Promoting Climate Change Literacy for Non-majors: Implementation of an atmospheric carbon dioxide modeling activity as an inquiry-based classroom activity

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Abstract

Students who are directly involved in scientific activities develop a deeper understanding and appreciation of both scientific knowledge and the scientific process. This understanding is critically important in scientific areas like climate change that are the focus of global public and political debate. Toward this end, we used a publicly available atmospheric carbon dioxide modeling activity in a non-major biology course to foster a deeper understanding and appreciation of climate change science. This activity steps students through the development of a basic model of carbon flow between the land, the atmosphere, and the ocean. Students manipulate components of the model to optimize the model based on known data. The model is then used to make predictions for future atmospheric carbon dioxide under scenarios that the students generate and test. For the initial implementation of this lab, pre/post assessment questions evaluated the student's confidence in science and general science knowledge, as well as gauged the usefulness of this class activity. Assessment data and student feedback indicated that the students enjoyed this activity and learned about climate change dynamics and also about the climate change modeling process.

INTRODUCTION

This lesson was developed in our Environmental Biology course, a course designed for non-biology majors that meets the “Environment” liberal education requirement for graduation. There is an option to take the course with an accompanying laboratory to meet an additional liberal education requirement of “Biological Sciences with a Laboratory Experience”. It is a relatively large-enrollment course (120-170 students) and is generally taught in an “active learning classroom.” These classrooms have round tables of nine students with each table having access to a monitor and a white board for group activities. Students who take the course come from varied backgrounds and majors (engineering, theater, business, education, etc.). Some of the students in the course are self-described as science-phobic and it can be a challenge engaging them in the course material.

In the process of teaching our unit about climate change, we noticed an apparent lack of understanding and trust in the extensive use of models in climate change science. Reading through pedagogical literature about teaching this topic, we found that climate change appears to be poorly understood by undergraduates and is underrepresented in college curriculums (1). We hypothesized that this lack of trust in climate models reflected students’ lack of experience developing models and using them to test various scenarios, a hypothesis that is supported by previous studies (2,3,4,5). So we sought to give students an opportunity to construct and use a simple model. Dr. Williams found a publically available activity to model atmospheric carbon dioxide that we thought would be a valuable extension of what the students learn about the carbon cycle (6). This lesson represents Dr. Williams’ adaptation of the carbon dioxide model to help students better understand the

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teaching resources available for teaching information about Mauna Loa Observatory over the past 80 years. There are other behaviors of atmospheric carbon dioxide as measured at the model that students develop in Microsoft Excel to model the climate change teaching tool.

For teaching purposes, simplifying and modeling current and historic conditions and to predict future data regarding these processes. These data can be used to help predict future atmospheric CO$_2$ levels.

Carbon dioxide (CO$_2$) is the most influential GHG released by human activities (13,14). It is emitted mostly from the burning of fossil fuels like coal, oil, and natural gas. This GHG can also be sequestered, or removed from the atmosphere, by processes like plant uptake through photosynthesis and ocean absorption. We have detailed historic and current data regarding these processes. These data can be used to model current and historic conditions and to predict future conditions (13,15,16). For teaching purposes, simplifying and teaching the math formulas that model the processes affecting the behavior of atmospheric GHGs can prove to be a valuable climate change teaching tool.

Our lesson describes the development and use of a simple model that students develop in Microsoft Excel to model the behavior of atmospheric carbon dioxide as measured at the Mauna Loa Observatory over the past 80 years. There are other teaching resources available for teaching information about atmospheric carbon dioxide. Examples include time-lapse videos (17), introducing the chemical science of what makes a gas a “greenhouse” gas (18), examining and comparing the modern CO$_2$ record between the North Pole, the tropics (Mauna Loa), and the South Pole (19), and examining trends in global mean temperatures (20). Our lesson appears to be unusual in that it teaches students how atmospheric CO$_2$ levels are modeled by climate scientists, what global processes affect atmospheric CO$_2$ levels, and how previously measured data can be used to help predict future atmospheric CO$_2$ levels.

This lesson takes place during the course climate change unit (the last unit of the semester) after students have learned about the carbon cycle, through reading and lecture. Before the day of the activity, students are given a short amount of background material to read independently (21) and an activity handout to read. The background article can be challenging for some students. Throughout the course, we ask students to read from the primary literature and we instruct students to accept that they will not understand every detail of the articles they read. We ask them to read the articles for the “big picture.” By this point in the semester, the students seem comfortable with this approach. However, we also include a worksheet (Supporting File S2) with questions to guide reading as a tool to provide more structure to the reading assignment.

