At Home Ocean Acidification Experiment: Shipwrecks, Oyster Middens, and Metal Artifacts

Grade Level:

9-12

Timeframe:

45 minutes per week for 1 month

Materials:

4 liters (~1 gallon) of distilled water
8 Tbsp sea salt
1 sharpie pen
5 pieces of brass
5 pieces of stainless steel
5 pieces of stainless steel with zinc
5 pieces of copper
5 oyster shell fragments
Baking soda as needed
Distilled white vinegar (5% acidity) as needed
1 large bowl/pot
25 mason jars with lids + 1 extra
1 handheld pH meter or pH test strips
Filter paper
Measuring cup and measuring spoons

*Instructor's Note: The metals utilized in this experiment can be purchased in the "small fasteners" section of most hardware stores. Pure metals and samples of copper, zinc, steel, and brass are necessary for this experiment. Additional metals such as iron and bronze can provide the opportunity to expand upon this experiment. Smaller pieces of oyster shell may be used if the class has limited time as it will provide results in a shorter amount of time.

Activity Summary

Through this lesson, students will obtain first-hand experience conducting a scientific experiment concerning the corrosion of metals and the disintegration of oyster shells in acidic oceanlike environments. Students will expose a variety of different metals and oyster shells to different levels of acidity in saltwater representing both present and projected future ocean acidification conditions.

Learning Objectives

At the completion of this lesson, student should be able to:

- Describe ocean acidification and the causes/processes underlying this aspect of climate change.
- Explore the impact of ocean acidification on underwater cultural resources.
- Reconstruct ocean saltwater conditions.
- Alter pH levels to accurately represent current and potential future ocean conditions.
- Make detailed observations regarding ocean acidification's impacts on the corrosion of brass, copper, stainless steel, stainless steel with zinc, and oyster shells over time.

Why Should We Care About This Experiment?

What makes us human? This is often considered the question of all questions. Archaeology provides the ability to study former societies and encourages the desire to uncover, understand, and reflect upon the stories, cultures and lives of people through the analysis of cultural material. There is something very special about holding a stone tool, ceramic, glass bead, animal bone, etc. in the palm of your hand, knowing that hundreds of years ago a person used that artifact or ecofact (e.g. animal bone or plant material) for some purpose. Every artifact has a story to tell and because these objects can't speak for themselves, it is an archaeologist's job to decipher these messages and write the stories for the public today.

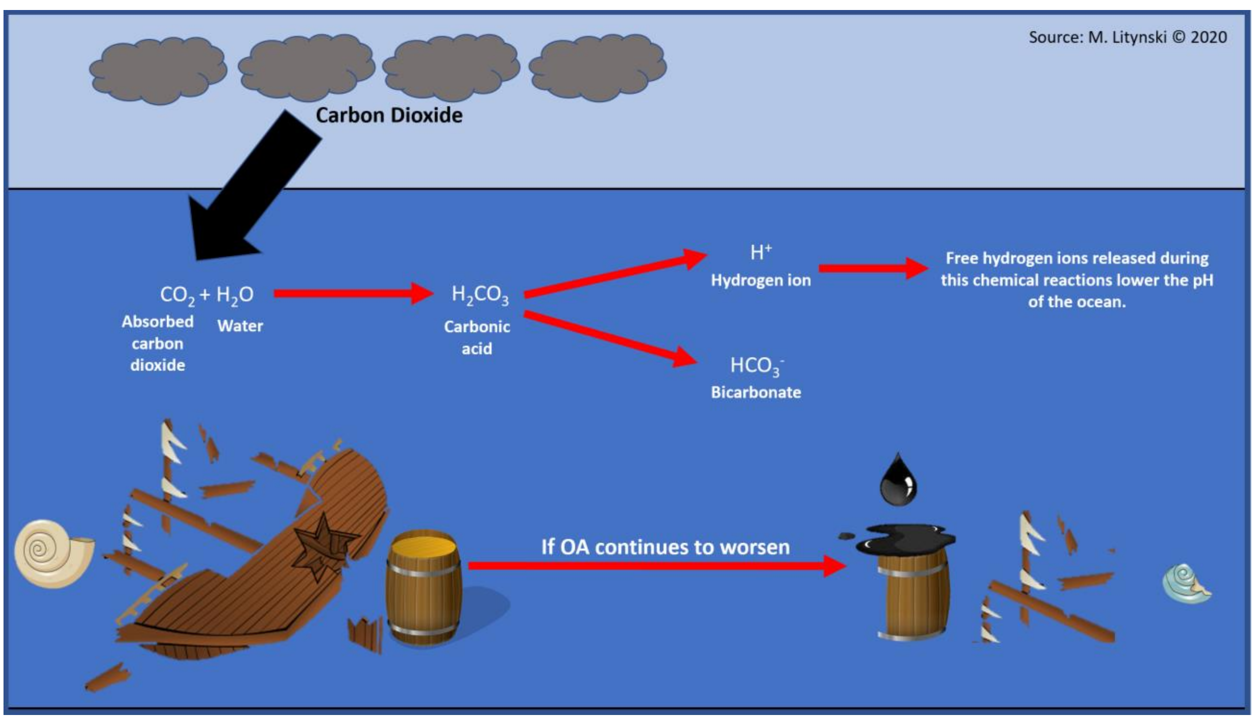
Archaeology is not about finding valuable or revolutionary sites or artifacts. Instead, anthropology and archaeology are scholarly tools that construct a broader understanding of our human past based on examining and analyzing all of the objects, big and small, and the environments that make up our past. Stephen Dean said, "Archaeology is like a jigsaw puzzle, except that you can't cheat and look at the box and not all the pieces are there". Artifacts do not come with a tag stating what it is, what it was used for, and how it got to its' destination in the archeological record. Through archaeology, we can add more pieces to the jigsaw puzzle and answer questions pertaining to site function, ethnicity, race, slavery, status, human-environmental interactions, and beyond.

