

Ocean Acidification

Demonstration Lesson Plan



This demonstration lesson plan includes a general science PowerPoint, and a chemistry focused PowerPoint. Both PowerPoints can be accessed from the website. Detailed instructions on demonstration set-ups and an extension activity can be found in this document.

Ideal for grades: 9-12

Appropriate for grades: 8-12

Activity Categories: Pre and post-visit activities

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Introduction to the Demonstration

This demonstration is a model of a series of outcomes when excess carbon dioxide is released into the atmosphere.

(1) Increased carbon dioxide concentration in the atmosphere can trap heat, often referred to as the greenhouse effect. The greenhouse effect causes an increase in global atmospheric temperature and average ocean temperature. *Demo part I*

(2) Increased ocean temperature due to greenhouse effect will decrease ocean's capability to hold dissolved carbon dioxide in aqueous form. By releasing CO₂ back into the atmosphere, it enhances the greenhouse effect and induces a positive feedback loop. *Demo part II*

(3) Our marine ecosystem acts as one of the biggest sinks of carbon dioxide. When excess carbon dioxide is released into the atmosphere, it will reestablish equilibrium with dissolved carbon dioxide in the ocean and some CO_{2(gas)} will be converted into CO_{2(aqueous)}. When dissolved carbon dioxide concentration increases in the ocean it leads to ocean acidification due to the production of carbonic acid. *Demo part III*

(4) Increased ocean acidification can have an effect on shell forming marine animals. Shellfish communities find it challenging to form their shells under acidic conditions. Acids can react with marine animal shells, which are mainly made of calcium carbonate. *Demo part IV*

Curriculum Links: Sciences

Science 9

Big idea: The biosphere, geosphere, hydrosphere, and atmosphere are interconnected, as matter cycles and energy flows through them.

- Sustainability of systems: a systems approach to sustainability sees all matter and energy as interconnected and existing in dynamic equilibrium (e.g., carbon as a key factor in climate change, greenhouse effect, water cycle, etc.)
- Matter cycles: e.g., water, nitrogen, carbon, phosphorus, etc., human impacts on sources and sinks (e.g., climate change, deforestation, agriculture, etc.)

Related topics

Topic 4.1 How do the ideas of connections and sustainability help us think about Earth's spheres?

- Sustainability ensures balanced, healthy systems now as well as in the future
- Being a scientifically literate citizen matters to you both locally and globally

Topic 4.2 What is the role of the Sun's energy in Earth's spheres?

- Solar energy that reaches Earth is absorbed and reflected by Earth's atmosphere and Earth's surface
- Ocean currents redistribute thermal energy around Earth

Topic 4.4 What interactions cycle matter through Earth's spheres?

- Carbon is cycled through interactions between living and non-living things

Curricular Competencies

- Develop and use models and other methods to construct evidence-based explanations for energy flow and matter cycles within ecosystems
- Seek patterns and connections to describe and evaluate sustainability of Earth's systems
- Apply a variety of ways of knowing, including First Peoples perspectives and knowledge, to reflect on and interpret interconnectedness and sustainability
- Analyze cause-and-effect relationship

Science 10

Big idea: Energy is conserved, and its transformation can affect living things and the environment.

- Local and global impacts of energy transformations (pollution, habitat destruction, carbon dioxide output) from technologies

Related topics

Topic 3.3 How does energy transformation affect global systems

- Earth's atmosphere is heated by the transformation and transfer of solar energy and the thermal energy
- Energy transfer and energy transformation moderate Earth's temperature
- Energy transformation and transfer can harm aquatic and terrestrial ecosystems

Curricular Competencies

- Transfer and apply learning to new situations
- Contribute to finding solutions to problems at the local and/or global level

Chemistry 12

Big Ideas:

- Saturated solutions are systems in equilibrium.
- Acid or base strength depends on the degree of ion dissociation.

