, K-12 students often are not familiar with how models are created and used by scientists.

Models in science include physical replicas, diagrams, mathematical representations, analogies and computer simulations. These scientific models are used to generate questions, make and test predictions and communicate scientific ideas and explanations.

Explanatory models are a type of model used to explain natural phenomena. An explanatory model is a combination of pictures and text that explain a particular phenomenon. One of the main goals of this activity is for students to engage in developing and revising an explanatory model to answer the driving question "*How might increasing levels of CO_2 affect oysters in Maryland?"* As students develop and discover information related to carbon dioxide, oceans and oyster, they will add this information to their developing explanatory models. Throughout the course of the activity, students will have several opportunities to add to, and revise, their explanatory model. At the end of the activity, students will have an explanatory model that answers the driving question.

Explanatory models are a useful way to make thinking visible. As a teacher, this can be a useful for formatively assessing student understanding. But making thinking visible is also important for student learning. Explanatory models that make thinking visible can support students as they communicate their ideas to each other. Models allow students to make the unobservable, observable. For example, students cannot observe carbon dioxide directly in real life. But they can represent it with symbols in their explanatory models. Being able to refer to a picture or diagram of 'unobservable' ideas in their discussions can help students to assess and critique their own ideas and those of their peers.

Many students may initially be unfamiliar with what an explanatory model is, and how to create one. Below are some suggestions for scaffolding the process with your students.

- Discuss with students the purpose and the components of an explanatory model.
    - Contain pictures, diagrams, arrows
    - Contain text to explain and connect ideas
    - Make it clear that explanatory models are not simply lists of idea, but rather a collection of pictures, diagrams, and words or phrases connected to each other with arrows that explain a natural phenomenon.
- Consider having the class develop and agree on specific drawing conventions that all groups can use. If symbols are used, a legend is necessary for others to interpret their model.

- Providing a template (see Appendix D) for their explanatory model can be useful to get students started
- Scaffold the process for students by helping them generate '*Gotta Have'* lists of ideas and concepts they should address in their models. It is important that teachers don't just provide these lists to students, but rather that teachers support the students in generating the list. This provides opportunities for students to consider and begin making connections among all the information and ideas they've been learning.
- Very often students are concerned about making mistakes. They might be reluctant to revise information they have already recorded on their model. It is important to constantly remind them that the models they are making are *meant* to be changed and revised- that is their purpose. Let them know that scientists are constantly revising and revisiting their models based as their understanding of the phenomenon increases or changes due to new evidence. You might consider having them use different colored markers or pens at each stage of model development so they can trace how their ideas have changed over time.
- Ideally, students will have large, poster size paper on which to generate their models. Make sure to have extra pieces available if students need to start over. Large white boards are another option, as they make changing and revising ideas easy.

For more information about using explanatory models in the K-12 classroom, check out the resources below.

- https://www.researchgate.net/publication/263471256_The_Modeling_Toolkit_Making_Student_Thinking_Visible_with_Public_Representations
- https://www.teachingchannel.org/blog/ausl/2015/05/04/explanatory-models-a-highly-effective-way-to-support-science-learning-ngss-and-mbi/
- https://www.rubicon.com/next-generation-science-standards/
- http://nstahosted.org/pdfs/ngss/resources/201203_framework-krajcikandmerritt.pdf
- http://ambitiousscienceteaching.org/wp-content/uploads/2014/09/Models-and-Modeling-An-Introduction1.pdf

Appendix U. Rubric for Assessing Explanatory Models

This rubric is intended for teacher use, and not necessarily for student use.

Please note that students' initial ideas can be evaluated in several ways. Some may be visible because students have crossed them out and made changes. If students erase initial ideas as their understanding changes and develops, you can evaluate these changes as they are happening. If you are evaluating a final version of the explanatory model that does not include evidence of developing ideas, you may not be able to use this criteria in your evaluation. However, there is value in encouraging students to show evidence of their changing ideas, as it provides feedback to students on their own learning.

