

EARTH SYSTEMS

in a Bottle

Building Earth systems teaches students an integrated environmental lesson

EARTH AND ITS SYSTEMS, A NATURAL integrated unit, incorporates an understanding of biology, physics, chemistry, and geology. The various systems on Earth (the atmosphere, hydrosphere, biosphere, lithosphere, and cryosphere) are interrelated; changes in one system control or regulate changes in another. Earth is home to all of us, making the topic relevant to students, and studying Earth and phenomena that take place on our planet as a set of interrelated systems allows students to learn how scientists work. Earth systems can be used for a conceptual, methodological, and philosophical approach to teaching (Mayer, 1991) and as a means to unstuff an overcrowded curriculum (Fortner et al, 1992).

Integrated science topics or activities significantly incorporate more than one core science discipline. Although many class activities could be considered from the vantage point of multiple sciences, many educators rarely look at them in this way. Because students must often use knowledge from multiple science areas to be successful, I have developed a topic and activity that involves integrated science.

When dealing with real-world occurrences like global temperature change, oceanography, or evolutionary events, many scientific organizations value an Earth systems-based approach. Earth Systems Science Education Program (ESSE, a group supported by NASA and the National Academy of Sciences) and Project ALERT (an Earth science education project undertaken by NASA and the California State University) are among the groups developing integrated, interdisciplinary science courses around this topic. These modules can be used at the high school level. ESSE, for example, has a website with links to several courses and resources that could be adapted to the high school level (Figure 1).

USING AN EARTH SYSTEM

An eco-column activity using 2 L soda bottles incorporates Earth systems and provides an integrated science

approach. The activity itself is not new (Ingram, 1993), but I have modified it for use as a culminating integrated science project. Some features that make it unique include the following:

- ✳ Students have complete freedom in designing their ecosystems.
- ✳ All the sciences are emphasized in the activity, not just biology.
- ✳ Students equate what happens in the columns to Earth and its systems.

The activity is open ended with only general requirements. First, the ecosystems must have land plants and animals, aquatic plants and animals, and an atmosphere. The land, water, and air sections of the ecosystem should be connected and interdependent, but the entire system must be closed. Because only sunlight enters the system, the ecosystem models Earth's interacting systems.

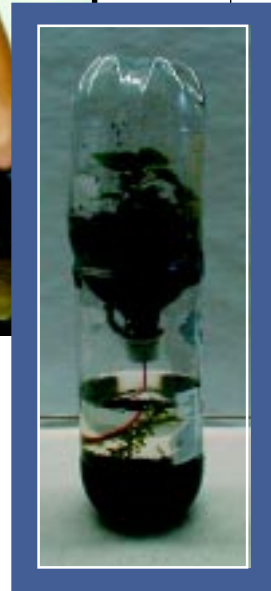
Second, students must monitor the ecosystems by having thermometers and bromo-thymol blue (BTB, a liquid acid-base indicator) built into the systems so they can observe relative amounts of carbon dioxide, pH values, and temperature. Beyond these instructions, students are free to develop their own design, observing classroom safety standards.

Prior to developing a complex eco-column, students practice making single units to grow plants, keep aquatic animals and plants alive, or keep land animals and plants alive. Each group records what they did and what they observed over a period of time, and they share results and learn from one another. After they have learned how to keep everything alive, students develop their multi-sectioned eco-columns.

Failed systems provide teachable moments. Students and the teacher monitor each other's process to prevent catastrophes, and it is important to be sure students include a food source for the animals. This is the



LAURA HENRIQUES



ideal time to discuss food webs and food chains. Students sometimes need to be reminded to include a mechanism for getting water to the plants, and we discuss the properties of water and water's importance in plant growth.

When students construct their models (Figure 2), they make baseline readings of the conditions (temperature, pH, dissolved oxygen, and dissolved nitrates) in their "worlds." Then they add living organisms and close the system. Containers of BTB and thermometers are built into the system, and students monitor those readings daily. Thermometers are taped inside the bottles, and BTB in small clear cups or vials is placed in the "land" section. Students cover the vials with netting so crickets and other creatures do not drown.

