Photosynthesis, Respiration, and the Short-Term Carbon Cycle

Setting the Stage

This lab lesson is designed to put the processes of photosynthesis and respiration within a global perspective.The Earth functions as a closed system. All materials needed for the maintenance of life cycle within the Earth system. Plants provide all oxygen that animals need to carry out respiration. Before photosynthesis evolved on Earth about 2.5 billion years ago there was very little free oxygen in the atmosphere. It took another 500 million years for respiration to evolve, which would not have been possible at the low levels of oxygen in early Earth's atmosphere. Plants evolved from these early organisms that carried out photosynthesis and animals evolved from these early organisms that carried out respiration. Since then plants and animals have been involved in a cycle where plants provide oxygen for respiration and animals provide carbon dioxide for photosynthesis. Without plants, animals could not exist, and without animals, plants could not reach their current size and population. The carbon cycle could be parsed into two parts: long-term and short-term. The former involves long-term storage of carbon in rocks and deep oceans, whereas the latter involves the cycling of carbon through living organisms, the ocean, and atmosphere. This lesson is focused on the short-term cycling of carbon.

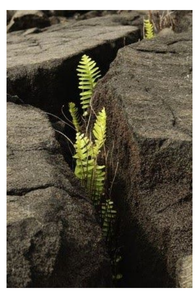


Photo credit: Freestock.com

Lesson Overview

The students will investigate the "short carbon cycle" and apply the results to atmospheric carbon dioxide levels.

- *Activity 1 – Engage (30 minutes) Initial Models of the Short-term Carbon Cycle*
  Plants in water - How do they survive? Introduce BTB as an indicator of O2 and CO2
- *Activity 2 – Explore (30 minutes) Plants and the Short-term Carbon Cycle - Part 1*
  How can we demonstrate photosynthesis and respiration using BTB indicator solution?
- *Activity 3 – Explain (15 minutes) Plants and the Short-term Carbon Cycle - Part 2*

Gather and analyze the results from the investigation; update model of short-term carbon cycle (terrestrial and aquatic) applying what was learned from the investigation

- *Activity 4 – Elaborate (15 minutes) Inputs and Outputs of the Short-term Carbon Cycle* Change the inputs to the model and predict the resulting outputs
- *Activity 5 – Evaluate* (*30 minutes*) *Connecting our Model to Global Carbon Dioxide Levels.* Apply their models to the Keeling curve and relate it to an imbalance in material cycles.

Instructional Overview	
Grade Level	Middle School
Total Instructional	120 minutes (*total time*)
NGSS Standards Alignment	**NGSS:** MS.LS1.C MS.ESS2.A MS.ESS3.D
Learning Goals	The students will be able to: ● Create a model of the short carbon cycle involving photosynthesis and respiration. In their model they will identify sources and sinks of carbon dioxide. ● Explain the mechanisms that take place within the short carbon cycle. ● Predict changes in the carbon cycle when inputs and outputs are adjusted. ● Analyze atmospheric carbon data relative to the short carbon cycle components and mechanisms, including animal and fossil fuel sources.
Materials	For each four-student team: ● Bromothymol Blue solution(approximately 400 mL per team) ● 4 test tubes with stoppers or plastic wrap ● 2 beakers to hold the test tubes ● Aluminum foil ● 2 straws ● 1 cotton ball ● 2 sprigs of Elodea (available at aquarium or pet stores) ● Laboratory goggles and aprons for each student ● Chart paper, markers, sticky notes If lab materials are unavailable, one of these two videos could serve as an alternative. Adjust the activities accordingly if videos are used instead of the lab materials. Bromothymol Blue Color Change: https://www.youtube.com/watch?v=r-TZMnH3NIA Photosynthesis and Elodea: https://www.youtube.com/watch?v=SZsQG_rPJwQ