Beneath the surface of our oceans and other bodies of water lie important physical evidence of our human past, with some examples including shipwrecks and lost cities. The study of shipwrecks reveals interesting insights about diaspora, colonization, trading networks, and marine navigation. Many of the archaeological sites lying underneath the sea can relate to your cultural heritage. One example includes how present day African American marine archaeologists are searching for the ships that carried enslaved Africans to America. Diving With a Purpose (DWP) is working to discover, reconstruct, and tell the stories of millions of Africans who were taken from their homes and enslaved in the Americas.

Unfortunately, shipwrecks and other types of underwater archaeological sites are at risk of deteriorating due to ocean acidification. More acidic waters can strip away the concretion (a protective layer that forms when rust interactions with saltwater, organic material, and/or microscopic organisms) surrounding historical shipwrecks and their hulls. If enough concretion erodes away, metal fasteners will disintegrate and the shipwrecks resting on the ocean floor will lose their integrity. Why should you care about this? When these shipwrecks crumble, so do the valuable lessons we can learn from studying these complex cultures and the ways in which they can inform us about the present. The loss of these underwater cultural resources as our oceans become more acidic oceans prevents a piece from being added to the puzzle of humankind and your history.

This experiment provides students and members of the public an opportunity to learn about underwater cultural resources, as well as, better understand how present and future ocean acidification can negatively impact these aspects of the archaeological record. Brass, copper, steel, and zinc are all metals commonly found on historical shipwrecks. As the ocean becomes more acidic, the rate of corrosion and deterioration of metal will increase, resulting in the loss of cultural heritage and history. Through this experiment, students will engage in hands-on learning opportunities that may allow for a better understanding and appreciation for our archaeological shell middens, shipwrecks, and artifacts. This experiment can promote discovery and learning and help students develop an understanding of the scientific method through direct interaction with the data collected.

Background Information: OA and Cultural Resources



The ocean is a major aspect of the carbon cycle, absorbing over 30% of the carbon dioxide (CO_2) from the atmosphere. The burning of fossil fuels and other human activities (e.g. the production of cement) has drastically increased the amount of carbon dioxide released into the atmosphere. As the ocean absorbs the excess CO2, it combines with water to make a weak acid called carbonic acid. This chemical reaction makes the world's oceans more acidic. The ocean pH prior to the Industrial Revolution was approximately 8.2. Today, the average ocean pH has decreased to 8.1. While the ocean is still considered to be on the alkaline side of the pH scale (7 is neutral and less than 7 is acidic), it is important to understand that when the pH decreases from 8.2 to 8.1, the ocean has already become 30% more acidic and has absorbed the majority of heat resulting from human-caused global change over the last 150 years. If our fossil fuel emissions continue at the same rate, it has been estimated that by the year 2100, the oceans pH may fall as low as 7.0 (NOAA 2020).

