Investigating the Greenhouse Effect

BY JULIE LAMBERT, LAURA COTTONGIM, AND CYNDY LEARD

PURPOSE

The primary objective of this classroom activity is to demonstrate how air temperature can be affected by pumping additional greenhouse gases into Earth's atmosphere. Students measure air temperature in a simulated "enhanced" greenhouse environment produced by adding carbon dioxide gas to a bottle and comparing it to an environment where no greenhouse gases are added. Because carbon dioxide is a major greenhouse gas, students will be introduced to the carbon cycle and its integral relationship to global climate change.

AUDIENCE

This investigation is designed for sixth through tenth grade science students, and possibly for advanced elementary-level students. Students should have prior knowledge of the concepts of heat, heat transfer, and Earth's energy budget. This investigation has been piloted several times with elementary-level (K–8) pre-service teachers. Feedback has been incorporated into this activity.

BACKGROUND

Most of the sun's solar radiation reaches Earth at visible and near-visible wavelengths. A small percentage of this short-wavelength solar radiation is absorbed by land, water, and vegetation. The rest is reflected or radiated back from Earth into the atmosphere in the form of longer-wavelength **infrared** radiation. Much of this infrared radiation cannot pass back out into space through the atmosphere because water vapor, carbon dioxide, methane, and a few other gases in the atmosphere absorb it, and also re-emit it as heat back down to Earth's surface. This process is commonly called the "greenhouse effect" and is the reason why Earth's average temperature is about 14°C (57°F). Without this atmospheric "blanket," Earth's average temperature might be as low as –18°C (–0.4°F). It is important to note that although the greenhouse gases in Earth's atmosphere act as a form of barrier, reducing the amount of heat lost back into space, a greenhouse does not actually work in the same way. A greenhouse gets hot because the glass prevents wind and convection from carrying heat away (think of a car on a sunny day with the windows open vs. windows closed).

Over at least the last several decades, Earth's lower atmosphere has been heating up as more greenhouse gases are being emitted, trapping more heat (the so-called "enhanced greenhouse effect"). The Intergovernmental Panel on Climate Change (IPCC, 2007) estimated that Earth's average temperature has increased by 0.74°C since the early 1900s. The panel, consisting of scientists from all over the world, are brought together by the United Nations every five years to assess our understanding of and potential impacts of climate change, and to identify options for decreasing the rate of change and mechanisms to help societies adapt to climate change. They project that during this century, temperatures will rise much more than during the past one.

RESEARCH QUESTION

Students use a model to investigate one aspect of the greenhouse effect and how changes in the concentration of carbon dioxide affect the temperature of a closed environment. This investigation also helps students develop an appreciation for the complexity of Earth's greenhouse effect.

Julie Lambert *(julielambert@att.net) is Associate Professor of Science Education, Department of Teaching and Learning, Florida Atlantic University, Boca Raton, FL, USA.* **Laura Cottongim** *is a science teacher at the University Laboratory School, Honolulu, Hawai'i, USA.* **Cyndy Leard** *does curriculum development and research for Future Vision Productions, St. Petersburg, FL, USA.*

APPROACH

The 5-E Instructional Model (Bybee, 1993) is the framework used to develop this inquiry-based lesson. A teacher would begin by assessing students' prior ideas and ***engaging*** them in the learning. To uncover students' ideas, the following questions could be asked: (1) What is the greenhouse effect? How does it work on Earth? Make a drawing with labels. (2) How is Earth's greenhouse effect different from the way a real greenhouse works? (3) What would Earth be like without the greenhouse effect? (4) What are greenhouse gases? (5) What natural processes increase greenhouse gases? What processes decrease greenhouse gases? (6) How is human activity affecting the amount of greenhouse gases in the atmosphere? (7) Draw and explain the carbon cycle and its connection to global climate change.

Demonstrating a few properties of dry ice is an effective way to engage the students in the lesson. If a large piece of dry ice is placed in a beaker of warm, colored water, the students will observe the process of sublimation (change from a solid to gas). The frozen carbon dioxide changes into gas and bubbles up through the water and into the air. The extreme cold temperature surrounding the beaker of water causes water vapor in the air to condense, forming a cloud. Students will observe this cloud sink because carbon dioxide is heavier than the air.