To fully appreciate this application-oriented activity, students need to understand acid-base reactions and photosynthesis. Using BTB in the system allows students to see

variations in amounts of carbon dioxide, an indication of photosynthesis. Other biology concepts are involved in understanding the bottle ecosystem. Students study life cycles of plants and insects during the unit, and they germinate seeds outside the column while their plants begin sprouting inside. Students compare the plant growth outside the column to plant growth inside the column. In some cases, students germinate plants prior to building their ecosystem and add those plants to their columns.

The project involves more than biology and Earth science concepts, though. Students who use green soda bottles often get different results from those who use colorless bottles, and this difference leads to a discussion about light and color. Students discover that the amount and color (wavelength) of light shining on plants influences photosynthesis. They also learn that plants receive

only green light will not photosynthesize because green light is reflected, not absorbed. (Note that green bottles are not perfect monowavelength filters, but students can see differences in plant growth.) Students often do additional experiments with colored cellophane and filters to test the effects of different colored light on plant growth. This activity can be used to introduce a discussion about how humans see and how colors mix and reflect. We also use a computer program to demonstrate how color, reflection, and absorption of light affects plant growth. Students are able to grow virtual plants exposed to different colored lights at varying intensities, which allows them to instantly see multiple trials of plant growth under different circumstances.

After several weeks of observing, students dismantle their eco-columns, determine which organisms were the most successful, and test each organism's environment. For example, students test the hydrosphere

SciLINKS
THE WORLD'S A CLICK AWAY
 Keyword: Food webs
 Go to: www.scilinks.org
 Code: TST0049

FIGURE 1.

Useful resources.

- ✦ Earth System Science Education Program—homepage includes links to university-developed Earth Systems courses, and the rationale for and definition of the Earth systems approach: www.usra.edu/esse/essonline.
- ✦ Earth Systems and Global Change—college course homepage that includes links to related sites as well as science background for teachers interested in teaching this topic: seis.natsci.csulb.edu/rbehl/300.htm.
- ✦ Project ALERT—project to improve Earth science education, includes modules and activities: www.projectalert.nasa.gov.

FIGURE 2.

Directions for assembling eco-columns.

Safety concerns and teacher notes: Care should be taken when using X-Acto knives. Students should cut away from themselves, making the initial cut with the X-Acto knife and then using scissors. Students should use clean bottles.

Materials needed:

- ✦ clean, empty, 2 L soda bottles
- ✦ X-Acto knives or scissors
- ✦ hammer and nail (for poking holes in soda tops)
- ✦ cotton string
- ✦ wide, clear packing tape or glue gun—to attach segments of bottles together
- ✦ dirt/potting soil, plants, and/or seeds (I use white alyssum plants and grass seed)
- ✦ netting
- ✦ assortment of animals such as crickets, which are available from pet stores. Small crickets do not have mature wings and are silent. Large crickets can chirp. A small piece of fruit or vegetable provides crickets with food and moisture. Pillbugs, worms, snails, and spiders can all be found outside. Pillbugs are decomposers and are found in moist, dark areas under rocks or in low growing ground cover. Small freshwater fish (guppies or goldfish) and aquarium plants are also required. I ask the pet store clerk for the hardiest species. Aquaria rocks should be obtained to finish off the water environment.