	0	**1**	**2**
STUDENTS' INITIAL IDEAS*	The model does **not** include students' initial ideas that respond to the scientific question.	The model includes **limited** student initial ideas that **partially** respond to the scientific question.	The model includes students' initial ideas that respond to the scientific question.
INTEGRATING EVIDENCE	The model does **not** integrate evidence from the investigations, models and readings.	The model integrates **partial** evidence either from the investigations, models and readings.	The model integrates **all** available evidence from the investigations, models and readings.
CLARITY/ ORGANIZATION	Students do **not** use drawings, inscriptions **or** written explanations in their models.	Students use **either** drawings, inscriptions **or** written explanations in their models and the response to the scientific question is **unclear.**	Students use drawings, inscriptions **and** written explanations in their models to **clearly** respond to the scientific question.
EVALUATING MODELS	Students are **not** able to evaluate the strengths and weaknesses of their peers' models in explaining the natural phenomena of impact of ocean acidification on oyster larvae.	Students can **either** evaluate strengths **or** weaknesses of their peers' models in explaining the natural phenomena of impact of ocean acidification on oyster larvae.	Students can evaluate strengths **and** weaknesses of their peers' models in explaining the natural phenomena of impact of ocean acidification on oyster larvae.

Appendix V: Answers to Student Handout Questions (Middle School)

Carbon Dioxide

1. What does carbon dioxide (CO_2) in our atmosphere do for the earth?

Carbon dioxide is a greenhouse gas, which means it is a heat-trapping gas. Because carbon dioxide traps heat, it helps to warm our atmosphere and the earth. Without greenhouse gases, the earth would be too cold for life, as we know it, to survive.

2. What happened when people starting burning fossil fuels for energy?

During the industrial revolution (~300 years ago) humans started burning lots of fossil fuels for energy. Fossil fuels, like oil, coal and natural gas, release lots of carbon dioxide when they are burned. This additional carbon dioxide is released into our atmosphere, causing the extra heat to be retained, warming the earth.

3. Does carbon dioxide that is absorbed by the ocean contribute to a warming atmosphere? Why or why not?

The ocean naturally absorbs a lot of carbon dioxide from the atmosphere and carbon dioxide that is dissolved in the ocean does not contribute to a warming atmosphere.

4. What are you going to be figuring out in this series of activities?

We're going to explore how the increased amount of carbon dioxide entering the ocean (due to the increased amount of carbon dioxide being released by the burning of fossil fuels) is affecting marine organisms, like oysters.

Whaddya know?

5. Write your observations, inferences and questions you have about the object below.

Answers will vary; typical student answers might include:

Observations	Inferences	Questions
It's rough on the outside, smooth on the inside. There are markings on the object.	It's an oyster shell. An oyster used to live in this shell.	What do oysters look like? How do oysters move? What do oysters eat? Where do shells come from?

6. How does carbon dioxide affect temperatures in the atmosphere?

Students answers will vary based on their background knowledge. Typical answers might include the following.

Carbon dioxide is a greenhouse gas, which means it traps heat. Carbon dioxide causes our atmosphere to hold more heat, which warms the earth. This is a good thing, as we need the atmosphere and the earth to warm. But increasing levels of carbon dioxide in the past 200 years, due to burning of fossil fuels by humans, is leading to increased warming, leading to global warming and climate change.

7. What is the **driving question** for this activity?
How might increasing levels of CO_2 affect Oysters?

Constructing an Explanatory Model

8. Using your Explanatory Model graphic organizer, begin to construct a model to illustrate and explain how burning fossil fuels affects the amount of CO_2 in the environment.
Students may include the following in their explanatory model:

- Burning fossil fuels releases CO_2 into atmosphere
- Oceans absorb CO_2
- More CO_2 in atmosphere leads to more CO_2 being absorbed by the ocean
- Warming oceans take up less CO_2
- Warming oceans take up less CO_2

Investigation 1: CO_2 and Ocean pH

9. What is the investigative question you are trying to answer?
What effect does increasing the amount of CO_2 in the ocean have on ocean pH?

10. What do you predict will happen to the pH of saltwater when CO_2 is added? Why do you think this?
Student answers will vary. They might predict pH will increase, or decrease or stay the same. Their explanations of *why* they think this will happen will likely not include accurate information. This is to be expected, as students will be gaining additional information throughout all the instructional activities that will allow them to build an accurate understanding of what is happening. Note that we have intentionally asked students to make a prediction, and not a hypothesis. For more information on the difference, visit https://mrdrscienceteacher.wordpress.com/2014/11/02/teaching-the-hypothesis/.

11. With members of your group, design an investigation to answer the investigative question. You will have access to the following materials:

- Beakers (up to 2)
- Salt water
- pH strips (up to 4)
- Straw (up to 2)
- Tape (for labeling beakers)

a. Write the protocol for your investigation below. It should contain enough details so someone not in your group could conduct the investigation. It should also contain a place to record any data you plan to collect.
Example protocol. Note that students may come up with many different ways to design their investigation using the materials provided. The design below is just one example.

a) Put 30 ml of water in a beaker labeled salt water (control)
b) Put 30 ml of water in a beaker labeled salt water + carbon dioxide.
c) Blow into the beaker labeled 'salt water + carbon dioxide' for 45 seconds
d) Measure the pH of each beaker. Write the results in table below.
e) Repeat steps a-d with new salt solutions.