Many historical shipwrecks are composed of metal: copper sheathing lines the bottom of wooden vessels; metal fasteners, nails, and bolts of many sizes hold the vessel together; iron cannons were once used as weapons; anchors secured the vessel in place; and different metal tools were used by crewmembers. When seawater and the surrounding environment interact with the rust on these metal objects, a protective layer begins to form. This coating is often referred to as "concretion" and includes the encapsulation of marine shellfish and coral, sediments from the ocean floor, and other artifacts that will clump together into unrecognizable lumps. Concretion in maritime environments is mainly composed of calcium carbonate, which is very susceptible to dissolving in acidic environments. Therefore, ocean acidification has the potential to disintegrate these metal artifacts, including metal fasteners, and cause historical wrecks to crumble. The loss of these shipwrecks may also lead to the loss of artificial reefs that play a role in a healthy ecosystem.

The preservation of organic remains and cultural artifacts in an archaeological context is largely determined by climatic conditions, the surrounding materials, and the natural environment. Archaeological materials in waterlogged environments prevent the growth of bacteria that typically grow or feed upon organic materials. Without oxygen, over 75% of organic materials like wood, textiles, basketry, faunal remains, and plant materials survive in underwater archaeological contexts. This differs from sites on land where significantly reduced materials survive in the archaeological record. For this reason, underwater sites are a rich source of information contributing to our understanding of history and the human past.

Ocean acidification has the potential to destroy underwater archaeology sites, including the organic material that provides important insights to our past in maritime environments. For instance, oyster shell middens were formed over time as Native American tribes consumed these invertebrate resources as part of a healthy diet. Warmer and more acidic seawater has the potential to disintegrate the calcium carbonate that make up these oyster shell. If these middens disappear due to higher levels of acidification in the oceans, then the stories that can be uncovered by studying them will never be learned.

Key Terms:

1. Ocean Acidification: an aspect of climate change that can be defined as a long-term increase in acidity of the ocean. As carbon dioxide (released from fossil fuel burning) is absorbed by the ocean, the pH lowers and the water becomes more acidic.
2. Carbon dioxide: a colorless gas that is released through the burning of carbon and organic compounds and during plant respiration. Excess carbon dioxide is released into the atmosphere through the burning of fossil fuels.
3. pH: A logarithmic scale expressing the acidity or alkalinity of water by measuring hydrogen ion concentration. A pH of 7 is considered neutral, >7 is considered alkaline, and < 7 is considered acidic
4. Cultural resources: any physical evidence or place of past human activity. Some examples may include an archaeology site, artifact, structure, or feature.
5. Artifact: an object made by a human being in the past.
6. Ecofact: a natural organic compound that has been modified by past human activity.
7. Oyster midden: a heap of ancient oyster shells deposited over time due to the consumption of oyster shells as part of the diet of Native Americans and/or European colonists.

Experimental Procedure:

1) Students should develop of a hypothesis regarding the experimental procedure and possible end results. In order to develop a hypothesis that can be tested by scientific research, students should consider the following:
   - Formulate the hypothesis by asking a focused, specific, and researchable research question about this experiment. Many hypotheses follow an *if…then* form, where the first part of the question states the independent variable and the second part of the question states the dependent variable.
   - Complete preliminary research focused on what is already known about ocean acidification.
   - Refine the hypothesis in order to ensure that the question is specific and testable.
   - Identify the variables within the hypothesis, predicted correlations or effects, and differences that may be found through this experiment.

2) Before the start of the experiment, students should make some general observations concerning the different types of metals and oyster shells collected. Describe the appearance of the metals and oysters and document the objects if possible by taking photographs. If possible, have students weigh each metal object and shell as a way to record the original mass prior to exposure to different levels of pH.

