hhmi | BioInteractive

The Breathing Biosphere and Human Contribution

Click & Learn
Educator Materials

OVERVIEW

In the Click & Learn *The Breathing Biosphere and Human Contribution*, students explore factors that contribute to patterns seen in the **Keeling Curve**: a continuous record of atmospheric CO_2 starting in 1958, as measured at the Mauna Loa Observatory in Hawaii.

- The first tab, **"Natural Processes,"** focuses on the processes of respiration and photosynthesis. Students adjust parameters in a model of these processes to match the model with "adjusted" data from Mauna Loa.
- The second tab, **"Human Contribution,"** shows the original data from Mauna Loa. Students adjust a human contribution parameter in the model to match the Keeling Curve.

The accompanying "Student Worksheet" guides students through the Click & Learn. Students use the Keeling Curve to explore processes that add and remove CO_2 from the atmosphere. They also manipulate the model to test different inputs and outputs and find out how predictions match observations. By the end of the worksheet, students should be able to explain the processes and causes of the patterns in Keeling Curve.

Additional information related to pedagogy and implementation can be found on this resource's webpage, including suggested audience, estimated time, and curriculum connections.

KEY CONCEPTS

- The concentration of CO_2 in the atmosphere can be directly measured, and there is a continuous record of CO_2 measurements going back to 1958.
- The amount of CO_2 in the atmosphere responds to natural processes, which can add CO_2 to and remove it from the atmosphere.
- The natural processes of photosynthesis and respiration cannot account for the overall rise in atmospheric CO_2 since 1958.
- Human activities release CO_2 into the atmosphere and have significantly increased overall CO_2 levels.

STUDENT LEARNING TARGETS

- Use a simulator to adjust the parameters in a model to match observed CO_2 levels.
- Describe processes that add CO_2 to and remove it from the atmosphere, respectively.
- Use model fitting to estimate anthropogenic inputs of CO_2 to the atmosphere.

PRIOR KNOWLEDGE

Students should have a general understanding of:

- the carbon cycle — specifically processes that release carbon into the atmosphere (carbon sources) and processes that remove carbon from the atmosphere (carbon sinks)
- photosynthesis — specifically its inputs/outputs and seasonal/geographical patterns in photosynthesis rates
- respiration — specifically its inputs/outputs and that it is the "inverse" of photosynthesis
- how humans contribute to carbon emissions
- interpreting line graphs

MATERIALS

- copies of the "Student Handout"
- access to the Click & Learn *The Breathing Biosphere and Human Contribution*

BACKGROUND

Carbon

Although carbon dioxide is essential for maintaining livable global temperatures, it is also the primary greenhouse gas that contributes to anthropogenic (human-induced) climate change. Numerous solutions exist for decreasing carbon emissions, to reduce the impacts of human activity on the environment.

Photosynthesis and cellular respiration are key processes in the cycling of carbon. The carbon cycle between the biosphere and atmosphere has both natural and human components that are distinguishable and can be measured.

Keeling Curve

The Keeling Curve is a continuous measurement of Earth's atmospheric CO_2 levels taken at the Mauna Loa Observatory at the top of Hawaii's Mauna Loa volcano. It is named after scientist Charles Keeling, who founded the program that takes these measurements. This program, the Scripps CO_2 Program, has been recording CO_2 levels in the atmosphere at Mauna Loa since 1958. Although Keeling passed away in 2005, the Scripps CO_2 Program continues under the leadership of his son Ralph F. Keeling.

The Keeling Curve illustrates fluctuating seasonal atmospheric CO_2 levels, as well as an overall increase in CO_2 levels due to human actions (like fossil fuel combustion). Importantly, it was one of the first examples of measuring a global-scale biogeochemical cycle. Data from the curve has led to critical, ongoing research on the environmental impacts of rising CO_2 and actions that may mitigate the current trend.

TEACHING TIPS

Implementing the Resource

- The "Procedure" section provides a sample procedure for implementing the Click & Learn with its accompanying "Student Worksheet."
- If you are concerned about engaging all students in discussions, after asking each question, encourage them to talk with a partner before soliciting whole-class responses.

