Carbon Cycle
Off Balance

NGSS curriculum Unit
Hawaii DOE Standards for High School
Biology
Healthy Climate Communities
AUTHORS

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SUPPORT AND MATERIALS

Healthy Climate Communities is committed to education and action in Hawaii to fight climate change.

This Hawaii place-based Next Generation Science Standards unit contains Hawai‘i Department of Education grade-level standards for biology. Materials such as student worksheets and slide shows for use in class are available on our website www.healthyclimatecommunities.org. Please contact us for support or to provide feedback on the unit, or just to let us know you will use it. healthyclimate@hawaii.rr.com

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LESSON 1
How do plants transform carbon from the atmosphere to a form that can be taken up by other spheres?

Performance Expectation:
**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.

Disciplinary Core Idea:
**LS2.B:** Cycle of Matter and Energy Transfer in Ecosystems. 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.

Science and Engineering Practices:
Using Mathematics and Computational Thinking

Cross Cutting Concepts:
Energy and Matter

PHENOMENON
Plants react to light.

Explore. Elodea Demonstration.
Students guess: What do you think will happen when this plant is exposed to light?

Set-up:
• Obtain two batches of Elodea (a water plant). Place one batch of Elodea in a clear container with water and shine a bright light on it, in a second clear container, place the other batch of Elodea with no light.
• Set up before class to allow time for the light on the Elodea to take effect. You should see bubbles produced from the plant because of the shining light and fewer bubbles produced from the plant with no light.

Demonstration:
• Do not tell students anything of what is happening, just note what you are doing and the materials used. Allow students to observe and make their own conclusions.
• If unable to obtain Elodea and light source, or if it is not working properly, use the following YouTube video link to observe the phenomenon: https://www.youtube.com/watch?v=xRMKiLlpATk. It is also embedded in the second slide in the slide show below.

Discussion:
What did you observe?
They should observe that plants take in and/or give off substances from their environment.

Guided Instruction. Use the Photosynthesis Respiration slides to go over concepts of:
• Chemical equations
• Molecules and compounds
• Conservation of matter
• Inputs to the processes and where they are found
• Equations for photosynthesis and respiration
• Which organisms engage in photosynthesis and/or respiration

Click to download http://healthyclimatecommunities.org/photosynthesis-respiration/

Practice.
Students fill out the worksheet to review and use what they learned in the slide show presentation.

Wrap up.
Ask students (available on the last 2 slides):
• Can you explain scientifically what you observed with the elodea at the beginning of class?
• How do plants transform carbon from the atmosphere to a form that can be taken up by other spheres?
It's All a Balancing Act

A chemical equation contains reactants (substances that go INTO the reaction) and products (substances that come OUT of the reaction). An arrow (→) separates the two and tells us that a reaction is occurring.

To balance a chemical equation, means that the elements that make up the reactants are equal to the elements that make up the products. This is due to the Law of Conservation of Matter which states that nothing is created nor destroyed.

The Periodic Table

To the left is a Periodic Table which lists all known elements. It’s symbol is represented by either one capital letter, or a capital and lower case letter.

A molecule is two or more elements bonded together. They usually tend to stick together unless something (like energy or a better bond) breaks them apart.

Photosynthesis and cellular respiration are two important processes that occur naturally on earth. They provide the necessary molecules for life to exist. Below we will explore how it works.

THE ELEMENTS THAT MAKE UP THE PROCESSES

1. Write down the element name to match the symbols provided below:

   C
   H
   O

2. The elements listed above are used to create molecules significant in the processes for both photosynthesis and cellular respiration. Write down the molecule name to match the symbols provided below:

   CO₂
   H₂O
   O₂
   C₆H₁₂O₆

3. On the left side of the → are the chemicals going IN to a chemical reaction, on the right side of the → are the chemicals going OUT of a chemical reaction. In a chemical reaction, what does the “→” signify?

   ____________________________________________
PHOTOSYNTHESIS

\[ \text{CO}_2 + \text{H}_2\text{O} + \text{light energy} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + \text{O}_2 \]

4. According to the above chemical equation, the process of photosynthesis uses ____________________,  
   ____________________, and ____________________ to produce ____________________ and  
   ____________________.

5. The chemical equation above is not balanced (remember the Law of Conservation of Matter?). To balance a  
   chemical equation, the elements that make up the reactants must equal the elements that make up the products.  
   So, step #1 will be to count how many elements are found on the reactant and the product side. This has been done  
   for you below as an example.

\[
\begin{array}{ccc}
\text{Reactants} & \text{Products} \\
\text{CO}_2 & \text{C}_6\text{H}_{12}\text{O}_6 \\
\text{H}_2\text{O} & \text{O}_2 \\
\text{light energy} & \\
\end{array}
\]

Is the above chemical equation balanced? ______ Why or why not? ________________________________________

6. Step #2 is to balance the equation. Do this by changing the coefficient number to increase the number of molecules  
   available. Note: the coefficient number applies to each element that makes up the molecule. Fill in the blanks (the  
   coefficient number) and the resulting reactant and product numbers to show your balanced photosynthesis  
   equation:

\[
\begin{array}{ccc}
\text{Reactants} & \text{Products} \\
\text{CO}_2 & \text{C}_6\text{H}_{12}\text{O}_6 \\
\text{H}_2\text{O} & \text{O}_2 \\
\text{light energy} & \\
\end{array}
\]

WHERE DO THE MOLECULES COME FROM?