Related topics

- Dynamic nature of chemical equilibrium: reversible nature of reactions, relationship to PE diagram
- Le Châtelier's principle and equilibrium shift: concentrations of reactants and products

- Water as an equilibrium system
- Applications of acid-base reactions: environmental impacts, buffers

Curricular Competencies

- Contribute to finding solutions to problems at a local and/or global level through inquiry
- Implement multiple strategies to solve problems in real-life, applied, and conceptual situations
- Consider the role of scientists in innovation

Environmental Science 11

Big Ideas:

- Complex roles and relationships contribute to diversity of ecosystems.
- Changing ecosystems are maintained by natural processes.
- Human practices affect the sustainability of ecosystems.
- Humans can play a role in stewardship and restoration of ecosystems.

Related topics

- Abiotic characteristics: aquatic (pH, flow, dissolved oxygen, turbidity, salinity)
- Human actions: harvesting, resource extraction and consumption, population growth, urbanization, habitat loss and fragmentation, climate change, pollution, introduced species, invasive species, forest fires and their impact on ecosystem integrity
- Restoration practices: the process of renewing and recovering a degraded, damaged, or destroyed ecosystem (e.g., riparian zone recovery, invasive species removal, native species planting, ecological engineering, dam removal, hatcheries, wildlife, forestry and fisheries management)

Curricular Competencies

- Contribute to finding solutions to problems at a local and/or global level through inquiry
- Implement multiple strategies to solve problems in real-life, applied, and conceptual situations
- Analyze cause-and-effect relationships

Environmental Science 12

Big Idea: Human activities cause changes in the global climate system.

Related topics

- Changes to climate systems: sinks and sources of greenhouse gases, snow and ice coverage, land surface coverage, solar radiation, energy balance, ocean temperatures, sea levels
- Impacts of global warming: increase in extreme weather events, flooding, desertification, ocean acidification, permafrost melting, drought, wildfires, hurricanes, migratory changes, human health, food security, traditional ways of being and doing

Curricular Competencies

- Contribute to finding solutions to problems at a local and/or global level through inquiry
- Implement multiple strategies to solve problems in real-life, applied, and conceptual situations
- Analyze cause-and-effect relationships

Demonstration Set-up

You can ask a few student volunteers to help you set up the demonstration. The demonstration will be presented in four different small demos. Each demo focuses on a different topic.

Part I: Greenhouse Effect

This experiment demonstrates how the temperature will increase more significantly under the significant presence of carbon dioxide gas. It shows the nature of carbon dioxide as a greenhouse gas.

Materials:

- 2 Containers (beaker, Erlenmeyer flask, or glass jar)
- Heat lamp (any tabletop lamp with at least 100W lightbulb)
- Lid (e.g. rubber stopper with holes, parafilm, etc.)
- Thermometer (digital, glass, or probes if any software is available)
- 2-4 Antacid tablets and water (or dry ice)
- a tube, a Büchner flask, and a rubber stopper without holes

Procedure:

Diagram illustrating the greenhouse effect demonstration setup. A heat lamp is positioned above two flasks, labeled "Flask 1" and "Flask 2". Wavy arrows labeled "heat" point from the lamp to the flasks. A tube labeled "CO₂(g)" leads from a beaker containing "water" and "Antacid Tablet(s)" into the neck of "Flask 1". "Flask 1" is labeled "More CO₂(g)". "Flask 2" is labeled "Normal atmospheric composition". A power strip is shown to the right of the flasks.

