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Development and Evaluation of an Inquiry-Based Unit for Teaching about Paleoclimate and Climate Change

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DEVELOPMENT AND EVALUATION OF AN INQUIRY-BASED UNIT FOR TEACHING PALEOCLIMATE AND CLIMATE CHANGE

by

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The purpose of this action research study is to develop and evaluate a sequence of four lessons for an introductory earth science course taken by future elementary teachers. Action research is a reflective process of data collection and analysis used by teachers to improve their classroom practice. This study's goal is to produce a series of lessons that align with the course philosophy of student-driven learning through guided-inquiry and are effective at improving students' understanding of climate change.

Three data sets were used to evaluate the lessons: 1) student knowledge gains on an objective pre- and post-test, 2) students' self-reported confidence with the lesson content, and 3) classroom observations to monitor lesson implementation and student engagement. Data analysis in the Spring 2012 and Fall 2012 semesters reveal that students were able to identify natural mechanisms that cause climate to change, distinguish between weather and climate, and identify greenhouse gases as contributing to global warming. However, they struggle with interpreting graphs and identifying how natural processes affect the concentration of carbon dioxide in the atmosphere. These results guide changes for future lesson implementation to complete the action research study.

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INTRODUCTION

Problem Statement

Major advances in science have taken place since the development 15 years ago of the national benchmarks which are used to guide all current state science standards (Next Generation Science Standards, 2013). Recent reform efforts such as the development of the Next Generation Science Standards and Earth Science Literacy Principles emphasize the importance of climate literacy among citizens and the big ideas that are most important for all citizens to know as determined by earth science research and educational communities. (National Science Foundation, 2009) It is of upmost importance that future teachers also have a competent level of climate literacy because they will be educating future generations. However, at WMU the current teacher preparation course in earth science does not include climate science. Thus, a sequence of lessons was developed to meet this climate literacy need.

Purpose Statement

The purpose of this study was to develop a sequence of educational lessons on the topic of global climate change that could be used in a pre-service elementary education earth science course. To ensure that these lessons met the specific needs for the course and were as effective in meeting their objectives as possible, an action research approach was used.

Theoretical Framework

This sequence of lessons was designed to improve students' content knowledge as well as follow the course philosophy of student-driven learning through constructivism and guided-inquiry. The course philosophy is reinforced by a study completed by Piburn et al. (2011) of eight instructors' classrooms. Results from Piburn et al. (2011) show that substantial and meaningful changes are needed beyond the traditional lecture to teach students more effectively. Piburn et al. (2011) found that the highest learning gains were achieved not by traditional lecture, but by utilizing cooperative learning, modeling instruction and problem-based learning, which are all aspects of scientific inquiry teaching. Futhermore, a study by Kulik (1979) found that for students to develop stronger cognitive skills such as problem-solving abilities, a discussion instead of a lecture teaching approach is more effective. Also, research done by Johnson et al. (1991) found that in comparing students who experienced a cooperative learning environment to students who experienced a competitive or individualistic learning environment, the students from the cooperative learning environment experienced greater academic achievement and had more positive interactions with their classmates.

According to Paparozzi (1998), constructivism is based on Piaget's theory of learning which encourages group interaction among students as well as utilizing authentic data in order to achieve learning through discovery. Scientific inquiry, as defined by the National Science Education Standards (National Research Council, 1996), is "the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities through which students develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world." Although the term scientific inquiry can refer to multiple meanings, for the purpose of this study, it is intended as a specific teaching approach.

According to Wiley and Royce (1999), there are three levels of teaching scientific inquiry. In the first level of inquiry the teacher establishes the problem and the methods to be used, but allows students to draw their own conclusions. This level of inquiry is used in the vast majority of science course lab investigations and is sometimes jokingly referred to as “cookbook” style, as for example in labs where the students just follow a “recipe” of methods in order to complete a laboratory assignment. Also, because the teacher usually directly teaches the concepts involved in the lab prior to the students starting the activity, very little student-constructed knowledge is achieved, because the students may already know the expected outcome before conducting any experiment. The secondary level of inquiry allows the students to determine the methods they will use to produce their own conclusions to a problem posed by the teacher. This level of inquiry is also known as “guided inquiry” because the teacher plays the role of a guide to the students as opposed to being the source of all the answers for the students. In the third level of inquiry, or “open inquiry”, the students select the topic to be studied and the methodology used to yield their own conclusions from the investigation (Wiley and Royce, 1999). The course where these lessons were introduced utilizes scientific inquiry in a guided approach (secondary level) rather than primary or completely open inquiry (tertiary level).

Action Research

Action research is a cyclical process described by Minstrell (2000) as a combination of the planning process of engineering and the analytical nature of science where lessons are developed, tried, modified, and then tried and modified again until the final product is a lesson that meets the needs of the students and learning goals of the curriculum. Studies such as Zhang (2009) and the case studies contained within Goodnough (2011) have shown how successful action research projects can be in improving a specific aspect of one's teaching as well as students' learning.

Course Context

Elementary education teacher preparatory programs in the state of Michigan are required to prepare future elementary teachers to teach science at the K-8 level under state accreditation guidelines (Michigan State Board of Education, 2011). At WMU, the science program for students enrolled in the elementary education or special education curriculum includes six science content courses. GEOS 2900 is one of these content courses. It has been explicitly designed to prepare future teachers to teach earth science at the K-8 level with reference to state and national benchmarks for scientific literacy (GEOS 2900 Course Pack, 2012).

> "The specific course goals of GEOS 2900 are that students will: 1) understand why it is important for children to learn earth science, 2) learn key concepts of earth science through the process of inquiry, 3) be able to reflect upon the nature and practice of earth science as a process rather than a body of disconnected facts to be memorized, 4) be better able to

> make decisions concerning what concepts in earth science are the most important for children to learn, and 5) reflect upon how they themselves learn earth science and the implications of these reflections for how it should be taught. By the end of the course students will be familiar with the Michigan Grade Level Content Expectations (v. 1.09) within Discipline 4 – Earth Science: Earth Systems (ES), Solid Earth (SE), Fluid Earth (FE), and Earth in Space and Time (ST) and be able to relate the study of earth science to contemporary, historical, technological, and societal issues." (GEOS 2900 Course Pack, 2012)

As part of a nationally accredited teacher preparation program, the GEOS 2900 course must be regularly evaluated for alignment with the standards outlined by both the Michigan Department of Education and the accrediting body. The most recent evaluation in 2010 revealed that the alignment could be improved, thus the course is being revised to: (1) better meet the state and accreditation standards, (2) meet additional criteria for the preparation of middle school teachers, and (3) meet criteria for Western Michigan University General Education in Area VII (Science, Technology, and Society). The revised course will have more of an emphasis on the applications of earth science to society, and will target content appropriate for upper elementary and middle school grade levels. Thus the development of the new lessons must incorporate these changes into the course while staying true to the course's philosophy and utilizing best teaching practices. The teaching philosophy of GEOS 2900 is that learning is a socially mediated activity where students learn by doing and not only understand the earth science content but also learn about the nature of science and scientific inquiry (GEOS 2900 Course Pack, 2012).

As part of the revisions to GEOS 2900, the course will include a new unit, on earth history and global climate change. Because these new lessons will be covering a topic that could be viewed as "controversial" to some students, approaches similar to those mentioned in Heffron and Valmond (2011) regarding how teachers can effectively teach the topic of global climate change while avoiding the controversy that exists in the media were taken. To avoid some of the alarmist positions taken by the media Heffron and Valmond (2011) advise that students should be given authentic data to come to their own conclusions. Another approach mentioned in the literature, which is utilized in these lessons, as well as in GEOS 2900 in general, is the idea of challenging students to be critical of information and to learn how to differentiate between ideas that are fact and ones those that are opinion. The third approach mentioned by Heffron and Valmond (2011) in which instructors explain the nature of the scientific method is addressed more broadly in GEOS 2900 as a course.

Curriculum Design

The four lessons that we developed will be integrated into a new GEOS 2900 third unit. Currently, topics in earth history and geologic time (for example, fossils, radiometric dating, relative ages, the geologic time scale, and the geologic history of Michigan) are covered in the fourth unit of the course. However, the course structure will change from four units to three, and these four lessons will broaden the third unit to incorporate paleoclimate and climate change into earth history and geologic time.

The focus of the lesson sequence is on the greenhouse gas (GHG) carbon dioxide because it is the greenhouse gas that currently contributes the most to anthropogenic climate change. In determining the order of the lessons, the rationale is to have the students learn first about the chemical species of carbon, including where various carbon-bearing species exist on the Earth, and how carbon can transform from one chemical species to another. This objective was achieved in the first lesson by having the students produce a model of the carbon cycle, identifying primary sources, sinks and fluxes of carbon. The next lesson allows the students to determine some properties of carbon dioxide and other GHGs, together with how these are connected to the Earth's average temperature. The third lesson provides the students an opportunity to see how climate scientists determine temperature averages and to determine from temperature graphs how much the Earth's average temperature has changed over the past 50+ years. In the fourth lesson, the students study ice core data, a climate proxy, to determine how the Earth's temperature varies naturally, as well as to identify possible departures from naturally occurring trends in recent time.

The first of the four lessons focuses on the carbon cycle. The goal of this lesson is for students to understand fluxes and reservoirs of carbon in the carbon cycle by constructing a paper and string model of the carbon cycle. This lesson is taught via a jigsaw teaching approach. A jigsaw is a cooperative learning teaching technique that allows students to work in small, structured groups (Hanze and Berger, 2007). To utilize this technique, students were first taken out of their original four-person groups and placed into four new groups of six people; each new group worked together to study an aspect of the carbon cycle. Each group is assigned one of the four spheres of the Earth: the biosphere, geosphere, atmosphere or hydrosphere.

Using information in a handout provided in the student laboratory course pack, students determined the important carbon reservoirs, fluxes between reservoirs and how large of an effect each flux has on the reservoir as a whole. The handout was prepared from textbooks and peer-reviewed scientific literature, and was face validated by a biogeochemist and a biologist. It is provided to prevent the students from using internet sources or their textbooks where they would likely find diagrams of the carbon cycle. This would circumvent the goal of the lesson which is for the students to better understand the carbon cycle by developing their own model of it.

After the groups determine reservoirs and fluxes for their particular reservoir, the students return to their original 4-person groups. In these original groups, each student serves as an "expert" regarding their particular reservoir of the Earth. By combining what each student has learned, each group develops a reasonably complete carbon cycle model. This lab is modified from "Understanding the Carbon Cycle: A Jigsaw Approach" by David Hastings of Eckerd College (http://serc.carleton.edu/NAGTWorkshops/ climatechange/activities/15162.html). The two largest modifications were: 1) Rather than having students answer research questions at home about the carbon cycle and bring them to class the next day, they are given a document with all the information they need so they can work during class. 2) Instead of having each student group focus on individual processes, each group considers a given reservoir.

The second lesson is a guided-inquiry based experimental lab and computer simulation covering the topic of greenhouse gases and their effect on Earth's temperature. The goal of this lesson is for the students to evaluate the effect of added carbon dioxide, and other greenhouse gases, on the rate of heating of the Earth's atmosphere, and to develop an understanding of why the greenhouse effect occurs. According to Lueddecke (2001), the Earth's greenhouse effect operates on the large scale within the Earth's atmosphere but can also be modeled in the small scale using laboratory materials fairly easily.

In the first part of the lesson the students model the greenhouse effect using two 2-liter plastic soda bottles with thermometers. In accordance with guided inquiry principles, students are given the task of designing an experimental setup to compare the change in temperature between "normal" room air and carbon dioxide-enhanced air when both are heated for an hour. To complete this task, students are given two 2-liter bottles, Alka-Seltzer tablets, tap water, two digital thermometers and a lamp, with the expectation that they will use these to produce two different "atmospheres" in their bottles. To produce carbon dioxide-enhanced air the students place the Alka-Seltzer tablets into water in one of the bottles. To make sure that the volume of air that is being heated is equal, the students place the same volume of tap water into the second bottle, but do not include Alka-Seltzer tablets (i.e. contents are "normal" room atmosphere). The lamp mimics the heat from the sun to heat up the two "atmospheres". The digital thermometers are connected to a computer to record the temperatures in both bottles over the course of an hour. Via a computer program, the digital thermometer data is automatically entered into a data table and also graphed for the students. The students answer open-ended questions based on their observations and data. The first part of this lab is a modified version of the "Greenhouse Effect Laboratory" by the Environmental Literacy & Inquiry Working Group at Lehigh University (http://www.ei.lehigh.edu/eli/cc/sequence/

day2.html) except that the lab developed in this study uses Alka-Seltzer and water instead of vinegar and baking soda to create a high CO_2 atmosphere.

In the second part of the lesson, the students observe a simulation on the University of Colorado at Boulder PhET simulation website (http://phet.colorado.edu/en/simulation/greenhouse). The simulation has three parts, however, the students use only two parts because the third did not pertain to the planned lesson. In the first part of the simulation, students can adjust the number of air molecules in the "simulated atmosphere" and then "fire" infrared and visible photons at the molecules of methane (CH_4), carbon dioxide (CO_2), water vapor (H_2O), nitrogen (N_2), and oxygen gas (O_2). The photons travel through each molecule unaltered if they are not absorbed. However, when the molecules absorb the energy particle, the simulator shows the proton "particle" entering the molecule, shaking and then being re-emitted in a new direction. The goal of this part of the simulation is to help students visualize how energy particles become "trapped" in the Earth's atmosphere due to the presence of greenhouse gases.

The second part of the simulation is a hypothetical Earth location showing the movement of visible and infrared photons as well as the air temperature at that location due to changeable parameters. These parameters can be adjusted according to time period and can be set to: Today, the year 1750, and the Ice Age. At each of these time periods the greenhouse gas concentration adjusts to the approximate levels associated with that time period. The students can also adjust the overall greenhouse gas concentration to extreme levels: one with no greenhouse gases present in the atmosphere, and another with much greater concentrations of greenhouse gases in the atmosphere than are present today. The students produce a table with the data they collect from the two parts of the simulation and then answer open-ended questions based on their observations. This lesson was produced by combining the modified version of the "Greenhouse Effect Laboratory" activity with the University of Colorado at Boulder PhET simulation.