7. Where is CO\textsubscript{2} found in our environment? ________________________________

8. Where is H\textsubscript{2}O found in our environment? ________________________________

9. What could be a source of light that drives the chemical reaction to occur? ________________________________

10. What organisms would go through this chemical process of photosynthesis? ________________________________

11. Looking at the chemical equation, why is CO\textsubscript{2} on the left of the \( \rightarrow \) and why is O\textsubscript{2} on the right of the \( \rightarrow \)? ________

12. Explain the overall purpose of photosynthesis?
CELLULAR RESPIRATION

C₆H₁₂O₆ + O₂ → CO₂ + H₂O + chemical energy

13. According to the above chemical equation, the process of cellular respiration uses ____________________ and ____________________ to produce ____________________, ____________________ and ____________________.

14. Step #1, count how many elements are found on the reactant and the product side.

C₆H₁₂O₆ + O₂ → CO₂ + H₂O + chemical energy
<table>
<thead>
<tr>
<th>Reactants</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td></td>
</tr>
</tbody>
</table>

Is the above chemical equation balanced? ______ Why or why not? ____________________________

15. Step #2, balance the equation.

____C₆H₁₂O₆ + ____O₂ → ____CO₂ + ____H₂O + chemical energy

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td></td>
</tr>
</tbody>
</table>

WHERE DO THE MOLECULES COME FROM?

16. Where is C₆H₁₂O₆ found in our environment? ____________________________

17. Where is O₂ found in our environment? ____________________________

18. What is the chemical energy produced in the end used for? ____________________________

19. What organisms would go through this chemical process of cellular respiration? ____________________________

20. Looking at the chemical equation, why is O₂ on the left of the → and why is CO₂ on the right of the →? ______

21. Explain the overall purpose of cellular respiration?

Extension Questions

22. Cellular respiration occurs in BOTH plants and animals. Why do plants need cellular respiration?

23. In the diagram below, use red arrows to show the movement of CO₂ and blue arrows for O₂.
LESSON 2
How does carbon cycle between spheres?

Performance Expectation:
**HS-ESS2-6.** Develop a quantitative model to describe the cycling of carbon among the hydrosphere, atmosphere, geosphere, and biosphere.

**HS-LS2-5** (Cont.) Develop a model to illustrate the role of photosynthesis and cellular respiration in the cycling of carbon among the biosphere, atmosphere, hydrosphere, and geosphere.

Disciplinary Core Ideas:
**ESS2.D:** Weather and Climate. Changes in the atmosphere due to human activity have increased carbon dioxide concentrations and thus affect climate.

**LS2.B:** Cycle of Matter and Energy Transfer in Ecosystems (cont.).

Science and Engineering Practices:
Developing and Using Models; Analyzing and Interpreting Data; Using Mathematics and Computational Thinking

Cross Cutting Concepts:
Systems and Systems Models; Energy and Matter

PHENOMENON
Carbon is found in every sphere of the Earth, even in the absence of plants.
Do you have ideas about this? What do you wonder?

Explore.
Step by step slides available for download here: [http://healthyclimatecommunities.org/lesson-2-lab-1/](http://healthyclimatecommunities.org/lesson-2-lab-1/)
You can also use instead of live demonstration if needed.

- Follow Lab 1 instructions. Students explore what happens to pH of water when carbon dioxide is added to it through diffusion.
- Students can complete this experiment in groups or can be done as a teacher demonstration.
- NOTE: pH strips or a pH meter can be used instead of the Bromthymol blue solution if available, or a number value for pH is preferred. In which case, deionized water (tap water or even ocean water) can be substituted for the Bromthymol blue solution, as long as a before and after observation is taken.
- NOTE: Materials will be reused to flow readily into Lab 2. Save the liquid in the 3 beakers and the “Experiment” plastic cup for reuse.
Lab #1: How does carbon cycle between spheres?

Background Information:
In this lab, we will explore what happens to the pH of water when exposed to different substances. The water will be measured using a pH scale. A pH value is a number from 1 to 14, with 7 as the middle (neutral) point. Values below 7 indicate acidity, 1 being the most acidic. Values above 7 indicate alkalinity, 14 being the most alkaline. See the diagram (www.usgs.gov) for reference. Bromthymol blue is a solution that acts as an indicator of pH by changing colors.