3) Pour the four liters of water into a large bowl/pot. Then proceed to add 8 Tbsp of sea salt into the water and stir until thoroughly combined. Within the ocean, seawater on average has a salinity of 35 parts per thousand. This is equivalent to approximately 35 grams of salt to one liter of water. One tablespoon of salt is approximately 17 grams. Therefore, two tablespoons of salt is on average 34 grams which is within close proximity of the 35 grams of salt per one liter of water required for the experiment.

4) Lay out all 25 mason jars and add one piece of metal or shell to each jar. For organizational purposes, try to keep the metals and oyster shells organized in rows. See example below:

   Example: Copper (C); Brass (B); Steel with Zinc (SZ); Steel (S); Oyster Shells (OS); Pure Vinegar (PV)

C pH 8.1	B pH 8.1	SZ pH 8.1	S pH 8.1	OS pH 8.1
C pH 7.9	B pH 7.9	SZ pH 7.9	S pH 7.9	OS pH 7.9
C pH 7.7	B pH 7.7	SZ pH 7.7	S pH 7.7	OS pH 7.7
C pH 7.5	B pH 7.5	SZ pH 7.5	S pH 7.5	OS pH 7.5
C PV	B PV	SZ PV	S PV	OS PV

5) Using a sharpie pen, label the lids of each mason jar according to the metals/oysters to be placed and studied inside the jars, the intended pH measurement and pure vinegar. You may choose varying increments of pH depending on whether a pH meter is used or test strips. Values on test strips vary. Keep in mind the pH of ocean water today at 8.1 compared to projected values of 7.5 by the year 2100. Select equally spaced increments. Examples of increments include 8.1, 7.9, 7.7, 7.5, and pure vinegar.

6) If using a handheld pH meter, fill the extra mason jar with pure distilled water. This water will be used to rise the calibrated pH meter in between measurements. Follow the manufacturer instructions for calibrating the pH meter and using the distilled water in between readings.

7) Using the calibrated pH meter or test strips, measure the initial pH of the seawater.

8) To set up the pH range for each row of jars, add baking soda or vinegar in small increments (Note: It is important to stress to students that pH is a sensitive reading and a little amount of baking soda or vinegar goes a long way). Neutral water has a pH of approximately 7.0. For our experiment, we added baking soda at 1/8 teaspoon increments to raise the pH. In the event that the pH is higher than 8.1, students can use

vinegar to lower the pH. Again, vinegar should be used in small increments (1/8 to 1/2 teaspoon at a time). Vinegar is acidic with a pH of 3.3.

9) As each value of pH is attained, add the water to the corresponding 10 four ounce jars using a measuring cup making sure to dry out the cup in between using paper towels. As the volume of water decreases in the bowl/pot, it is even more important to not over adjust for pH and use 1/8 teaspoon increments of baking soda. Continue following steps 6 and 7 until all the jars are complete. *Note: To save time and resources, instructors can create appropriate solutions ahead of time and distribute to the student groups during class. After each jar has been filled, screw the lid on tightly. This will prevent the evaporation of the seawater.

10) After 24 hours has gone by, students should take observations of the metals and oysters at each corresponding pH level. Students may keep track of their observations with a spreadsheet and/or handwritten notes in their laboratory journal. Here are some examples of questions students should consider when conducting their observations:

    Is the metal/oyster reacting in its environment?
    Is there any noticeable carbon dioxide bubbling occurring, especially in the case of the oyster shell in pure vinegar?
    Is a galvanic reaction occurring? This is an electrochemical process in which one metal corrodes preferentially when two dissimilar metals are coupled in the presence of an electrolyte under water. The galvanic series determines the nobility of metals and semi-metals. The less noble metals (ex. zinc) have lower electrode potential in comparison to the more noble metals (ex. brass).
    *Note: Students should not open the jars or remove the artifacts until the end of the experiment to avoid evaporation of the saltwater.

11) Continue observations and record them daily, weekly, or according to the class's laboratory schedule. Observations should include detailed descriptive notes and photographs to document change over time. See Appendix A for an example observation sheet. If possible, students should dry and weigh the shells and metals at the end of the experiment for comparison.

