Thinking... Like an Ecologist

Students make connections between their influence on global change and current field research

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Students make connections with what they know. Unfortunately, many students have never been formally introduced to human impact issues and hold a number of misconceptions. Correcting these misconceptions is imperative if students are to be cognizant of their everyday effects on the environment and make educated, ecologically conscious decisions regarding their actions in the future.

So where do we start as science teachers? In this article I present a lesson in which students examine current field research on global change. In particular, students investigate the effect of carbon dioxide and tropospheric ozone on ecosystems by applying their knowledge of scientific inquiry and photosynthesis. The goal of the activity is for students to think like ecologists and draw connections between the data and their everyday energy choices.

Current global change research

Since the industrial revolution, the documented increase in the atmospheric concentration of carbon dioxide (CO_2) has increased by over one-third, from about 280 ppm in 1850 to about 380 ppm today. This number is expected to continue to rise as fossil fuel use persists and land is cleared of vegetation for development and agriculture. Beyond predictions such as rising sea levels, changes in weather patterns, and regional climate shifts, increased CO_2 is known to directly affect plant photosynthesis and water use (Karnosky et al. 2003). This could potentially increase the plant growth in both agricultural and natural ecosystems. CO_2, however, is not the only gas in our atmosphere that influences plant growth. Ozone (O_3), when found in the troposphere near ground level, is considered a pollutant that is detrimental to plant growth and also poses human health problems. The majority of tropospheric O_3 is formed by the reaction of sunlight on air containing carbon monoxide, nitrogen oxides (NOx), and volatile organic compounds (VOCs). The major anthropogenic sources of these O_3 precursors include motor vehicle exhaust, industrial emissions, and chemical solvents.

I became interested in the impacts of increased O_3 and CO_2 when I participated in a graduate class, Global Change for Teachers, offered by Michigan Technological University in Houghton, Michigan. The most memorable experience of the class was visiting a current global change research facility—the Aspen FACE research site in Wisconsin. Aspen FACE is a "multidisciplinary study to assess the effects of increasing tropospheric O_3 and CO_2 levels on the structure and function of northern forest ecosystems," specifically, on the growth of aspen trees (Facts II: The Aspen FACE Experiment 2005). FACE is the acronym for Free-Air Carbon dioxide Enrichment experiment. More than 25 FACE research sites are scattered across the globe, each with almost 100 scientists conducting long-term research on the ecological effects of expected CO_2 gas in a natural environment. The experimental design at FACE involves twelve 30 m tree rings where scientists control the concentrations of CO_2 and tropospheric O_3 to simulate the levels expected in 50 years. The effects of the gases on ecosystem balance, including changes in plant growth and soil carbon, can then be assessed (Facts II: The Aspen FACE Experiment 2005).

Unlike a greenhouse, FACE's open-air design allows the ecosystems to develop as naturally as possible; including allowing the growth of tall trees. The data collected at the FACE research sites are helping scientists anticipate the possible impacts of global change—both positive and negative.

Bringing Aspen FACE to the classroom

After spending a day in the field among the researchers at Aspen FACE, I wanted to bring this experience back to the classroom. The case studies examined in biology classes are often decades old and conducted in a lab, with corresponding activities that ask students to verify what has already been discovered. Aspen FACE is an example of current field research where the systems are complex and all of the possible variables are not known; the researchers are finding many trends, but there is still much uncertainty for the future. Analyzing an experiment such as Aspen FACE would allow students to think like ecologists. In addition, students would:

- reason through the scientific inquiry used at Aspen FACE;
- analyze and interpret the data from the Aspen FACE site;
- make connections to the effects humans (specifically themselves) have on ecosystems;
- propose solutions to global climate issues; and
- understand the uncertainties of research investigating current environmental issues.

FIGURE 1

Student responses to a free-write exercise.

This exercise assesses student understanding of the issues of greenhouse gases, global climate change, and tropospheric ozone.

Student A: *Aerosols, we use aerosol hairspray that deplete the ozone. One big negative effect is skin cancer, this damages your skin and can hurt you a lot. On plants, it helps them grow a lot and sometimes overgrow.* (**Misconception:** CFCs and depleting ozone relates to the stratospheric ozone layer, not tropospheric ozone which would harm, not help, the plants. In addition, aerosols no longer contain CFCs in the United States.)