Group Materials: 3 100mL glass beakers, 3 oz. paper cup, 2-clear 10 oz. plastic cups, 2 petri dish lids, 100mL graduated cylinder, grams scale, masking tape, Bromthymol blue (or other pH indicator), vinegar, baking soda, white paper towel, sharpie marker, water, drain cleaner

Individual Student Materials: PPE (goggles since vinegar is acidic; apron and gloves since Bromthymol blue can stain clothing and skin)

Procedures:
1. Place 30 mL of Bromthymol blue solution into each of the 3 100mL beakers.
2. Label one beaker “vinegar (acid)”, 2nd beaker “water (neutral)”, and 3rd beaker “drain cleaner (alkaline)”.
3. Place 30 mL of vinegar in the correctly labeled beaker. Observe any color changes.
4. Place 30 mL of water in the correctly labeled beaker. Observe any color changes.
5. Place 30 mL of drain cleaner in the correctly labeled beaker. Observe any color changes.
6. Leave these beakers on the side for reference of color.
7. Label one 10 oz. plastic cup as the “control”, the other as the “experiment”.
8. Place 60 mL of Bromthymol blue solution into each plastic cup.
9. In the 3 oz. paper cup, measure and place 2 grams of baking soda.
10. Use a piece of masking tape to tape the paper cup to the top inside of the plastic cup labeled “experiment,” so that the paper cup is NOT touching the liquid and is about 1 cm below the opening of the plastic cup.
11. Place both plastic cups onto a white paper towel (this makes it easier to see the color change).
12. Add 6 mL of vinegar to the paper cup with the baking soda. NOTE: be careful not to spill any vinegar or the mixture into the Bromthymol blue.
13. Cover both plastic cups (experiment and control) with the petri dish lid.
14. Allow about 10 minutes to pass then take observations on the Bromthymol blue liquid. What color is it? Is there any gas formation? Any solid or liquid left over in the paper cup? Compare these results of the plastic cups to the results of the beakers.
15. Write your data into the data table below.
16. Clean up lab area according to instructor. Save the liquid in the 3 beakers and “experiment” plastic cup, they will be used in lab #2.
Lab #1 Group Members Names: __________________________________________ Date: __________

Data:

<table>
<thead>
<tr>
<th></th>
<th>OBSERVATIONS BEFORE EXPERIMENT</th>
<th>OBSERVATIONS AFTER EXPERIMENT</th>
<th>pH (Acidic, Neutral, or Alkaline)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinegar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drain Cleaner</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experiment</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Discussion Questions:

1. What was the purpose of the Control? What did it show?

2. When vinegar (CH₃COOH) is mixed with baking soda (NaHCO₃), a chemical reaction occurs to form sodium acetate (CH₃COONa), carbon dioxide (CO₂), and water (H₂O). The sodium acetate and water combine to form an aqueous solution. Based on your observations what happened with the carbon dioxide in the paper cup?

3. Based on your observations what happened with the Bromthymol Blue liquid in the “experiment” plastic cup after the 10 minutes?

4. When carbon dioxide (CO₂) is combined with water (H₂O), another chemical reaction occurs to form carbonic acid (H₂CO₃). This acid breaks down further within the water and releases its hydrogen ions (H⁺) which decreases the pH of water. Use this information to explain and diagram what happened within the paper cup and the “experiment” plastic cup, that made you conclude the pH of the Experiment is acidic, neutral, or alkaline.

5. How does this experiment relate to one way carbon cycles between the spheres?
TEACHER NOTES FOR DISCUSSION FOLLOWING THE LAB:

• Remind students about the carbon cycle, where carbon dioxide and oxygen are continuously cycling within a balanced ecosystem through photosynthesis and respiration. If carbon dioxide is added to the atmosphere at a rate faster than can be sequestered by plants, where does this extra carbon go?

• In the lab, the high concentration of carbon in the air of the Experiment cup diffused into the water in the cup. Similarly, Carbon Dioxide passes back and forth between the atmosphere and the surface of the ocean. If the concentration is higher in the air, it diffuses into the water. This carbon can be taken down to the deep parts of the ocean and be stored there for long periods of time.

• According to NASA, the land plants and the ocean have taken up about 55% of the extra carbon humans have put into the atmosphere while about 45% has stayed in the atmosphere. Eventually, the land and oceans will take up most of the extra carbon, but as much as 20% will remain in the atmosphere for many thousands of years.

https://earthobservatory.nasa.gov/features/CarbonCycle/page5.php

Practice.

1. Create a model of the carbon cycle.

• Materials available here:

• Before class cut out and laminate all pictures, labels, and board beforehand. It will allow for reuse.

• Other supplies needed: 3 colored whiteboard markers (thin) per group

• BACKGROUND INFORMATION:

  o Carbon is continually recycled on Earth, changing from one chemical compound to another.
  o Processes that release carbon to the atmosphere are called carbon sources (they release more carbon than they absorb), while processes that absorb it from the atmosphere are called carbon sinks (they absorb more carbon than they release).
  o Natural sources of carbon: decomposition, cellular respiration, digestion, volcanoes, fires, and, when they warm up, oceans and freshwater bodies can release large amounts of carbon.
  o Natural sinks of carbon: forests (plants), oceans and freshwater bodies, diatoms and other algae, rocks, permafrost, soil, shells and coral, and fossil fuels
  o The amount of carbon in the atmosphere at any one time depends on the balance that exists between the sinks and the sources.
  o Carbon sinks are able to become carbon sources, such as when forests storing carbon are cut down, or when fossil fuels are burned.
  o Carbon enters the ocean through marine algae, organic matter in river water, diffusion from the atmosphere to the surface of the ocean. Once in the ocean water, carbon binds with calcium and is used by coral and marine organisms to build their hard structures.
  o Soil carbon – dead organic matter that has not decomposed yet is still part of the biosphere. Most of the carbon stored in the biosphere is in the soil in forested areas and wetlands.
  o Carbon becomes part of the Earth’s crust (lithosphere) when dead plants and marine organisms do not decompose and are compressed and heated for thousands of years to form coal, oil and natural gas. Dead coral and shells made of calcium carbonate eventually become marine sediment, and then form limestone. Limestone makes up most of the carbon stored in the Earth’s crust – about 80%, with the remaining 20% of the carbon being fossil fuels.
  o Excess carbon in the atmosphere warms the planet and helps plants on land grow more. Excess carbon in the ocean makes the water more acidic.
2. Share and discuss.
   - Choose one or two groups to present their poster to the class.
   - Discuss the importance of carbon on Earth and how it continually cycles.
   - Share the background information as needed to correct misconceptions and fill in gaps in understanding.
   - Point out (by highlighting the arrows in yellow) the arrows that are coming out of the atmosphere. Then, point out (by highlighting the arrows in green) the arrows that are going to the atmosphere. Point out that the arrows don’t show us how much carbon is going from one sphere to another. Therefore, how do we know if it is balanced? Discuss with the class. Tell them we will do a worksheet to better understand the quantities.

3. Complete worksheet and discuss.
   - Pass out the worksheet “Carbon Stores and Fluxes” to for each group to complete together.
   - Discuss with the class what the model they filled in shows. Compare it to their poster.
   - Pass out the worksheet with discussion questions for each group to complete together. After completing, discuss their answers.
     - Question 3: The answer is the ocean - while CO₂ has increase most in the atmosphere, the atmosphere is not a sink or a source for itself.
     - Question 8: After sharing connections they see from the IPPC graphs, clarify as needed that the temperature rise depicted in the bottom graph is what we refer to as Global Warming and that the release of “greenhouse” gases, primarily CO₂, as depicted in the top graph, has been driving the increase in temperatures.
Cycling of Carbon Diagram

Carbon is found within all living things. It can also be found within the ocean, the atmosphere, and the soil. Carbon cycles continuously as one of the major biogeochemical cycles. We already learned some of the ways carbon cycles: through photosynthesis, respiration and diffusion (between air and water). Processes that release carbon are called carbon sources, while processes that absorb it are called carbon sinks.

Work in a small group of 3 and use the picture cut-outs to diagram how the cycling of carbon occurs and identify the carbon sources and sinks in our world. Your completed diagram will help you to answer the discussion questions.

1. **Diagram the cycling of carbon**

   Step 1: Obtain a set of laminated pictures and labels from your teacher.
   
   Step 2: Match the pictures with the correct labels. HINT: there may be more than one picture per label.
   
   Step 3: Write in the correct balanced chemical equation for the photosynthesis label, as well as the cellular respiration label. Use whiteboard markers.
   
   Step 4: Organize the pictures + labels on a large laminated sheet of paper (14’x18’). Arrange them so the carbon is able to flow and cycle through all the pieces. Use a little scotch tape to place pictures, this will be so they are moveable. Place the title piece on the top and write in an appropriate one, use whiteboard markers.
   
   Step 5: Consult will all members of your group and be sure everyone agrees with the arrangement.
   
   Step 6: Use whiteboard markers to draw in arrows to show the flow of carbon.
   
   Step 7: Peer share your diagram with a neighboring group who is done. Share and explain the flow of carbon in the diagram and the reason or method of flow. For example: The carbon in the atmosphere gets taken in by the plants in the form of carbon dioxide through the process of photosynthesis. When the plants die, they decompose and some of the carbon gets sequestered back into the Earth or become sediment within the ocean...
   
   Step 8: Now that you have shared, come back to your own group and consult with all your members. Be sure everyone agrees with the arrangement and understands the flow and labeling.
   
   Step 9: Using two different colored whiteboard markers, circle where your group thinks are the carbon sinks and the carbon sources. Carbon sinks can be circled red and carbon sources circled in blue.
   
   Step 10: A class discussion will take place with your teacher. Label and take notes on your diagram with whiteboard markers.

2. **Fill in the quantitative model and answer the discussion questions with your group.**
Carbon Stores and Fluxes – Quantitative Model

Use the estimates of carbon stores and changes to complete the table and model.

1. Rank the spheres by the amount of carbon stored, with 1 being the most carbon.
2. Calculate the current carbon stored where there have been changes due to industrialization. Numbers are measured in Petagrams of Carbon.
3. Put the updated data in the model.
4. The lines indicate annual flows between spheres. Black lines are natural processes, red lines are human caused. Draw arrow heads to indicate the direction of the flows.

<table>
<thead>
<tr>
<th>Rank</th>
<th>Sphere</th>
<th>Pre-industrial</th>
<th>Change</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Atmosphere</td>
<td>589</td>
<td>+ 240</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Biosphere</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>vegetation</td>
<td>450-650</td>
<td>-30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>soil</td>
<td>1,500-2,400</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Geosphere</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fossil fuel reserves*</td>
<td>1,002-1,940</td>
<td>-365</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ocean floor sediment</td>
<td>1,750</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sedimentary rocks</td>
<td>66,000,000-100,000,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hydrosphere</td>
<td>38,000</td>
<td>+155</td>
<td></td>
</tr>
</tbody>
</table>

*Fossil fuel reserves are limited to resources that have been discovered and are possible to extract.