Presentation of Results

As part of this project, students should write a short research paper (~3-5 pages double-spaced) and create a brief in-class presentation summarizing the results of their study. The research paper should consider the following:

- Did the result of your study support or refute your hypothesis? Was there an aspect of the experiment that surprised you? Please, describe using thoughtful sentences and descriptions.
- What did you learn about ocean acidification and its impacts on underwater cultural resources? Has this experiment affected your understanding of ocean acidification and for cultural resources? After conducting this experiment, do you/do you not have a greater appreciation for underwater cultural resources? Please explain.
- Reflect upon the experimental procedure and note any errors that may have impacted the results.
- What results did you find most important? How do these results relate to underwater cultural resources in a real-life environment and situation? Do you foresee ocean acidification negatively/positively impacting underwater cultural resources? Why?
- Develop possible solutions to ocean acidification's effects on underwater cultural resources.

Results of Experiment for Comparison – By McKenna Litynski

The results of this experiment conducted by McKenna Litynski over a one month timeframe provides students with the opportunity to compare and contrast the results that come from exposing brass, stainless steel, stainless steel with zinc plating, copper, and oyster shell to different to saltwater environments with differing pH levels, as well as to a pure vinegar solution. Below are descriptions of Litynski's findings:

<u>Oyster Shell:</u>

One oyster shell was exposed to a solution of pure vinegar, in which the oyster shell experienced a strong reaction between the calcium carbonate and the acetic acid. Carbon dioxide bubbles rose to the surface of the jar throughout the majority of my experiment. Approximately six days after the start of my experiment, one-quarter of the shell had dissolved. Half of the shell had deteriorated in the vinegar by the ninth day of my experiment. Finally, less than a third of the shell remained after the one-month long period, with the remaining shell consisting of a translucent "floppy" and soft appearance and texture. In my experiment, calcium carbonate crystallization occurred on the outside rim of the jar.

Oyster shells within saltwater environments with a pH levels of 7.5 and 7.7 experienced some darkening, with the texture of the oyster shell appearing somewhat chalkier and soft. This indicates deterioration of the oyster shell within more acidic environments. On the other hand, the oyster shells exposed to saltwater and pH levels of 7.9 and 8.1 experienced no major change in appearance. I tested the pH levels in the jars containing saltwater at the end of the experiment. All of the pH levels in jars containing oyster shell increased, indicating the saltwater became more basic as the oyster deteriorated with time.

Stainless Steel with Zinc

The stainless-steel screw with zinc plating reacted with the pure vinegar solution throughout the course of my experiment. This reaction resulted in the production of hydrogen ions, which created hydrogen gas in the form of bubbles. Eventually, the entire screw turned completely black and cemented itself to the bottom of the jar. The vinegar itself turned different colors over the course of the experiment. At first, the vinegar became white and cloudy. The vinegar then proceeded to turn greyish-green, greenish-brown, orange-brown, and finally reddish brown. The differing colors likely indicates further deterioration of the zinc plating on the screw. By the end of the experiment, the zinc plated screw within pure vinegar experienced severe deterioration with the body and head of the screw appearing much more thin, fragile, and extremely black. The zinc plated screws exposed to pH levels of 7.5, 7.7, 7.9, and 8.1 experienced some blackening and corrosion around the body of the screw.

Copper

The copper within the pure vinegar solution became very shiny in appearance. This is similar to many experiments involving cleaning the copper oxide off of pennies. There was no apparent change to the quality or color of the vinegar. Copper is one of the least salt-resistant metals. Over time, the copper screws in salt water corroded and caused the bottoms of the jars containing pH levels of 8.1, 7.9, 7.7, and 7.5 to turn blue. The bottom of the jar containing a pH of 8.1 was the least blue and the copper screws themselves turned a deep red over time. The jar containing a pH of 7.5 became a dark turquoise blue by the end of the experiment and the edges of the copper screws within this jar corroded away. The screws exposed to pH levels of 7.5 and 7.7 appear to have green copper patina in certain areas. Copper screws exposed to pH levels of

7.7 and 7.9 experienced reddening and darkening. Finally, the copper exposed to a pH of 8.1 experienced darkening, reddening, and rusting.