We generally give minimal instruction about the details of the activity and do not do a formal presentation to the class. We have found the students have done well using the instructional material on their own and will ask questions as needed. As common questions come up, we may make general clarifications to the class, but such interruptions are rarely necessary, and students seem motivated to use the class time to work on the project: students are on-task during the entire period, in contrast to some other activities we do in this class. This lesson takes the average student approximately 60 minutes. A few students do not finish within the class time, but can finish the activity as homework afterward. During the activity, students are situated in groups of two to three students who share a single computer. Most students bring their own computers, although we provide computers for those who prefer to use ours. In our class, the students have been working in the same groups for most of the semester at this point, so they are reasonably adept at working together. Within their tables of nine, we let them self associate into groups of two to three, and we generally allow students to work independently on this project if they choose (though they rarely do).

Students first open an Excel file (Supporting File S3) that has a column with “year” containing rows for the years 1958 to 2014. There is another column with “atmospheric CO$_2$ levels” for those years as measured at Mauna Loa, HI (22). Other columns include “Fossil Fuel” and “Land-use” emissions. The groups walk through the handout instructions (Supporting File S1) that guide them to calculate and then graph total atmospheric CO$_2$ by year. These data are graphed along with the yearly atmospheric CO$_2$ levels as measured at Mauna Loa. Students can see from the graph that a discrepancy exists between CO$_2$ levels measured at Mauna Loa and calculated total atmospheric CO$_2$. With provided data, students then add carbon sinks into the model formula by adjusting the carbon sinks until there is good agreement between the calculated (modeled) and observed CO$_2$ levels.

For the rest of the activity, the students develop either a “pessimistic,” “intermediate,” or “optimistic” scenario for what will happen in future years with changes in fossil fuel or land-use emission values. The definitions of these scenarios are provided in the lab handout (Supporting File S1). Students have
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flexibility in deciding if their intended change in atmospheric CO₂ is large or small. They are required to develop and explain one to three scenarios (depending on time demands). They create their scenarios through manipulation of the projected carbon sinks and sources for their own determined number of years by adding a row for each projected year. Students turn in a graph of their modeled forecast and a written description.

Intended Audience
The intended audience is undergraduate students with majors other than biology. A variety of majors are represented in the course and students ranged from first to fourth year and non-traditional students.

Required Learning Time
Most students should be able to finish this lesson in a 60 to 75-minute session. This lesson lends itself to easy modification and can be made to fit into a shorter time period (30 to 60 minutes), or more steps can be added throughout the lesson for either longer lab or class sessions, or to achieve additional learning outcomes.

Pre-requisite Student Knowledge
Students should feel comfortable working with spreadsheet software. The lesson handout (Supporting File S1) steps students through their activities and includes a basic overview of how to graph in Excel. Students who are not familiar with Excel can do this activity, but may require a bit more instructor or teaching assistant help.

Pre-requisite Teacher Knowledge
The instructor should understand

- how the amount of atmospheric CO₂ is affected from contributions by fossil fuels, land-use activities, vegetation, and ocean uptake.
- how carbon dioxide and other greenhouse gasses influence the earth's surface temperature.
- how to use Microsoft Excel to perform the lesson activities.

SCIENTIFIC TEACHING THEMES

Active learning
Students actively engage in learning climate change concepts by completing the exercises required to conduct and finish this lesson. They conduct hands-on computer work, and make predictions based on a variety of future scenarios. This lesson requires the group to discuss how future carbon emissions might change from current trends and they will observe the effect of those changes on carbon dioxide levels.

Assessment
Students answer questions within the handout (Supporting File S1) regarding their predictions and reflect on the lesson and what they learned from it. Summative assessment includes exam questions regarding the carbon cycle and atmospheric carbon dioxide levels.

Inclusive teaching
This lesson provides students with different ways to engage with the material, including reading, interactive discussion, and hands-on computer work. As a result, it creates an inclusive atmosphere for students with different learning preferences. By working in pairs or groups of three, students can work with students who have distinct knowledge, strengths, and experiences.

LESSON PLAN

BEFORE CLASS

Assign the students to:

- read the lesson handout (Supporting File S1)
- read the assigned article (an optional worksheet to guide reading of this article is provided in Supporting File S2)
- answer the “Check Yourself” questions in the lesson handout (Supporting File S1).