Student B: *CO_2 is the greenhouse gas that is of most concern. Burning fossil fuels, automobile exhaust, cutting and burning forests worldwide, and factory pollution are human actions that have contributed to the emission of CO_2.* (**Correct:** Although other gases like water vapor and methane also function as important greenhouse gases; in fact, the warming effect of water vapor is greater than that of CO_2. Ozone in the upper troposphere also acts as a greenhouse gas.)

Student C: *Bad ozone found near the ground is a health hazard. It's known to cause coughing, congestion, and chest pains. It's also known to worsen conditions such as asthma and bronchitis. Humans aren't the only organisms damaged by negative ozone, however. Plants are also damaged; bad ozone stops the plant from photosynthesizing.* (**Correct.**)

Student D: *In recent years CO_2 and ozone have played a big part in the environment. The increase in CO_2 is depleting the ozone and killing plants.* (**Misconception:** CO_2 does not deplete the ozone layer and tropospheric ozone is detrimental to plant growth [Karnosky et al. 2003]. CO_2 actually increases plant growth.)

Understanding the independent variables: CO_2 and O_3

Before introducing students to Aspen FACE, they must understand the independent variables in the experiment: CO_2 and O_3. I begin by gauging my students' prior knowledge of the subject with a free write about what they know about ozone, greenhouse gases, and global atmospheric changes (Figure 1). One of the biggest misconceptions I have encountered in my students is the difference between "good ozone" and "bad ozone." Good ozone is found in the stratosphere as the ozone layer that protects us from harmful ultraviolet rays. Bad ozone is found in the troposphere at ground level and can be created by a chemical reaction when NOx reacts with VOCs emitted mainly from automobiles and industry in the presence of sunlight. Students have heard *ozone action* days announced on news programs but may think that it refers to the stratospheric O_3 layer rather than ground-level ozone. Students typically understand that daily activities, such as driving automobiles, emit CO_2 and contribute to the greenhouse effect. Fewer students also understand that these activities also can contribute to low-level O_3 production. Students do not, however, always make the link between increased low-level O_3 and CO_2 and impacts on plant growth

In order for students to understand the FACE experiment and the effects of CO_2 and O_3 on plants, I needed them to correct their misconceptions and successfully distinguish between greenhouse gases, good ozone, and bad ozone. I have found that students are most successful when they are driving the research; therefore, I schedule my first day of this activity in the computer lab. During this time, students use the internet (documenting their sources), along with their textbook and other supplementals I have provided, to research and record their findings to the questions on the worksheet found in Figure 2.

FIGURE 2

Understanding CO_2 and O_3.

Your goal: *Paint a complete picture of the environmental issues surrounding CO_2 and O_3 by researching and answering the questions below. Organize and record your findings in your science notebook. Be sure to keep a complete list of the resources you have used.*

The greenhouse effect and global climate change

- What is the greenhouse effect?
  - List three greenhouse gases.
- What is global climate change?
  - What has been the trend over geologic time? Recently?
  - What greenhouse gas is of most concern? Why?
  - What human actions contribute to the emission of this gas?
  - Sketch a graph of how the concentration of this gas has changed over time.
  - What are the predicted consequences?
  - How might it impact plants?
  - Can it be stopped? Slowed? Reversed? What are some possible solutions?

Ozone

- You most likely know about "good ozone."
  - Where is it found?
  - What is its importance?
- There is also "bad ozone."
  - Where is it found?
  - What two main types of compounds are involved in the chemical reaction that forms it?
  - What weather condition contributes to the formation?
  - What human actions contribute to its formation?
  - What are the negative effects overall? On plants? Find a photo showing the effects of ozone on leaves and describe.
  - What are possible solutions?
- Contrasting good and bad ozone.
  - Which type is found in the stratospheric ozone layer? Which type is found in the troposphere?
  - What is an ozone action day? Which type of ozone does it address?

Resources (please list what resources you used)

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The first supplemental I provide is a copy of the brochure *Ozone: Good Up High, Bad Nearby*, published by the Environmental Protection Agency (2003). The brochure compares and contrasts good and bad ozone in a straightforward and succinct manner. Another resource I provide students with is a presentation by Bill Holmes, an Aspen FACE researcher from the University of Michigan. Even though the presentation, *Elevated CO_2 and Ozone: Causes and Consequences,* was designed for teachers, many of my students found the diagrams and descriptions (in the slides and in the speaker notes) very useful. This presentation is available on the NSTA website at *www.nsta.org/highschool/connections.aspx*.