<u>Brass</u>

The brass screw within the pure vinegar solution became very shiny and gold-like over time. Vinegar has the capability to remove the tarnish off of brass metals, which is likely why the screw became so clean and shiny. The vinegar itself became cloudier over the course of the experiment and by the end of the experiment, the vinegar was no longer translucent. All of the brass screws corroded and rusted within the saltwater environments at varying pH levels. Salt tarnishes brass very quickly, even though brass is generally considered to have high corrosion resistance. Dezincification, which is a leaching form of corrosion, is one of the main reasons why brass corrodes in saltwater. The screws exposed to the various pH levels of 7.5, 7.7, 7.9, and 8.1 experienced severe rusting and corrosion.

<u>Stainless Steel</u>

The stainless-steel screw within the pure vinegar solution did not corrode. Instead, the stainless steel only became slightly shinier within the vinegar. Interestingly, a second screw placed within the vinegar solution that was thought to consist only of stainless steel screws likely had nickel or zinc plating considering it reacted very strongly with the acetic acid. Perhaps, this was a mistake in packaging? This occurrence made me realize the importance of understanding the source and accuracy of materials before utilization, especially if the material was to be used in ship building. It turned black almost immediately and bubbles rose to the surface of the jar throughout the majority of my experiment. Towards the end of my experiment, the vinegar itself became very white and cloudy due to the corrosion of the unidentified screw. Screws exposed to the pH levels of 7.5 and 7.7 experienced blackening in certain areas and rusting on the tips of the screws. Finally, the stainless-steel objects exposed to pH levels of 7.9 and 8.1 did not change in appearance. A small amount of rust occurred at the very tip of the stainless-steel screws within the saltwater environments with pH levels of 7.5 and 7.7. The results of this experiment conclude that stainless-steel does not rust or corrode easily when exposed to saltwater. However, more acidic saltwater conditions might lead to the rusting and corroding of the metal at a faster rate.

Sources

Heather. (2014). Ocean acidification: An experiment to try at home. *University of Southampton,* http://moocs.southampton.ac.uk/oceans/2014/11/19/ocean-acidification-an-experiment-to-try-at-home/

Innes-Gold, Annie, Ackerman, Sophie, and Rajic, Ljiljana. (2018). Impacts of Ocean Acidification on Mussel and Oyster Shells. *Pioneer Valley Coral and National Institute,* https://pvcnsi.org/wp-content/uploads/2018/08/Impacts-of-Ocean-Acidification-on-Mussel-and-Oyster-Shells.pdf

Kennedy, Caitlyn. (2010). Ocean Acidification, Today and in the Future. *National Oceanic and Atmospheric Administration,* https://www.climate.gov/news-features/featured-images/ocean-acidification-today-and-future#:~:text=In%20the%20high%2Demissions%20scenario,acidification%20that%20has%20already%20occurred.&text=The%20models%20simulate%20ocean%2Datmosphere,the%20complex%20feedbacks%20among%20them.

NOAA. (2020). Ocean Acidification Experiment: Impacts of carbonated seawater on mussel and oyster shells. *National Oceanic and Atmospheric Administration,* http://www.cisanctuary.org/ocean-acidification/PDFs-WorkshopPage/Impacts%20of%20Carbonated%20Sea%20Water%20on%20Mussel%20and%20Oyster%20Shells_Oct_%202015.pdf

Northeast Fisheries Science Center. 2019. How Will Changing Ocean Chemistry Affect the Shellfish We Eat? *National Oceanic and Atmospheric Administration Fisheries,* https://www.fisheries.noaa.gov/feature-story/how-will-changing-ocean-chemistry-affect-shellfish-we-eat

Ocean Acidification Portal. (2014). Ocean Acidification: Visualizing Ocean Acidification. http://ocean-acidification.net/2014/03/20/creating-a-portal-to-ocean-acidification/#:~:text=Compared%20with%20preindustrial%20levels%20shown,continue%20(RCP*%208.5).

Williamson, Kim M. (2019). Most Slave Shipwrecks Have Been Overlooked – Until Now. *National Geographic,* https://www.nationalgeographic.com/culture/2019/08/most-slave-shipwrecks-overlooked-until-now/#close

Additional Resources

Bennett, Jennifer and The Ocean Portal Team. (2018). Ocean Acidification. *Smithsonian*, https://ocean.si.edu/ocean-life/invertebrates/ocean-acidification

Bethencourt et al. (2018). Study of the Influence of Physical, Chemical, and Biological Conditions that Influence the Deterioration and Protection of Underwater Cultural Heritage. *Science of The Total Environment*, Vol. 613-614, pp. 98-114.