Once engaged, students ***explore*** their ideas by participating in a learning experience (the activity described below). After exploring or doing the investigation, teachers and students discuss ***explanations*** about how the greenhouse effect works. Students are then challenged to ***extend*** their conceptual understanding to a new context. Online resources (including interactive carbon cycle simulations) are provided to help students extend their understanding of the greenhouse effect and the role of carbon dioxide within the carbon cycle. During the fifth "E" phase, students are ***evaluated***; however, evaluation should also take place throughout a lesson to assess students' developing ideas. The previous questions may be used again to evaluate students' understanding of the greenhouse effect after the lesson.

MATERIALS

- Colored markers or pencils
- Distilled water
- Two drinking water bottles (empty, plastic, same size, clear)
- Dry ice (broken pieces)
- Flame source—candle
- Graduated cylinder
- Lamps (radiant heat)
- Modeling clay
- Paper clip
- Plastic tubes
- Scissors (or razor)
- Stop watch or watch with second hand
- Two Styrofoam cups
- Thermometers
- Tongs (to handle dry ice)

ACTIVITY

To construct your control greenhouse model and your enhanced greenhouse model, begin by collecting all the materials other than the dry ice.

1. To prepare the enhanced greenhouse model, use a flame from the candle to heat the end of a paper clip. Use the hot paper clip to make a small hole in the side of one of the plastic drinking bottles. Make this hole about half way between the top and bottom of the bottle. Make sure that the plastic tubing will fit into the hole.
2. Put 200 ml of distilled water into each of the two bottles.
3. Place the plastic tubing into the hole that you made for the "enhanced greenhouse" effect model. Use clay to prevent any air from leaking out once the experiment begins.
4. Place a thermometer into the top of each bottle so that the end of the thermometer is in the center of the bottle. Hold in place and seal off the bottle top opening using the modeling clay.
5. To prepare the container for inserting the dry ice vapor, obtain two Styrofoam cups. One should be larger than the other or you can cut one to fit beneath the other. Punch a hole in the bottom of the larger cup on the top. Insert the plastic tubing and use the clay to prevent any leakage of the carbon dioxide.
6. Obtain a piece of dry ice that fits into the smaller Styrofoam cup. Add enough water to begin sublimation.
7. Connect the plastic tubing to the bottle and let the carbon dioxide gas to flow into the bottle for 90 seconds. Take the tubing out and close the tubing hole with clay once you have added the carbon dioxide.
8. Place both bottles the same distance from a heat lamp and turn on the light (Figure 1).

Figure 1. Control and enhanced greenhouse models in front of heat lamp.

9. Begin recording the temperature as soon as you have closed the hole and turn on the light (i.e., Table 1). Record the temperature every two minutes for twenty minutes in the table.
10. Construct a graph of your data.

GENERAL COMMENTS

Students should observe a greater temperature increase for the bottle with the enhanced greenhouse effect. Initially, this bottle may have a lower temperature due to the input of the gas; however, the temperature should begin to rise at a higher rate. Temperature data should be collected for at least 20 minutes. Based on the average of several trials conducted by the pre-service teachers, the expected temperature change for the bottle with the "greenhouse effect" is 5°C, and 8°C for bottle with the "enhanced greenhouse effect."

This simulation-type investigation was developed to help students understand the greenhouse effect and its relationship to global warming, by using carbon dioxide gas as opposed to similar experiments using a plastic covering to prevent convection. Students are often not familiar with the concept of a greenhouse and using a plastic covering may cause the students to think there is a type of physical barrier above Earth—a common misconception. Many studies have found that students confuse the cause of global warming with the depletion of and/or holes in the ozone layer (Boyes and Stanisstreet, 1993, 1997, 1998; Frances et al., 1993; Rye et al., 1997; Koulaidis and Christidou, 1998; Andersson and Wallin, 2000; Lee et al., 2007).

POSSIBLE MODIFICATIONS OR EXTENSIONS

One modification is to use the investigation to teach students about experimental design. Have the students make a hypothesis, and identify the independent variable (i.e., concentration of carbon dioxide) and the dependent variable (i.e., temperature). Discuss the need for a control in an experiment and how this activity is set up to provide a control. Students may also write a scientific report about their investigation, including an introduction, methods, results, and conclusions section.