Data: Ciais et al. 2013. IPCC Fifth Assessment Report. [https://www.esrl.noaa.gov/gmd/education/info_activities/pdfs/TBI_co2_and_the_carbon_cycle.pdf](https://www.esrl.noaa.gov/gmd/education/info_activities/pdfs/TBI_co2_and_the_carbon_cycle.pdf)

Cycling of Carbon – Discussion Questions

Answer as a group, using your diagram and your quantitative model to help with your answers.

1. Name the carbon sink(s) in your diagram.

2. Name the carbon source(s) in your diagram.

3. Which carbon sink has sequestered additional carbon since the industrial revolution?

4. How does carbon get to be sequestered in the carbon sink you identified in question #3?

5. Explain how a carbon sink is able to become a carbon source. Provide an example of the process.

6. Humans have greatly impacted the carbon cycle. Name examples of human made carbon sources.

7. Explain how human made carbon sources disrupted the carbon cycle.
8. What happens when the carbon in our atmosphere increases?

Carbon gases trap heat from the sun. Otherwise the Earth would be as cold as outer space. Look at the graphs. The first one shows human emissions of carbon to the atmosphere. The second one shows average global temperatures. What do you deduce from the patterns you see?

9. Think back on what you observed in Lab #1. What happens when carbon increases in our oceans?

10. What are ways we can help restore the balance of the carbon cycle?
LESSON 3
How does a change in the carbon cycle affect marine ecosystems?

Performance Expectation:
**HS-LS2-6.** Evaluate the claims, evidence, and reasoning that the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.

Disciplinary Core Idea:
**LS2.C:** Ecosystem Dynamics, Functioning and Resilience. A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient), as opposed to becoming a very different ecosystem. Extreme fluctuations in conditions or the size of any population, however, can challenge the functioning of ecosystems in terms of resources and habitat availability.

Science and Engineering Practices:
Analyzing and Interpreting Data; Engaging in Argument from Evidence

Cross Cutting Concepts:
Stability and Change; Cause and Effect

PHENOMENON
Lobsters of the same species, raised in different environments, can be different.

What do you wonder about the differences you see in the photos?
Explore.

Follow Lab 2 instructions. Must plan for at least 2-day span. Step by step slides available for download here. [http://healthyclimatecommunities.org/lesson-3-lab-2/](http://healthyclimatecommunities.org/lesson-3-lab-2/)

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**Set up beakers with shells**

---

**Measure mass of each dried shell**

---
Lab #2: How does a change in the carbon cycle affect marine ecosystems?

Background Information: Based on Lab #1, it was discovered that carbon dioxide within the atmosphere can mix with water to form carbonic acid which releases hydrogen ions as it breaks down further to make carbonate ions. All those released hydrogen ions are what decreases the pH value and makes the water acidic. This is a natural process, but will increasing concentrations of carbon dioxide in our oceans affect marine ecosystems?

Group Materials: 5 250mL glass beakers, graduated cylinder, masking tape, sharpie marker, distilled water, local ocean water, lab #1 liquids, sea shells (similar shape and size; e.g. from a mussel or cockle or sea urchin; bought or collected from the beach), pH strips or digital pH meter, grams scale, paper towel

Individual Student Materials: PPE (goggles since vinegar is acidic)

Procedures:
1. Obtain the 5 250mL glass beakers and label them using the tape and marker: vinegar, water, drain cleaner, ocean water, lab #1 experiment liquid
2. Measure and place 50 mL of the correct liquid in each respective beaker. NOTE: the amount of liquid depends on the size of the shell. Be sure the shell is completely submerged in the liquid, so may want to test out beforehand. But all 4 beakers should have the same amount of liquid.
3. Use pH strips or pH meter to measure the pH level of each liquid. Record the results in the data table.
4. Obtain 5 (similar in size and shape) shells. Measure the mass for each shell on a grams scale. Record the results in the data table.
5. Place the shell in the correctly labeled beaker with the liquid. Observe what happens to the shells for about a minute. Record your observations in the data table.
6. Leave the beakers on the side of the classroom where it will not get disturbed, for about 2 days.
7. After 2 days, take some time to observe and compare the shells and liquids in the different beakers. Record your observations in the data table.
8. Carefully remove the shell from one beaker and dry it on a paper towel.
9. Measure the number of grams for the shell on a grams scale. Record the results in the data table.
10. Repeat step 8 and 9 for the other 4 shells.
11. Clean up your lab area according to your instructor.
### Data:

<table>
<thead>
<tr>
<th></th>
<th>pH value</th>
<th>Before - Shell mass (g)</th>
<th>Before Observations</th>
<th>After Observations</th>
<th>After – Shell mass (g)</th>
<th>Difference in Shell mass (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>VINEGAR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WATER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRAIN CLEANER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OCEAN WATER</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAB #1 EXPERIMENT LIQUID</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Line Graph:** pH vs. Difference in Shell Mass (g)

**Discussion Questions:**
- List the liquids in order from most acidic to least.
Practice.
Evaluate the claims, evidence, and reasoning in article on scientific research.