Alternative set-up:

Alternative

Dry Ice

Flask 1

CO₂(g)

OR

Vinegar + baking soda

CH₃COOH + NaHCO₃

↓

NaCH₃COO + H₂O + CO₂

Data Analysis

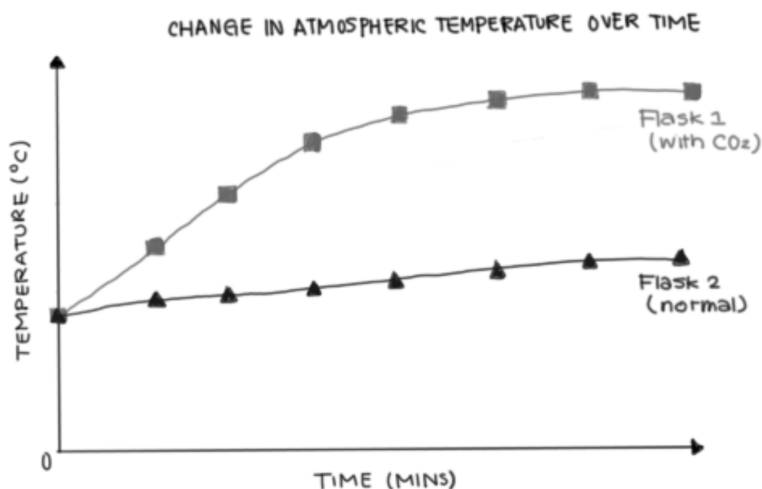
Record temperature change relative to change in time

e.g. time	Flask 1	Flask 2
0 min		
1 min		
2 min		
3 min		
4 min		
5 min		

1. Set up two sets of apparatus: each has one Erlenmeyer flask, one thermometer, and a rubber stopper with holes. (Shown in the above diagram)
2. Connect the tube to the Büchner flask. Add water into the Büchner flask. Put 2-4 Antacid tablets into the Büchner flask and completely seal it with a rubber stopper without holes.
3. When the antacid tablets start to bubble, the carbon dioxide gas will travel to the Erlenmeyer flask (flask 1).
4. Record the current temperature of air in both Erlenmeyer flasks and turn on the heat lamp. Make sure the heat lamp is placed nicely, so it can heat up both flasks.
5. Record the change in temperature relative to change in time.

Results:

- You can ask your students to plot a graph to show the change in temperature (adjust the time interval based on how fast the temperature increases, does not have to be one minute interval)
- Flask 1 (with more carbon dioxide gas) will have a larger increase in temperature in comparison to Flask 2 (with atmospheric carbon dioxide amount)
- Sample graph:



Guiding questions:

- Does the result confirm your hypothesis?
- What is the independent variable in this experiment? What is the dependent variable in this experiment?
- What effect does carbon dioxide have on the atmospheric temperature?
- Why does adding carbon dioxide to the beaker increase in temperature?
- How does this experiment demonstrate the greenhouse effect?
- Is this an accurate representation of our atmosphere?

Tips

- You can pour the carbon dioxide into the beaker after it's produced instead of using a tube. Carbon dioxide is denser and tends to stay at the bottom of the beaker.
- If you choose to produce carbon dioxide and pour it over, you can place a ping pong ball into the beaker containing carbon dioxide to check the level of carbon dioxide.
- Dry ice is a great alternative for production of carbon dioxide.
- If antacid tablets and dry ice are inaccessible, reacting vinegar with baking soda can also produce a significant amount of carbon dioxide.
- Digital thermometers are easier to read than glass thermometers.
- If thermometer probes and the corresponding software are available, you can use it to plot the real time temperature vs. time graph to get a better result.

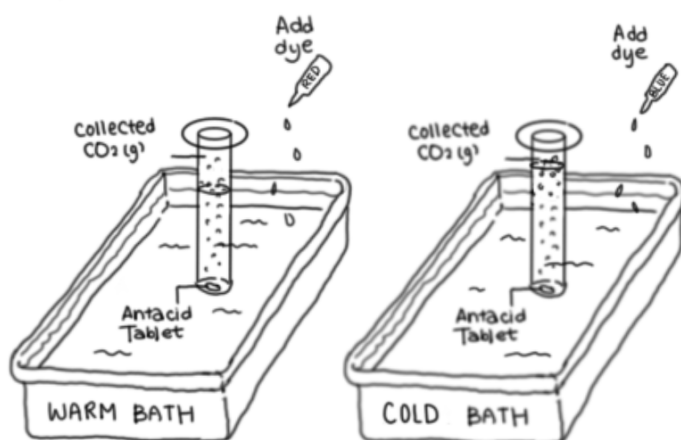
Part II: Solubility of Carbon Dioxide

This experiment demonstrates how the solubility of carbon dioxide varies in water under different temperatures. It shows how change in ocean temperature can have an effect on the ocean's capability of being a carbon sink. (Important: this DOES NOT represent that the ocean will transfer all the carbon dioxide back into the atmosphere under warmer water temperature. Think of an equilibrium.)