The third lesson covers the difference between daily weather and climate. The goal of this lesson is for students to be able to understand how temperature changes on different time scales (daily, annually, and over decades) and to develop an understanding of the distinction between weather and climate. According to Encyclopedia Britannica (2012) (http://www.britannica.com/EBchecked/topic/121560/climate), climate is the atmospheric conditions (solar radiation, temperature, humidity, precipitation, atmospheric pressure, and wind speed and direction) at a particular location over a long-period of time. However, this lesson only focuses on the property of temperature over the long-term. The purpose is to simplify the exercise while still correctly conveying the idea of climate.

This activity has two parts: the first part asks students to determine temperature averages over varying periods of time. The students first look at temperature data for St. Louis, Missouri and consider how it changes over the course of a day in summer and a day in winter, determining the average temperature for each of these days. Next, the students consider daily temperature data over the course of the year 2004 in Kalamazoo, Michigan and determine the average temperature for that year. The students then examine a temperature graph on Google Earth showing the temperature from 1950-2008 for Allentown, Pennsylvania. Students are directed to examine two ten-year periods and determine the average temperature during each ten-year period, and then determine the average temperature over the course of the entire 58 years shown on the graph. This allows them the opportunity to see how temperature averages of temperature are calculated.

This leads into the second part of the lesson, in which students consider average yearly temperature over 58 years at various locations on the Earth. In this part of the lesson students use Google Earth to compare and contrast temperature data of the past 58 years for fifteen locations on the Earth to ascertain the average temperature change at each location over this time period. The students then answer open-ended questions based on their observations. This lab is created by combining the laboratory activity “Investigating Weather and Climate with Google Earth” (http://www.ei.lehigh.edu/eli/cc/sequence/day2.html) by the Environmental Literacy & Inquiry Working Group at Lehigh University with graphs produced for the first part of the lesson from weather data obtained through the National Climatic Data Center on NOAA’s website (http://cdo.ncdc.noaa.gov/ulcd/ULCD).

The fourth lesson covers the natural causes of climate change using ice core data from the Late Pleistocene and Holocene. The goal of this lesson is for students to recognize Milankovitch cycles as an important natural driver of Earth’s long-term climate, and to recognize that the most recent period of warming cannot be explained by these cycles. In the activity, students analyze ice core data by looking for correlations between temperature, carbon dioxide concentration, and Milankovitch cycles.

The students are given graphs of Vostok ice core data that goes back 350,000 years for parts one and three of the lesson. In the first part of the lesson, students determine periods of high carbon dioxide and methane concentrations over the past 350,000 years. They then make predictions of cool and warm periods by coloring regions of the graph red for warm and blue for cold. In part two of the lesson the students access the "Milankovitch Cycles" tutorial on the "Virtual Courseware for Earth and Environmental Sciences" website (http://www.sciencecourseware.org/eec/GlobalWarming/Tutorials/Milankovitch/) and then answer questions as they follow along with the tutorial. In the third part of the lesson, students observe patterns in the Vostok ice core data graphs with respect to carbon dioxide and Milankovitch Cycles. After determining the effect Milankovitch Cycles have on the Earth's climate the students create a hypothesis regarding the cause of the most recent period of climatic warming on Earth. This lesson was created by combining the "Milankovitch Cycles" tutorial on the Virtual Courseware for Earth and Environmental Sciences" website with data and graphs that were obtained from "Using Real Data from Ice Cores and Salt Cores to Interpret Paleoclimate" by Kathy Benison of Central Michigan University (http://serc.carleton.edu/NAGTWorkshops/sedimentary/activities/13695.html) and "Long-Term Climate Change" by William F. Ruddiman and Jacqueline E. Huntoon of the American Geological Institute.

Role of the Researcher

The first author develops and modifies the lessons and assesses the efficacy of the lessons and activities by observing in the classroom and via pre-/post-testing. A separate instructor teaches the lessons, therefore the first author can act as an outside observer and devote class time to observing the whole class rather than splitting duties among teaching, assisting students and observing.

Summary of Significance of Work

The goal of this study was to develop a sequence of lessons that fulfills the requirements of GEOS 2900 and improves the students' understanding of concepts associated with global climate change. In addition to introducing these lessons to other teachers for use and modification for their own classrooms, this study also could serve as a guide for teachers who wish to use action research to improve their own classrooms.

CHAPTER II

DEVELOPMENT AND EVALUATION OF AN INQUIRY-BASED UNIT FOR TEACHING PALEOCLIMATE AND CLIMATE CHANGE

Introduction

Climate change is one of the most important and controversial topics of today. According to the Yale Project on Climate Change Communication (2010), “63 percent of Americans believe that global warming is happening, but many do not know why.” However, understanding climate change is one piece of a broader push toward earth, environmental, and climate science literacy. Today there are many challenges facing man such as climate change, declining mineral and energy resources as well as water shortages that are directly related to the earth sciences. (National Science Foundation, 2009). It is crucial today, more than ever that we, as a business community and nation, have a strong understanding of the Earth’s systems to make informed decisions. (National Science Foundation, 2009). According to the National Science Foundation (2009), “It will take a deep and subtle understanding of Earth’s systems for future generations to be able to feed, clothe, house, and provide a meaningful existence for all humans. We need citizens and businesses that are earth science literate.”

This emphasis is of greatest importance in classrooms. Addressing misconceptions and accurately teaching how Earth’s climate has changed today and in the past is now more critical than ever. Students’ knowledge and understanding about environmental issues learned in the classroom affects their future decisions. One cannot expect them to make well-reasoned environmental decisions if they do not have a sound understanding of the science and human interactions behind issues such as climate change (Nam et al., 2011). Therefore it is imperative that teachers address and correct students' misconceptions when teaching complex topics such as climate change so that students can make well-informed future decisions.

In this study the first author developed a sequence of four lessons created from a combination of new and existing laboratory activities and integrated these into a unit on climate change and Earth's history. These lessons addressed students' misconceptions and used guided inquiry methods. Their effectiveness was tested in an earth science content course (Exploring Earth Science: Geology – EESG) taught by the second author that is part of a program for preparation of elementary teachers at Western Michigan University (WMU).

Methods

Research Design

This study consisted of three research questions:

- How well did the students learn the targeted concepts during the lessons?
- Do the students acknowledge that they have learned new concepts?
- How can the lessons be improved for the future?

Various sources (formative, summative, student feedback) of data were collected for this study. The lessons were considered effective if students achieved statistically significant learning gains as measured through pre- and post-test scores as well if students self-reported an improved level of confidence with respect to teaching this content to their future students. The participants, types of data collected, as well as how we collected and analyzed that data are explained further in the next sections.

Participants

The participants in this study are K-8 pre-service elementary teachers at WMU enrolled in GEOS 2900. Although demographic data were not collected as part of the study, we can report the typical characteristics of this population based on the second author's teaching experience over nine years. Students are predominately female (80-90%), white (90-95%), and of traditional undergraduate age (19-22). All of the students are pursuing an undergraduate major in either elementary education or early childhood education, and most are in their third or fourth year of this program when they take the earth science course. Because the course is part of a sequence of science education courses that all follow a guided inquiry format, students are usually familiar with this pedagogical approach and comfortable in a constructivist learning setting. A consent form with three options: (1) allow permission to use any data collected from their group and individual work, (2) allow permission for use of group work only, or (3) allow no permission to use any data collected from this course was given to each student in the class. Only data from students consenting to participate in the project (85% of the total population consented) are reported here.

Lesson Development

The lessons were developed in fall 2011. These lessons were designed to follow the GEOS 2900 course philosophy, which incorporates constructivism, nature of science and guided inquiry into lessons. The students enrolled in GEOS 2900 were pre-service K-8 teachers, and therefore typically had a limited science background. Due to their limited content knowledge, guided-inquiry was utilized rather than open inquiry, i.e. students were given open-ended questions instead of the freedom to develop their own questions. According to Mayer (2004), who has compared research on open and guided-inquiry since the 1960's, guided-inquiry leads students to more meaningful understandings of scientific concepts. Furthermore, Marbach-Ad and Classen (2001) conclude that students who do not have strong background knowledge are unable to conduct sophisticated open-ended investigations and consequently need direct instruction to develop their own questions. Guided-inquiry allows students to conduct investigations with a pre-determined scientific question. For the GEOS 2900 population, this approach is likely to have a better chance of achieving learning goals compared to an open-inquiry approach.

Curriculum Design

Prior to implementation of the new lesson sequence developed and assessed in this study, GEOS 2900 was divided into four units: (Unit One - Plate Tectonics, Earthquakes and Volcanoes, Unit Two – Minerals and Rocks, Unit Three – Surface Processes, Unit Four – Geologic Time and Earth History). The course was revised to incorporate more emphasis on the connections between earth science and society, and the new lessons were part of that change.

Topics related to Earth history and geologic time (for example, fossils, radiometric dating, relative ages, the geologic time scale, and the geologic history of Michigan) were originally covered in the fourth unit of the course. However, the course was restructured from four units to three units, and the four lessons developed in this study are incorporated into the revised third unit. This unit was broadened to incorporate concepts related to paleoclimate and climate change into a unit on Earth history and geologic time. Because these lessons take place at the start of the new unit, it expected that students will start the lessons with little prior knowledge regarding the main concepts to be covered. This lesson sequence has taken that expectation into consideration throughout its development.

The focus throughout the unit is on the greenhouse gas (GHG) carbon dioxide because it is the greenhouse gas that currently contributes the most to anthropogenic climate change. In determining the order of the lessons, a decision was made to first have students learn about the chemical species of carbon, including where they are found on the Earth, and the processes that transform carbon from one chemical species to another. This objective was achieved in the first lesson (Carbon Cycle) by having students produce a simple model of the carbon cycle, identifying primary sources, sinks and fluxes of carbon. This lesson is taught via a jigsaw teaching approach. A jigsaw is a cooperative learning teaching technique that allows students to work in small, structured groups (Hanze and Berger, 2007). The next three lessons are based on guided-inquiry: students either obtain their own data or are given authentic data to draw their own conclusions. The second lesson (Greenhouse Gases) utilizes an experimental lab activity and a computer simulation covering the topic of greenhouse gases and their effect on Earth's temperature. This lesson allows students to visualize some properties of carbon dioxide and other GHGs, together with how these are connected to the Earth's average temperature. The third lesson (Weather and Climate) is an opportunity for students to learn how climate scientists establish temperature averages and to determine from temperature graphs how much the Earth's average temperature has changed over the past 50+ years. In the fourth lesson (Paleoclimate), students study a climate proxy, Vostok ice core data, to determine how Earth's temperature varies naturally according to the

Milankovitch cycles, as well as to identify departures from natural controls in more recent time. Detailed instructor notes and student lab handouts for each lesson are provided in Appendices C-J.

Data Sources and Instrumentation

To assess how well the lessons improved student knowledge and confidence, four sources of data were collected: a content assessment test, a feedback survey, student work from the lessons and the first author's observations. To determine students' incoming knowledge and misconceptions, students took a content assessment test before the first of the four lessons began. This test was modified from the Climate Science Knowledge Inventory in Lutz et al. (2011) (see Appendix L). The original test in Lutz et al. (2011), which was validated with a population of undergraduate elementary education students, contained forty predominantly multiple-choice questions. Rather than use all of the questions, we administered ten questions that were most closely related to the content covered in the four lessons of this project, together with three newly-created open-ended questions.

The same content assessment test was given at the end of the sequence of four lessons to assess the learning gains. The results were used to help us identify changes in lessons that would be required to ensure that future students' misconceptions would be addressed more effectively. Due to the small population of our study (N=53) the revised instrument was not re-validated. A feedback survey was used to evaluate the effectiveness of the four lessons based the students' opinions. Student work associated with each lesson, such as graphs, data tables and responses to "outcome questions" was also collected. Lastly, the first author's classroom observations of students completing each of the laboratory activities also served to help us identify the strengths and weaknesses of the lessons for further improvement.

Data Collection

The content assessment test was initially given to students prior to the first lesson. The test was then re-administered at the end of the fourth lesson to gauge learning gains. Eight questions from the test were given to students immediately after completion of the fourth lesson (two weeks after the pre-test) while the remaining five questions were included as questions on the GEOS 2900 final exam (approximately four weeks after the pre-test). The feedback survey was passed out to students at the end of each class period and collected as they walked out of the classroom. The survey included a mix of open and closed response options. The survey asked the students four questions:

- Did you have enough prior understanding to complete this activity? Students choose one of three response options: Yes, Somewhat, No
- Do you have confidence in this topic to teach it to your own set of K-8 students? Students choose one of three response options: Yes, Somewhat, No
- What part of this activity best helped you learn this topic? Open-ended response
- What was your least favorite part of this activity? How could it be improved? Open-ended response

Student work was collected electronically through the university's online learning interface. Observations and notes were taken by the first author during the lessons. The first author and instructor then debriefed at the conclusion of each lesson.

Data Analysis

Student learning gains were determined by comparing scores on the content assessment test given before the first and at the end of the fourth lesson to evaluate items for which there was improved understanding, no gains, or a decline in understanding the content of the lessons. Descriptive statistics on the full data sets were used to examine student test scores. We subsequently looked at the distribution of pre- and post-test scores within each class section of students. A one sample Kolmogorov-Smirnov test was used to determine whether the pre- and post-test data within each section met assumptions of normal distribution. The outcome questions from the individual lessons were used to determine if the students' responses reflected understanding of the concepts within each lesson. These questions were also used to determine whether the student responses became more sophisticated and well-reasoned during the progression of the four lessons because they all built upon one another. The effectiveness of each lesson was also revealed through feedback surveys and observations that the first author made during the administration of the four lessons. The feedback surveys assessed student opinion data regarding the four lessons, as well as how confident they were regarding the content knowledge. Class observations made by the first author helped to determine how well each lesson worked and identify areas in need of improvement. For example, if multiple students were confused regarding a particular aspect of the instructions for a lesson then we would focus on improving those directions to minimize confusion in the next implementation of that lesson.

