The Biosphere Bottle

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A Teacher Demonstration

A biosphere bottle is simply a closed terrarium. It serves as a wonderful model of the Earth and the biosphere in that it is a closed system just like the Earth is. No significant amounts of matter enter or leave, but energy is absorbed and radiated freely. All the materials needed by life in the bottle must be there at the time the lid is snapped on. Biological processes recycle most of the matter in the bottle, just like on planet Earth. The biosphere bottle has its own climate, water cycle, carbon and nitrogen cycles, and other ecological systems that achieve a balance over time. The bottle also has its own unique biodiversity, which includes the plants you introduce, as well as myriad soil organisms. The soil may be home to nematodes, fungi, algae, bacteria, protozoa, soil mites, springtails, mollusks, centipedes, and many others.

And like the Earth, the biosphere bottle responds to changes imposed on it. If for instance you deprive the bottle of light, the green plants may die, and fungi, followed by bacteria will likely take over. Similarly, exposing the bottle to direct sunlight even for short periods of time will induce a kind of global warming in the bottle, making conditions inside unfavorable for green plants.

You will need

You will need a set of the following equipment to construct your biosphere bottle:

- 1 Large, fully-enclosed glass or plastic container, with cap
- Pea-sized gravel (3 L)
- Activated charcoal (1 L)
- Sterilized potting soil (4-6 L)
- Natural twigs and tree bark
- 3 or 4 humidity-loving houseplants
- Plant sprayer
- Metre stick or 75cm wooden dowel
- Large-mouth plastic funnel (can be cut from a plastic container)
- Newspaper or plastic sheet

Note: One of the best containers to use for this activity is a 20L (5-gallon) plastic water jug, used to distribute purified water. Check with local distributors: they may have supplies of slightly damaged jugs that cannot be re-used, and can be obtained for free. Otherwise, the bottles may be purchased for the price of the deposit, which is between $5.00 and $10.00 in most places.

Common houseplants can be used in the biosphere bottle, many of which can be cultured from cuttings. Look around your school: there may be many potted plants from which cuttings or slips may be taken. Ferns, spider plants, and ivy are common and work well in a terrarium setting. Houseplants suitable for a closed terrarium are available at the best prices direct from local growers. Call local greenhouses and ask for recently started young plants. Consult with your local grower for the best available varieties.

In addition you will need:

- A class set of Student Activity 1 (Part C), *The Biosphere Bottle*

Procedure

Making a Biosphere Bottle

Prepare the bottle

1. Spread some newspaper or plastic sheet over your workspace.
2. Mix the activated charcoal and gravel and pour into the bottom of the container, using the wide-mouth funnel. You will need a layer 3 centimetres deep.
3. Add a layer of dry soil to the container. This layer will need to be about 8 cm deep over the pebbles.

4. Spray the soil down with about 500ml of water, to moisten (but not saturate) the soil.

Insert the Plants

5. Prepare 3 or 4 young plants by removing them from their plastic pots, and gently shaking some of the soil from their roots. Remove only enough soil to allow each plant to fit through the mouth of the bottle.
6. Decide how you would like to arrange your plants. The smallest should go towards the outside, and the largest (or those that will eventually grow to become the tallest) should be planted in the center.
7. Insert the smallest plants first. Using the stick, poke a hole in the soil down to the level of the gravel, and wide enough to accommodate the roots of the plant. Drop the plant into the bottle, and use the dowel to nudge the plant into the hole, roots first. Push a little soil up around the plant stem to cover the roots. Gently pack the soil around the roots and stem of the plant.
8. Insert the remaining plants, as above. Leave a few centimetres of space between them. If you have mosses, plant them last.

Add Water and Decorations

9. At this point, the soil should be moist, but not wet. Use the plant sprayer to gently mist the plants. If any soil clings to the side of the container, adjust the plant sprayer to the "squirt" setting, and wash the clinging soil down.
10. Scatter the woody materials - bark and twigs around on the soil between the plants. A decorative stone or two can add some interesting visual detail.

Seal the Bottle

11. Seal the bottle using the cork or cap. Be sure you can easily open it again to add more water if necessary.
12. Monitor the condition of the plants over the next few days. If they appear to wilt slightly, add more water with the plant sprayer. Use no more than about 200 mL at a time. It is important not to over-water: if the soil becomes saturated, the plants' roots will rot, and undesirable bacteria and fungi will take over and kill the plants.