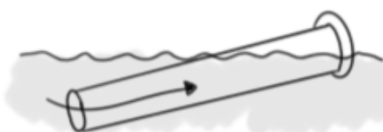
Materials:

- Food colouring dyes (2 different colours)
- 2 large bins capable to contain water
- Warm water bath and cold water bath
- 2 graduated cylinders
- 2-4 Antacid tablets

Procedure:

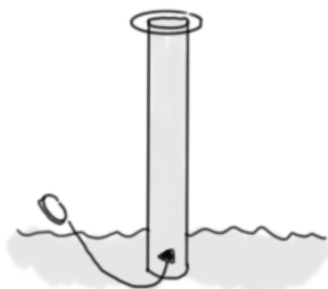


STEP 1:



Fill up the graduated cylinders and invert it upside down

STEP 2:



Quickly put the Antacid tablet into the graduated cylinder

STEP 3:



Carbon dioxide will be released and collected in the graduated cylinder

1. You can invite a student volunteer to help you with the demonstration, so both tablets can be placed in the graduated cylinders at the same time.
2. Add food colouring dyes into both water baths.
3. Immerse both graduated cylinders in water baths, fill up the graduated cylinders with water.
4. Invert both graduated cylinders upside down.
5. Quickly put Antacid tablets (1 or 2 for each cylinder) into the graduated cylinders. Make sure no gas can escape.
6. Observe both graduated cylinders, and compare the volume of gas collected.

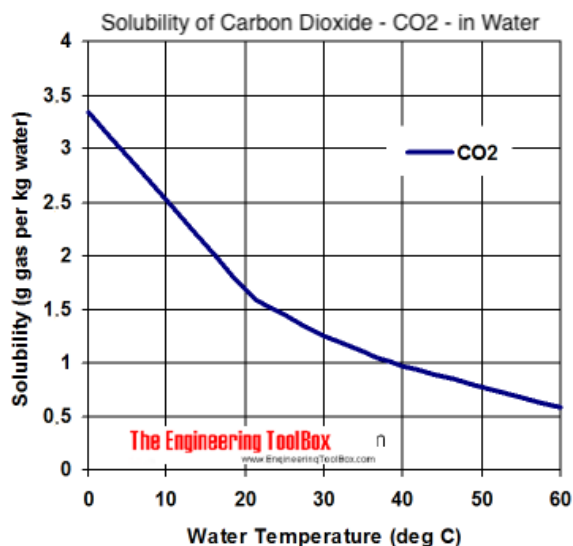
Results:

- The warm water column (inverted graduated cylinder) will show a larger volume of carbon dioxide gas than the cold water column.
- Cold water can dissolve and absorb more carbon dioxide than warmer water.
- (The general concept behind this phenomenon is due to the increase in kinetic energy when temperature increases. The greater kinetic energy suggests that gas particles will be more likely to break away from intermolecular bonds.)

Guiding Questions:

- What is solubility? How do we determine if something is soluble in water?
- What does this change in solubility of carbon dioxide in water suggest?
- What will happen if the ocean temperature increases?
- What will happen if the ocean releases more carbon dioxide back into the atmosphere?
- Is this model an accurate depiction of reality?
- (*Open inquiry*) If the temperature fluctuates between day and night, does that mean overall it does not have an impact on our atmosphere? Why or why not?
- Describe the following diagram:

(source: *Engineering ToolBox*, (2008). *Solubility of Gases in Water vs. Temperature*. [online] Available at: https://www.engineeringtoolbox.com/gases-solubility-water-d_1148.html [Accessed 25 May, 2022].