Results and Discussion

Implementation #1

The first implementation of the lessons occurred in spring 2012 with one section of twenty students. However, one student declined to have their individual work included in the study, therefore, only nineteen students' data could be used.

Evaluation #1

After initial implementation in spring 2012, the majority of students (67-95%) self-reported that they had sufficient prior knowledge to complete the Greenhouse Gases, Weather and Climate and Paleoclimate lessons (shown in Fig. 1). However, only 24% of students did not report sufficient prior knowledge to complete the Carbon Cycle lesson (Fig. 1).

The students self-reported the highest confidence (72%) for the Weather and Climate lesson (shown in Fig. 2). The students were evenly split with respect to whether they felt confident regarding content covered in the Greenhouse Gases and Paleoclimate lessons. For the Carbon Cycle lesson the students had very little confidence (10%) regarding the content (Fig. 2).

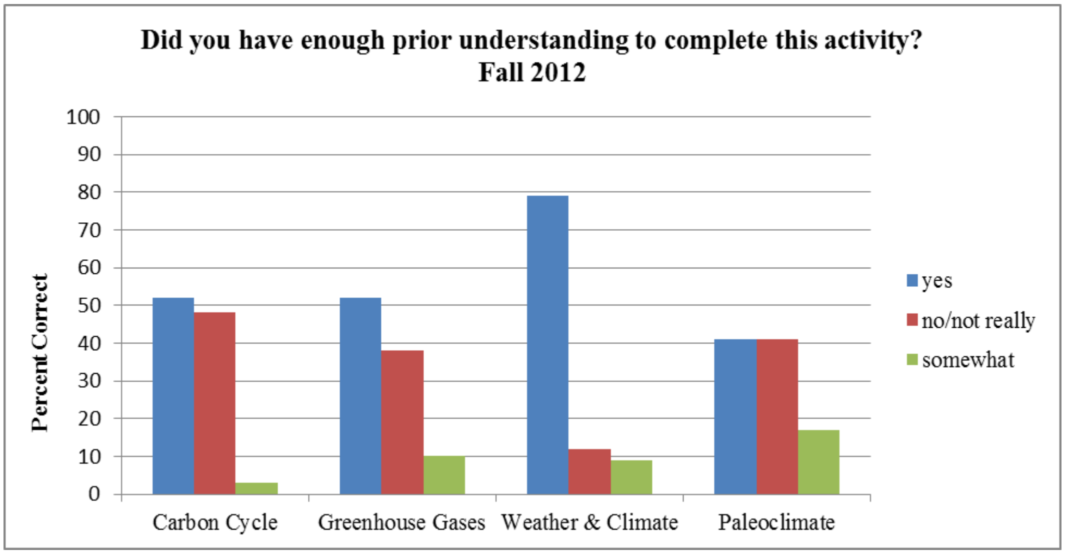


Figure 1. Responses to question one: “Did you have enough prior understanding to complete this activity?” on the feedback survey for spring 2012.

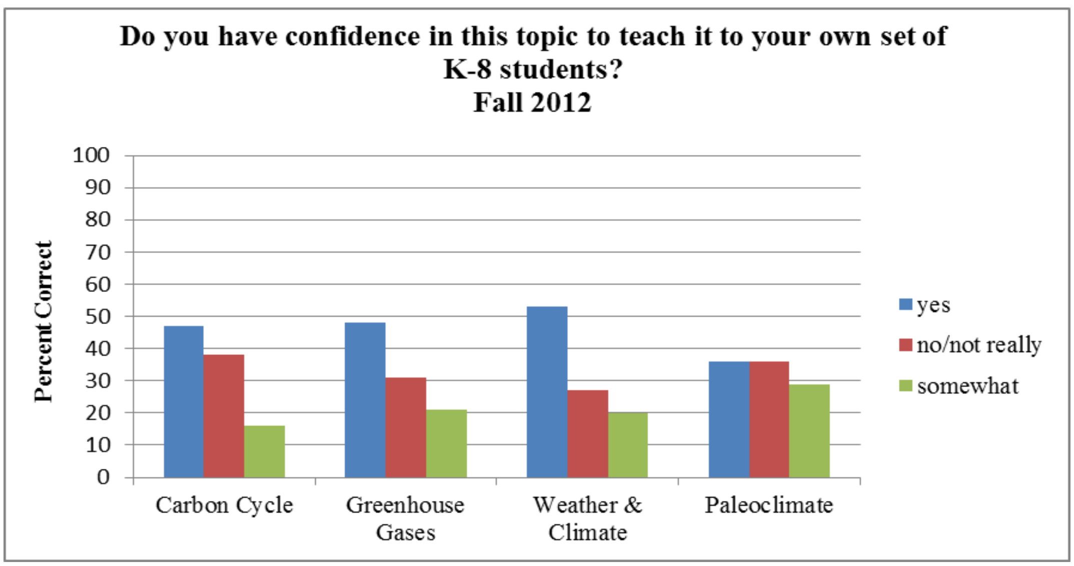


Figure 2. Responses to question two: “Do you have confidence in this topic to teach it to your own K-8 students?” on the feedback survey for spring 2012.

Questions three (“What part of the activity best helped you learn this topic?”) and four (“What was your least favorite part of this activity? How could it be improved?”) on the feedback survey helped us determine which aspect of the lessons each student felt helped them learn the content best and least, and allowed suggestions for improvement of these lessons. The comments usually mirrored the confidence levels students had shown in question two. For example, students seemed to enjoy the Weather and Climate activity and also felt very comfortable with the lesson content. “The Google Earth was a great way to utilize the technology. I liked finding different things about each location” (Student-SS0112). Students seemed to enjoy the physical, hands-on nature of the Carbon Cycle jigsaw activity; “Forming the web because it was visual and hands on.” (Student-SS0512) and “I liked putting the board together.” (Student-SS1112).

In contrast, the responses to question four were helpful in pointing out weak areas of each lesson. For example, in the Carbon Cycle lesson there was a lot of confusion regarding which process connected which reservoirs: “Taping all of the strings and processes down was very confusing. Everything became very jumbled together.” (Student left no name on the feedback survey). Very few students preferred the more “direct” instruction (like handouts and lecture) while the majority preferred the activities and perceived that the active work helped them to learn the content better. It is also interesting to note that the same parts of activities the students thought helped them learn also were sometimes noted as their least favorite to complete. For example, the majority of students reported that the Google Earth activity helped them learn but also reported that it was their least favorite part of the lesson (Figures 3-5).

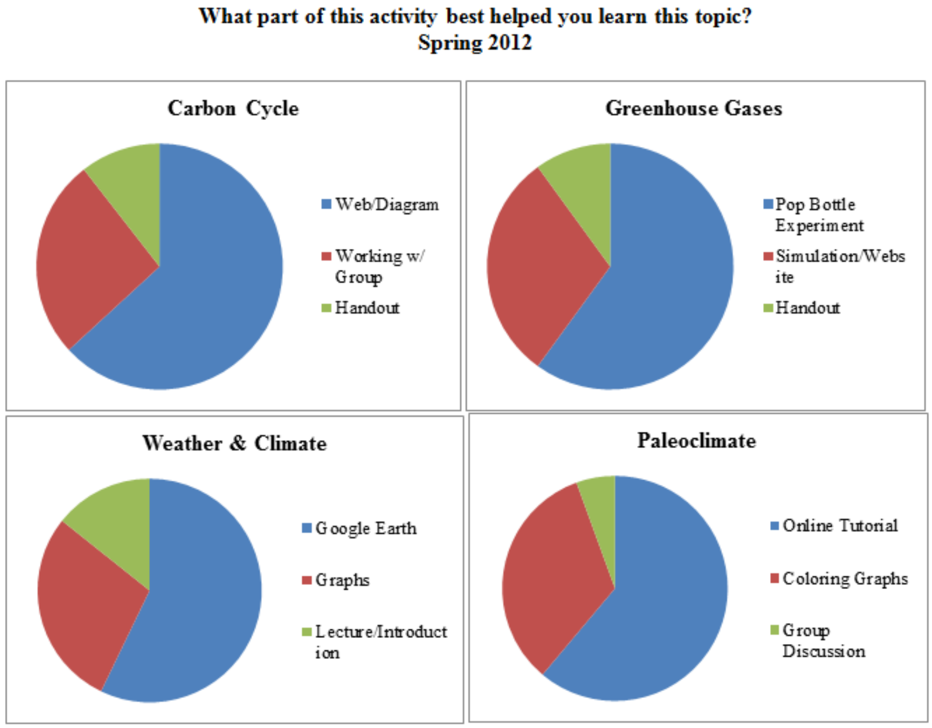


Figure 3. Responses to question three: "What part of this activity best helped you learn this topic?" on the feedback survey for spring 2012.

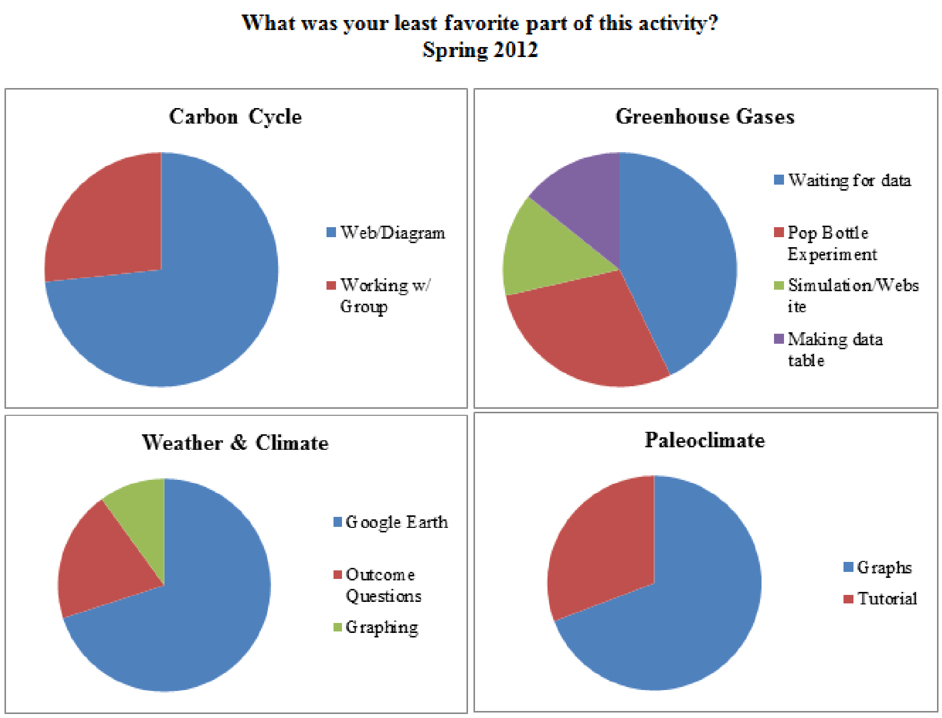


Figure 4. Responses to question four: "What was your least favorite part of this activity?" on the feedback survey for spring 2012.

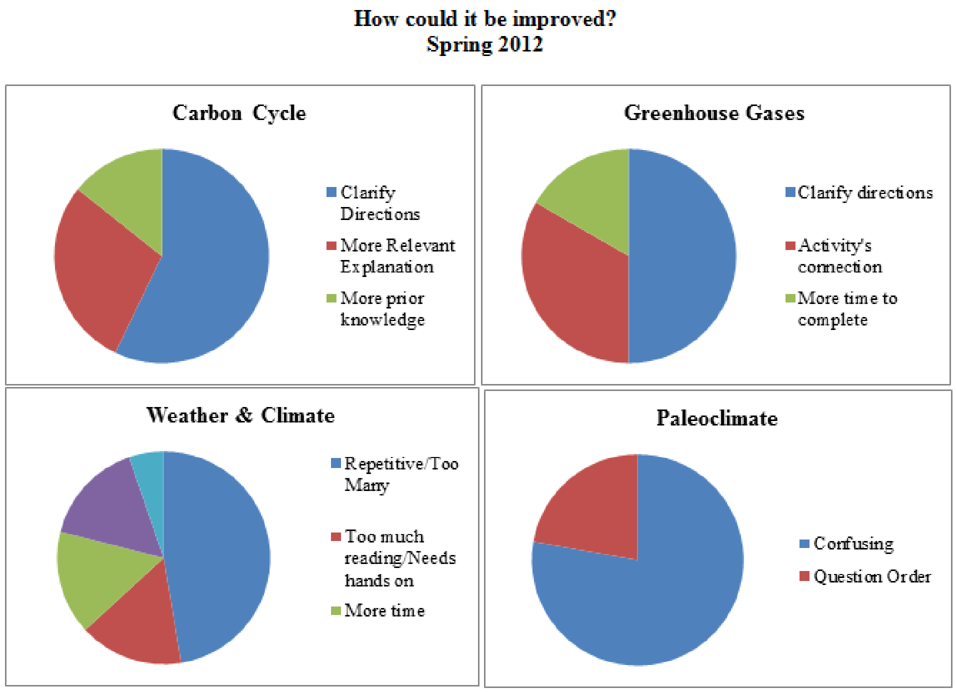


Figure 5. Responses to the second part of question four: "How could it be improved?" on the feedback survey for spring 2012.

Classroom observations were used as another way of determining each lesson's efficacy, as well as parts of each lesson requiring adjustments. For example, observation during the Carbon Cycle lesson pointed to a lot of student confusion during the jigsaw activity. The students had difficulty calculating residence times because they weren't sure if they should calculate a time for the entire "sphere" or just for the individual reservoirs within a given sphere. They were also confused regarding exactly how to divide the hydrosphere and atmosphere. For example, some students incorporated birds into the atmosphere. While birds do fly in the atmosphere, they are typically considered to be part of the biosphere; for simplicity, students were only to consider the gases comprising the atmosphere and not what might live in it. Because the carbon cycle is very complex, one purpose of this activity was to produce a simple model of the carbon cycle, without sacrificing too much accuracy or important functional detail, at a level accessible to students and which could also be utilized by the students when they eventually become teachers.