Bradford, Brittni. (2019). Climate Changing Heritage: Destructive Sea Levels and Acidity. *Saving Antiquities for Everyone*, http://savingantiquities.org/climate-changing-heritage-destructive-sea-levels-and-acidity/

Hester, Jessica L. (2018). Climate Change is Coming for Underwater Archaeological Sites. *WIRED, https://www.wired.com/story/climate-change-is-coming-for-underwater-archaeological-sites/*

McCombes, Shona. (2020). How to write a hypothesis. *Scribbr*, https://www.scribbr.com/research-process/hypotheses/

NOAA. (2020). Ocean Acidification. *National Oceanic and Atmospheric Administration*, https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification

Perez-Alvaro, Elena (2016) Climate change and underwater cultural heritage: Impacts and challenges. *Journal of Cultural Heritage*, Vol. 21, pp. 842-848

Spalding, Mark J. (2011). Perverse Sea Change: Underwater Cultural Heritage in the Ocean is Facing Chemical and Physical Changes. *Cultural Heritage and Arts Review*, https://oceanfdn.org/sites/default/files/Perverse%20Sea%20Change%20MJS1.pdf

Wright, Jeneva. 2016. Maritime Archaeology and Climate Change: An Invitation. *Journal of Maritime Archaeology*. Vol. 11, No. 3, pp. 255-270.

Appendix A: Example Observation Sheet

Date	Material	pH	Observations

HS.Weather and Climate

HS.Weather and Climate

Students who demonstrate understanding can:

HS-ESS2-4. **Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.** [Clarification Statement: Examples of the causes of climate change differ by timescale, over 1-10 years: large volcanic eruption, ocean circulation; 10-100s of years: changes in human activity, ocean circulation, solar output; 10-100s of thousands of years: changes to Earth's orbit and the orientation of its axis; and 10-100s of millions of years: long-term changes in atmospheric composition.] [Assessment Boundary: Assessment of the results of changes in climate is limited to changes in surface temperatures, precipitation patterns, glacial ice volumes, sea levels, and biosphere distribution.]

HS-ESS3-5. **Analyze geoscience data and the results from global climate models to make an evidence-based forecast of the current rate of global or regional climate change and associated future impacts to Earth systems.** [Clarification Statement: Examples of evidence, for both data and climate model outputs, are for climate changes (such as precipitation and temperature) and their associated impacts (such as on sea level, glacial ice volumes, or atmosphere and ocean composition).] [Assessment Boundary: Assessment is limited to one example of a climate change and its associated impacts.]

The performance expectations above were developed using the following elements from the NRC document *A Framework for K-12 Science Education*:

Science and Engineering Practices

Developing and Using Models

Modeling in 9–12 builds on K–8 experiences and progresses to using, synthesizing, and developing models to predict and show relationships among variables between systems and their components in the natural and designed world(s).

- Use a model to provide mechanistic accounts of phenomena. (HS-ESS2-4)

Analyzing and Interpreting Data

Analyzing data in 9–12 builds on K–8 experiences and progresses to introducing more detailed statistical analysis, the comparison of data sets for consistency, and the use of models to generate and analyze data.

- Analyze data using computational models in order to make valid and reliable scientific claims. (HS-ESS3-5)

Connections to Nature of Science

Scientific Investigations Use a Variety of Methods

- Science investigations use diverse methods and do not always use the same set of procedures to obtain data. (HS-ESS3-5)
- New technologies advance scientific knowledge. (HS-ESS3-5)

Scientific Knowledge is Based on Empirical Evidence

- Science knowledge is based on empirical evidence. (HS-ESS3-5)
- Science arguments are strengthened by multiple lines of evidence supporting a single explanation. (HS-ESS2-4), (HS-ESS3-5)

Disciplinary Core Ideas

ESS1.B: Earth and the Solar System

- Cyclical changes in the shape of Earth's orbit around the sun, together with changes in the tilt of the planet's axis of rotation, both occurring over hundreds of thousands of years, have altered the intensity and distribution of sunlight falling on the earth. These phenomena cause a cycle of ice ages and other gradual climate changes. *(secondary to HS-ESS2-4)*