Caveats/Clarifications

- In the "Natural Processes" tab of the Click & Learn, the data was adjusted to remove the contribution from human activity. This was done by removing the annual increase and assuming a steady-state model in which photosynthesis and respiration are balanced.
- The "Natural Processes" and "Human Contribution" tabs have a "fit score" that is calculated by comparing the student estimates to the optimal value for each parameter. Four parameters go into this score: peak month and peak rate of photosynthesis and peak month and peak rate of respiration. Each parameter is scored on a scale of 0–1 with 1 being a perfect fit to the model. The four scores are then multiplied to give the overall fit score.

Extensions and Supplements

- The BioInteractive short film *The Science of Climate Change* features the Keeling Curve. You can use this film to show students how atmospheric CO_2 measurements are made and how the data fits into longer records of CO_2 from ice cores and marine sediments.
- Students interested in learning more about human contributions to carbon emissions can explore their individual impact through the activity "What Is My Carbon Footprint?" This activity will introduce them to, and guide them through calculating, their household's carbon footprint.

- Students interested in developing a deeper understanding of the carbon cycle (particularly those who are currently taking, or will later take, AP Biology or college-level biology) can complete the "Earth Systems Activity."

PROCEDURE

The procedure below is just one way to implement this resource, specifically with a general or honors high school biology class. You should feel empowered to use this resource in a manner that is both responsive to your students as learners and supportive of your own teaching skills. Additionally, you may need to adjust implementation based on your students' prior learning and/or current preconceptions.

Warm-up

Before introducing the main resource, review concepts as needed from the "Prior Knowledge" section.

In particular, students should be familiar with reactants and products of **cellular respiration and photosynthesis**, oxygen and carbon dioxide in particular. Importantly, they should understand where the reactants come from and where the outputs go, so as to correctly identify carbon sources or sinks.

- As review, you could have students write out the chemical equation for each process, identify where the reactants come from, and indicate where the products go once made. Discuss as a whole class once all students have written something down.
- You can use the *Photosynthesis* animation to introduce or review photosynthesis as well.

Students may also benefit from a short tutorial or review on **graph interpretation**. The Identify and Interpret (I^2) strategy developed by BSCS Science Learning is one highly effective approach for interpreting graphs.

Part 1

Begin by providing students with a brief verbal background of the Keeling Curve, including its history and what type of data it shows. This may be especially important for students who've had limited prior engagement with the carbon cycle.

- You can use the "Trends in Atmospheric Carbon Dioxide" Data Point to introduce students to the Keeling Curve. Use the discussion points in the Data Point's "Educator Materials" to provide students with a solid foundational understanding of the curve and its significance.
- Be careful not to give away answers to the questions in Part 1 of the "Student Worksheet."

Distribute the "Student Worksheet" and have students work collaboratively with a peer to answer each of the questions in Part 1. Once all students have had a chance to write their initial thoughts, regroup as a whole class. Encourage students to share their thoughts and guide them to the correct answers.

This will be an important opportunity to determine which misconceptions about cellular respiration/photosynthesis persist, and whether students were able to make connections between microlevel metabolic pathways and macrolevel biogeochemical cycles.

Part 2

Before students move on to Part 2 of the "Student Worksheet," it is recommended to give them a tour of *The Breathing Biosphere and Human Contribution* Click & Learn — in particular, a demonstration of how to use the model in the "Natural Processes" tab.

- You can project your screen (for in-person settings) or screenshare (for online settings) to show the Click & Learn to the entire class.
- You can engage students by manipulating the model settings and asking them to explain what trends they observe, which doubles as practice with graph interpretation.
- You can also ask students to guide you to which settings to manipulate or ask them how to manipulate certain settings to reflect different environmental conditions.

Have students work individually on computers, tablets, or mobile devices to engage with the Click & Learn and answer the questions in Part 2 of the worksheet.

- If the number of devices is limited, multiple students can share.
- If students require additional time to complete Part 2, it can be assigned as homework (if all students will have access to the Click & Learn) or finished the following day in class.

Once students have completed Part 2, you can review by projecting/sharing your screen and filling out the model settings as guided in the activity. Ask students to contribute their responses to each of the questions.