Many students will forget to include a place to collect their data. Encourage students while they are writing their protocols to consider where they are going to collect their data. Developing data tables is a skill and will help students become more specific in what they are testing and what data they are collecting. Below is an example of a data table.

Beaker	Trial 1 pH value	Trial 2 pH value
Salt water		
salt water + carbon dioxide		

Alternative example protocol

a) Put 30 ml of saltwater in a beaker labeled "A".
b) Put 30 ml of saltwater in a beaker "B".
c) Measure the pH of each beaker. Write the results in table below.
d) Blow into each beaker for 45 seconds and measure the pH using the test strips.
e) Repeat steps a-d with new salt solutions.

Many students will forget to include a place to collect their data. Encourage students while they are writing their protocols to consider where they are going to collect their data. Developing data tables is a skill and will help students become more specific in what they are testing and what data they are collecting. Below is an example of a data table.

Beaker	Beaker A pH values	Beaker B pH values
Trial 1		
Trial 2		

b. Share your investigation design with another group. Use the Peer Review rubric to provide feedback to the other group on their design.
Students should provide feedback to each other about their protocols using the rubric provided in Appendix I.

c. Incorporate feedback from the Peer Review process into your investigation design. Record your changes below.
Students should incorporate any changes based on the peer review feedback.

d. Conduct your investigation!
Each student group should conduct their own investigation and record their data.

12. Use data from your investigation and what you know about pH to write a scientific explanation below to answer the question *What effect does increasing the amount of CO_2 in the ocean have on ocean pH?* Make sure to include evidence and reasoning to support your claims. Student answers will vary. Below is an example of the type of evidence and reasoning students may provide.

Claim (answers the question):	Adding carbon dioxide to salt water causes the pH of salt water to decrease.

Evidence (from your investigation):	Reasoning (scientific ideas that connect your evidence to your claim, explains why the
• The pH of salt water with no carbon dioxide introduced is 8.3. • The pH of salt water after blowing into it is 6.7.	• When we exhale, we release CO_2. • By blowing into the beaker with the straw, I added CO_2 into the water, but nothing was added to the other (control) beaker. • The pH scale goes from 0-14 and indicates how acidic or basic a substance is. • If the pH is lower than 7, the substance is considered acidic. • If the pH is 7, the substance is considered neutral. • If the pH is above 7, the substance is considered basic. • The introduction of carbon dioxide results in a decrease of pH. • Adding carbon dioxide to oceans makes them more acidic.

Constructing an Explanatory Model

13. Add information to your explanatory model to illustrate and explain how increasing atmospheric CO_2 affects ocean pH. Remember, you are constructing this explanatory model to address the driving question "*How might increasing levels of CO_2 affect oysters?*"

Students may include the following in their explanatory model:

- Extra $C0_2$ in the ocean causes the water to become more acidic (it causes the pH to go down).

The Carbonate Model Challenge

14. What investigative question are you trying to answer in the Carbonate Model Challenge?
The investigative question is *How does increasing the amount of CO_2 in the ocean affect an oyster larva's ability to build shell?*
Students will address this question by figuring out which of these oceans (black bowl or white bowl) in the *Carbonate Model Challenge* represents a healthy ocean and which represents an acidified ocean.

15. What does each object represent in the Carbonate Model?

Object in Carbonate Model Challenge	What object represents in model
Water-beads	Water molecules (H_2O)
Black beads	Carbonate ions (CO_3^{-2})
White beads	Calcium ions (Ca^+)
Red beads	Hydrogen ions (H^+)
Black bowl	An ocean (unknown if healthy or acidified)
White bowl	An ocean (unknown if healthy or acidified)
Black and White beads connected together	Calcium carbonate molecules ($CaCO_3$)
Black and Red beads connected together	Bicarbonate ions (HCO_3^-)

16. Conduct the *Carbonate Model Challenge* using instructions on laminated sheets.
Each student group will complete at least two trials of the *Carbonate Model Challenge* and record their results on the laminated sheet using dry erase markers.