Make sure the computers that will be used for the lesson have a copy of Microsoft Excel and the required Excel file (Supporting File S3).

CLASS PERIOD - DAY OF LESSON

Students should have read the material before coming to class, but providing an overview of the lesson is a good way to begin the work.

1. We allow students to self-assign groups of two to three students within their larger group of nine. The group work benefits if the small group uses one computer, but students can also work independently on their own computer while talking through their lesson decisions. Occasionally, a student will choose to work independently and we allow this choice in our class. In our classrooms, each table of nine has an LCD monitor, so some groups decide to project one of the computers to the table’s monitor so others can more easily see what they are doing.

The student handout (Supporting File S1) presents an introduction to the material that the students read. We have found the students are enthusiastic to begin the lesson and do not need a presentation on the day of the lesson, given their reading and in-class discussion of the carbon cycle and the greenhouse effect.

If desired, the instructor can begin with a question based on the pre-reading assignment such as: “Fossil fuel emissions increased by 29% between 2000 and 2008 from the production and international trade of goods and services, and from the use of coal as a fuel source. In contrast, emissions from land-use were nearly constant. What are some mechanisms that might explain these trends with the flat line changes seen from land-use activities?” The students should have enough background from the reading and with the lecture overview to discuss and answer a few questions.

2. After a five to ten-minute overview and discussion, the students can open the provided Excel file (Supporting File S3) that we post on the course learning management system (Moodle) and start working on the carbon modeling lesson.

The first part of the lesson is designed to show the students the importance checking the modeled CO₂ in the atmosphere against actual data. The students first graph the currently known values of atmospheric CO₂ as measured by the Mauna Loa group (8). They create a new column in Excel in which they calculate a new atmospheric CO₂ value through the process of adding empirical sources of CO₂ with provided
The goal of the lesson was to introduce students to the concepts of climate modeling as a fundamental component of understanding global climate change. We want to help students understand how modeling carbon flow can help scientists examine effects on atmospheric carbon dioxide levels and make predictions based on these models. More broadly, we want the students to have firsthand experience in the modeling process so they better understand the development and use of other types of other climate change models (for example, predicting temperature, sea level rise, organism distribution, etc.).

Based on student comments in their reflections, this lesson met this goal in an engaging, inquiry-based environment. Students commented that for some it was their first experience with modeling, and that it helped them understand the carbon cycle. They also mentioned that they appreciated the skills they gained in Excel. Many said they enjoyed the lesson. Furthermore, students appear to reach a higher level of learning as they developed their own scenarios of how carbon emissions might be influenced in future conditions and how those emissions will affect atmospheric CO₂ levels. For example, students understood the connections between the land, ocean, and atmospheric carbon pools and they understood how human activities have affected these pools in the past and how our future activities will also affect them. The questions asked by the students during the lesson suggest that they were starting to understand the importance of modeling making in policy decisions. Some students expressed a desire to continue modeling in other disciplines. Students also asked many questions about how to use Excel. We could see that some students were challenged with the extensive use of Excel and felt that this lesson provided a bonus level of learning for those students who gained new skills in the use of this software.

**TEACHING DISCUSSION**

The next part of the lesson is designed to show the students the importance of accounting for both sources and sinks of CO₂ to the atmosphere and teaching the students how a model can be modified to better reflect known data. Here, students are directed to the worksheet titled “Part B.” This worksheet has information from Part A, plus it provides percentage estimates of CO₂ absorption by oceans and vegetation. In the spreadsheet, absorption percentages are constant year-to-year; however, students are encouraged to modify the percent absorption over time to see the effects on calculated atmospheric CO₂ levels. The new calculated values of atmospheric CO₂ will take into account the previous year’s atmospheric CO₂ level, plus the current year’s CO₂ emissions, minus the current year’s CO₂ sinks. Students will develop the calculated values for all of the years in the spreadsheet (1958-2013). They will then graphically compare their calculated values of annual atmospheric CO₂ with the empirically measured values from Mauna Loa with the goal of optimizing their model by adjusting CO₂ uptake to more accurately predict the empirically measured values.

Once the students’ newly established model closely models known CO₂ values, each group uses their model to extend their predictions of atmospheric CO₂ levels into the future (Figure 1, Part C). At this point, the students develop at least one of three possible scenarios - a “pessimistic,” “intermediate,” or “optimistic” scenario which they will use to create their projected pools of CO₂; ultimately predicting atmospheric CO₂ levels for the future 100 years. The definitions of these scenarios are provided in the lab handout. Students must use critical thinking skills to develop their own scenarios and have flexibility in deciding if their intended change in atmospheric CO₂ is large or small.