Material Preparation	❏ Gather lab supplies and prepare the Bromothymol blue solution: 10 ml Bromothymol Blue (0.04% aqueous) to 1 liter of water.
Laboratory Safety	Always use safe laboratory practices. Students should wear aprons and goggles and should be warned not to inhale the BTB solution in Activity 1. Dispose of laboratory materials appropriately as prescribed by the manufacturer.
Vocabulary	Photosynthesis: The process by which green plants convert light energy into chemical energy and produce oxygen as a by-product Plant Respiration: The process by which plants utilize sugars and oxygen to create energy for plant growth and produce carbon dioxide as a by-product Short-term Carbon Cycle: Carbon is cycled through reservoirs such as the atmosphere, living organisms, and water in short periods of time

Activity 1 (Engage)
Initial Models of the Short-term Carbon Cycle (25 minutes)

Ask students where they (humans) fit into the short-term carbon cycle which includes carbon dioxide and oxygen, plants, animals, atmosphere, oceans. Ask them to draw a model that explains how these components of the carbon cycle are connected (10 minutes). Ask students to share their models with their partners, and then develop a class consensus model that can be referred to and updated throughout the lesson.

To confirm that humans exhale carbon dioxide and to familiarize students with the lab materials, students will perform a quick demonstration that confirms that we exhale carbon dioxide. Move students into their laboratory teams (3-4 students) and distribute all the lab supplies. Ask students how they know they exhale carbon dioxide. They will likely say that they just know that they exhale carbon dioxide. Tell them that they will be gathering evidence to demonstrate that they exhale carbon dioxide.

Tell students to fill a test tube about one-third full with the BTB solution. Mention that BTB is an “indicator solution” which will demonstrate the presence of carbon dioxide with a color change. Carbon dioxide when bubbled into water creates weak carbonic acid, which is indicated when the BTB solution turns from blue (no carbon dioxide) to green (low levels of carbon dioxide) to yellow (high levels of carbon dioxide), depending on the concentration of carbon dioxide. Tell students to place a straw in the solution, and place a cotton ball in the test tube opening to prevent the BTB from spilling over the test tube. Ask one student in each group to gently blow into the solution. Ask students to document in their notebook the color change in the test tube as it relates to the input of carbon dioxide.Tell them that they will be using this observation in the next part of the lesson.

Close this part of the lesson by asking how we can use this demonstration to model other parts of the short-term carbon cycle. They may mention that there may be a way to use it to model photosynthesis and respiration, but will likely not have a way to do so.

Clean-up: Dispose of the BTB solution as per the manufacturer's suggestions. Dispose of the straw and cotton ball properly, and clean the test tube.

Activity 2 (Explore)
Plants and the Short-term Carbon Cycle:Part 1 (30 minutes)

Ask students to describe the role of plants in the short-term carbon cycle. Review the chemical equations for photosynthesis and respiration highlighting oxygen and carbon dioxide in each equation.

Photosynthesis: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

Respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$

Tell them that they will be gathering evidence for the presence of carbon dioxide and oxygen as it occurs in each of the processes. Remind them of the results from the previous activity, and show them the materials (BTB, Elodea plants, foil, test tubes) they will use to gather evidence. Provide teams to design a controlled investigation using those materials while considering the equations for photosynthesis and respiration. If students have not had experience in designing controlled experiments, take a few minutes to identify key characteristics of such investigations.

After 10 minutes, ask teams to share their ideas while listening to ensure that they understand that respiration occurs in the absence of light, and photosynthesis occurs in the presence of light.

Distribute the materials (4 test tubes with caps, 2 beakers, 2 sprigs of Elodea, aluminum foil, BTB solution, straw, cotton ball). Tell students to use the following protocol.

