Curriculum for the Bioregion[1]

How Many Plants Make a Future? The Carbon Dioxide Challenge

A hands-on lab activity for introductory college courses in biology, oceanography, or environmental science, and, science education courses with pre-service middle and high school teachers.

Vanessa Hunt, Central Washington University, huntv@cwu.edu
Rus Higley, Highline Community College Marine Science & Technology Center
Timothy Sorey, Central Washington University

Summary

The story of Biosphere 2 is introduced to the students in the context of a discussion of the carbon cycle, climate change, and CO_2 accumulation in the atmosphere. The lab activity focuses on the role of photosynthesis in a sustainable future. Students explore the effect of photosynthesis and respiration in one liter 'closed systems' containing plankton, marine plants, and fish. By calculating carbon dioxide uptake and production in these systems, students predict a plant: animal ratio sufficient to maintain a system in carbon dioxide 'balance' for one hour. Building and testing the system, then extending it to a longer time period, demonstrates to the students that carbon dioxide accumulation, even in a simple system for a short time period, is not a trivial matter. Students apply concepts from biology, solution chemistry, and exercise considerable quantitative reasoning from real data as they design and fine-tune their systems.

Learning Goals and Big Ideas

This activity focuses on the role of photosynthesis in a sustainable future. During the course of the activity, the students learn about the chemistry of carbon dioxide dissolution in water, make chemical and technologically- based measurements of water parameters, and use these measurements to calculate CO_2 uptake (by phytoplankton and marine plants)and production (by plankton,

[1] *The Curriculum for the Bioregion is an initiative of the Washington Center for Improving the Quality of Undergraduate Education at The Evergreen State College. This "teaching and learning activity" is one of several developed by a faculty learning community in math studies in February, 2010.*

plants, and fish) in their closed systems. The mathematical skills employed are basic, but the quantitative reasoning required is quite sophisticated, and this simple model serves to demonstrate the complexity of this "real-world" problem.

By calculating carbon dioxide uptake and production in these systems, they predict a plant: animal ratio sufficient to maintain a system in carbon dioxide 'balance' for one hour. Accounting for the effects of confounding variables in their systems also develops student understanding of the challenges of applying the scientific method to complex situations. This activity demonstrates to the students that carbon dioxide accumulation, even in a simple system for a short time period, is not a trivial matter.

Keywords: carbon dioxide, photosynthesis, respiration, closed systems, sustainability, deforestation.

Context for Use

How Many Plants Make a Future? The Carbon Dioxide Challenge is a hands-on lab activity integrating biology, chemistry, and quantitative reasoning suitable for introductory biology, oceanography, or environmental science courses. It has also been used profitably in science education courses with pre-service middle and high school teachers. This activity attempts to experimentally balance photosynthesis and respiration in a closed system, and makes clear that this is not a trivial matter. The story of Biosphere 2 is introduced to the students in the context of a discussion of the carbon cycle, climate change, and CO_2 accumulation in the atmosphere. We stress the role of deforestation in this problem, and emphasize the role of photosynthetic organisms in a sustainable future. One hour of lecture followed by a three hour lab period is sufficient to complete the basic activity. However, variations of the activity (such as having students examine the photosynthetic rates of different plant species) will generate more discussion and require more time.

During the course of the activity, the students learn about the chemistry of carbon dioxide dissolution in water, make chemical and technologically- based measurements of water parameters, and use these measurements to calculate CO_2 uptake (by phytoplankton and marine plants)and production (by plankton, plants, and fish) in their closed systems. The mathematical skills employed are basic, but the quantitative reasoning required is quite sophisticated, and this simple model serves to demonstrate the complexity of this "real-world" problem.

A data-based prediction employs quantitative skills using the student's own data to design a closed system where the ratio of photosynthetic mass to respiring mass is sufficient to balance CO_2 for a short time period. When this system has been constructed and tested by the students, a class discussion frequently reveals that the initial predictions of plant/animal mass have failed to balance CO_2 in the system over a one hour period, providing an opportunity to discuss some of the confounding variables involved in the experimental set-up. An extension to the activity has students design a system that will remain balanced for 24 hours, incorporating a 12 hour dark period where respiration continues but photosynthesis ceases.