Another example of an important observation occurred during the Greenhouse Gases lesson. While some of the groups measured a slight increase in air temperature in the bottle with carbon dioxide compared to the bottle with just ambient atmosphere, the experiment did not consistently or accurately model the concept of greenhouse gas heat trapping. Greenhouse gases in the atmosphere aid in the earth retaining its heat and this experiment doesn't visually represent the retaining of heat very well therefore a cool down period should be added for the fall 2012 semester to represent this.

Reflect/Revise #1

After the first implementation of the lessons in spring 2012, it was discovered that there was a strong need to improve the Carbon Cycle lesson. Therefore, a large portion of the adjustments made to the four lessons over the summer of 2012 was to the Carbon Cycle lesson because it had the lowest student confidence scores. Four major adjustments were made to the Carbon Cycle activity: 1) Simplification of the support document. We reduced the number of processes to be considered because the students seemed overwhelmed. We condensed aerobic and anaerobic respiration into "respiration" while death and decomposition were combined into one process called "death". Silicate weathering was removed, as were seafloor dissolution of $CaCO_3$, feeding of producers by consumers and sedimentation/burial. Another modification was to remove smaller reservoirs within the "spheres", such as producers and consumers in the biosphere, or soil/marine sediments, fossil fuels and carbonate sedimentary rocks in the geosphere. Instead, students only considered the four “spheres” without further subdivision.

2) Clarification on the support document, specifically regarding definitions of the four “spheres”. For example, because there was a lot of confusion about the hydrosphere, this statement was added: “On Earth, the hydrosphere is made up of lakes, oceans, groundwater, rivers and glaciers. For the purpose of this assignment, we will only consider the oceans. When looking at particular processes, ask yourself ‘Does this process add/remove carbon from the water in the ocean?’ Gases dissolved in water are included in the hydrosphere and not in the atmosphere reservoir. For example, carbon dioxide gas exhaled by fish in the ocean is part of the hydrosphere, rather than the atmosphere. The seafloor sediment of the ocean is considered part of the geosphere.”

3) Clarification was also added to the support document regarding calculation of residence time. We added a sample problem to help the students determine residence times for reservoirs in the lesson. This addition, as well as the simplification of the reservoirs, seemed to greatly reduce the confusion with respect to calculation of residence times. 4) Visualization of reservoir sizes. Students originally cut out equal-sized squares of paper to represent each reservoir. An adjustment was made such that students cut out pieces of paper representing the relative sizes of each of the four carbon reservoirs. This helped them to better visualize the total quantity of carbon contained in each reservoir.

For the Greenhouse Gases activity, the biggest revision was to have students consider both increases and decreases in temperature for both bottles (high CO_2 and ambient atmosphere). In the initial spring semester, students only recorded the temperature as the bottles were heated. This adjustment of adding a cooling period observation gave the students a more accurate representation of how greenhouse gases retain heat instead of just observing which bottle heated up the fastest.

For the Weather and Climate activity, very little was adjusted between semesters. A few of the outcome questions were re-written for clarity. Question six from part two of the lesson was removed due to redundancy with another question from part one.

Similarly to the Weather and Climate activity, very little was adjusted between semesters for the Paleoclimate activity. One minor addition was a graph showing all three Milankovitch cycles superimposed on each other to represent their combined effect to help explain their role in the “natural” controls on climate change. Another minor adjustment to the lesson was the addition of some explanation/clarification to the outcome questions.

Implementation #2

The second implementation of the lessons occurred in fall 2012. There were two sections, both taught by a graduate student instructor (not one of the authors). Of the thirty-three students enrolled in the two sections, data from only ten students in the morning section and seventeen students from the afternoon section could be used in this study. This was because, either the student did not consent to allow their individual student work to be included in the study, or the pre-test or post-test data was not gathered for that student. The lack of pre-test or post-test data prevented us from detecting changes in overall scores.

Evaluation #2

A lower percentage of fall 2012 students across both sections reported they had sufficient prior knowledge compared to students in the spring semester (Fig. 6) for the Greenhouse Gases, Weather and Climate and Paleoclimate lessons. However, a higher percentage in fall 2012 felt that they had sufficient prior knowledge for the Carbon Cycle lesson compared to students in the spring semester. Student confidence in the Carbon Cycle and Greenhouse Gases lessons was much stronger in the fall than in the spring (Fig. 7). According to the feedback surveys from both semesters, the students had the highest incoming content knowledge and highest overall confidence with the Weather and Climate lesson. However, the gap between students who felt confident regarding the Weather and Climate content decreased by 19% between semesters. In the spring semester, 72% of students reported being confident, while in the fall semester only 53% of students reported confidence with respect to the lesson. In spite of this decrease, overall the number of students who felt confident and adequately prepared was still relatively high (>50%) in both semesters. In both the spring and fall semesters, students were split nearly evenly with respect to whether or not they felt confident with content from the Paleoclimate lesson. In the spring semester the students reported that they had enough prior knowledge to complete the activity, however in the fall semester students were split nearly evenly regarding their prior knowledge. Interestingly, however both groups reported the same confidence after completing the lesson.

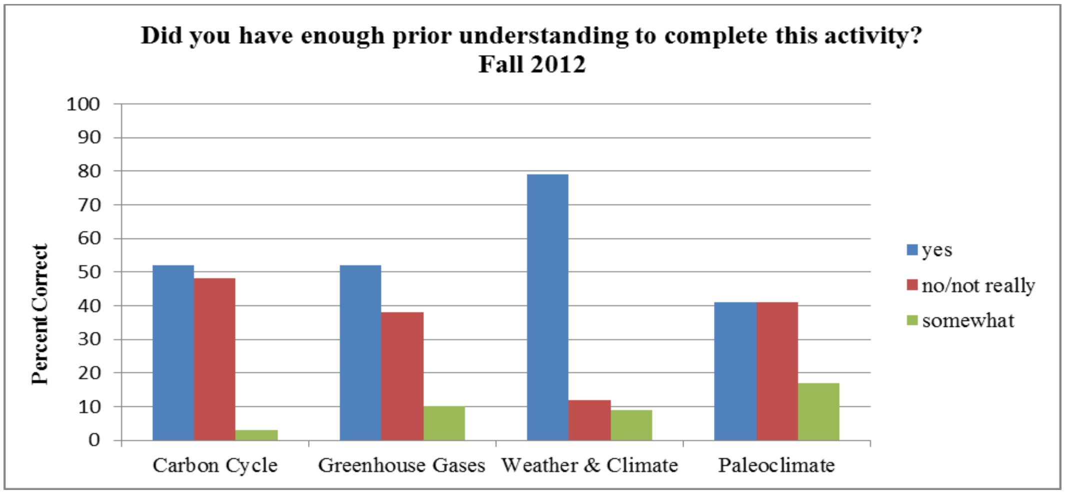


Figure 6. Responses to question one: "Did you have enough prior understanding to complete this activity?" on the feedback survey for fall 2012.

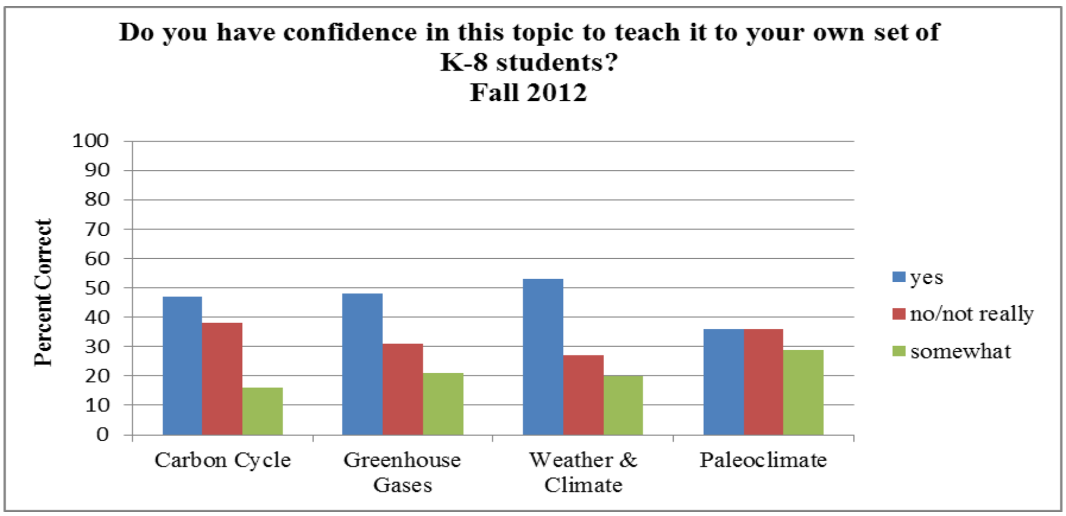


Figure 7. Responses to question two: "Do you have confidence in this topic to teach it to your own set of K-8 students?" on the feedback survey for fall 2012.

Figures 8, 9, and 10 show the student responses to questions three (Which part of the activity best helped you learn this topic?) and four (What was your least favorite part of this activity? How could it be improved?) for the fall 2012 semester. For the Weather and Climate activity, students stated that there were too many cities to complete the Google Earth exercises: "Looking up all the information was tedious, instead of 15 cities, maybe 8-10." (Student-FS0612) The students also seemed a bit overwhelmed by the number of graphs included in the Paleoclimate activity: "The activity was well planned out, maybe the use of so many graphs was a little overwhelming at some points during activity." (Student-FS1712) and also seemed to struggle with interpreting them "Comparing the graph was a bit difficult. Distinguishing between all the little lines was very hard." (Student-FS0912). The students seemed to enjoy the computer simulation portion of the Greenhouse Gases activity, "I think the website helped me learn about the different gases." (Student-FS1712) however students reported mixed results for the experimental portion of the lesson: "The bottle part actually went pretty well in our group, but it sounds like it needed improvement in other groups." (Student FS2712) and "Our experiment didn't go as expected, probably because we had slightly more water in the bottle that contained Alka-Seltzer. The experiment should include a specific amount of water to use or lines on the bottles." (Student-FS1512) The experiment had to be adjusted "on the fly" during the class period for some of the groups. This need for adjustments during class could explain the drop in student confidence during the fall semester. Modifications to these lessons for future implementation will take these comments into consideration.

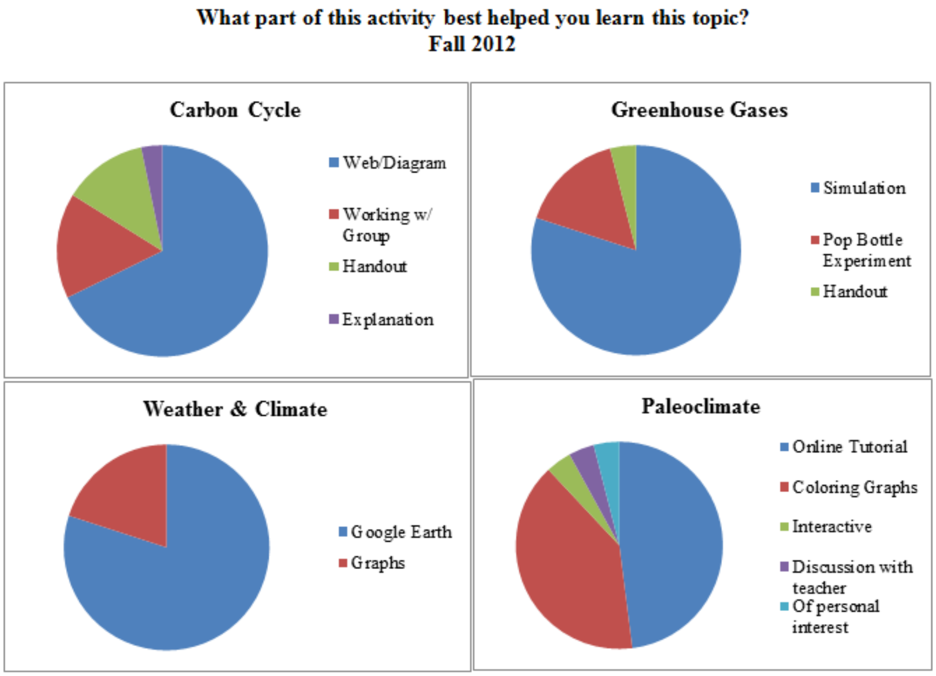


Figure 8. Responses to question three: "What part of this activity best helped you learn this topic?" on the feedback survey for fall 2012.

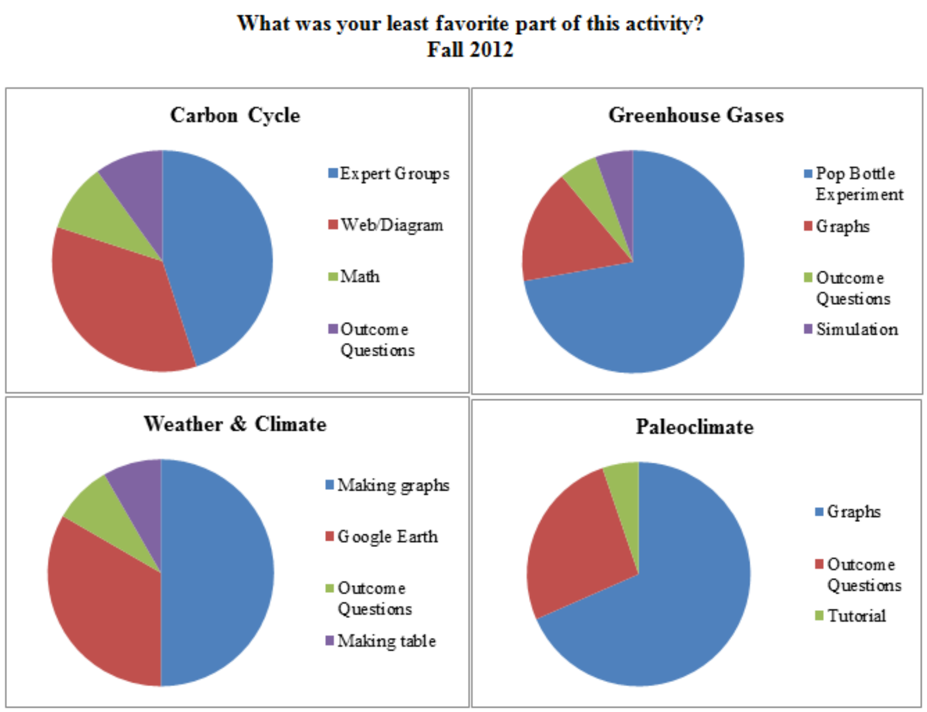


Figure 9. Responses to question four: "What was your least favorite part of this activity?" on the feedback survey for fall 2012.