1. Bubble carbon dioxide into the BTB solution using the straw until the color changes to yellow, while taking care not to inhale or bubble the BTB solution over the edges of the container.
2. Label the test tubes A-D. Fill the test tubes as follows:

   Test Tube A: BTB solution (half full)
   Test Tube B: BTB solution (half full) and Elodea sprig
   Test Tube C: BTB solution (half full)
   Test Tube D: BTB solution (half full) and Elodea sprig

3. Ask them to wrap Test Tube C and Test Tube D in aluminum foil, and place them in one beaker, and place (unwrapped) Test Tube A and Test Tube B in the other beaker. Place the beaker with Test Tubes A and B in a well lit area.
4. Set the beakers aside to be viewed the next day.
5. Clean up lab spaces as needed.

Ask students to make predictions in their notebooks about what they might expect to happen in each test tube, and why they think so. Ensure they focus on the processes and equations of photosynthesis and respiration, as well as the reason why BTB color changes in their predictions. They should also consider their initial model of the short carbon cycle. A data table such as the one below could help students organize their predictions and data gathering. Mention that they will pick up with the investigation the next day.

Sample Data Table with sample results:

Test Tube	BTB Color Before	Predictions after 24 hrs	Explain	BTB Color After	Explain
A	*yellow*			*yellow*	
B	*yellow*			*blue*	
C	*yellow*			*yellow*	
D	*yellow*			*yellow*	

Activity 3 (Explain)
Plants and the Short-term Carbon Cycle: Part 2 (15 minutes)

(Next day)

Ask students to share their predictions with the class while encouraging a discussion among all students. For example, ask students if they agree or disagree and why, or if they have different ideas of what to expect when they return to their investigations.

Students return to their investigations and record what they see in each test tube while considering why the changes that took place.

After students clean up their investigations, bring them back as a class to debrief their results. Ask them to share their results by tallying the results on chart paper or a marker board. Ask students to create an explanation based on evidence for what occurred. They should include the processes and equations of photosynthesis and respiration, as well as the reason why BTB solution changed color in Test Tube B. After 10 minutes, ask them to share their explanations with another group, and then ask a few students to share with the class.

Ask students how what they learned from the investigation will help them understand the short-term carbon cycle. Refer them to their models. They should connect photosynthesis and respiration to the cycling of carbon. Ask them how carbon cycling varies locally, and across the country while citing evidence for their arguments. Encourage them to think about local differences in vegetation. Ask them to adjust their carbon cycle models to account for local variations across the country.

Ask students if their models include enough detail to take into account global inputs and outputs for the short-term carbon cycle. For homework, ask them to generate a list of as many inputs and outputs (at least 5 of each) as they can, and that they will use this information in the next class period.

Activity 4 (Elaborate)
Inputs and Outputs of the Short-term Carbon Cycle (15 minutes)

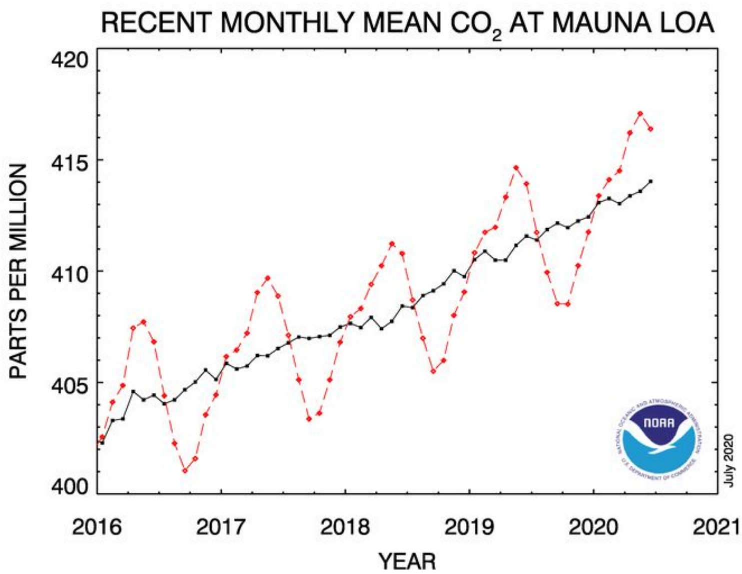
Open class by asking students to place the items on their homework list in a place where everyone in class can see like chart paper, or a marker board. They may use sticky notes, or write directly on the surface, but should be separated into two groups - inputs and outputs. If using sticky notes, then items that are the same could be stacked. Ask two students to sort the items into clusters they think refer to similar inputs.