I guide the research of my lower-level students by providing a list of websites that address the issues at an appropriate level (see "On the web" at the end of this article). The following day, we engage in an educated discussion regarding students' findings. I encourage students to ask questions and correct any misconceptions they had by recording corrections in a different color in their journal.

Applying scientific inquiry in the field

Often in high school, scientific experiments are conducted in a laboratory and have definite, predetermined conclusions. Aspen FACE breaks both of these traditions; it is in-progress field research with no final results. The goal of the activity described in Figure 3 (p. 54) is for students to think like ecologists conducting research in the field. I begin by presenting students with the very basics of the Aspen FACE experiment using a color overhead of Figure 4 (p. 55) and asking them to brainstorm ideas that a scientist might study at the site. We then compare our ideas with the long list of interconnected ecological research that is being carried out at Aspen FACE, online at *http://aspenface.mtu.edu/investigators.htm*.

Next, I focus the class on one specific question: What are the effects of increased CO_2 and O_3 on plant growth? This question is a simplified form of what many of the FACE researchers are studying. Students take on the role of ecologists working in the field as they complete an inquiry into the Aspen FACE experiment. The inquiry is designed to lead students through designing a procedure, posing hypotheses, analyzing data, drawing conclusions, and identifying sources of error and uncertainty. In Figure 3, a guided lab report, students use the photos and descriptions in Figures 4, 5 (p. 55), and 6 (p. 56) to discover the Aspen FACE experiment by applying their knowledge of scientific investigations. For the inquiry to be effective, I am very careful not to tell stu-

FIGURE 3

Exploring the Aspen FACE experiment.

Your goal: To think like an ecologist. You will be investigating a current field research project. You must use your expertise in scientific investigations, photosynthesis, carbon dioxide, and tropospheric ozone to help analyze this real-life experiment. Use the following sections to help you organize and record your findings in your science notebook.

Problem: What are the effects of increased CO_2 and ozone on plant growth?

- **Background information:** What is needed for a plant to grow? What is the equation for photosynthesis?
- **Procedure:** Design a simple experiment to test the problem. Then, compare and contrast your design with the FACE experimental design shown in Figure 5. In the Aspen FACE experimental design:
  - What is the dependent variable?
  - How many of the treatments are experimental groups? What is the independent variable in each of the treatments?
  - What does ppm stand for? ppb? What do they both measure?
  - Which treatment is the control? Why is a control needed?
  - What are the constants?
  - Why is the "free-air" part of the design so important?
- **Hypothesis:** Keeping in mind the equation for photosynthesis and your research, create three hypotheses; one for each of the experimental groups.
- **Data:** Growth can be measured in a number of ways. We will be analyzing growth above ground, measured with a volume growth index. To calculate the volume growth index, scientists took the diameter squared and multiplied it by the height of the tree. Data Table 1 shows results from three years.
  - Create a multiple line graph comparing the growth in each experimental group and the control from 1998–2000.
  - The photos in Figure 6 (p. 56) were not taken systematically. Look closely at the pictures to find a way to compare and contrast the three plots.
  - Use the trends in your graph to label the three pictures in Figure 6 as elevated CO_2, elevated O_3, or elevated CO_2 + O_3.
- **Conclusions:** Now, write a conclusion for each of your hypotheses.
  - Restate your hypothesis.
  - Tell whether it was correct using supporting data from your graph.
  - Explain why, using your research from the activity in Figure 2 (p. 53).
- **Sources of uncertainty:** How would each of the following affect the results?
  - How growth was measured.
  - What plant was used.
  - The time period.

Data Table 1: Volume Growth Index (diameter^2 x height in cm) of Aspen trees.
(The data in this table is from Karnosky et al. 2003).