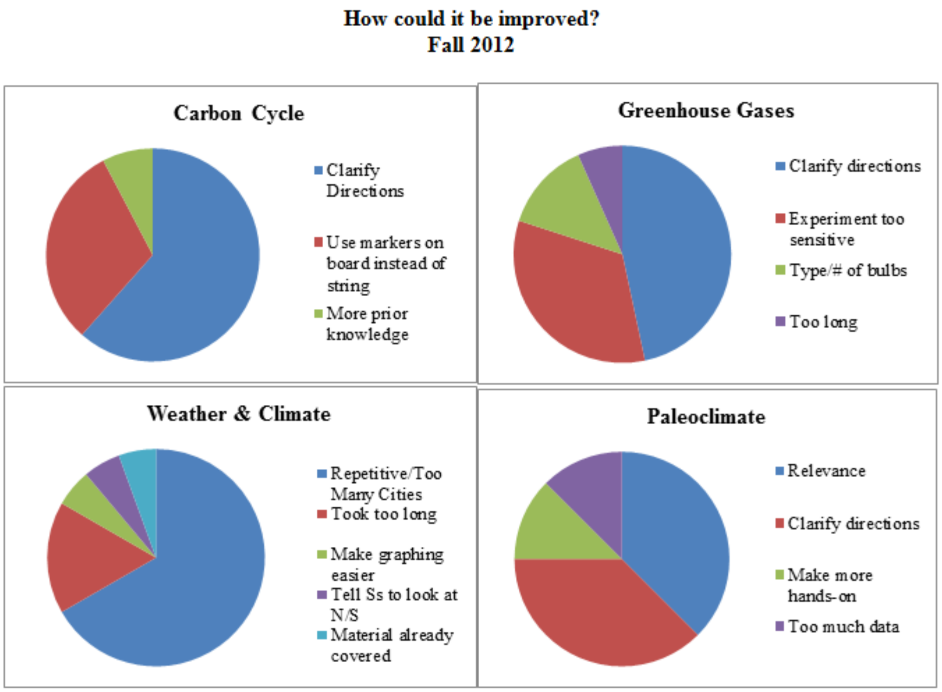


Figure 10. Responses to the second part of question four: "How could it be improved?" on the feedback survey for fall 2012.

In addition to the student feedback, the observations made during the spring semester will help guide adjustments for future implementation of these lessons. Although the Carbon Cycle lesson was improved from the spring 2012 semester, further adjustments could still be made. One student group was confused during the Carbon Cycle lesson and thought that the number of processes (fluxes) connecting reservoirs was equivalent to the quantity of carbon entering or leaving that reservoir; in other words, they did not understand the quantitative aspect of the fluxes, and that an individual flux value might be small or large. In future offerings, more time should be devoted to explaining the magnitudes of each of the fluxes. Another group realized that the boards would be less cluttered if instead of using string to connect the reservoirs, they simply drew arrows and labeled them each with markers. Another observation regarding the Greenhouse Gases lesson was that the group with a light source about a foot away achieved the best results for the exercise involving heating up and cooling down the bottles. Another observation was that some of the groups seemed confused regarding how to set up the bottle experiment. It was observed during the Paleoclimate lesson that some of the groups were reading the graphs upside down and thus incorrectly interpreting warming/cooling periods. Changes from these observations will be implemented in the future.

Figure 11 shows the percentage of students who correctly responded to questions on the pre-test and post-test for the spring and fall semesters. The questions are grouped according to the lesson covering the question content. For the majority of the questions, a gain occurred between the pre-test and post-test for both the spring and fall semesters. However, because the number of the students for each question was fairly small, it was not possible to test observed changes for statistical significance. Therefore, any gain experienced for these questions can not be specifically credited to these lessons.

Figure 12 shows aggregated data for the pre-test and post-test scores of all three sections of students. It is clear that all students, except one, had either increased or equivalent test scores on the post-test compared to the pre-test.

However, in contrast to the individual student test scores and test questions, we were able to check for statistical significance in changes for the three student sections. The results from the one sample Kolmogorov-Smirnov test were $p>.05$ for each test within each section, indicating that data was normally distributed. Therefore parametric tests were used for statistical tests.

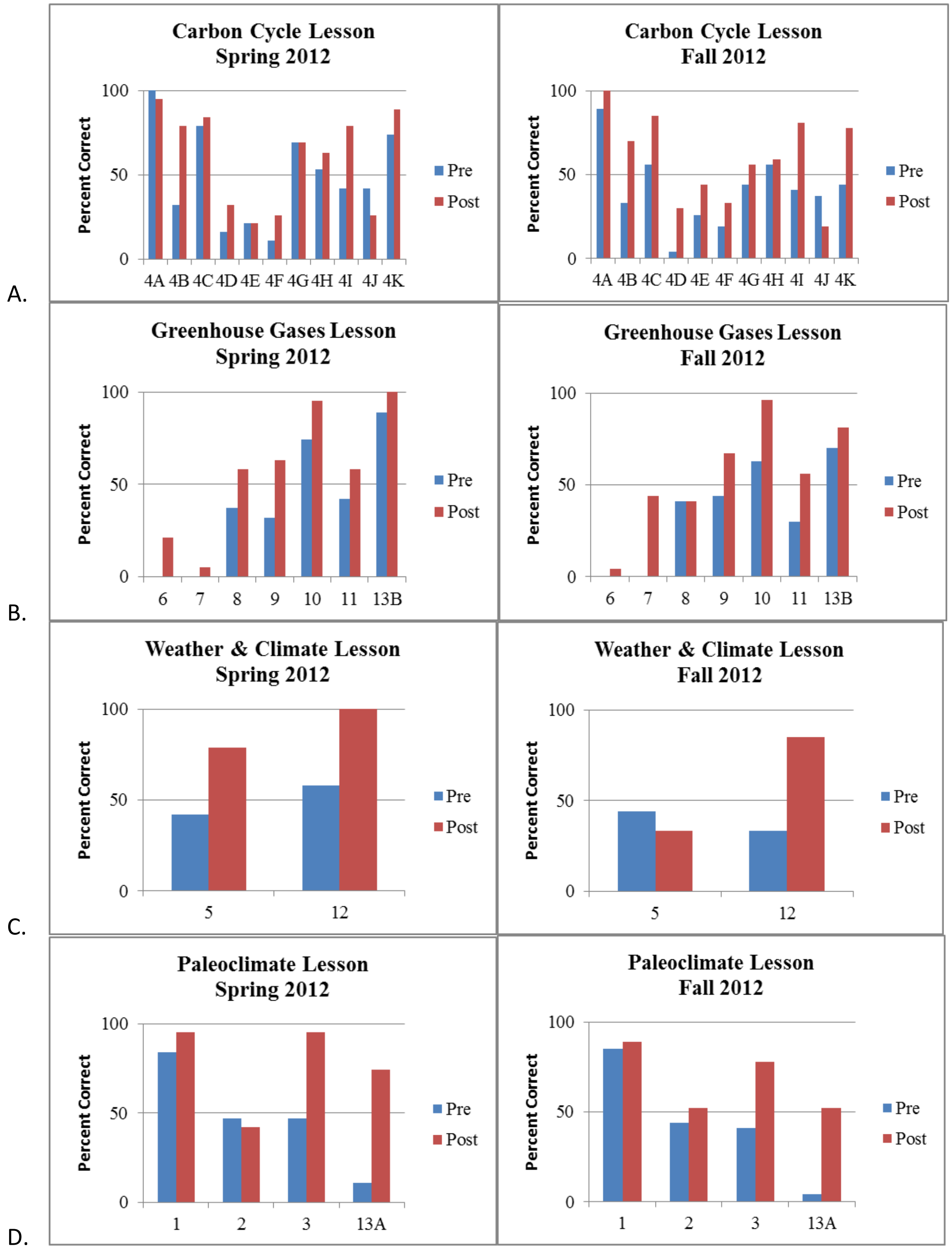


Figure 11. Responses to pre-test and post-test questions for spring 2012 and fall 2012. A) Carbon Cycle; B) Greenhouse Gases; C) Weather and Climate; D) Paleoclimate.

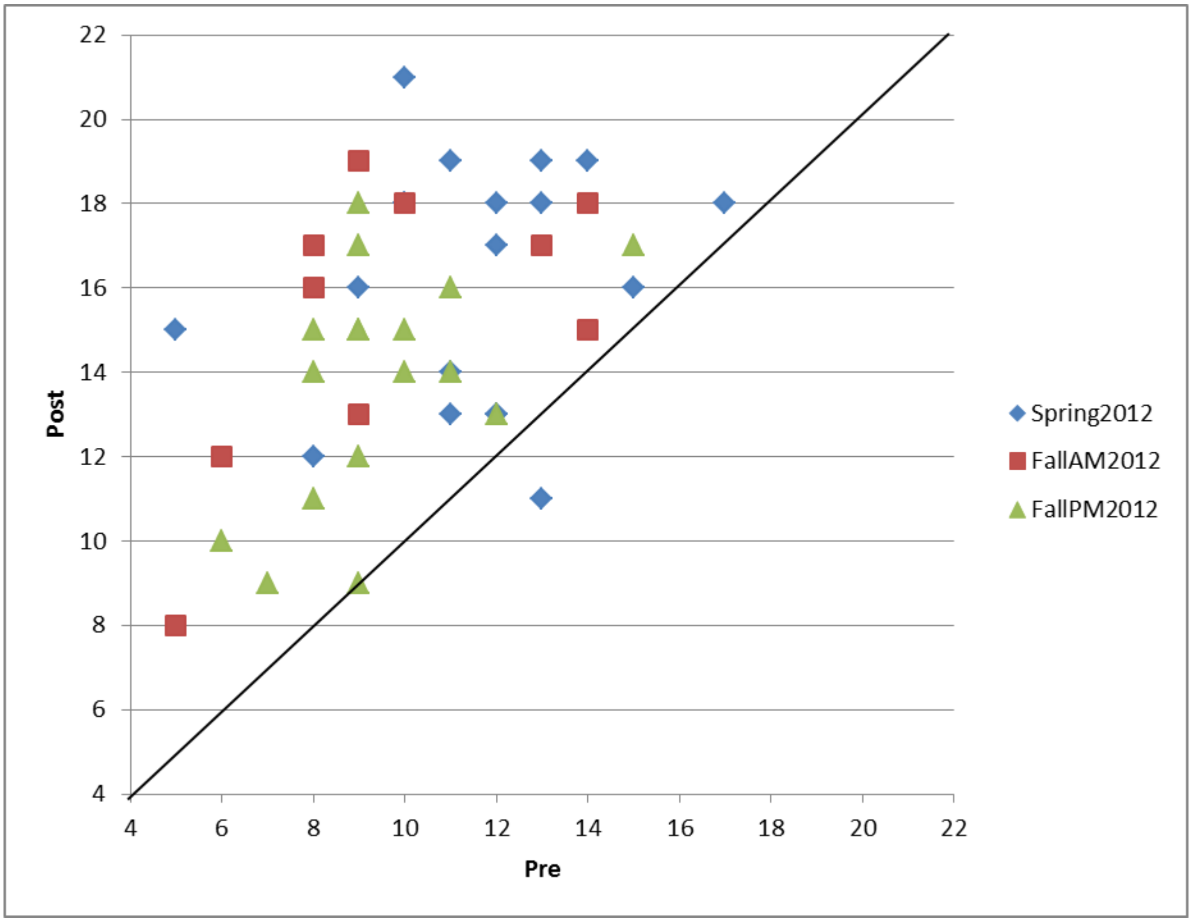


Figure 12. Pre-test and post-test scores for students from spring 2012 and both fall 2012 sections (morning and afternoon).

Pre-test scores were compared between all three sections (spring, fall morning and fall afternoon). Results of a one-way ANOVA found significant differences between course sections ($p<.05$). We followed up with an independent t-test to compare means and score distributions between individual course sections. No significant differences were found between the spring and fall morning sections ($p=.101$), and the fall morning and afternoon sections ($p=.853$). However, a difference was found between the spring section and the fall afternoon section ($p=.014$). The fall afternoon and morning sections, which had the same instructor and curriculum, were then combined for further analysis (and renamed “term 2”). Both are normally distributed data with no statistical difference in the mean or distribution of pre-test scores.

Lastly, we checked pre-test to post-test gains for each section using paired sample t-tests. The difference in pre-test to post-test mean was not significant in spring 2012 ($p=0.444$) however the difference was significant in fall 2012 ($p=.004$). In both semesters the students improved their mean test scores from pre-test to post-test, however, this change was only statistically significant in the fall semester since the $p<.01$. Students in the spring semester had significantly higher incoming test scores than in the fall semester. This means that we cannot determine whether the “improved” gains in the fall semester are a result of their lower incoming test scores, or due to the improvements in the lessons. It is interesting to note, however, that although the fall semester students came in with lower scores, they left the lessons with scores comparable to the spring semester students.