Maintaining your biosphere bottle

If everything has been done carefully, very little care and maintenance is required to keep your plants growing and the mini-biosphere healthy.

Keep the bottle away from direct sunlight. Sunlight may heat the air inside the bottle to a temperature that will kill the plants. Place the bottle near a fluorescent grow light, or near a north-facing window, where it can get indirect skylight.

Keep the bottle sealed. Do not water or fertilize. The plants inside will adjust to the amount of water and nutrients, and will not be helped by adding more water, or more fertilizer. It is important to not over-water the biosphere bottles. The excess water fills the spaces between the soil particles creating conditions that favor undesirable fungi and bacteria, which ultimately kill all the plants. It is best to water the bottles sparingly, and watch the plants over the next day or two for signs of wilting. If the plants appear to be wilting, use a plant sprayer to add another 100ml of water.

Note: Not all terrariums work out the first time. It is possible that soil fungus could develop in your bottle, or that other problems could occur which kill your plants. If this happens, you can start it again, re-using the gravel and the bottle. Wash both with a mild bleach solution to sterilize, and rinse thoroughly afterwards. Start again with fresh soil and plants. Be careful not to over-moisten. It is better to leave the soil a little too dry, and add small amounts of water if the plants appear wilted, than to start off with too much water, which will kill everything.

A completed biosphere bottle

Lessons from the Biosphere Bottle

A series of discussion questions are given in the Student Activity 1 (Part C), T*he Biosphere Bottle*. The student activity sheet may be distributed to your class for individual or group work, or used in a more informal class discussion to probe for understanding.

Throughout this demonstration, it is very important to draw the following parallels between the biosphere bottle and the Earth's biosphere:

1. Except for the transfer of solar and infrared energy, both systems are essentially closed.
2. The matter inside each system is finite, and must be recycled. Carbon, water, nitrogen, oxygen and other molecules essential to life must be re-used, circulating with the air, water, and soil of both systems.
3. Both systems reach a balance between the energy entering and the energy leaving (equilibrium). Temperatures in the system stabilize when the incoming and outgoing energies reach this balance. However, if any other variable in either system is disturbed, each must go through a period of adjustment to reach a new energy balance, and a new temperature. The climate variables common to both the earth and the biosphere bottle include the amount of incoming light, the quality of the medium through which the light must pass (glass or plastic; the atmosphere), the nature of the surfaces which absorb the energy, and the kinds and quantities of living organisms present. At the scale of the Earth's biosphere, an adjustment period brought about by disturbing one or more of these variables would be manifested as a period of global climate change.
4. In both systems, living things are an integral part of the process. Without organisms to absorb and re-emit water, atmospheric gases and light, conditions would likely be very different in both cases. (Imagine what physical conditions on Earth would be like without organisms to process inorganic constituents and solar energy: the Earth's oxygen-rich atmosphere is largely a product of the photosynthetic activity of plants.)

Questions

The following key provides suggested discussion points and answers to the questions on Student Activity 1 (Part C), *The Biosphere Bottle*. On most of these questions, student answers may vary.

1. The biosphere bottle is sealed and no air can get in or out. Despite this, the plants use carbon dioxide from the air inside the bottle, and make leaves, stems, and roots, until the bottle is filled with plants. Obviously, there is not enough carbon dioxide in the air of the bottle to support all this plant growth. Where does the rest of the carbon come from?

*The additional carbon is supplied in the form of carbon dioxide released by decomposing bacteria and tiny animals living in the soil of the biosphere bottle. The plants themselves produce some carbon dioxide as they live and grow. **All** plants must respire, burning some of the sugar they produce to support normal metabolic processes. **Most** plants also photosynthesize, absorbing carbon dioxide and yielding oxygen (there are some non-green plants such as Indian Pipe which are parasitic, and have no chlorophyll).*