ESS2.A: Earth Materials and Systems

- The geological record shows that changes to global and regional climate can be caused by interactions among changes in the sun's energy output or Earth's orbit, tectonic events, ocean circulation, volcanic activity, glaciers, vegetation, and human activities. These changes can occur on a variety of time scales from sudden (e.g., volcanic ash clouds) to intermediate (ice ages) to very long-term tectonic cycles. (HS-ESS2-4)

ESS2.D: Weather and Climate

- The foundation for Earth's global climate systems is the electromagnetic radiation from the sun, as well as its reflection, absorption, storage, and redistribution among the atmosphere, ocean, and land systems, and this energy's re-radiation into space. (HS-ESS2-4), *(secondary to HS-ESS2-2)*
- Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate. (HS-ESS2-4)

ESS3.D: Global Climate Change

- Though the magnitudes of human impacts are greater than they have ever been, so too are human abilities to model, predict, and manage current and future impacts. (HS-ESS3-5)

Crosscutting Concepts

Cause and Effect

- Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-ESS2-4)

Stability and Change

- Change and rates of change can be quantified and modeled over very short or very long periods of time. Some system changes are irreversible. (HS-ESS3-5)

Connections to other DCIs in this grade-band: **HS.PS3.A** (HS-ESS2-4); **HS.PS3.B** (HS-ESS2-4),(HS-ESS3-5); **HS.PS3.D** (HS-ESS3-5); **HS.LS1.C** (HS-ESS3-5); **HS.LS2.C** (HS-ESS2-4); **HS.ESS1.C** (HS-ESS2-4); **HS.ESS2.D** (HS-ESS3-5); **HS.ESS3.C** (HS-ESS2-4); **HS.ESS3.D** (HS-ESS2-4)

Articulation of DCIs across grade-bands: **MS.PS3.A** (HS-ESS2-4); **MS.PS3.B** (HS-ESS2-4),(HS-ESS3-5); **MS.PS3.D** (HS-ESS2-4),(HS-ESS3-5); **MS.PS4.B** (HS-ESS2-4); **MS.LS1.C** (HS-ESS2-4); **MS.LS2.B** (HS-ESS2-4); **MS.LS2.C** (HS-ESS2-4); **MS.ESS2.A** (HS-ESS2-4),(HS-ESS3-5); **MS.ESS2.B** (HS-ESS2-4); **MS.ESS2.C** (HS-ESS2-4); **MS.ESS2.D** (HS-ESS2-4),(HS-ESS3-5); **MS.ESS3.B** (HS-ESS3-5); **MS.ESS3.C** (HS-ESS2-4),(HS-ESS3-5); **MS.ESS3.D** (HS-ESS2-4),(HS-ESS3-5)

Common Core State Standards Connections:

ELA/Literacy –

RST.11-12.1	Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. (HS-ESS3-5)
RST.11-12.2	Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms. *(HS-ESS3-5)*
RST.11-12.7	Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem. (HS-ESS3-5)
SL.11-12.5	Make strategic use of digital media (e.g., textual, graphical, audio, visual, and interactive elements) in presentations to enhance understanding of findings, reasoning, and evidence and to add interest. *(HS-ESS2-4)*

Mathematics –

MP.2	Reason abstractly and quantitatively.(HS-ESS2-4),(HS-ESS3-5)
MP.4	Model with mathematics. (HS-ESS2-4)
HSN-Q.A.1	Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays. (HS-ESS2-4),(HS-ESS3-5)
HSN-Q.A.2	Define appropriate quantities for the purpose of descriptive modeling. (HS-ESS2-4),*(HS-ESS3-5)*
HSN-Q.A.3	Choose a level of accuracy appropriate to limitations on measurement when reporting quantities. (HS-ESS2-4),(HS-ESS3-5)

*The performance expectations marked with an asterisk integrate traditional science content with engineering through a Practice or Disciplinary Core Idea.
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*This experiment may meet the requirements as set forth under the *Weather and Climate* section of the Next Generation Science Standards (NGSS) for high school students.