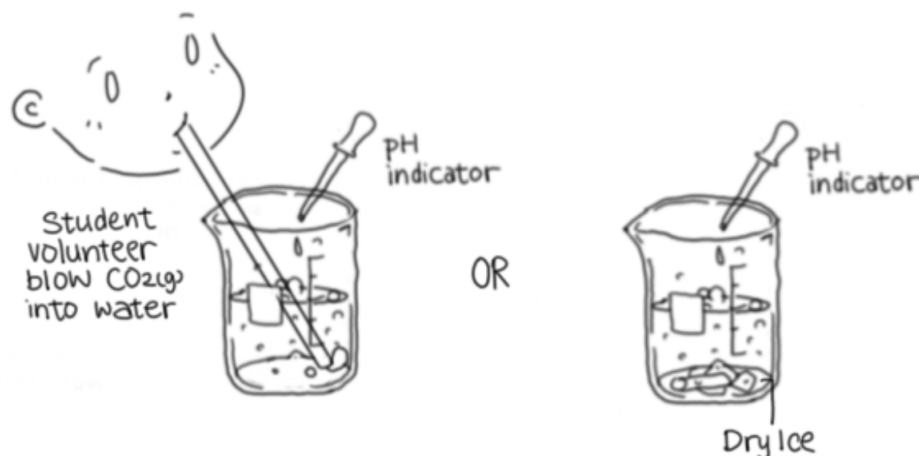
Part III: Ocean Acidification

This experiment demonstrates how the increase in carbon dioxide gas concentration will also increase carbon dioxide concentration in the ocean. It shows when carbon dioxide concentration increases, ocean acidification will take place.

Materials:

- A beaker
- A Straw (or dry ice)
- Universal pH indicator (if not available, can use cabbage indicator)
- Water

Procedure:



1. Add a few drops of universal pH indicator into a beaker half filled with water. (Prior to the experiment, you can ask your students to identify the pH of the current solution.)
2. Ask a student volunteer to blow carbon dioxide gas into the solution (Beware! Remind the student not to suck up or ingest any liquid.) until an obvious colour change can be observed
OR
Put dry ice into the solution and observe colour change.
3. You can continue the reaction (have the student continue blowing into the solution) and observe the endpoint of the colour change.

Results:

- The pH will drop as carbon dioxide continues to dissolve in the solution. Depending on the initial pH of the water, the colour might be different. (e.g. initial colour yellow slowly turning more orange colour.)
- Carbon dioxide reacts with water and forms carbonic acid. Carbonic acid dissociates into bicarbonate ions and hydrogen ions, resulting in an increase in hydrogen ion concentration.
- If the experiment continues, the pH will stabilize at one point. The pH will not go below a certain point due to the solubility of carbon dioxide in water at a given temperature.

Guiding Questions:

- What is pH? Why is there a change in pH?
- Why does the pH/colour stop changing at a certain point?
- Is this an accurate representation of our ocean? Why or why not?
- What might be the potential effects on the aquatic ecosystem?

Part III: Marine Calcifiers Dissolution

This experiment demonstrates how change in ocean acidity can have an impact on the marine calcifiers (e.g. shellfish).

Procedure:



1. You can reuse any carbonated water from the previous demos. (It's okay to use coloured solutions)
2. If you don't have any carbonated water from the previous demos, you can simply repeat the steps in demo III. (Using dry ice, or having a student volunteer blowing carbon dioxide into the solution)
3. Place a seashell into the carbonated solution for 20-30 minutes, leave it in for a longer time if needed. (Remember! Do not take any shells from beaches, you can get shells from commercial seafood such as clams and mussels.) OR you can also use eggshells as an alternative.
4. Observe the change in mass of the seashell and test its strength.