Year	Control CO_2/O_3 Concentrations (360/32 ppm)	Elevated CO_2 Concentration (560 pm)	Elevated O_3 Concentration (360 ppm)	Elevated CO_2 + O_3 Concentrations (560/360 ppm)
1998 (Volume Growth Index)	1050 cm^3	1100 cm^3	1000 cm^3	1020 cm^3
1999 (Volume Growth Index)	4500 cm^3	5600 cm^3	3300 cm^3	3800 cm^3
2000 (Volume Growth Index)	7000 cm^3	9200 cm^3	5600 cm^3	6700 cm^3

dents too much about the FACE research findings during the introduction. The idea is for students to analyze and interpret data (see Figure 7, p. 56, for an example) from a large-scale research project; some students draw conclusions similar to the experts' and others use the data to support their own hypotheses.

Making connections

The activity in Figure 3 requires students to carefully analyze the FACE data and understand the impact of CO_2 and ground-level O_3 on plant growth. It also leads students to begin thinking about larger global issues and making connections between Aspen FACE and global change issues of CO_2 and O_3. In the activity described in Figure 2 (p. 53), students learned about the negative effects of increased CO_2 on ecosystems, but the FACE data analyzed in Figure 3's activity show that adding more CO_2 (the reactant) increases photosynthesis and therefore tree growth, while O_3 reduces tree growth. When asked about effects of O_3, one student says "Tropospheric ozone smothers plants and they will not be able to use CO_2 and make O_2. The human race would suffer." After analyzing the FACE tree growth data, some students make the hypothesis that "The positive growth effects of CO_2 will be cancelled out by the negative effects of O_3." Students are asked to support statements such as this with *evidence* from the FACE data. We also discuss what these opposite effects mean and if scientists really know what is going to happen as a result of global change. They see that research often leads to new findings and more questions and investigations.

FIGURE 4

Introduction to Aspen FACE.

One of the major tools for investigating effects of elevated CO_2 and ozone on plants and ecosystems is the Free Air CO_2 Enrichment (FACE) experimental design. The photo on the bottom shows the 12 rings at Aspen FACE in Wisconsin; a close-up of a ring is shown in the top photo. The Aspen FACE site is focused primarily on the effect of global change on the Trembling Aspen *(Populus tremuloides)*, the most widely distributed tree species in North America, but the site also contains white paper birch and sugar maple. There are over 25 FACE sites scattered over the globe representing the diverse ecosystems of the world.

FIGURE 5

Aspen FACE experimental design.

	Treatment 1: Control (normal air)	Treatment 2: Elevated CO_2	Treatment 3: Elevated O_3	Treatment 4: Elevated CO_2 + O_3
Concentration of CO_2 (ppm)	360	560	360	560
Concentration of O_3 (ppb)	32	32	56	56
Number of 30 m rings	3	3	3	3

At Aspen FACE, each 30 m ring of plants is surrounded on the perimeter by a series of vertical ventpipes (see photo, left) which push CO_2, O_3, CO_2 + O_3, or normal air into the center of the ring. The concentrations of these gases are measured in parts per million (ppm) or parts per billion (ppb). For example, in the control, there are 360 parts of CO_2 for every million parts of air. The system that controls the concentration of gases in the air is computer controlled and adjusts the amount of gas released every second in order to maintain a stable, elevated concentration of CO_2 and/or O_3 throughout the experimental plot. In the past, most studies were designed on a small scale with groups of plants enclosed in open-top chambers with controlled atmospheres and were limited because as mini greenhouses, they provided unnatural protection from wind exposure and other natural occurrences. The FACE design is unique because it has open-air control of atmosphere conditions, is fairly large in scale, is being carried out for a longer period of time, and involves a large team of scientists and researchers.

Interesting extension activities involve looking at the FACE data for other variables, such as tree height, diameter, soil response, and pest interactions. Students can look at research questions currently being investigated by FACE researchers (*http://aspenface.mtu.edu/resquest.htm*), including:

- Where is the missing carbon from global carbon models? Is it being sequestered by forests?
- Are forests net carbon sources or sinks? Do they change over time?
- Will elevated CO_2 alleviate other stresses (e.g., O_3, drought, low fertility)?
- Will our forests become more or less productive over time under elevated CO_2?
- How will elevated CO_2 affect insect and disease interactions with trees?
- How do CO_2 and the greenhouse gas O_3 interact?

As their final assessment, students are asked to write a five-paragraph essay conveying their understanding of the connections between global change and the Aspen FACE experiment, and their proposals for solutions. Any remaining misconceptions become strikingly apparent in the final essays and can be remediated before their ecology assessment (Figure 8).

As students move through the activities, it is gratifying

FIGURE 7

Student-generated graph.