Note: This activity was designed as part of a marine science unit, but translates well into freshwater systems.

Description and Teaching Materials

Scaffolding Activities: Delivered as Lecture/Discussion

1. Discuss global warming, and the buildup of excess atmospheric carbon dioxide as a primary contributing factor.

2. Review the carbon cycle, stressing the roles of respiration and photosynthesis. Emphasize that the uptake of carbon dioxide by photosynthetic organisms is being increasingly reduced by deforestation, and potentially reduced by a decline in photosynthetic plankton if the oceans become more acidic. Pose the problem: how much plant mass is required to balance respiration in our closed global system? We sometimes show the video *Acid Test* (see resources) at this juncture.

3. Point out that this is not a trivial problem, and that so far our best efforts to balance the uptake and production of carbon dioxide in a complex system have failed. Tell the story of Biosphere 2, an ‘earth in a bottle’ experiment that cost upwards of $200 million, and involved nine years of focused planning by NASA scientists and engineers. The 3.15 acre system choked on carbon dioxide after two years, following adverse affects to humans, other vertebrate animals, pollinating insects and trees. This dramatic story is beautifully illustrated on a number of websites (see resource section for recommendations). Inform the students that in the laboratory activity to follow, they will be challenged to balance carbon dioxide uptake and production in a 1 liter beaker, with one species each of plant and animal.

4. Students need to know the following content:

a) Equations for photosynthesis and respiration, noting that carbon dioxide is the product of respiration and a reactant in photosynthesis. They should be aware that all organisms respire continuously, whereas photosynthesis is limited to phytoplankton and plants in the presence of light.

b) The solution chemistry of carbon dioxide in water, specifically the relationship between CO_2 concentration and pH. At a minimum, students need to be aware that dissolving carbon dioxide in water results in formation of both bicarbonate and carbonate ions, thus dissolved carbon dioxide cannot be measured directly. However, dissolving CO_2 gas in seawater also leads to increased concentration of hydrogen ions (H+) and thus increases acidity and decreases pH. Thus a decrease in pH is to be expected as CO_2 is dissolved in water, and an increase as CO_2 is consumed. Therefore, changes in pH indicate CO_2 production and consumption.

Obtaining a quantitative estimate of dissolved CO_2 requires knowing pH and also kH. kH or carbonate hardness (aka carbonate alkalinity) is a measure of presence of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) ions resulting from the dissolution of CO_2 gas. It is usually expressed either as *parts per million* (ppm or mg/l), or in *degrees* **KH** (from the German *"Karbonathärte"*). kH is easily measured with an inexpensive carbonate hardness kit available from any store catering to marine aquaria.

Possession of a pH and kH measurement for a water sample allows calculation of the CO_2 concentration of that sample. The necessary formula is: CO2 (in PPM) = 3 * KH * $10^{(7\text{-pH})}$ Alternatively, students can input their pH and kH values into the online calculators contained in aquarists' websites (see resources for a suggestion).

As with other solutes, the solubility of CO_2 in water is related to temperature (we remind the students of the tendency of soda pop to go 'flat' at room temperature). Thus we attempt to retard temperature changes in the activity by keeping the experimental beakers submerged in a water bath. We check on the success of this by measuring temperature before and after. If the temperature has changed by more than 1 degree centigrade, the results are to be interpreted with caution: we inform the students that they will be required to research and reason out the possible effects on their data if a larger temperature change occurs.