17. Fill in the information below using the class data set.
Answers will vary based on actual student results.

	Ocean	
	Black bowl	White bowl
Class average number of calcium carbonate molecules made in 90 seconds	16	8

18. Examine the class data for patterns and trends. Make a graph if it helps you to visualize patterns. Write down any patterns and trends you detect below.

Students will typically find that they are able to make more calcium carbonate molecules (black and white beads) in the black bowl versus the white bowl. They should be able to make up to 40 in the black bowl, but can only make up to 10 in the white bowls.
Having student's use class averages of multiple trials can be helpful, as some groups of students might have more trouble putting beads together, and therefore their trials may not show the anticipated pattern.

19. Watch the video "*Effect of Ocean Acidification on Shell-building Organisms*" and answer the following questions. Your teacher will provide a written transcription of the video for you to refer to when answering the questions.

a. What two chemical reactions take place when CO_2 is absorbed into the ocean?

1) Carbon dioxide (CO_2) combines with water to form carbonic acid.

2) Carbonic acid breaks down into bicarbonate ions and hydrogen ions.

b. What two types of ions do oysters need to form shells?

Oysters combine calcium ions with carbonate ions to make calcium carbonate. Oysters use calcium carbonate to build their shells.

c. When CO_2 enters the ocean and undergoes chemical reactions, it produces lots of hydrogen ions. All these extra hydrogen ions makes the ocean water more acidic (decreasing its pH). What happens to many of these extra hydrogen ions?

The extra hydrogen ions bind with carbonate (making bicarbonate).

d. What happens to oysters if there are too many hydrogen ions in the ocean?

If there are too many hydrogen ions in the ocean, they bind to the carbonate. This means there is not enough carbonate left for the oysters to use to make their shells. If baby oysters (larvae) can't make shells they disappear (die).

20. Read *"Ocean Acidification Causes, Chemistry and Impacts"* and answer the following reflection questions.

a. How does carbon dioxide affect the pH of the ocean?

Carbon dioxide that is absorbed into the ocean causes ocean acidification. This happens when carbon dioxide reacts with water and produces a lot of hydrogen ions. The extra hydrogen ions decrease the pH of the ocean.

b. How do oysters build their shells?

The combine calcium ions (Ca^{+2}) and carbonate (CO_3^{-2}) ions into calcium carbonate ($CaCO_3$) molecules.

c. Why do oysters have trouble building their shells in oceans that are becoming more acidic?

In more acidic ocean waters, the extra hydrogen that result from carbon dioxide reacting with water bind to carbonate ions (forming bicarbonate). The means there is less carbonate available for oysters to use to combine with calcium to form calcium carbonate. Oysters use calcium carbonate to build their shells. If oyster larvae can't build their shells, they will die.

d. What other issues, besides ocean acidification, are facing oysters in the Chesapeake Bay?

In addition to ocean acidification, oysters in the Chesapeake Bay have faced over-harvesting, disease and loss of habitat.

21. Make a claim, and support it with evidence and reasoning, for which bowl represents a healthy ocean and which bowl represents a more acidic ocean.

Claim (answers the question): The black bowl represents a healthy ocean and the white bowl represents a more acidic ocean.

Evidence (from your investigation):	Reasoning (scientific ideas that connect your evidence to your claim, explains why the evidence is important)
In the black bowls, we were able to make an average of 16 calcium carbonate molecules in 90 seconds. In the white bowls, we were able to make an average of 8 calcium carbonate molecules in 90 minutes.	Oyster larvae must combine calcium and carbonate into calcium carbonate to make shell. In healthy oceans, there is enough carbonate for oysters to make shells. In acidified oceans, there is less carbonate available. This is because CO_2 reacts with saltwater to form carbonic acid. Carbonic acid breaks down into hydrogen and bicarbonate. The extra hydrogen from the carbonic acid breakdown binds to carbonate, leaving less carbonate available for oysters to use to form their shells.

Constructing an Explanatory Model

22. Go back to your Explanatory Model Graphic organizer and add information you learned from the Carbonate Model Challenge, video and reading to illustrate and explain the how increasing the amount of CO_2 in the ocean affects oyster larvae's ability to build shell. Remember, you are constructing this explanatory model to address the driving question "*How might increasing levels of CO_2 affect oysters?*".