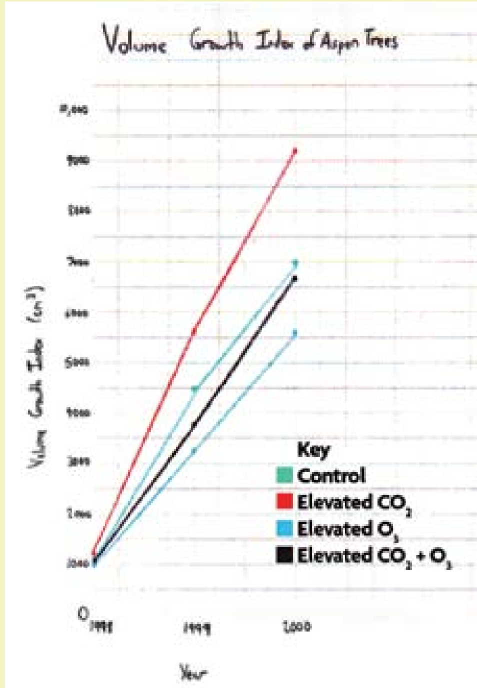

FIGURE 6

Growth of trees in experimental groups at Aspen Face.

(1) Top left is elevated CO_2—notice height of trees is above top rail; (2) bottom left is elevated O_3—notice height of trees is below bottom rail; and (3) right is elevated $CO_2 + O_3$—notice height of trees is mostly between the rails.

FIGURE 8

Student activity C: Assessment.

Now that you understand the issues, it is your job as an ecologist to educate others by writing an essay explaining the environmental issues of CO_2, O_3, and how the research at Aspen FACE is contributing to an understanding of these issues. Use your science notebook; you have already collected most of the information you need. The idea now is to make connections!

	Criteria 1	Criteria 2	Criteria 3
Paragraph 1: Introduction	Thesis inadequate or not present	Thesis adequate, CO_2 and O_3 and consequences introduced	Thesis clear, establishes connection between CO_2, O_3, and Aspen FACE
Paragraph 2: Rising CO_2	Contributing human activities identified	Human activities and consequences listed, but not explained	Clear connections made between multiple human activities and multiple consequences
Paragraph 3: O_3	O_3 is defined	Good O_3 and bad O_3 are defined	Good O_3 and bad O_3 defined, effects of tropospheric O_3 on plants and humans described
Paragraph 4: Aspen FACE: What are the effects of CO_2 and O_3 on plant growth?	Conclusions from Aspen FACE stated, but not supported with data	Conclusions from Aspen FACE stated and supported with data	Conclusions from Aspen FACE are supported with data, and uncertainties are identified
Paragraph 5: Conclusion	Gives one or two suggestions each for reduction of CO_2 and O_3, no mention of Aspen FACE	Summarizes Aspen FACE and gives two suggestions each for reduction of CO_2 and O_3	Relates Aspen FACE conclusions to the environmental issues of CO_2 and O_3 as previously discussed, and gives three suggestions each for reduction of CO_2 and O_3

as a teacher and an environmentally conscious citizen to watch students connect their knowledge of photosynthesis to ongoing field research in such a prominent environmental issue such as global change and relate it to their daily lives and the energy choices they make. ■

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References

EPA Office of Air and Radiation (EPA). 2003 *Ozone: good up high bad nearby. www.epa.gov/oar/oaqps/gooduphigh*

Facts II: The Aspen FACE Experiment. *http://aspenface.mtu.edu*

Karnosksy, D., et al. 2003. Tropospheric O_3 moderates responses of temperate hardwood forests to elevated CO_2: A synthesis of molecular to ecosystem results from the Aspen FACE project. *Functional Ecology* 17: 289–304.

On the web

The greenhouse effect and global climate change

Greenhouse Effect (EPA): *http://epa.gov/climatechange/kids/greenhouse.html*

Global Warming Is Hot Stuff: *www.dnr.state.wi.us/org/caer/ce/eek/earth/air/global.htm*

Ozone

SunWise Kids Ozone Layer (EPA): *www.epa.gov/sunwise/kids/kids_ozone.html*

Ozone Action (SEMCOG): *www.semcog.org/Services/OzoneAction/Kids.htm*

What's Ozone? (Smog City): *www.smogcity.com/welcome.htm*