Part 3

Part 3 of the "Student Worksheet" can be repurposed as a formative assessment to be completed individually in class. This part touches on each of the student learning targets, so you can use students' responses to determine which key concepts require additional review in advance of a summative assessment.

ASSESSMENT GUIDANCE

PART 1: Carbon in the Atmosphere

1. Describe two main patterns in Figure 1.
   Answers will vary. Students should note the sawtooth pattern and the overall rise in CO_2.

2. Figure 1 shows that the amount of CO_2 in the atmosphere changes over time.
   a. Based on what you already know, what are some processes that *add* CO_2 to the atmosphere?
      Cellular respiration is the key process for this activity. Other answers include decomposition/decay, fossil fuel emissions, cement manufacturing, deforestation, land-use change, volcanoes, and exchange with the ocean.

   b. What are some processes that *remove* CO_2 from the atmosphere?
      Photosynthesis is the key process for this activity. Other answers include exchange with the ocean and rock weathering.

3. Match the following processes and equations to the letters in the model. Record the matching letters in the table.

Process or Equation	Letter
$6CO_2 + 6H_2O$ + light energy $\rightarrow C_6H_{12}O_6 + 6O_2$	***D***
$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + chemical energy	***C***
Photosynthesis	***B***
Respiration	***A***

4. Match the following scenarios to each of the graphs. Record the letters for the matching graphs in the table.

Scenario	Graph
Respiration = Photosynthesis	***B***
Respiration > Photosynthesis	***C***
Respiration < Photosynthesis	***A***

PART 2: Seasonal Variations in Natural Processes

5. Once you find your best possible fit, record your settings and fit score in the following table.

Setting/Score	Value
Photosynthesis Peak Rate	***4.35 ppm/month***
Photosynthesis Peak Month	***June***
Respiration Peak Rate	***2.7 ppm/month***
Respiration Peak Month	***June***
Fit Score	***1***

6. The observed data in the simulator come from the Mauna Loa Observatory in Hawaii, which is in the northern hemisphere. Would you expect the same pattern from an observatory in Antarctica? Explain your answer.
Answers will vary depending on students' prior knowledge. They may say that seasons are opposite in the southern hemisphere, so the pattern may have the same shape shifted by a few months. Students may also say that there is less vegetation in Antarctica, so the rates of photosynthesis and respiration would be less pronounced.

PART 3: The Human Contribution

7. In addition to seasonal variations, the Keeling Curve (Figure 1) also shows an overall increase in CO_2 since 1958. Based on what you've learned from the previous questions, can the natural balance of respiration and photosynthesis account for this increase? Explain your answer.
Answers will vary. Students should note that if respiration and photosynthesis are balanced, then there should be no overall increase of CO_2 in the atmosphere. So these natural processes cannot account for the observed increase.

8. Which process in Figure 2 is the most likely to be responsible for the increase in atmospheric CO_2? (*Hint*: Look for the biggest *unbalanced* movement of carbon to the atmosphere.)
Fossil fuel emissions are most likely responsible for the increase in atmospheric CO_2, since they cause the biggest unbalanced movement of carbon to the atmosphere (9 billion tons per year).

9. Once you find your best possible fit, record your settings and fit score in the following table.

Setting/Score	Value
Annual Human Contribution	***2.6 ppm/year***
Fit Score	***1***

10. Human activity releases excess CO_2 to the atmosphere, which is causing global climate change. What are some actions that individuals and society can take to reduce CO_2 emissions?
Answers will vary depending on students' prior knowledge. Students could mention individual actions, such as reducing energy use, switching to a hybrid car, using public transportation, eating a plant-based diet, etc. They could also mention collective and systemic actions, such as implementing carbon pricing, transitioning to renewable energy sources, improving agricultural practices, etc.

REFERENCES

Keeling, C. D., S. C. Piper, R. B. Bacastow, M. Wahlen, T. P. Whorf, M. Heimann, and H. A. Meijer. "Exchanges of atmospheric CO2 and 13CO2 with the terrestrial biosphere and oceans from 1978 to 2000." I. Global Aspects. *UC San Diego: Library – Scripps Digital Collection* (2001). https://escholarship.org/uc/item/09v319r9.

CREDITS

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