1. Predict
   • Students look at the images of the two lobsters from the phenomenon shared at the beginning of the class. They turn to a side-partner (pair-share) and discuss: Which lobster do you think lives in ocean water that is more acidic? Why?
   • As a class fill out a T-H-D chart:
     What do you Think?
     How can we find out?
     What do we Do?
• Discuss and complete the T with the class based upon their answer they pair-shared. Possible methods: tally students who think the smaller lobster lives in more acidic waters and tally students who think the larger lobster lives in more acidic waters. Also include the reasoning of WHY student think this is happening to the lobsters. There are no right or wrong answers since it is just asking what they “think”.
• Discuss and complete the H with the class. Possible methods: Provide a post-it note to each student and have them write down what methods to use to find out the correct answer, then to stick it on the chart paper. Have someone or the teacher organize the post-its into similar categories to discuss with the class. Common categories are: research, videos, experimentation, outdoor exploration. Use these ideas to work into the upcoming lessons so students have a voice in their learning experiences.
• Tell students D will be completed at the end of class. It will be their exit ticket.

2. Read Article “Acid Test: Study reveals both losers and winners of CO2-induced ocean acidification”

3. After reading the article, students use the ACES format to write a formal answer to the following question:
   Based on the article, who are the “losers” and who are the “winners” of CO₂ -induced ocean acidification and how do you know?
   A - Answer the question or prompt clearly (topic sentence or claim)
   C - Cite evidence with concrete details
   E - Evaluate/Explain how the evidence supports your topic sentence or claim
   S - Summarize

4. Photo Summary and discussion
• Go through the slide show of images connected to the research in the article: Ocean Acidification and Ecosystem Change. Download here:
http://healthyclimatecommunities.org/ocean-acidification-ecosystem-change/
• Follow the slides to discuss with students the central lesson claim: “Complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions, but changing conditions may result in a new ecosystem.” Have them apply this idea to Ocean Acidification and identify the claim, the evidence and the reasoning. Then have them evaluate the claim, evidence and reasoning.
• Ask students to identify additional relevant evidence not provided.

5. What do we Do?
Close by asking students to think of ideas that they would like to test out to find out more about the effects of ocean acidification.

6. Optional: Watch the following video to reinforce and expand on their understanding of ocean acidification: https://www.youtube.com/watch?time_continue=7&v=GL7qJYKzcsk  Link is also available on the slide show.
LESSON 4
How can understanding the carbon cycle be used to protect marine ecosystems?

Performance Expectations:
**HS-LS2-7.** Students identify a problem of impact of human activity on the environment and biodiversity. Students identify a problem, describe a proposed solution, define criteria and constraints, evaluate the solution against the criteria, and refine or optimize the solution.

**HS-ETS1-1.** Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

**HS-ETS1-2.** Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

**HS-ETS1-3.** Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

Disciplinary Core Ideas:
**LS2.C:** Ecosystem Dynamics, Functioning, and Resilience. Anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change—can disrupt an ecosystem and threaten the survival of some species.

**ETS1.A:** Defining and Delimiting Engineering Problems. Criteria and constraints also include satisfying any requirements set by society, such as taking issues of risk mitigation into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them. Humanity faces major global challenges today, such as the need for supplies of clean water and food or for energy sources that minimize pollution, which can be addressed through engineering. These global challenges also may have manifestations in local communities.

**ETS1.B:** Developing Possible Solutions. When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts.

**ETS1.C:** Optimizing the Design Solution. Criteria may need to be broken down into simpler ones that can be approached systematically, and decisions about the priority of certain criteria over others (trade-offs) may be needed.

Science and Engineering Practices:
Constructing Explanations and Designing Solutions; Obtaining, Evaluating and Communicating Information

Cross Cutting Concepts:
Scale, Proportion and Quantity; Cause and Effect
PHENOMENON
Bodies of water are impacted by plants in them.

How do you think a plant can change the water it is in?

Explore.

1. Demonstrate how plants restore alkalinity to slightly acidic waters.

Demonstration set-up:
- Obtain 3 test tubes and place 10 mL of Bromthymol Blue solution into one tube. Cover the test tube with a stopper and place on the side in a test tube rack.
- Fill a 250mL Erlenmeyer flask with 30mL of Bromthymol Blue solution.
- Pick a student volunteer to blow bubbles into the flask with the solution using a straw. The student will keep blowing bubbles into the solution until it turns yellow or light green.
  - Remind the class what we all breathe out (carbon dioxide), which is going into the solution. Another reminder is that the Bromthymol Blue solution is a pH indicator (blue...
when alkaline, yellow when acidic). Therefore, what happens when carbon dioxide mixes with water? (carbonic acid is created)

- Place 10 mL each of the carbon filled Bromthymol Blue solution into the two other test tubes.
- Break off a branch of Elodea (a water plant) to place into one of the two test tubes. Cover the test tube with a stopper and place on the side in a test tube rack.
- Cover the last test tube which contains just the carbon filled Bromthymol Blue solution. Place in the test tube rack.
- Set the test tube rack on the side in a sunlit area for 24 hours. Could be left for 48 hours if needed.