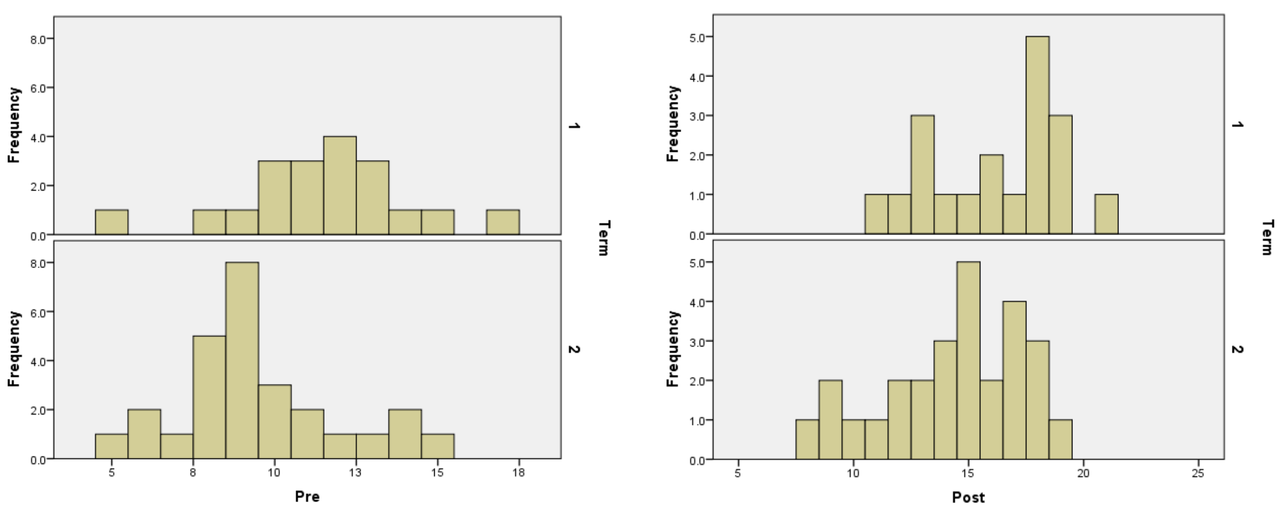


Figure 13. Histogram of pre-test and post-test scores (by section: 1 = spring semester, 2= combined fall sections).

The difference in pre-test to post-test mean is not significant in the spring semester ($p=0.444$) while the difference in the fall semester is significant ($p=0.004$) (Figure 13). This means that while it cannot be determined what specifically caused the increase in the students' content knowledge between pre-test and post-test in the fall semester, the increase is not random. We assume that the improvement in both semesters is due to the lessons, but we cannot determine whether the larger gain in the fall semester students is due to their lower level of incoming knowledge, or due to the improvements we made in the lessons.

Reflect/Revise #2

Although student confidence increased for the Carbon Cycle lesson in the second offering (fall semester), more adjustments could still be implemented. One minor improvement would be to have students simply use markers to draw arrows to represent fluxes (processes) and then label those arrows with processes rather than using string to connect each reservoir. Another minor adjustment would be to make sure that students better visualize the magnitude of each carbon flux by having the students include the numerical flux of carbon transferred by each process in addition to writing the name of the process on their boards.

For the Greenhouse Gases lesson, the biggest recommended adjustment would be to establish a set heating and cooling time frame, as well as a set amount of water to be used in each bottle. This will ensure reproducible results that students could easily use in their future classrooms. Another useful addition would be a video or animation comparing the Earth's greenhouse effect to that on Venus and Mars. This would provide another way for students to see how the concentrations of greenhouse gases in the atmosphere affect a planet's climate. A third recommended addition would involve the concept of incoming solar energy to the Earth. Many students mistakenly thought that most of the incoming solar energy is in the ultraviolet portion of the electromagnetic spectrum. Therefore, more emphasis on this topic, through the use of diagrams representing the percentage of each wavelength of energy in the solar output should be added to the lesson.

For the Weather and Climate lesson, the biggest adjustment recommended is to minimize the number of geographical locations used in the Google Earth exercise. One way to do this would be to divide the locations among the groups and then have the groups come together to share their compiled data.

After completion of all four lessons, students remained confused regarding the processes related to chlorofluorocarbons, the ozone layer, and the greenhouse effect. Some students had the notion that the hole in the ozone layer created by the chlorofluorocarbons would let more sunlight in, therefore increasing the greenhouse effect. Class time should be spent directly confronting this misconception, because it persisted in student responses on the pre-tests and post-tests after both semesters.

We recommend the greatest adjustments to the Paleoclimate lesson, because there was very little improvement in student confidence from the spring 2012 semester to the fall 2012 semester implementation. Within the lesson, some of the students confused seasonal changes in Earth's tilt with the Milankovitch cycle of obliquity. More emphasis is needed to clarify that the obliquity (tilt) refers to changes in the degree of Earth's tilt (22.1° to 24.5°) that would result in much different climates (and seasons) for various locations on the planet. Another minor clarification would be to improve the labeling of the climate graphs because some of the students did not look at the numbers on the axes to determine the proper orientation of the graph, and therefore would read the graphs upside down. More in-class work needs to be done prior to beginning the activity to insure that students read the graphs correctly.

Since the Paleoclimate lesson ends with an outcome question asking the students to think about what would cause the dramatic increase in carbon dioxide levels from the natural Milankovitch cycles a larger scale improvement would be the addition of one more lesson that focuses on anthropogenic effects on climate. This lesson could also address a few of the alternate possibilities that the students believe could be causing climate change naturally such as the solar cycles. This extra lesson would be helpful in clarifying and solidifying the concepts within the sequence.

Implications

The action research approach is an effective method to improve student learning because it allows for documented constant observation, evaluation and modification over as long of a period of time as needed. This is important because every school year new students with varying background knowledge may struggle with different aspects of a lesson. Thus, teachers must continually modify lessons in order for the greatest number of students to successfully master the lesson content. It should be noted that these lessons, although designed and tested for a pre-service elementary teacher course, could be easily adapted to other types of classes such as high school or college non-major earth science courses.

Conclusions

The purpose of this study is to develop a sequence of lessons to meet the needs of an elementary education earth science course (GEOS 2900) and to increase the students' confidence and content knowledge level regarding the subject matter. A fifth lesson focusing further on the anthropogenic effect on climate change is needed in the future. However, these lessons do fulfill a significant gap in the content required in the updated course. Students assessed in the fall and spring semester sections of the course show improvement in their pre-test to post-test scores, however, the improvement was only statistically significant in the fall semester. Furthermore, the overall confidence level of students with respect to the content in the four lessons either improved or stayed relatively the same from fall to spring semester.

This action research study serves as a model for training pre-elementary education students to utilize action research in their own classrooms by developing lessons that best meet their unique learning goals. While the lesson sequence utilized in this study covers the topic of climate change in a pre-service earth science classroom, these lessons could be modified for use in any K-12 science classroom.

REFERENCES

AnaerobicRespiration.net. Equation of anaerobic respiration. 2013. Available at http://www.anaerobicrespiration.net/general/equation-of-anaerobic-respiration/ (accessed 28 November 2011).

Benison, Kathy. Using Real Data from Ice Cores and Salt Cores to Interpret Paleoclimate. SERC: The Science and Resource Center at Carleton College. Available at http://serc.carleton.edu/NAGTWorkshops/sedimentary/activities/13695.html (accessed 29 September 2011).

Berger, Wolfgang H. Climate Change: Earth's Climate System - Climate in the Spotlight. The Marine Carbon Cycle. Available at http://earthguide.ucsd.edu/virtualmuseum/climatechange1/06_3.shtml (accessed 30 October 2011).

Collins, Jocelyn. Feb. 1, 2001. Deforestation. Available at http://www.bcb.uwc.ac.za/envfacts/facts/deforestation.htm (accessed 15 October 2011).

Dictionary.com. Flux. 2013. Available at http://dictionary.reference.com/browse/flux (accessed 20 November 2011).

Dictionary.com. Reservoir. 2013. Available at http://dictionary.reference.com/browse/reservoir?s=t (accessed 20 November 2011).

DiVenere, Vic. Introduction to Earth Sciences I: The Carbon Cycle and Earth's Climate. 2012. Available at http://www.columbia.edu/~vjd1/carbon.htm (accessed 24 October 2011).

Encyclopedia Britannica (2012). Available at http://www.britannica.com/EBchecked/topic/121560/climate (accessed 13 November 2012).

Environmental Literacy and Inquiry Working Group at Lehigh University. Greenhouse Effect Laboratory. ELI: Environmental Literacy and Inquiry. Available at http://www.ei.lehigh.edu/eli/cc/sequence/day11.html (accessed 1 October 2011).

Environmental Literacy and Inquiry Working Group at Lehigh University. Investigating Weather and Climate with Google Earth. ELI: Environmental Literacy and Inquiry. Available at http://www.ei.lehigh.edu/eli/cc/sequence/day2.html (accessed 5 November 2011).

Feldman, A. and Minstrell, J. (2000). Action Research as a Research Methodology for the Study of the Teaching and Learning of Science. In E. Kelly and R. Lesh (Eds.), Handbook of research design in mathematics and science education. Mahwah, NJ: Lawrence Erlbaum Associates.

Goodnough, Karen (2011). Taking Action in Science Classrooms Through Collaborative Action Research: A Guide for Educators. Rotterdam, The Netherlands: Sense Publishers. pp. 100.

Hanze, M., and Berger, R. (2007). Cooperative learning, motivational effects, and student characteristics: An experimental study comparing cooperative learning and direct instruction in 12th grade physics classes. Learning and Instruction 17: 29–41.

Hastings, David. Understanding the Carbon Cycle: A Jigsaw Approach. SERC: The Science and Resource Center at Carleton College. Available at http://serc.carleton.edu/NAGTWorkshops/climatechange/activities/15162.html (accessed 12 October 2011).

Heffron, Susan G. and Valmond, Kharra. (2011). Teaching About Global Climate Change. The Geography Teacher 8, 2: 91-95.

Johnson, David W. and Johnson, Roger T. and Smith, Karl A. (1991). Cooperative Learning: Increasing College Faculty Instructional Productivity. ASHE-ERIC Higher Education Report No. 4. Washington, D.C.: The George Washington University, School of Education and Human Development.

Kulik, James A. and Kulik, Chen-Lin C. (1979). Chapter 4: College Teaching. Research on Teaching: Concepts, Findings, and Implications. Berkeley, CA: McCutchan Publishing Corporation. p. 70-93.

Kump, Lee R., Kasting, James F. and Crane, Robert G. (2004) The Earth System, 2nd Edition. Upper Saddle River, NJ: Pearson Prentice Hall, Inc.

Liu, Zaihua, Yuan, Daoxian and He, Shiyi. Contribution of Carbonate Rock Weathering to the Atmospheric CO2 Sink. 1999. Available at http://www.karst.edu.cn/carbon/rockd.htm (accessed 13 December 2011).

Lueddecke, Susann B., Pinter, Nicholas and McManus, Scott A. (2001). Greenhouse Effect in the Classroom: a Project- and Laboratory-Based Curriculum. Journal of Geoscience Education. 49, 3: 274-279.

Lutz, R.V., Lambert, J.L., Bleicher, R.E., Lindgren, J., Edwards, A., and Soden, B. (2011). Addressing Pre-service Teacher's Ideas About Global Climate Change. Abstract ED11D-08 presented at the 2011 Fall Meeting, AGU, San Francisco, Calif., 3-9 Dec.

Marbach-Ad, G. and Classen, L. A. (2001). Improving students' questions in inquiry labs. American Biology Teacher 63: 410-419.

Mayer, R. E. (2004). Should there be a three-strikes rule against pure discovery learning?: The case for guided methods of instruction. American Psychologist 59: 14-19.

Michigan State Board of Education. Science Grade Level Content Expectations v.1.09 Department of Education. Available at www.michigan.gov/mde/ (accessed 23 September 2011).

Morelock, Jack, Ramirez, Wilson, Hallock, Pamela and Hubbard, Dennis. Geological Oceanography Program. Biogenic Sediments. 2005. Available at http://geology.uprm.edu/Morelock/dpseabiogenic.htm (accessed 5 December

2011).

Nam, Y. and Ito, E. (2011). A Climate Change Course for Undergraduate Students. Journal of Geoscience Education 59, 229-241.

National Climatic Data Center: NOAA. Unedited Local Climatological Data. Available at http://cdo.ncdc.noaa.gov/ulcd/ULCD (accessed 8 March 2012).

National Geographic. The Carbon Bathtub. 2013. Available at http://ngm.nationalgeographic.com/big-idea/05/carbon-bath (accessed 2 December 2011).

National Research Council (1996). National Science Education Standards. Washington, DC: National Academy Press.

National Science Foundation (2009). Earth Science Literacy Principles. Available at http://www.earthscienceliteracy.org/ (accessed 23 February 2013)

National Science Foundation and California State University. Virtual Courseware for Earth and Environmental Sciences. Milankovitch Cycles. Available at http://www.sciencecourseware.org/eec/GlobalWarming/Tutorials/Milankovitch/ (accessed 20 February 2012).

Neff, Jason. GEOL 1070: Global Changes 2 An Earth Sciences Perspective. Chapter 4: Introduction to Biogeochemical Cycles. Available at http://www.colorado.edu/GeolSci/courses/GEOL1070/chap04/chapter4.html (accessed 10 November 2011).

Next Generation Science Standards (2013). Purpose of Next Generation Science Standards. Available at http://www.nextgenscience.org/faq#1.1 (accessed 5 March 2013).

Paparozzi, Christina. (1998). Implementing Constructivism in the Middle School Classroom. Ann Arbor, MI: UMI Company.

Petcovic, Heather. (2012). GEOS 2900 Course Pack. Kalamazoo, MI: Western Michigan University.

PhET Interactive Simulations. University of Colorado at Boulder. Available at http://phet.colorado.edu/en/simulation/greenhouse (accessed 10 October 2011).

Piburn, Michael D., van der Hoeven Kraft, Kaatje and Pacheco, Heather 2011. A New Century for Geoscience Education Research. National Academies Board on Science Education Committee on the Status, Contributions, and Future Directions of Discipline-Based Education Research pp. 24.

Ruddiman, William F. and Huntoon, Jacqueline E. Long-Term Climate Change. American Geological Institute: Earth Inquiry Project. Available at http://www.earthinquiry.com/module3/index.html?sid=e152150e18f57fb2923528c2b3413778 (accessed 20 December 2011).