Students might include any of the additional information they learned from the following:

- Carbonate Model Challenge
- *Effect of Ocean Acidification on Shell-building Organisms* Video
- *Ocean Acidification Causes, Chemistry, and Impacts* Reading

- *What is Ocean Acidification?* Summary Video

Big ideas from these resources include:

- Oyster larvae must combine calcium and carbonate into calcium carbonate to make shell.
- In healthy oceans, there is enough carbonate for oysters to make shells.
- In acidified oceans, there is less carbonate available. This is because CO_2 reacts with water to form carbonic acid.
- Carbonic acid breaks down into hydrogen and bicarbonate.
- The extra hydrogen from the carbonic acid breakdown binds to carbonate, leaving less carbonate available for oysters to use to form their shells.
- It's harder for oysters to build shells in acidified oceans because there is not enough carbonate available.
- If baby oysters (larvae) can't build their shells, they can't eat and they die.

23. Participate in a Gallery Walk to give and receive feedback on your explanatory models.

24. Use feedback and comments you received on your explanatory model during the Gallery Walk to revise and improve your model.

25. What can be done to address the issue of increasing atmospheric CO_2?

Addressing the issues of climate change resulting from increasing CO_2 emissions will require a complex set of solutions aimed at both reducing CO_2 emissions and mitigating the effects of CO_2 that has already been released.

Student response will vary and may include:

- Cut down on the amount of fossil fuels that are burned to decrease the amount of CO_2 released into the atmosphere.
    - Drive less
    - Use renewable energy resources such as wind and solar
    - Conserve energy
    - Lower the thermostat
- Continue to research how increasing atmospheric CO_2 is affecting organisms and ecosystems so we can better understand what is happening as we seek to mitigate the effects of climate change.
- Work to mitigate the effects of ocean acidification on organisms (such as exploring whether adding 'antacids' to the ocean can keep the pH from decreasing).
- Explore ways to sequester and remove excess CO_2 from the atmosphere.

Appendix W: Answers to Student Handout Questions (High School)

Carbon Cycle

1. What does carbon dioxide (CO_2) in our atmosphere do for the earth?

Carbon dioxide is a greenhouse gas, which means it is a heat-trapping gas. Because carbon dioxide traps heat, it helps our atmosphere hold onto more heat and warm the earth. Without greenhouse gases, our atmosphere and the earth would be too cold for life, as we know it, to survive.

2. What happened when people started burning fossil fuels for energy?

During the industrial revolution (~300 years ago) humans started burning lots of fossil fuels for energy. Fossil fuels, like oil, coal and natural gas, release lots of carbon dioxide when they are burned. This additional carbon dioxide is released into our atmosphere, causing the extra heat to be retained, warming the earth.

3. Does carbon dioxide that is absorbed by the ocean contribute to a warming atmosphere? Why or why not?

The ocean naturally absorbs a lot of carbon dioxide from the atmosphere and carbon dioxide that is dissolved in the ocean does not contribute to a warming atmosphere.

4. What are you going to be figuring out in this series of activities?

We're going to explore how the increased amount of carbon dioxide entering the ocean (due to the increased amount of carbon dioxide being released by the burning of fossil fuels) is affecting marine organisms, like oysters.

Whaddya know?

5. Write your observations, inferences and questions you have about the object below.

Answers will vary; typical students answers might include:

Observations	Inferences	Questions
It's rough on the outside, smooth on the inside. There are markings on the object.	It's an oyster shell. An oyster used to live in this shell.	What do oysters look like? How do oysters move? What do oysters eat? Where do shells come from?

6. How does carbon dioxide affect temperatures in the atmosphere?

Students answers will vary based on their background knowledge. Typical answers might include the following.

Carbon dioxide is a greenhouse gas, which means it traps heat. Carbon dioxide causes our atmosphere to hold more heat, which warms the earth. This is a good thing, as we need the atmosphere and the earth to warm. But increasing levels of carbon dioxide in the past 200 years, due to burning of fossil fuels by humans, is leading to increased warming, leading to global warming and climate change.

7. What is the **driving question** for this activity?
How might increasing levels of CO_2 affect Oysters?

Constructing an Explanatory Model
8. Using your Explanatory Model graphic organizer, begin to construct a model to illustrate and explain how burning fossil fuels affects the amount of CO_2 in the environment.
Students may include the following in their explanatory model:

- Burning fossil fuels releases CO_2 into atmosphere
- Oceans absorb CO_2
- More CO_2 in atmosphere leads to more CO_2 being absorbed by the ocean
- Warming oceans take up less CO_2

Investigation1: CO_2 and Ocean pH
9. What is the investigative question you are trying to answer?
What effect does increasing the amount of CO_2 in the ocean have on ocean pH?