**NOTE:** This demonstration takes time to see the end results. So, the teacher could set up the experiment the day before. A student could still blow into the Bromthymol Blue solution on the day of the demo to see the color change.

- After completing the experiment, ask the students the following question: What happened to the color of the solution? Why?

2. **Analyze a graph on the concentration of Atmospheric and Oceanic CO₂ and Ocean pH.**

Project the following graph (on slide show) for the class to read.

What are the relationships, if any, between the trends measured?

How does the demonstration relate to trends measured in the graph?
- **Red line:** Student’s breath
- **Blue line:** Student breath dissolved in the solution
- **Green line:** increased acidity of the solution

Based on the graph, what has to happen to restore the ocean pH to pre-industrial levels?
- Atmospheric CO₂ must decline

What possible solution to the problem of ocean acidity does the demonstration suggest?
- Plants!

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**Culminating Project: Local Solutions to Save our Oceans**

**Practice.**

Use scientific knowledge to design a solution to protect marine biodiversity from the effects of ocean acidification through local action.

- **Brainstorm in groups.** Break up students into groups of 3-4. Give each group a worksheet “Local Solutions to Save our Oceans.” Tell each group to work together to discuss and come up with their answer for the first two questions on the worksheet. Answers should be based upon their previous learning. Groups can write or diagram their answer on the worksheet.
• **Share Hawaii policy and data.** Use the slide show images, or information on paper.
  
  o **The State of Hawaii has committed to become Carbon Neutral by 2045.** Other countries, cities and states have made similar commitments. This is necessary to slow and reverse ocean acidification, but it has not been done before and the best way to do it is not clear. Many decisions about how to transition need to be made by our leaders in government, business and science. These decisions will create different costs in terms of how much money and other resources are needed, and different positive or negative impacts on biodiversity and our environment.

  o **Review Table 1. Carbon Flux and Storage in Hawaii.** See the big picture of actual greenhouse gas emissions and sequestration in our state / island. Students can see where the 3 solutions they proposed would fit in. They can see how large an impact different human needs have on emissions in Hawaii and the potential each provides to improve the carbon balance. This real data can be used to refine one solution to choose for their design task (and later to define their criteria or goals for question 5).

• **Narrow the focus and seek teacher approval.** Either allow groups to choose between human needs which contributes to Hawaii’s carbon emissions, or assign different groups different needs to ensure they will learn about all of them from each other. They are: 1) Power, 2) Transportation, 3) Land Use, or 4) Food. Information packets are available on the website so students can easily access Hawaii data and get an overview of the issue of Land Use, Power, Transport and Food.
  

• **Check in.** Once they have filled in their chosen local solution, have them check in with you for approval before proceeding. They may need redirection, or just refinement on the scope (too big or too small).

• **Go through items 4 – 10 on the worksheet.** Define criteria (goals to be accomplished) and constraints (conditions that must be met). Flesh out the solution. Evaluate the solution to see if it met the criteria and worked within the constraints. Outside research is not required.

• **Pair share.** After completing the first 10 items in the worksheet have them pair share with another group to offer and receive feedback.
  
  o Pair up groups with one another (two groups together).
  o They are to take turns sharing their ideas. Use a timer to allow each group time to present. 5 minutes for presentation. 5 minutes for comments and questions. Then switch turns.
  o If time permits, allow groups to pair up with different groups and run through the pair share again.

• **Finish worksheet and create a poster.** The poster will advertise and educate others about their solution. Create a gallery walk by posting up all the posters for students to look at. Have them vote on the best idea to implement for each type of human need.
## Table 1.

### STATE & ISLAND LEVEL

<table>
<thead>
<tr>
<th></th>
<th>State</th>
<th>Oahu</th>
<th>Hawaii</th>
<th>Kauai</th>
<th>Maui</th>
<th>Molokai</th>
<th>Lanai</th>
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<tbody>
<tr>
<td>Population(^1)</td>
<td>1,361,790</td>
<td>953,207</td>
<td>186,738</td>
<td>66,921</td>
<td>144,444</td>
<td>7,345</td>
<td>3,135</td>
</tr>
<tr>
<td>Land area (acres)(^1)</td>
<td>4,034,560</td>
<td>382,080</td>
<td>2,577,920</td>
<td>353,280</td>
<td>465,280</td>
<td>166,400</td>
<td>89,600</td>
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</table>