Siebold, Eugen and Berger, Wolfgang H. (1996). The Seafloor: An Introduction to Marine Geology, 3rd Edition. New York, NY: Springer-Verlag.

Simmons, Jeffrey A. Teaching Issues and Experiments in Ecology. Decomposition and Soil CO_2 Emission. Feb. 23, 2009. Available at http://www.esa.org/tiee/vol/v6/experiment/soil_respiration/description.html (accessed 28 October 2011).

Spokes, Lucinda. Environmental Science Published for Everybody Round the Earth. The Oceans: Air-Sea Gas Exchange. Feb. 22, 2006. Available at http://www.atmosphere.mpg.de/enid/1w0.html (accessed 8 November 2011).

University of California Los Angeles: Bruin OnLine. The Relationship Between Plate Tectonics and the Carbon Cycle: Carbon Cycle. Available at http://dilu.bol.ucla.edu/home.html (accessed 3 October 2011).

Wikipedia: The Free Encyclopedia. Photosynthesis. Mar. 25, 2013. Available at http://en.wikipedia.org/wiki/Photosynthesis (accessed 2 December 2011).

Wikipedia: The Free Encyclopedia. Residence time. Feb. 28, 2013. Available at http://en.wikipedia.org/wiki/Residence_time (accessed 12 December 2011).

Wiley, David and Royce, Christina (1999). Earth and Space Science, Grades 4-8: Investigate and Connect. Grand Rapids, MI: Instructional Fair p. 6-8.

Yale Project on Climate Change Communication. Americans' Knowledge of Climate Change. Oct. 12, 2010. Available at http://environment.yale.edu/climate/ publications/knowledge-of-climate-change (accessed 10 February 2013).

Zhang, Meilan, Passalacqua, Susan, Lundeberg, Mary, Koehler, Matthew J., Eberhardt, Jan, Parker, Joyce, Urban-Lurian, Mark, Zhang, Tianyi, Paik, Sunhee. (2010). ‘‘Science Talks’’ in Kindergarten Classrooms: Improving Classroom Practice Through Collaborative Action Research. Journal of Science Teacher Education 21:161–179.

Appendix A

Human Subjects Institutional Review Board (HSIRB)

WESTERN MICHIGAN UNIVERSITY

Human Subjects Institutional Review Board

Date: January 3, 2012

To: Heather Petcovic, Principal Investigator
Steven Barone, Student Investigator for thesis

From: Victoria Janson, Interim Chair Victoria Janson

Re: HSIRB Project Number 11-12-20

This letter will serve as confirmation that your research project titled "Evaluation of an Inquiry-Based Unit for Teaching about Paleoclimate and Climate Change" has been **approved** under the **exempt** category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: January 3, 2013

Walwood Hall, Kalamazoo, MI 49008-5456
PHONE: (269) 387-8293 FAX: (269) 387-8276

Appendix B

Student Consent Form

WESTERN MICHIGAN UNIVERSITY
H. S. I. R. B.
Approved for use for one year from this date:

JAN 03 2012

x [signature]
HSIRB Chair

Western Michigan University
Mallinson Institute for Science Education
Principal Investigator: Dr. Heather Petcovic
Student Investigator: Steven Barone
Title of Study: Evaluation of an Inquiry-Based Unit for Teaching about Paleoclimate and Climate Change

You are invited to participate in a research project that is intended to evaluate teaching practices used in the unit on Paleoclimate and Climate Change within GEOS 2900. Participation in this research project will include completing a brief (5-minute) feedback form at the end of each class period. If you agree to participate, normal work collected from you in this class (such as in-class assignments, homework, course and unit pre-tests, and exams) as well as work from your group will be used by the investigators for course improvement and may also be used in external presentations and/or publications. Only data without your name or other identifying information will be shared with others, including your course instructor.

Participation in this study, or refusing to participate, will have no effect on your performance or grade in GEOS 2900. Your instructor will not know who is or is not participating in the study. You have the right to withdraw from this study at any time without penalty by contacting the student investigator. At the bottom of this form there is a box to indicate your consent for use of your data, either individual or group work. There is another box to indicate your refusal to have your data used. Please check the appropriate box and return one copy of this form to the folder in the front of the classroom. Please keep the second copy for your records.

If you have any questions or concerns about this study, you may contact Steven Barone (Student Investigator) at 248-344-1442 or Dr. Heather Petcovic at 269-387-5380. You may also contact the chair of Human Subjects Institutional Review Board at 269-387-8293 or the Vice President for Research at 269-387-8298 with any concerns that you have.

This consent document has been approved for use for one year by the Human Subjects Institutional Review Board as indicated by the stamped date and signature of the board chair in the upper right corner. Do not participate in this study if the stamped date is more than one year old.

Your signature below indicates that you have read and/or had explained to you the purpose and requirements of the study.

☐ YES – You may use data collected from my group **AND** my individual work during this course in external presentations and/or publications.

☐ YES – You may use data collected from my group **BUT NOT** my individual work during this course in external presentations and/or publications.

☐ NO – Please do not use data collected from me during this course in external presentations and/or publications.

Name (please print)	Signature	Date

Appendix C

Carbon Cycle Lesson

Carbon Cycle: An Earth Cycle

Problem: There are multiple natural cycles on the Earth. You have already learned about the Rock Cycle but there are many other natural cycles on the planet such as the Water Cycle, Nitrogen Cycle and, the one that will be covered today, the Carbon Cycle. What do cycles represent? How do components move from part of a cycle to another?

Learning Objectives: Identify carbon reservoirs, fluxes and residence times in a simplified version of the carbon cycle. Explain the carbon cycle and its role in effecting the Earth's climate.

Before You Begin:

1. What is carbon?

2. Where is carbon found on the Earth?

3. Can carbon move from place to place on the Earth? If so, give an example of this process.

Activity Part 1 – What Makes Up the Carbon Cycle?

<u>Materials:</u>
"Introduction to the Carbon Cycle" handout

<u>Procedure:</u>
1. This activity is an example of a teaching method called a "jigsaw." In this activity each person from your normal working group will be assigned to one of four specialty groups. Each person will work with his or her specialty group to become an "expert" in one particular topic, in this instance each topic is a different reservoir. When you rejoin your normal working group, each member will contribute their expertise, pooling their knowledge to complete the activity assigned.

2. You will be individually assigned to one of four specialty groups. In this activity each specialty group represents a particular place of storage where carbon can be found on Earth. We will call these storage areas "reservoirs". These "reservoirs" are the Atmosphere, Biosphere, Geosphere, and the Hydrosphere.

3. Use the "Introduction to the Carbon Cycle" handout to answer the outcome questions about your reservoir.

4. After you have responded to each of the below questions, draw an illustration showing the inputs and outputs of carbon within your reservoir. Have your instructor check your illustration before moving on to Part 2. Note that this is a SIMPLIFIED version of the

Carbon Cycle, there are many processes and smaller reservoirs that have been omitted for this exercise.

Outcomes Part 1:

1. Where is carbon found in the reservoir? (For example, in plants, as a gas)

2. What natural processes add carbon to the reservoir?

3. What natural processes remove carbon from the reservoir?
Note: The amount of carbon being added and removed should be equal or extremely close (within 0.5).

4. What is the residence time of carbon in this entire reservoir? (Only take the natural processes into consideration for this.)

Activity Part 2 – What Goes Around, Comes Around: Putting the Carbon Cycle Together

<u>Materials for each group:</u>
Sheet of paper – one for each reservoir
Index cards – one for each process
Spool of string – to connect processes to reservoir
Tape
Permanent marker
Scissors

<u>Procedure:</u>

1. Rejoin your original group. Each member should make a brief presentation with their carbon inputs/outputs diagram from their reservoir group.

2. Use the materials to make different parts of the carbon cycle. Label each piece of paper as one of the four reservoirs. Cut a piece of string for each process. The string will be used to connect the reservoirs together. Use the tape and marker to label the string with the name of the process.

3. Use the labeled paper and string to create a diagram of the carbon cycle.

Outcomes Part 2:

1. Which reservoir contained has the largest amount of carbon relative to the other reservoirs? Which contained the smallest amount of carbon?

2. Which process moves the MOST carbon within the cycle? Which process moves the lowest amount of carbon within the carbon cycle?

3. In which reservoir does carbon have the greatest residence time? Which reservoir has the lowest?

4 Can humans be considered carbon reservoirs? (Meaning they store carbon) If so, for how long? What living organisms are better long-term reservoirs than humans?

5. Now take into consideration human activities: deforestation and fossil fuel burning. What kind of an effect do humans have on the Carbon Cycle? Is it a large or small one?

Introduction to the Carbon Cycle

Process within Carbon Cycle	Carbon flux (billion tons of C per year)
Natural Processes	
Respiration	30
Photosynthesis	60
Weathering of Carbonate Rock	0.17
Formation of Calcium Carbonate Rock	0.40
Air-sea exchange (into atmosphere)	59.75
Air-sea exchange (into hydrosphere)	60
Volcanism	0.03
Death	30
Fossil Fuel formation	0.0001
Seafloor Dissolution	0.30
Formation of Carbonate Shells	0.40
Microbial Respiration/Decomposition	30
Human Activities	
Fossil Fuel burning	6
Deforestation	2

Data obtained and modified from http://www.colorado.edu/GeolSci/courses/GEOL1070/chap04/chapter4.html and figures used in “Understanding the Carbon Cycle: A Jigsaw Approach. The Earth System, Kump et al., 2004 Pearson Prentice Hall, Inc.

<u>Four Spheres of the Earth</u>

Atmosphere

The atmosphere is the body of air, composed of various gases, that covers the Earth.

Biosphere

On Earth, the biosphere is made up of all living things: plants, animals, fungi, bacteria, and other single-and multi-celled organisms. Since this is a simplified version of the Carbon Cycle, we will only consider land plants, animals, and bacteria NOT marine life.

Geosphere

The geosphere of the Earth is composed of soil, the sediment on the ocean floor, and the rocks of the continents and oceans.

Hydrosphere

On Earth, the hydrosphere is made up of lakes, oceans, groundwater, rivers and glaciers. Since this is a simplified version of the Carbon Cycle, we will only consider the ocean water. Do NOT take into consideration respiration/photosynthesis of marine life. Only look at geological/chemical processes that transfer carbon to and from this reservoir. When looking at particular processes, ask yourself "Does this process add/remove carbon from the **water** in the ocean." Gases dissolved in water are included in the hydrosphere and not in the atmosphere reservoir. The seafloor sediment of the ocean is considered part of the geosphere.

Processes

Air-sea exchange

Gases can move from the ocean into the atmosphere or from the atmosphere into the ocean. Gases tend to move spontaneously from areas of higher concentrations to areas of lower concentrations. For example, if carbon dioxide concentrations are higher in the atmosphere, then carbon dioxide will be taken up by the ocean.
Source: http://www.atmosphere.mpg.de/enid/1w0.html

Death occurs when a living organism dies. This process transforms carbon in living tissue of plants, animals, fungi and bacteria to inorganic (non-living) carbon in the soil.
Source: http://www.esa.org/tiee/vol/v6/experiment/soil_respiration/description.html

Fossil Fuel Formation

Fossil fuels (coal, oil/petroleum and natural gas) are chemical compounds that contain organic-carbon. Coal is formed from terrestrial plant matter, oil/petroleum is formed from microscopic marine organisms and natural gas is formed from either of these. The fossil fuels form after the dead organic matter is buried in sediments under high pressures and temperatures over long periods of time.
Sources: 1) http://dilu.bol.ucla.edu/home.html and 2) Edited by Dr. Carla Koretsky of Western Michigan University (May 1, 2012)

Formation of Carbonate Shells

Marine organisms remove carbon from ocean water to form calcium carbonate shells or skeletons on their body.
Source: http://earthguide.ucsd.edu/virtualmuseum/climatechange1/06_3.shtml

Formation of Carbonate Rock (Limestone)

Calcium carbonate ($CaCO_3$) rocks can form in ocean water in two ways. 1) Biochemically, by marine organisms that remove carbon from ocean water to form calcium carbonate shells or skeletons; when these organisms die, bits of their shells and skeletons sink to the ocean floor where they solidify into carbonate rock and 2) inorganically, when calcium and inorganic carbon in the ocean water react to form a calcium carbonate ooze, which gradually solidifies into rock on the ocean floor.
Source: http://earthguide.ucsd.edu/virtualmuseum/climatechange1/06_3.shtml

Microbial Respiration/Decomposition

“Decomposers” are organisms that feed on dead organic matter and break it down into carbon dioxide, water and nutrients through respiration. When decomposers break down the organic matter, some of the carbon is converted into carbon dioxide gas which is released into the soil pore spaces. The soil becomes highly concentrated in carbon dioxide gas and since liquids and gases move from areas of high concentration to areas of low concentration to even them out, carbon dioxide gas escapes from the soil into the atmosphere.
Source: http://www.esa.org/tiee/vol/v6/experiment/soil_respiration/description.html

Photosynthesis is a biochemical process that captures the energy in sunlight turning carbon dioxide gas and water into organic compounds, such as sugars, and releasing oxygen gas. Organisms that utilize this process are plants, algae, and many species of bacteria. Photosynthesis is a vital process for life forms on Earth because it produces oxygen gas which humans and other animals need to breathe.
Source: http://en.wikipedia.org/wiki/Photosynthesis

Seafloor dissolution
Seafloor dissolution is where calcium carbonate of the ocean floor dissolves back into the ocean water. Calcium carbonate is unusual in that its ability to dissolve increases with decreasing temperature. Deep ocean waters lend themselves to being very good locations for dissolution due to their low temperatures and high pressures.
Source: The Seafloor: An Introduction to Marine Geology. E. Siebold and W. H. Berger 3rd edition 1996.

Respiration is a process that happens inside the cells of organisms, in which sugars are broken down releasing energy. This process is very important for life because it occurs in all living cells. There are two types of respiration: aerobic and anaerobic.

-**Aerobic respiration** is a biochemical reaction in which oxygen gas reacts with sugars (organic compounds) to form carbon dioxide and water, releasing energy. Aerobic respiration is carried out by animals, plants, bacteria, fungi and archae.