10. What do you predict will happen to the pH of the saltwater when CO_2 is added?
Student answers will vary. They might predict pH will increase, or decrease or stay the same. Their explanations of *why* they think this will happen will likely not include accurate information. This is to be expected, as students will be gaining additional information throughout all the instructional activities that will allow them to build an accurate understanding of what is happening. Note that we have intentionally asked students to make a prediction, and not a hypothesis. For more information on the difference, visit https://mrdrscienceteacher.wordpress.com/2014/11/02/teaching-the-hypothesis/.

11. With members of your group, esign an investigation to answer the question *What effect does increasing atmospheric CO_2 have on ocean pH?* You will have access to the following materials:

- Beakers
- Salt water
- (4) pH strips
- Straw
- Tape (for labeling)

a. Write the protocol for your investigation below. It should contain enough details so someone not in your group could conduct the investigation. It should also contain a place to record any data you plan to collect.
Example protocol. Note that students may come up with many different ways to design their investigation using the materials provided. The design below is just one example.

f) Put 30 ml of water in a beaker labeled salt water (control)
g) Put 30 ml of water in a beaker labeled salt water + carbon dioxide.
h) Blow into the beaker labeled 'salt water + carbon dioxide' for 45 seconds

i) Measure the pH of each beaker. Write the results in table below.
j) Repeat steps a-d with new salt solutions.

Many students will forget to include a place to collect their data. Encourage students while they are writing their protocols to consider where they are going to collect their data. Developing data tables is a skill and will help students become more specific in what they are testing and what data they are collecting. Below is an example of a data table.

Beaker	Trial 1 pH value	Trial 2 pH value
Salt water		
salt water + carbon dioxide		

Alternative example protocol

f) Put 30 ml of saltwater in a beaker labeled “A”.
g) Put 30 ml of saltwater in a beaker “B”.
h) Measure the pH of each beaker. Write the results in table below.
i) Blow into each beaker for 45 seconds and measure the pH using the test strips.
j) Repeat steps a-d with new salt solutions.

Many students will forget to include a place to collect their data. Encourage students while they are writing their protocols to consider where they are going to collect their data. Developing data tables is a skill and will help students become more specific in what they are testing and what data they are collecting. Below is an example of a data table.

Beaker	Beaker A pH values	Beaker B pH values
Trial 1		
Trial 2		

b. Share your investigation design with another group. Use the Peer Review rubric to provide feedback to the other group on their design.
Students should provide feedback to each other about their protocols using the rubric provided in Appendix I.

c. Incorporate feedback from the Peer Review process into your investigation design. Record your changes below.
Students should incorporate any changes based on the peer review feedback.

d. Conduct your investigation!
Each student group should conduct their own investigation and record their data.

12. Watch the *Acids, Bases and Ocean Acidification* Video.

13. Use data from your investigation and any readings or videos you watched to write a scientific explanation below to answer the question *What effect does increasing atmospheric CO_2 have on ocean pH?* Make sure to include evidence and reasoning to support your claims.

Claim (answers the question): Adding carbon dioxide to salt water causes the pH of salt water to decrease.

Evidence (from your investigation):	Reasoning (scientific ideas that connect your evidence to your claim, explains why the evidence is important)
• The pH of salt water with no carbon dioxide introduced is 8.3. • The pH of salt water after blowing into it is 6.7.	• When we exhale, we release CO_2. • By blowing into the beaker with the straw, I introduced CO_2 into the water. • When carbon dioxide enters water, it forms carbonic acid. • Carbonic acid then releases hydrogen ions, which increase the acidity of water. • If acidity increases, pH decreases • The pH scale goes from 0-14 and indicates how acidic or basic a substance is. • If the pH is lower than 7, the substance is considered acidic. • If the pH is 7, the substance is considered neutral. • If the pH is above 7, the substance is considered basic. • The introduction of carbon dioxide results in a decrease of pH. • Carbon dioxide can make oceans less basic and more acidic. • Only the pH of the beaker I was blowing into changed, so it had to be because I was blowing into it.

Constructing an Explanatory Model

14. Add information to your explanatory model to illustrate and explain how increasing atmospheric CO_2 affects ocean pH.

Students may include the following in their explanatory model:

- When carbon dioxide enters water, it forms carbonic acid.
- Carbonic acid then releases hydrogen ions, which increase the acidity of water.
- As acidity increases, pH decreases
- The introduction of carbon dioxide results in a decrease of pH.
- Carbon dioxide can make oceans more acidic.