Results:

- Shells are made with calcium carbonate. When placed in acid, it will dissolve and become very fragile.
- You can pass around the shell for students to feel the strength of normal shells of marine calcifiers. Have the students examine the shell again after being placed in acid for a significant period of time.



Guiding Questions:

- Is this demonstration an accurate representation of our ocean? Why or why not?
- What will happen if the shells of the calcifiers lose their strength?
- Why is it significant to use a more extreme pH environment in this demonstration than using the accurate ocean pH?
- How can ocean acidification impact our daily life?
- If our ocean is not acidic, why should we care about ocean acidification?
- (*Open inquiry*) What other species might also be impacted by ocean acidification?
- (*Open inquiry*) What are the possible solutions to slow down or stop ocean acidification?

Q & A:

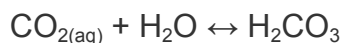
What is the extent of ocean acidification? How big are the impacts of the current observable change?

The pH of the ocean has gone from historically 8.2 to 8.1. Keep in mind that pH scale is a base 10 logarithmic scale. Each one digit change in pH indicates a 10 times difference in H^+ concentration. A solution of a pH of 8.2 has 6.3×10^{-9} mol/L of $[H^+]$. A solution of a pH of 8.1 has 7.9×10^{-9} mol/L of $[H^+]$. A pH of 8.1 is approximately 25% more acidic than a pH 8.2 solution. Having 1.25x more hydrogen ions available in the ocean can greatly impact the concentration of the carbonate ions available for calcifiers. (Some references stated it to be a 30% increase.) Even though the change in pH looks small, the change in the concentration was already significant enough to our marine environment.

You can also look at the scale of change from human's perspective:

E.g. We (humans) have to maintain our blood pH at a range of 7.35 to 7.45. Changing our blood pH by 0.1 will result in significant health problems, which needs to be treated immediately.

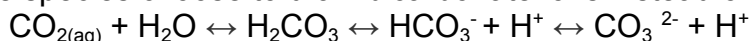
What is the chemical mechanism behind ocean acidification?



When carbon dioxide concentration increases, the concentration of carbonate ions decreases. This is because more carbon dioxide means more hydrogen ions present (pH decreases). Increase in hydrogen ions will react with carbonate ions to form bicarbonate ions (H^+ is more reactive than Ca^{2+} under the competition for CO_3^{2-}). When carbonate ions get consumed by the reaction, the aragonite (a form of calcium carbonate in shells) will start dissolving in order to release more carbonate ions.

Do some species adapt better than others under ocean acidification?

Dissolved carbon dioxide concentration is maintained under an equilibrium of a reversible reaction. The majority of calcifiers draw carbonate ions from its surroundings to form calcium carbonate (shells). However, some species choose to draw bicarbonate ions instead of carbonate ions.



Bicarbonate ion increases when dissolved carbon dioxide increases. Some species of lobsters, crabs, and shrimp can actually build stronger and larger shells from the abundance of bicarbonate ions present in the ocean. Some snail species benefit from increased food source (algae blooms) due to increased dissolved carbon dioxide. A lot of species can experience both positive and negative impacts at the same time, and continue to adapt to the drastic change of their living environment. Some species showed significant impact on its growth rate before maturing, and less of an impact on its adult.

Keep in mind, we cannot be looking at only one species. Some species might not be affected as much, or even doing better under increased acidity; all these changes will lead to other impacts within an ecosystem.

How can we fix it? Is it reversible?

Ocean acidification is mainly caused by increased carbon dioxide emission into the atmosphere. Acting on reducing carbon footprint and decreasing greenhouse emission can slow down the process of ocean acidification. However, it is difficult to completely shut down carbon emission all at once. Several studies suggested that growing sea plants can have an impact on slowing down ocean acidification. As sea plants undergo photosynthesis, they are capable of removing a significant amount of carbon dioxide from its surroundings, neutralizing the acidity. Ecological restoration can help marine ecosystems combat the drastic change, and usually comes at lower cost and fewer side effects. The effect of increased carbon dioxide is due to reestablishing equilibrium of the chemical equation. It is reversible. However, we need to look for a feasible solution that can shift the equilibrium back to where it was with a smaller cost.