As the student groups work on their modeling exercises, the instructor walks around the room and answers questions. The instructor can join conversations about scenarios that are known to affect carbon pools or can help students develop their thoughts about their own scenario. The final graded product is a report describing at least one scenario, at least one graph that was developed to show the resulting atmospheric CO₂ levels under that scenario, and their interpretation of their results. Students also completed a question at the end of their handout asking how they liked the lesson and how they thought it could be improved. A timeline of this Lesson can be found in Table 1.

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**REFERENCES**

1. Scott EC, Berbeco M. 2013. Climate in the Classroom. Scientific American. 309(4):14-14.
2. Ruebush L, Sulkowski M, North S. 2009. A simple exercise reveals the way students think about scientific modeling. Journal of College Science Teaching. 38(3):18-22.
3. Oh PS, Oh SJ. 2011. What teachers of science need to know about models: an overview. International Journal of Science Education. 33(8):1109-1130.
4. Smetana LK, Bell, RL. 2012. Computer simulations to support science instruction and learning; a critical review of the literature. International Journal of Science Education. 34(9):1317-1370.
5. Hansen IA, Barnett M, Makinster JG, Keating T. 2004. The impact of three-dimensional computational modeling on student understanding of astronomy concepts: a qualitative analysis. International Journal of Science Education. 26(13):1555-1575.
6. Jamous, M. 2012. Introduction to the principles of climate modeling, http://www.carboeurope.org/education/sciencedata.php. Accessed
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December 17, 2015.
7. Modell HL. 1989. Can technology replace live preparations in student laboratories? Advanced Physiological Education. 6(3):S18-S20.
8. Dewhurst DG, Hardcastle J, Hardcastle P, Williams AD. 1992. An interactive computer-simulation of experiments to teach the principles of nutrient transport in the small intestine. Alternatives to Laboratory Animals. 20:529-535.
9. Dewhurst DG, Williams A. 1993. Frog skin: a computer simulation of experiments performed on frog skin in vitro to investigate the epithelial transport of ions. Alternatives to Laboratory Animals. 21:350-358.
10. Gibbons NJ, Evans C, Payne A, Shah K, Griffin DK. 2004. Computer simulations improve university instructional laboratories. Cell Biology Education. 2004 Dec 21;3(4):263-9.
11. Cooper, S. 2007. Genetic Drift. http://serc.carleton.edu/sp/library/mathstatmodels/examples/14313.html. Accessed October 21, 2016.
12. IPCC Intergovernmental Panel on Climate Change. 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
13. Caldeira K. 2012. The great climate experiment. How far can we push the planet? Scientific American. 307(3):78-83.
14. Berner RA, Lasaga AC. 1989. Modeling the geochemical carbon cycle. Natural geochemical processes that result in the slow buildup of atmospheric carbon dioxide may have caused past geologic intervals of global warming through the greenhouse effect. Scientific American. 260(3):74-81.
15. Ahlström A, Raspach MR, Schurgers G, Smith B, Arnett A, Jung M, Reichstein M, Canadell JC, Friedlingstein P, Jain AK, Kato E. 2015. The dominant role of semi-arid ecosystems in the trend and variability of the land CO2 sink. Science. 348(6237):895-9.
16. Tans P, Thoning K. 2008. How we measure background CO2 levels at Mauna Loa. http://www.esrl.noaa.gov/gmd/ccgg/about/co2_measurements.html. Accessed December 17, 2015.

Table 1. Climate Change Literacy-Teaching Timeline

| Activity                  | Description                                                                 | Estimated Time |
|---------------------------|-----------------------------------------------------------------------------|----------------|
| **Class Period Before Lesson** |                                                                             |                |
| Assign to students        | Assign students to read the laboratory handout and the assigned journal article (along with optional worksheet) to be prepared for the next class period activity. | 5 minutes to distribute the handouts and to tell the students what they are for |
| **Class Session**         |                                                                             |                |
| Have students gather in groups. | Students will be groups of two or three to do this lesson.                   | 5 minutes      |
| Discuss reading assignments|                                                                             | 5-10 minutes   |
| Have students conduct activity |                                                                         | 30-45 minutes  |