<u>Materials required per group</u>

Three one liter beakers
Thermometer
Plastic wrap/rubber bands to seal beakers
Sea water to fill beakers to one liter
Digital Scale
Electronic pH meter
KH (carbonate hardness) testing kit (obtainable from aquarium stores)
Aquarium or cooler sufficient to hold three 1 – liter beakers in water bath
Grow – light (to place atop aquarium or cooler and stimulate photosynthesis)
Marine plant material (up to enough to half-fill one liter beaker). Eelgrass suggested if available. Plant material should be in good condition, and without roots or non-photosynthetic parts.
One marine fish (a tide pool fish small enough to survive one hour in a beaker is needed: we have used gunnels and sculpins)

Lab Directions to Students

(For full directions **see attachments)**

This activity challenges you to design and build a simplified version of Biosphere 2 – in a 1-liter lab beaker. That is, you are to produce a balanced system in terms of photosynthesis and respiration over a one hour period. Your system will contain only one species of animal and one species of plant. As this is a marine system, your system will also contain plankton. Some plankton are photosynthetic, others not. At any rate, the presence of plankton will have an effect upon the system, in terms of either taking up or producing carbon dioxide. The net effect of plankton upon the carbon dioxide concentration will be apparent from the control beaker.

Attachments

Data Collection/Analysis - Student Handout for: 'Earth in a Bottle: The Carbon Dioxide Challenge'

Lab Directions - Student Handout for 'Earth in a Bottle: The Carbon Dioxide Challenge'

Teaching Notes and Tips

An intriguing variation is to have the activity build on a field trip where students collect their own plants and animals for their system. This can either be a beach trip on a low tide day, or a trip to a wetland or local lake. Be aware that collecting permits may be required. Where field collecting opportunities are limited, this activity can be based upon aquarium plants and feeder goldfish obtained from a pet store. If marine plants are freely available, but animal collecting is a legal problem, consider obtaining invertebrates from a seafood market.

Invertebrates, such as clams and oysters, can substitute for fish if only the mass of the soft tissue is considered. In this case, take the mass of the animal <u>after</u> the conclusion of the experiment and after removing the shells. Be aware that the respiration rate of invertebrates tends to be considerably lower than that of fish.

This activity serves as a good springboard for ideas for small scale student projects suited to elementary biology classes. Students may become interested in the effects of plankton photosynthesis and respiration at different times and in different places, how photosynthetic rates vary with plant species, and the factors affect respiration rates in fishes.

Assessment

<u>Assessment and Feedback</u>

Completion of tables, necessary calculations, and design of a 'sustainable' system from experimentally derived data provide a mechanism that ensures understanding of the biological and chemical processes involved, and indicates that the student's quantitative reasoning is sound.

As a summative assessment, we suggest having each group distribute their results to others, including observations and comments. The plant: animal mass ratios that proved reasonably successful may vary. Have students review that results of others, and produce a report or short presentation on their thinking about class results.

Finally, we encourage students to extend their thinking. What about the activity interested or perplexed them? If they were to do a follow-up independent project, what would they choose to investigate? What ideas about methodology do they have?

Resources

Carbon Dioxide http://www.lenntech.com/carbon-dioxide.htm

Ocean Acidification: http://en.wikipedia.org/wiki/Ocean_acidification

"Acid Test: The Global Challenge of Ocean Acidification." National Resources Defense Council. 22 minute video available online at **http://www.nrdc.org/oceans/acidification/aboutthefilm.asp**

Wurts, W.A. and. Durborow, R.M.. 1992. Interactions of pH, Carbon Dioxide, Alkalinity and Hardness in Fish Ponds.
Southern Regional Agriculture Center
http://www.ca.uky.edu/wkrec/InteractionspHEtc.PDF

Biospherics: http://www.biospherics.org/
Online Calculator For CO_2 Concentration Based on pH and kH:
http://www.csd.net/~cgadd/aqua/art_plant_co2chart.htm

Tropical Deforestation:
http://earthobservatory.nasa.gov/Features/Deforestation/deforestation_update3.php

DOE (1994) *Handbook of Methods for the Analysis of the Various Parameters of the Carbon Dioxide System in Sea Water; version 2,* A.G. Dickson & C. Goyet, eds., ORNL/CDIAC-74. See Chapter 2: Solution Chemistry of Carbon Dioxide in Seawater. . http://cdiac.ornl.gov/ftp/cdiac74/chapter2.pdf