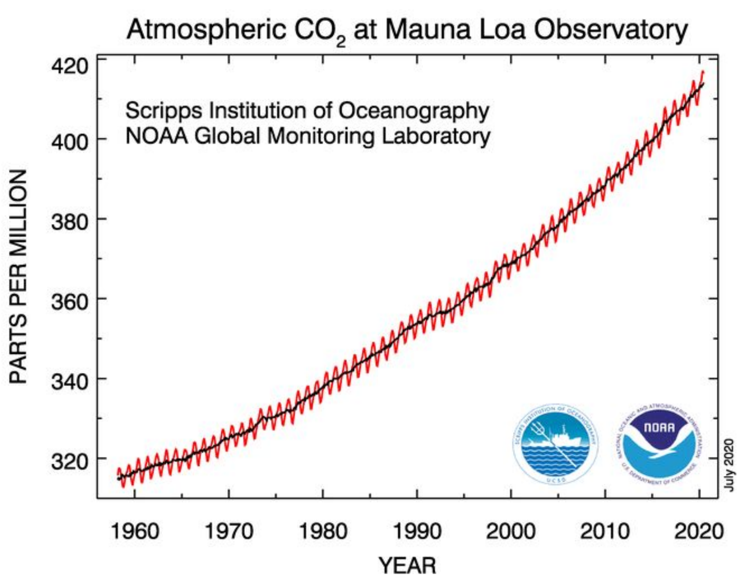
After they finish, allow two more students to view and adjust the work of the previous students. Mention that they will be using this list during the class period. Review the lists, and if inputs such as industry, transportation, living organisms, decomposition are not on the list, assist students with coming up with those items through questioning and discussions.

Allow them 10 minutes to update their models by adding the inputs and outputs from the class list. They should share their models with a partner to gather feedback to make adjustments.

Activity 5 (Evaluate)
Connecting our Model to Global Carbon Dioxide Levels (30 minutes)

To ensure students have included a global view of carbon dioxide, show them the most recent Global Carbon Dioxide Trend graphs from https://www.esrl.noaa.gov/gmd/ccgg/ such as these from July 2020:





Ask students to make observations of the data, and they will pick up on the positive trend in the data, but may not notice the subtle variability in the data. Mention the website where the data came from, and how scientists collected the data. Allow partners about 5 minutes to identify interesting aspects of the figures, and generate questions and “wonderings” (I wonder…) about the figures.

Ask students to report out their observations, and then ask them to connect this data with their models of the short-term carbon cycle. Important to pick out are the annual cycles in the data which are related to “greening-up” of vegetation in the Northern Hemisphere. Ask students how they would represent this trend in their models. Allow them 5 minutes to update their models by including this global trend in carbon dioxide.

Ask students to return to their lab teams with their models. In their lab teams, ask them to share their models, while other teammates provide feedback. Next, ask them to create a team consensus model on chart paper and hang it up. Using the “poster session” model, students walk around the classroom with sticky notes and leave comments on each other's models. After 10 minutes students retrieve their models and use the feedback to adjust their consensus model.

Remind students that models are useful, and that they can use their models to predict what would happen if one of the inputs or outputs are adjusted. Have them practice this by covering up one of the components in their model, and then predict what would occur to the short-term carbon cycle with that adjustment. For example, what would happen to the balance of oxygen and carbon dioxide should living organisms except plants disappear from the planet?
5. Assess the team consensus model for completeness, including connecting components, and evidence, along with the mechanisms for the transformations within the short carbon cycle.