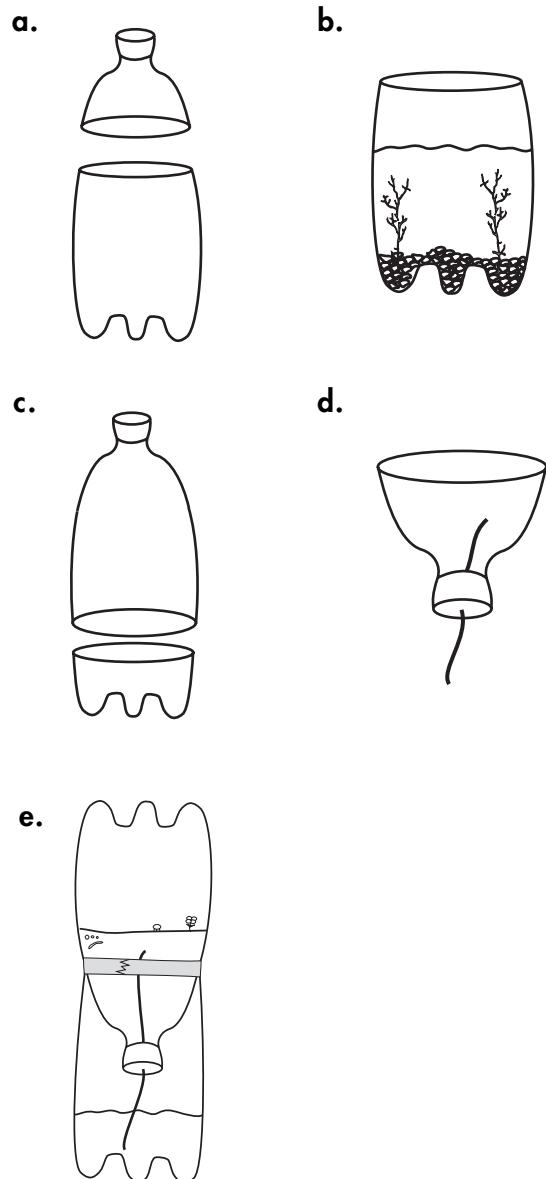
Making the hydrosphere/biosphere:

- ✦ Remove the top quarter of the bottle (Figure 2a).
- ✦ Fill the bottom segment 2/3 full with distilled water.
- ✦ Add aquaria rocks and plants. The plants serve as a food source as well the source of oxygen, and the rocks anchor the plants to the bottom (Figure 2b).
- ✦ Add fish.
- ✦ Store the unit in sunlight.

Making the lithosphere/biosphere/atmosphere:

The segments that contain plants need to have a source of water. Because the eco-columns are closed systems, students must develop their columns to be self-sufficient. To do this, students must use two or more bottles. The most common approach is to create a wicking system. Other approaches that students have tried include a water source that slowly drips water (like rain) from above and submerging the base of the plants into a water source (to mimic groundwater). To make the wicking system:

- ✦ Cut the bottom off a clean, empty bottle (Figure 2c).
- ✦ With a hammer and nail, poke a hole (or holes) into the plastic lid.
- ✦ Thread cotton string through the hole so the lid is in the middle of the string (see Figure 2d).
- ✦ Saturate the string in water.
- ✦ Reattach the lid. At this point, the string will be hanging from the empty bottle and sticking into the empty bottle.
- ✦ Flip the bottle upside down and fill it with dirt, covering the wet string. Be sure that the string is spread out in the dirt, not just at the bottom. This supplies water to the plants.
- ✦ Add plants or seeds.
- ✦ Cut the top off another bottle, at the bend in the bottle.
- ✦ Fill the bottom section of the second bottle with water to a depth of approximately 10 cm.
- ✦ Balance the bottle with the dirt and plants on the water reservoir. The wick from the top bottle should be in the water; the lid should not.
- ✦ Add animals and cover (Figure 2e).



and find that dissolved nitrates and oxygen levels are related to the status of the plants and fish. The death of a fish increases the amounts of nitrates, but overfeeding and the amount of waste produced also influence the nitrate level. These observations allow me to introduce students to the nitrogen cycle. Water from the hydrosphere eventually gets into the soil in the land section or goes from soil to the hydrosphere. If the water gets acidic, it can affect the soil because each section is connected (usually by a cotton wick). To help students apply this concept to Earth systems, we discuss runoff and water pollution.