### FLUX - Annual emissions minus annual sequestration

<table>
<thead>
<tr>
<th></th>
<th>Electric power(^2)</th>
<th>Transport(^2)</th>
<th>Food(^3)*</th>
<th>Stuff(^3)*</th>
<th>Waste(^3)</th>
<th>Livestock, ag, forest fires(^3)</th>
<th>Grassland(^4)</th>
<th>Urban trees(^2)</th>
<th>Shrubland(^3)</th>
<th>Forest(^4)</th>
<th>TOTAL NET EMISSIONS / YR</th>
<th>Long term carbon storage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10.18</td>
<td>6.77</td>
<td>0.77</td>
<td>0.35</td>
<td>0.78</td>
<td>0.05</td>
<td>0.02</td>
<td>0.02</td>
<td>-0.4</td>
<td>-0.23</td>
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<tr>
<td>Electric power(^2)</td>
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<td></td>
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</tr>
<tr>
<td>Transport(^2)</td>
<td>9.79</td>
<td>9.25</td>
<td>1.28</td>
<td>0.54</td>
<td>1.38</td>
<td>0.09</td>
<td>0.04</td>
<td></td>
<td>0.07</td>
<td>-0.08</td>
<td>21.49</td>
<td>19.03</td>
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<td>Food(^3)*</td>
<td>3.49</td>
<td>2.44</td>
<td>0.48</td>
<td>0.17</td>
<td>0.37</td>
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<td>0.18</td>
<td>-0.11</td>
<td>2.59</td>
<td>92.63</td>
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<tr>
<td>Stuff(^3)*</td>
<td>4.02</td>
<td>2.90</td>
<td>0.47</td>
<td>0.18</td>
<td>0.41</td>
<td>0.02</td>
<td>0.01</td>
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<td>0.13</td>
<td>-0.04</td>
<td>1.13</td>
<td>14.67</td>
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<tr>
<td>Waste(^3)</td>
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<td>0.72</td>
<td>0.14</td>
<td>0.07</td>
<td>0.13</td>
<td>0.01</td>
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<td>0.07</td>
<td>-0.08</td>
<td>0.02</td>
<td>5.34</td>
</tr>
</tbody>
</table>

### Land use

<table>
<thead>
<tr>
<th></th>
<th>Livestock, ag, forest fires(^3)</th>
<th>Grassland(^4)</th>
<th>Urban trees(^2)</th>
<th>Shrubland(^3)</th>
<th>Forest(^4)</th>
<th>TOTAL STORED</th>
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</thead>
<tbody>
<tr>
<td>Forest(^4)</td>
<td>143.79</td>
<td>19.03</td>
<td>92.63</td>
<td>0.03</td>
<td>21.25</td>
<td>223.77</td>
</tr>
<tr>
<td>Shrubland(^3)</td>
<td>22.31</td>
<td>1.84</td>
<td>14.67</td>
<td>0.01</td>
<td>2.05</td>
<td>22.36</td>
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<tr>
<td>Grassland(^4)</td>
<td>51.97</td>
<td>1.48</td>
<td>44.16</td>
<td>0.01</td>
<td>4.31</td>
<td>5.70</td>
</tr>
<tr>
<td>Soil / other land(^4)</td>
<td>5.70</td>
<td>0.02</td>
<td>5.34</td>
<td>0.00</td>
<td>0.29</td>
<td>0.02</td>
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</table>

**TOTAL STORED**

223.77

**22.36**

---

**156.80**

**0.05**

**27.91**

**10.35**

**6.30**

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*Mostly imported.

**Sources**

2. ICF International for DBEDt December 31 2008 (2007 for all island level data)
3. coolclimate calculator, UC Berkeley
4. CAH USGS study 2017
LOCAL SOLUTIONS TO SAVE OUR OCEANS!


2. Propose 3 solutions that could be implemented on your island to protect biodiversity in the oceans from ocean acidification. For each solution, state its scientific basis.

   1)

   2)

   3)
Get more input.
- Look at more information and data provided by your teacher.
- Consider the specific areas of focus your teacher asks you to choose between.
- Refine one of your previous solutions or create a new one.

3. Our chosen local solution is:

Get teacher approval before going further.

TEACHER APPROVAL SIGNATURE: ___________________________

4. **List the criteria you will use in your design.** Criteria are the outcomes you will achieve. (For quantitative data use Table 1 on the preceding page.)

Which human activities will you reduce or change and by what measurable quantity?

What measurable impacts will your solution have?

5. **List the constraints you will consider when planning your design.** These might include things like monetary costs, availability of resources, human power or transportation needs that will be impacted, the impact on biodiversity, or other environmental impacts. You can add to the list later as you learn more about your solution.
The constraints we will consider.

6. Read the relevant resource materials provided and do outside research if needed. Once you have learned more about existing technologies, costs and initiatives under way, come back together as a group to discuss and make decisions.

7. Decide on your time frame. You may have part of your solution take place in the short term with known costs and technologies, and other parts of your solution take place in the longer term with more uncertain costs and technologies. You can make up reasonable assumptions, just state what they are.

8. Decide on your location/s. Will your solution target the whole State, your whole island, or just one area on your island? Make sure the solution you pick matches the resources and potential of the location you pick.
9. Decide on the components of your solution (actions). Document the components and describe, with quantities where appropriate, how each meets your criteria and constraints. For example: If you are working on Electric Power, how many MW are you trying to produce? With what technology? In what location? What is the timeframe? How many million metric tons of CO2 will be avoided? What money or other resources will it require? What will the impact be on biodiversity? Are there other environmental impacts?
10. **Evaluate your solution.** How are human needs met compared to the way they are being met now? What are costs compared to current costs? What negative environmental impacts were avoided? What positive environmental impacts were created? Is your solution reliable and safe?

11. **Share your solutions within your class.** Pair up with another group and share your solution. 5 minutes to present, 5 minutes for comments and questions. Then switch turns.

12. **Refine the design – write down your ideas here.** Did you learn anything from the solutions of other groups that you can use to improve your own design? Can any solutions proposed different groups be combined better meet the criteria or minimize constraints?