A possible extension is to have students graph the average temperature and carbon dioxide concentration. Have students label the temperature on the *y*-axis on the left-hand side of the graph. On the same graph, have students label the concentration of carbon dioxide (parts per million) on the *y*-axis on the right side of the graph. Using a different colored pencil, graph the amount of carbon dioxide in the atmosphere from 1910 to 2010 (use data in Table 2). How does the change in measured temperature over a period of 100 years compare to the

Table 1. Temperature Change and the Greenhouse Effect

Type of Greenhouse Effect	Temperature (°C) (minutes)										
	0	2	4	6	8	10	12	14	16	18	20
Bottle with Greenhouse Effect											
Bottle with Enhanced Greenhouse Effect											

Table 2. Data for 10-year average of global temperature and carbon dioxide in the atmosphere

Year	Average Global Temperature for Previous Decade (°F)	Carbon Dioxide in Atmosphere (parts per million)
1910	56.7	298
1920	56.8	302
1930	57.0	305
1940	57.3	309
1950	57.2	310
1960	57.2	314
1970	57.1	321
1980	57.3	331
1990	57.7	346
2000	57.9	359
2010	58.4	400

change in temperature that they measured in their experiment?

Another possible extension is to have students explore the carbon cycle online resources to deepen their understanding of the greenhouse effect and the role of carbon dioxide. Students will learn that carbon dioxide constantly moves into and out of the atmosphere through four major processes: photosynthesis, respiration, organic decomposition or decay, and combustion or burning of organic material.

REFERENCES AND OTHER RECOMMENDED READING

Boyes, E., and M. Stanisstreet. 1993. The "greenhouse effect": Children's perceptions of causes, consequences and cures. *International Journal of Science Education* 15(5):531–552.

Boyes, E., and M. Stanisstreet. 1997. Children's models of understanding of two major global environmental issues (ozone layer and greenhouse effect). *Research in Science & Technological Education* 15(1):19–28.

Boyes, E., and M. Stanisstreet. 1998. High school students' perceptions of how major global environmental effects might cause skin cancer. *Journal of Environmental Education* 29(2):31–36.

Boyes, E., M. Stanisstreet, and V.S. Papantoniou. 1999. The ideas of Greek high school students about the "ozone layer." *Science Education* 83:724–737.

Bybee, R.W. 1993. Reforming science education: Social perspectives and personal reflections. Teachers College Press, New York, NY, 216 pp.

Frances, C., E. Boyes, A. Qualter, and M. Stanisstreet. 1993. Ideas of elementary students about reducing the "greenhouse effect." *Science Education* 77(4):375–392.

Gore, A. 2006. *An Inconvenient Truth: The Planetary Emergency of Global Warming and What We Can Do About It*. Rodale Books, New York, NY, 328 pp.

Flannery, T. 2005. *The Weather Makers: How Man is Changing The Climate and What it Means It Means For Life on Earth*. Grove Press, New York, NY, 359 pp.

Henson, R. 2008. *The Rough Guide to Climate Change: Symptoms, Science and Solutions*, 2nd ed. Rough Guides Limited, New York, NY, 384 pp.

Lee, O., B.T. Lester, M. Li, J. Lambert, and M. Jean-Baptiste. 2007. Conceptions of the greenhouse effect and global warming among elementary students from diverse languages and cultures. *Journal of Geoscience Education* 55(2):117–125.

Mooney, C. 2007. *Storm World: Hurricanes, Politics, and the Battle Over Global Warming*. Harcourt, Orlando, FL, 400 pp.

Rye, J.A., P.A. Rubba, and R.L. Wiesenmayer. 1997. An investigation of middle school students' alternative conceptions of global warming. *International Journal of Science Education* 19:527–551.

Sussman, A. 2000. *Dr. Art's Guide to Planet Earth: For Earthlings Ages 12 to 120*. Chelsea Green Publishing Company. White River Junction, VT, 128 pp.

Time. 2007. *Global Warming: The Causes, The Perils, The Solutions, The Actions: 51 Things You Can Do*. Time Inc. Home Entertainment, 140 pages.

ONLINE RESOURCES

Carbon Cycle Game
http://www.windows.ucar.edu/earth/climate/carbon_cycle.html

EPA Climate Change: Interactive Web Site
http://www.epa.gov/climatechange/kids/carbon_cycle_version2.html

Interactive Diagram
http://www.seed.slb.com/en/scictr/watch/climate_change/carbon.htm

Nature Conservancy's Carbon Calculator
http://www.nature.org/initiatives/climatechange/calculator