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

science behind climate change.

For this lesson, we modified the climate change activity from the CarboSchools carbon research and education website, which can be accessed on the website page called "Using Scientific Data" (6). We combined and modified the three activities listed on that page to make the workload appropriate for the time available to the students in our class. For example, we created our own images to use throughout the document and annotated various areas with Excel hints. We also added a "Background" section at the beginning of the document with several "Check Yourself" questions for the students to answer before they started the modeling section. To help with scenario development, an appendix was added to provide the students with a list of natural and anthropogenic activities that either add CO_2 to the atmosphere or remove CO_2 out of the atmosphere. We also modified the available Excel file to allow the students to progress through the first set of steps more quickly. This change gave them more time to develop their own hypotheses and analyses in the second half of the exercise. The supply requirements for this lesson are few: student pairs need a computer, the handout (or uploaded document-Supporting File S1.) showing the steps of the lesson, and the appropriate start-up Excel file (Supporting File S3).

A simulation is the process of using a model - a physical, digital (visualization), or mathematical formula that represents a system of interest - to study the behavior and performance of the system. Multiple studies highlight the benefits of using computer simulations when teaching various biological concepts (7,8,9,10,11). Benefits include the provision of topic-specific learning outcomes as well as the flexibility of time (when the assignment is done and for how long) and location for both student and instructor. Additional benefits include the reduction of infrastructure costs, decreased laboratory time, and greater control of the learning pace for students. For introductory and non-science major biology courses, the learning benefits from using models can be realized when teaching a scientific topic like climate change (12).

Climate change is defined as a long-term change in average weather conditions that comprise our global climate, including temperature, precipitation, and wind (13). Global climate is undergoing dramatic changes as the direct result of greenhouse gas (GHG) emissions from human activity (13,14). GHGs are gases in the atmosphere that act like a roof or barrier around the earth, trapping in heat that might otherwise radiate into space. This entrapment of heat in the atmosphere is referred to as the "greenhouse effect".

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 syears 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

flexibility in deciding if their intended change in atmospheric CO_2 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 CO_2 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 that 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 CO_2 in the atmosphere against actual data. The students first graph the currently known values of atmospheric CO_2 as measured by the Mauna Loa group (8). They create a new column in Excel in which they calculate a new atmospheric CO_2 value through the process of adding empirical sources of CO_2 with provided

CO_2 input sources from land use and fossil fuels. They then compare graphs of their new calculated values with the known empirically measured values. The goal of this section is to make the students aware that they can examine atmospheric CO_2 pools through this type of graphing process. By graphing the known values of atmospheric CO_2 and the known sources that contribute to atmospheric CO_2, they have a more solid understanding that there are multiple processes affecting atmospheric CO_2.

The next part of the lesson is designed to show the students the importance of accounting for both sources and sinks of CO_2 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 CO_2 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 CO_2 values. The new calculated values of atmospheric CO_2 will take into account the previous year's atmospheric CO_2 level, plus the current year's CO_2 emissions, minus the current year's CO_2 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 CO_2 with the empirically measured values from Mauna Loa with the goal of optimizing their model by adjusting CO_2 uptake to more accurately predict the empirically measured values.

Once the students' newly established model closely models known CO_2 values, each group uses their model to extend their predictions of atmospheric CO_2 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 CO_2; ultimately predicting atmospheric CO_2 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 CO_2 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 CO_2 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.

TEACHING DISCUSSION

The goal of this 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 CO_2 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.

SUPPORTING MATERIALS

- S1. Climate Chage Literacy-Activity Handout. This is the handout that students will use for this lesson. Background information is provided for this lesson, "Check Yourself" questions are embedded in the handout and there is an appendix in the back to provide students with a list of processes that either adds CO_2 or removes CO_2 from the atmosphere.
- S2. Climate Chage Literacy-Worksheet: Questions to Guide your Reading of LeQuere et al. 2009.
- S3. Climate Chage Literacy-Microsoft Excel workbook. This is the Excel workbook where students will do their activity exercises and graph their results.
- S4. Climate Chage Literacy-Microsoft Excel workbook with worked out exercises.

ACKNOWLEDGMENTS

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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