CROSSING BARRIERS

A lesson normally found in biology classes, this integrated science activity extends across the curriculum helping students realize that science in the real world is not separated into discipline-specific areas. Student reaction is positive, and students get attached to their columns and are eager to see how well their animals are doing. Some students even get over their distaste of insects during the unit because their goal is to keep them alive.

Students gain an appreciation of Earth and the complexity of our planet. They begin to understand how changes in one area of the world can be felt in other areas. Discussions about global weather patterns are easy for students to understand, for example, when they can relate increased evaporation rates to activity in their own columns. The various sections of the bottles are tiny models of the ocean, land, and air. To tackle and understand a problem, students must simultaneously use their understanding of biology, chemistry, physics, and geology. After mastering the content (Figure 3), some students are so interested

FIGURE 3.

Connecting eco-columns to the *National Science Education Standards* (National Research Council, 1996).

The eco-column activity and subsequent discussions foster student understanding of several key concepts:

- ✧ Scientific inquiry (page 176)—students design and investigate eco-columns over an extended period of time.
- ✧ Chemical reactions (page 179)—students examine nitrate reactions and investigate acids and bases.
- ✧ Interdependence of organisms (page 186)—food chains, ecosystems, photosynthesis' role in ecosystems, resources vs. population size, impact of humans on ecosystems.
- ✧ Matter, energy, and organization in living systems (page 186)—sunlight as initial energy to drive living systems, photosynthesis, nitrogen cycle.
- ✧ Energy in the Earth system (page 189)—sunlight as energy source, global climate change, convection currents in atmosphere and oceans, weather.
- ✧ Population growth and natural resources and environmental quality (page 198)—carrying capacity, Earth's chemical and physical cycles, populations' use of resources and creation of wastes.

that they become vocal advocates for the environment.

I assess students throughout the unit, and students self assess. For example, students build simple, single-chamber columns first. They gather data, share it with classmates, and use the information as a basis for building more complex systems. How well they use the diagnostic data from the first round of experiments shows me their level of understanding. Students keep journals throughout the unit and record reasons for different design decisions and data that support the decisions.

Test questions I ask in this unit include a diagram of an eco-column and a scenario to which they respond. Below are some scenarios students must address:

- ✧ Describe the long-term effects of using green soda bottles instead of colorless ones. Describe, in chronological order, the impact on plants and animals, levels of dissolved oxygen, nitrate and ammonia levels, and temperatures. Include your reasoning for any changes.
- ✧ Describe the long-term impact of a toxic liquid spill in the land section. Describe, in chronological order, effects on plants, animals, soil, and water. Include the cause-and-effect relationships that produce these results.
- ✧ Describe what would happen if the temperature rose dramatically. Describe the effects on plants, animals, evaporation rates, dissolved oxygen, nitrate, and ammonia levels. Include your reasoning for these results.

As a teacher, I want students to show an understanding of the interrelationships between living things and the environment in which they live. They should be able to cite reasons for the cause-and-effect relationships that occur when a stress is added to the system.

Students develop creative systems to incorporate all the required elements. Not all models that students built were successful, but students were able to see how failure or success in one system affected what happened in other sections. ✧

Laura Henriques is an assistant professor in the science education department at California State University, Long Beach, 1250 Bellflower Boulevard, Long Beach, CA 90840; e-mail: lhenriqu@csulb.edu.

REFERENCES

- Fortner, R., R. Pinnicks, E. Shay, P. Barron, D. Jax, W. Steele, and V. Mayer. 1992. Biological and Earth systems science: A program for the future. *The Science Teacher* 59(9):32-37.
- Ingram, M. 1993. *Bottle Biology*. Dubuque, Ia.: Kendall Hunt Publishing.
- Mayer, V.J. 1991. Earth-systems science: A planetary perspective. *The Science Teacher* 58(1):35-39.
- National Research Council. 1996. *National Science Education Standards*. Washington D.C.: National Academy Press.