The Carbonate Model Challenge

15. What investigative question are you trying to answer in the Carbonate Model Challenge?

The investigative question is *How does increasing the amount of CO_2 in the ocean affect an oyster larva's ability to build shell?*

Students will address this question by figuring out which of these oceans (black bowl or white bowl) in the *Carbonate Model Challenge* represents a healthy ocean and which represents an acidified ocean.

16. What does each object represent in the Carbonate Model?

Object in Carbonate Model Challenge	What object represents in model
Water-beads	Water molecules (H_2O)
Black beads	Carbonate ions (CO_3^{-2})
White beads	Calcium ions (Ca^+)
Red beads	Hydrogen ions (H^+)
Black bowl	An ocean (unknown if healthy or acidified)
White bowl	An ocean (unknown if healthy or acidified)
Black and White beads connected together	Calcium carbonate molecules ($CaCO_3$)
Black and Red beads connected together	Bicarbonate ions (HCO_3^-)

17. Conduct the *Carbonate Model Challenge* using instructions on laminated sheets.

Each student group will complete at least two trials of the *Carbonate Model Challenge* and record their results on the laminated sheet using dry erase markers.

18. Fill in the information below using the class data set.

Answers will vary based on actual student results.

	Ocean	
	Black bowl	White bowl
Class average number of calcium carbonate molecules made in 90 seconds	16	8

19. Examine the class data for patterns and trends. Make a graph if it helps you to visualize patterns. Write down any patterns and trends you detect below.

Students will typically find that they are able to make more calcium carbonate molecules (black and white beads) in the black bowl versus the white bowl. They should be able to make up to 40 in the black bowl, but can only make up to 10 in the white bowls.

Having student's use class averages of multiple trials can be helpful, as some groups of students might have more trouble putting beads together, and therefore their trials may not show the anticipated pattern.

20. Watch the video "*Effect of Ocean Acidification on Shell-building Organisms*" and answer the following questions. Your teacher will provide a written transcription of the video for you to refer to when answering the questions.

a. What two chemical reactions take place when CO_2 is absorbed into the ocean?
1) Carbon dioxide (CO_2) combines with water to form carbonic acid.
2) Carbonic acid breaks down into bicarbonate molecules and hydrogen ions.

b. What two types of ions do oysters need to form shells?
Oysters combine calcium ions with carbonate ions to make calcium carbonate. Oysters use calcium carbonate molecules to build their shells.

c. When CO_2 enters the ocean and undergoes chemical reactions, it produces lots of hydrogen ions. All these extra hydrogen ions make the ocean water more acidic (decreasing the pH). What happens to many of these extra hydrogen ions?
The extra hydrogen ions bind with carbonate ions (making bicarbonate).

d. What happens to oysters if there are too many hydrogen ions in the ocean?
If there are too many hydrogen ions in the ocean, they bind to the carbonate in the water. This means there is not enough carbonate left for the oysters to use to make their shells. If larval oysters can't make shells they die.

21. Read "*Ocean Acidification Causes, Chemistry and Impacts*" and answer the following reflection questions.
a. What is causing the increase in carbon dioxide in the air and the ocean since the start of the industrial revolution?
Since the industrial revolution, humans have burning increased amounts of fossil fuels. The burning of fossil fuels releases carbon dioxide into the atmosphere.

b. How would you respond if someone asked you if oceans were considered acidic or basic?
The pH of oceans has dropped from 8.2 to 8.1 since the beginning of the industrial revolution. So, oceans are becoming more acidic. However, any value above 7 on the pH scale is considered basic. So, oceans aren't considered acidic yet, but they are becoming more acidic.

c. Why do oyster larvae have difficulty building shells in oceans that are more acidic?
In more acidic ocean waters, the extra hydrogen that result from carbon dioxide reacting with water bind to carbonate ions (forming bicarbonate). The means there is less carbonate available for oysters to use to combine with calcium to form calcium carbonate. Oysters use calcium carbonate to build their shells. If oyster larvae can't build their shells, they will die.
d. In the example given in the reading, describe how each would the following affect the pH of the Bay?

Scenario	Affect on the pH of the Bay
Algal bloom	Algae will consume carbon dioxide for photosynthesis, therefore decreasing the acidity of the water, raising its pH.
Algal blooms blocking SAV access to sunlight	If SAV can't photosynthesize, they will be consuming less CO_2 and therefore the pH of the Bay would increase.
Massive algal bloom die-off	Bacterial respiration releases CO_2, decreasing the pH.

22. Make a claim, and support it with evidence and reasoning, for which bowl represents a healthy ocean and which bowl represents a more acidic ocean.