2. What would happen to the plants in the bottle if you placed the bottle in a sunny window? What would happen to the temperature inside?
   Placing the bottle in a sunny window would significantly increase the amount of incoming energy that the bottle would have to absorb. The result would be an increase in temperature. The temperature would rise until the amount of heat radiating from the bottle as infrared equaled the amount of visible light energy entering. This temperature could likely be too high for the plants to survive, and they could die. Putting the bottle in a sunny window is therefore not a good idea.
3. Eventually the amount of living plant material inside the bottle reaches a limit, and cannot increase any further. What might limit the amount of plant growth in the bottle?
   This limit is set by several factors, the most important of which are: water, carbon, nutrients, temperature, and space. The amount of carbon is finite, and the biosphere bottle establishes a balance between the amount of carbon stored in the soil, the amount in the air in the form of CO_2, and the amount stored in living plants. This balance is in turn dependent on the amount of water available, the temperature, and other factors.
4. The plants inside the biosphere bottle will grow for a period, and eventually will reach a maximum where plant growth seems to stabilize. The total amount of plant material remains steady, even though the plants appear to be growing new tissues all the time. Why doesn't the bottle fill up with the remains of dead plants?
   The plants continue to grow, but at some point, the rate at which leaves and stems die begins to equal the rate of new growth. The dead remains are quickly decomposed, releasing carbon dioxide, which is then "re-assimilated". This is in fact a mini-carbon cycle in operation inside the biosphere bottle.
5. In many ways, the biosphere bottle and the Earth's biosphere resemble each other. In both cases, the main input is light energy. Other than light, very little enters or leaves from either system. But there are some significant differences between the Earth and a biosphere bottle. What are some of those differences, and why are they important?
   There are many differences, mainly related to the scale of each system. One main difference is the time required for responses to manifest themselves. On Earth, changes in the energy budget, global temperatures, vegetation patterns and other variables require decades and centuries to show up after an initial disturbance. In contrast, the biosphere bottle responds to changes in energy within minutes, and the plants can exhibit responses within hours or days. Earth has large oceans which act as a giant buffer against rapid temperature fluctuations and climatic changes. The biosphere bottle is very susceptible to overheating because it has no large "thermal mass" to buffer against temperature changes.
6. What would happen to your biosphere bottle if a small amount of a toxic substance was present in the soil at the time you planted the bottle?
   Because the biosphere bottle is a virtual closed system, the toxin has no other place to go. It would either kill the plants altogether, or kill the more sensitive plants, and cause growth problems for the survivors. The same thing happens in the Earth's biosphere. Long-lived toxins like DDT and PCBs are passed along the food chain, causing problems for the organisms that ingest them. Unless they are broken down or safely trapped and stored in sediments, they remain active and dangerous to organisms for many years.
7. Speculate on what would happen to your biosphere bottle if you were to introduce some plant-eating beetles to the system.
   Insects could potentially destroy all the plants, and they themselves could starve. If only one or two very small beetles were introduced, it is possible that the amount they ate would be balanced by the amount of new plant growth. In this case, the beetles could possibly survive in equilibrium with the plants. This example illustrates one of the differences between this simulated biosphere and the real one: because it is so small and simple, it has very little ability to absorb damage or respond to changes without the risk of a catastrophic failure. The larger and more diverse the system, the more resilience it seems to have.

8. If you place your bottle under a grow lamp, the temperature will rise slightly, then remain steady. This is puzzling because the bottle receives continuous light, and has an ability to trap the heat just like a greenhouse. Logic tells you that if the bottle receives constant light, and converts some of it to heat, the bottle should get continuously warmer, as long as the lights are on. Why doesn't this happen?
   The input of new energy is eventually compensated for by the increase in heat radiating away from the biosphere bottle. During the adjustment period, the air inside the bottle warms up by a few degrees, but steadies out when infrared radiation emitted from the bottle balances the incoming visible light.
9. What would happen to your biosphere bottle if you could increase the concentration of carbon dioxide gas in the air inside the bottle?

The additional carbon dioxide added to the bottle may stimulate more vigorous plant growth. Greenhouses routinely do the same thing using CO_2 generators that burn natural gas. The effect is called "carbon dioxide fertilization". Eventually, plant growth would stabilize, probably with a higher living biomass than before the CO_2 was introduced. This can actually be performed as a demonstration or experiment: Try lowering a small flask containing dilute hydrochloric acid and marble chips into the biosphere bottle on a string. Allow the flask to bubble CO_2 into the bottle for half an hour or so and remove. Observe for changes in plant growth over the next two or three weeks.