What are some examples of marine species reacting to climate change?

- The epigenetic landscape of transgenerational acclimation to ocean warming
<https://www.nature.com/articles/s41558-018-0159-0>
- Are fish communities on coral reefs becoming less colourful?
<https://onlinelibrary.wiley.com/doi/abs/10.1111/gcb.16095>
- Thermally insensitive physiological performance allows neonatal sharks to use coastal habitats as nursery areas
<https://www.int-res.com/abstracts/meps/v682/p137-152/>
- Study: Ocean Acidification Is Dissolving Shells Of Young Dungeness Crab
<https://www.opb.org/news/article/dungeness-crab-ocean-acidification-dissolve-shell/>

Related Articles and Resources:

- UBC Professor and Researcher, Simon Donner, and his work on climate change adaptations
<https://geog.ubc.ca/profile/simon-donner/>
- UBC Harley Lab, Beaty Biodiversity Centre
<https://www.zoology.ubc.ca/harleylab/>
- Beaty researcher, Angela Steveston and her research on glass sponges and their sensitivity to climate change
https://explore.beatymuseum.ubc.ca/researchers-revealed/a_stevenson/
- Yearly Carbon Dioxide Peak (Climate Central)
<https://medialibrary.climatecentral.org/resources/yearly-carbon-dioxide-peak>
- Ocean Acidification: A Risky Shell Game (Woods Hole Oceanographic Institution)
<https://www.whoi.edu/oceanus/feature/ocean-acidification-a-risky-shell-game/>
- What is Ocean Acidification? (Oceana USA)
<https://usa.oceana.org/what-ocean-acidification/>
- Ocean Acidification (Nature): *detailed chemical mechanism explained*
<https://www.nature.com/scitable/knowledge/library/ocean-acidification-25822734/>
- Ocean Acidification (Smithsonian Institution, National Museum of Natural History): *Impacts on the ocean life; looking to the future*
<https://ocean.si.edu/ocean-life/invertebrates/ocean-acidification>
- Ocean Acidification (National Oceanic and Atmospheric Administration)
<https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification>
- ARC centre of excellence Coral Reef Studies
<https://www.coralcoe.org.au/news-and-media/media-releases>
- Ocean Atlas 2017: Facts and figures on the Threats to Our Marine Ecosystems (Heinrich-Böll-Stiftung)
https://www.boell.de/sites/default/files/2021-09/WEB_170607_Ocean_Atlas_Vektor_US_V102.pdf (Direct PDF Link) or
<https://eu.boell.org/en/2017/06/02/ocean-atlas-understanding-threats-our-marine-ecosystems>
- Interactive: Construct a Model
<https://ugc.berkeley.edu/construct-a-model/>

Extension Inquiry Project:

You are a **marine biologist** working alongside with other scientists to observe how species interact and adapt under the drastic change of our aquatic ecosystem due to climate change.

Your **GOAL** is to: research and find a research article/study that you find interesting!

For example, are fish communities on coral reefs becoming less colourful?

<https://onlinelibrary.wiley.com/doi/abs/10.1111/gcb.16095>

You can start from looking at this website to check out some interesting studies: ARC centre of excellence Coral Reef Studies <https://www.coralcoe.org.au/news-and-media/media-releases>

You are going to provide:

- 1 Annotated Bibliography
- 1 Presentation (poster or slide deck)

This is an individual project.

What is an annotated bibliography?

In 500 words, summarize the main intentions and results of your chosen research. You need to include a full bibliographic citation in MLA format, purpose of the study, scope of the study, main argument, methodology, conclusion, and your personal opinion on this study.

For your presentation, you can choose either format: a slide deck or a poster

You will have 10 minutes to present the information to your classmates. Remember to tell the story as if that was your own research project!