Claim (answers the question): The black bowl represents a healthy ocean and the white bowl represents a more acidic ocean.

Evidence (from your investigation):	Reasoning (scientific ideas that connect your evidence to your claim, explains why the evidence is important)
In the black bowls, we were able to make an average of 16 calcium carbonate molecules in 90 seconds. In the white bowls, we were able to make an average of 8 calcium carbonate molecules in 90 minutes.	• Oyster larvae must combine calcium and carbonate into calcium carbonate to make shell. • In healthy oceans, there is enough carbonate for oysters to make shells. • In acidified oceans, there is less carbonate available. This is because CO_2 reacts with saltwater to form carbonic acid. • Carbonic acid breaks down into hydrogen and bicarbonate. • The extra hydrogen from the carbonic acid breakdown binds to carbonate, leaving less carbonate available for oysters to use to form their shells.

Constructing an Explanatory Model

23. Go back to your Explanatory Model Graphic organizer and add information you learned from the Carbonate Model Challenge, videos and readings to illustrate and explain the how increasing the amount of CO_2 in the ocean affects oyster larvae's ability to build shell. Remember, you are constructing this explanatory model to address the driving question "*How might increasing levels of CO_2 affect oysters?*".

Students might include any of the additional information they learned from the following:

- Carbonate Model Challenge
- *Effect of Ocean Acidification on Shell-building Organisms* Video
- *Ocean Acidification Causes, Chemistry, and Impacts* Reading
- *What is Ocean Acidification?* Summary Video

24. Participate in a Gallery Walk to give and receive feedback on your explanatory models.

25. Use feedback and comments you received on your explanatory model during the Gallery Walk to revise and improve your model.

26. What can be done to address the issue of increasing atmospheric CO_2?
Addressing the issues of climate change resulting from increasing CO_2 emissions will require a complex set of solutions aimed at both reducing CO_2 emissions and mitigating the effects of CO_2 that has already been released.

Student response will vary and may include:

- Cut down on the amount of fossil fuels that are burned to decrease the amount of CO_2 released into the atmosphere.
    - Drive less
    - Use renewable energy resources such as wind and solar
    - Conserve energy
- Continue to research how increasing atmospheric CO_2 is affecting organisms and ecosystems so we can better understand what is happening as we seek to mitigate the effects of climate change.
- Work to mitigate the effects of ocean acidification on organisms (such as exploring whether adding 'antacids' to the ocean can keep the pH from decreasing.
- Explore ways to sequester and remove excess CO_2 from the atmosphere.
    - resources such as wind and solar
    - Conserve energy

Appendix X: Links and Resources

Claim Evidence and Reasoning

Below are links to several resources about using the Claim-Evidence-Reasoning framework to scaffold your students as they learn to formulate and evaluate scientific arguments and explanations.

- http://ptgmedia.pearsoncmg.com/images/9780137043453/downloads/McNeill-Ch.2.pdf
- http://learningcenter.nsta.org/products/symposia_seminars/nsta/files/howdoyouknowthat--helpingstudentswriteaboutclaimsandevidence_12-12-2012.pdf
- http://www.activatelearning.com/claim-evidence-reasoning/

Use of Models and Modeling in Science

Below are links to several resources about the use of models and modeling in your classroom.

- http://ambitiousscienceteaching.org/wp-content/uploads/2014/09/Models-and-Modeling-An-Introduction1.pdf
- https://www.teachingchannel.org/blog/ausl/2015/05/04/explanatory-models-a-highly-effective-way-to-support-science-learning-ngss-and-mbi/
- http://ncisla.wceruw.org/muse/models/index.pdf
- https://www.researchgate.net/publication/263471256_The_Modeling_Toolkit_Making_Student_Thinking_Visible_with_Public_Representations

Gallery Walk Facilitation Guide

Below is a resource about implementing and facilitating Gallery Walks in your classroom.

- http://ambitiousscienceteaching.org/wp-content/uploads/2014/10/Sticky-Note-Feedback-Tool-for-Students.pdf.

Materials

Most materials are readily available on the internet to be purchased. The hardest to find item are the pH test strips that are in small increments to show the slight change in pH.

- We purchase the Macherey-Nagel pH-Fix 6.0 – 10.0 color fixed indicator test strips. REF: 92122. 100 strips/container = $11.90. Order online at http://www.ctlscientific.com/cgi/display.cgi?item_num=92122&title=PH-FIX--6%2E0-10%2E0