-**Anaerobic respiration** is a biochemical reaction that takes place in the absence of oxygen, sugars are broken down to form lactic acid or alcohol, and carbon dioxide, releasing energy. This process is also known as fermentation.
Sources: 1) http://www.anaerobicrespiration.net/general/equation-of-anaerobic-respiration/ and 2) Edited by Dr. Carla Koretsky of Western Michigan University (May 1, 2012)

Weathering of Carbonate Rocks
Carbonates make up approximately 62% of the deep ocean floor. Weathering (dissolution) of carbonate rocks can occur when they come into contact with very cold or mildly acidic water.
Sources: 1) http://www.karst.edu.cn/carbon/rockd.htm and 2) http://geology.uprm.edu/Morelock/dpseabiogenic.htm

Volcanism
Carbon dioxide can be released into the atmosphere by volcanic activity either on land or on the ocean floor. There are two sources of this carbon dioxide: 1) carbon-rich rocks that are subducted and heated at plate boundaries or 2) carbon-rich gases that are deep within the Earth’s mantle.
Source: http://www.columbia.edu/~vjd1/carbon.htm

Human Activities

Fossil Fuel Burning
When fossil fuels are burned, carbon dioxide is released into the atmosphere.
Source: http://dilu.bol.ucla.edu/home.html

Deforestation
Deforestation is the removal trees to develop larges of land for agricultural, residential or industrial purposes. Trees contain organic carbon and also take in carbon dioxide by photosynthesis, therefore when they are cut down, less photosynthesis occurs and less carbon dioxide is removed from the atmosphere. Furthermore, during deforestation many trees are burned. This converts organic carbon in the trees into carbon dioxide which is released into the atmosphere. It is estimated that deforestation accounts for one third of all carbon dioxide released into the atmosphere by people.
Source: http://www.bcb.uwc.ac.za/envfacts/facts/deforestation.htm

How to Determine the Residence Time of an Element in a Reservoir

Flux: passage or movement
Source: http://dictionary.reference.com/browse/flux

Reservoir: a place where anything is collected or accumulated in great amount
Source: http://dictionary.reference.com/browse/reservoir?s=t

$$\text{Residence Time} = \frac{\text{Amount of element in reservoir}}{\text{[total flux in] OR [total flux out]}}$$

Source: http://en.wikipedia.org/wiki/Residence_time

Example Problem:

$$\frac{\text{8 billion tons of carbon}}{\text{4 billion tons per year}} = \text{2 years}$$

Conclusion to be made from this residence time example – One unit of carbon will be in the reservoir for 2 years before moving naturally onto another reservoir in the carbon cycle.

Appendix D

Carbon Cycle Instructor Notes

Carbon Cycle Activity

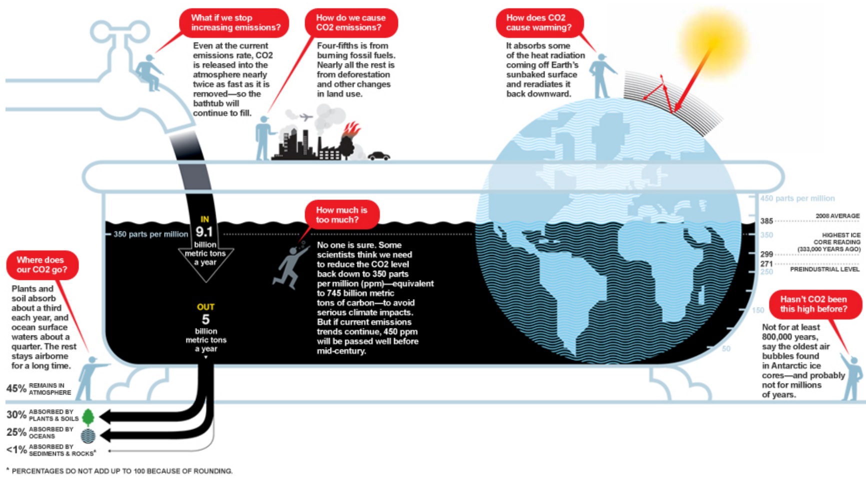
Things to do before class begins:

1. Place the following agenda on the board:
   a. Announcements
   b. Activity
      i. Turn in all Outcomes
      ii. Have me check your Carbon Cycle model part 2
2. Get supplies. Per student group:
   a. White board and markers
   b. "Introduction to the Carbon Cycle" handout
   c. Four sheets of paper (one for each reservoir)
   d. Cut-up index cards (one for each flux)
   e. Spool of string
   f. Tape
   g. Permanent marker
3. Get supplies for the class to share:
   a. Spools of string
   b. Tape

Order of events with approximate times to complete each task.

1. Announcements and go over daily agenda (2-5 minutes)
2. If exams have been graded, hand back and allow students to look over work. Students can take home the exams to review them, but **all exams need to be returned to the instructor no later than the start of the next class period**. Students may make an appointment or come to see the instructor during office hours with questions related to the exams. Class time will not be spent going over the exam.
3. Introduce Activity. Direct students to discuss Before You Begin questions on the white boards. (5 minutes) Discuss responses as a whole class (10-15 minutes)
   a. What is carbon?
      i. Typical responses: a gas, an element on the periodic table
   b. Where is carbon found on the Earth?
      i. It can be found "everywhere": geosphere (in rocks, in soil), hydrosphere (in oceans, in rivers, in groundwater), biosphere (in animals, in plants), and atmosphere (carbon dioxide gas, methane gas)
   c. Can carbon move from place to place on the Earth? If so, give an example of this process.
      i. Yes, it can move from place to place. Processes: Breathing, Eating, Photosynthesis, Burning of fossil fuels, etc.
4. Introduce the concept of the "Carbon Bathtub".

a. Draw a bathtub on the board. Explain terms: source, sink, reservoir and flux in terms of a common bathtub in someone's house with water. Source: water coming in from faucet or from municipal water supply. Sink: water leaving through the drain to the water treatment plant. Reservoir: amount of water in the bathtub. Flux: flow of water.



http://ngm.nationalgeographic.com/big-idea/05/carbon-bath

b. Ask the students: If the drain hole is plugged, and the faucet is on full, what will happen?
   i. The bathtub will overflow.
c. Ask the students: If the drain hole is open, and the faucet is off, what will happen?
   i. The bathtub will empty.
d. Now what if 5 gallons of water are coming into the bathtub every hour and 1 gallon of water is leaving the bathtub every hour. Is the bathtub gaining or losing water?
   i. The bathtub is gaining water.
e. How do we make it so that the bathtub doesn't gain or lose water? How much water should come in and how much should come out?
   i. Have the same amount of water going into the bathtub as leaving it.
f. For our example of water in a bathtub, residence time is the amount of time it takes for one drop of water to stay in the bathtub before it eventually goes down the drain. This can be determined by:

$$\text{Residence time} = \frac{\text{Amount in reservoir}}{\text{Flux (total in or total out)}}$$

100 gallons of water
4 gallons of water in per hour

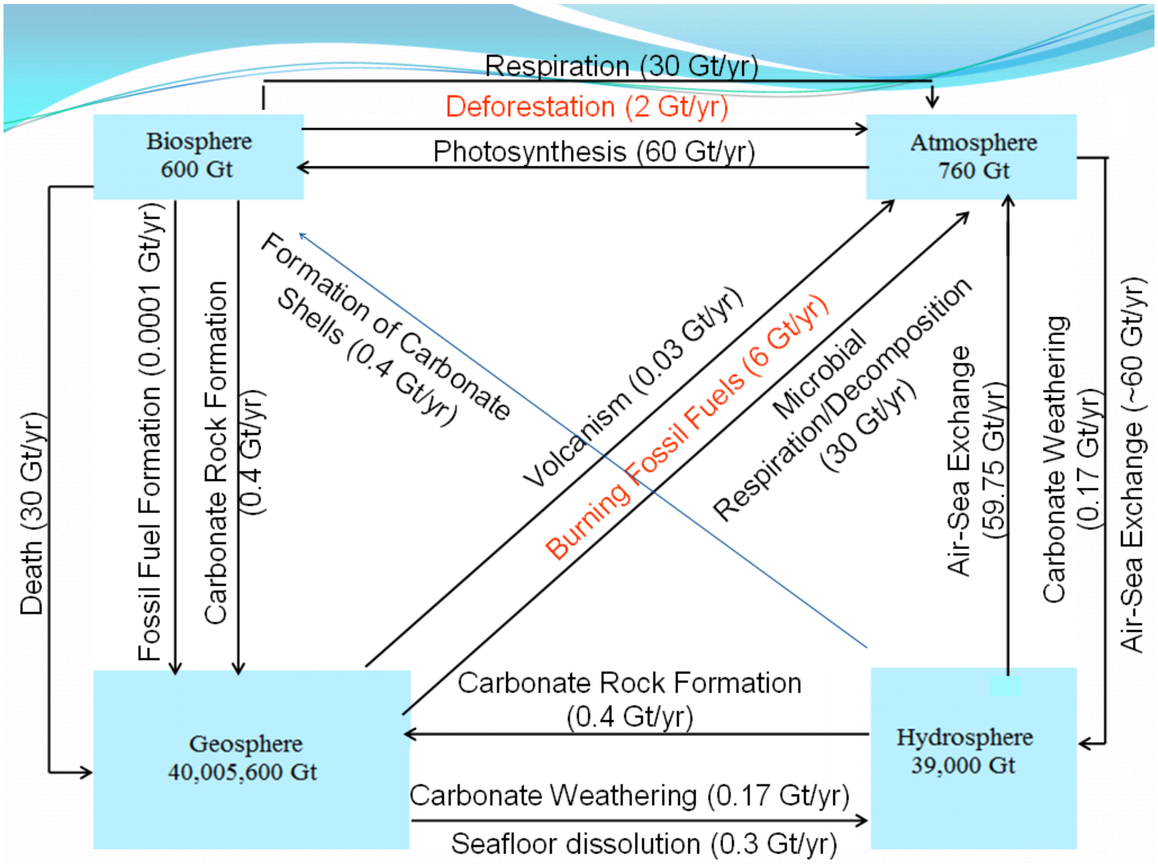
$$\frac{100 \text{ gallons}}{4 \text{ gallons/hr}} = 25 \text{ hours}$$

5. Instruct the students that they will be leaving their normal groups of four to create four larger groups of six with their classmates to complete today's assignment. Write the four reservoir names on the board: Atmosphere, Hydrosphere, Biosphere and Geosphere and ask the groups to choose one member to represent one of the four reservoirs. Direct the students to four separate designated areas of the classroom which correlate with each of the four reservoirs.
6. Have students complete Activity Part 1. Ask students to answer Part 1's Outcome questions together in their "reservoir" groups before rejoining their normal groups. (30 minutes)
    a. Circulate among the groups as they complete part 1 to help clarify thinking and answer questions.
    b. There was some confusion with the hydrosphere group. To clarify, have the students in that group ask themselves "Does this process add carbon to the **water** in the ocean?" Or "Does this process remove carbon from the **water** in the ocean?" Since this activity has been simplified to just deal with the ocean, not ALL bodies of water in the hydrosphere.
        i. Carbon dioxide gas released by fish in the ocean would be considered "gas bubbles" that are in the water, not as a gas that is part of the atmosphere.
        ii. The seafloor of the ocean is considered part of the geosphere.
        iii. All animals, regardless of where they live are considered part of the Biosphere.
            1. Birds in the air are part of the biosphere, not atmosphere.
            2. Fish in the ocean are part of the biosphere, not hydrosphere.
            3. Worms in the ground are part of the biosphere, not hydrosphere.
7. Have students rejoin their normal groups and complete Activity Part 2. Ask students to create a diagram of the carbon cycle and answer Part 2's Outcome questions. (30 minutes)
    a. Circulate among the groups as they complete part 2 to help clarify thinking and answer questions.
8. When all students are finished, hold a wrap-up discussion of the activity to review main points. **NOTE: If class time runs short, instruct students to complete the Outcome questions. The group discussion can be held at the beginning of the next class period.**
    a. Draw a carbon cycle diagram on the board with reservoir "box" size being respective of their relative sizes to one another.

b. Go over the fluxes that involve biological processes (respiration, decomposition, death, deforestation, photosynthesis) carbon first.
c. Then go over geological processes (carbonate weathering, air-sea exchange, volcanism, carbonate weathering, carbonate formation)
d. Highlight/underline processes that moved the most carbon in another color.
e. Draw students' attention to the number of arrows that go into and leave each of the reservoirs.
f. Ask the students questions similar to i. and ii. for the other reservoirs.
    i. How many ways does carbon enter the atmosphere?
        1. Six: Volcanism, respiration, microbial respiration/decomposition, air-sea exchange, fossil fuel burning, and deforestation.
    ii. How many ways does carbon leave the atmosphere?
        1. Three: Photosynthesis, air-sea exchange and carbonate weathering.
    iii. Air-sea exchange is very important, as the atmosphere gains carbon (carbon dioxide), some of is transferred to the oceans to "even out" the amount of carbon dioxide in both. However, the net effect is an overall increase in carbon dioxide for both.
        1. When oceans gain a lot of carbon dioxide, they become more acidic, which affects life living in the oceans. Ex. Disappearing coral reefs, plants/animals dying, etc.

9. After class, review Outcome questions in E-learning. Grade work or comment and return to students for further work as needed.

Wrap Up



Source: Barone, Steven. (2013) Development and Evaluation of an Inquiry-Based Unit for Teaching Paleoclimate and Climate Change.

Scoring guide to Outcome questions (20 points)

Italicize the answers
Re-arrange the order in carbon cycle to fit table.

Outcomes Part 1:

1. How much carbon is in the entire reservoir? (2 points)
Atmosphere – 760 billion tons
Geosphere – 40,005,600 billion tons
Biosphere – 605 billion tons
Hydrosphere – 39,000 billion tons

2. Where can carbon be found in the reservoir? (2 points)
Atmosphere – Carbon is found in the air
Geosphere – Carbon is found in the rocks and soil
Biosphere – Carbon is found in plants and animals
Hydrosphere – Carbon is found in the ocean

3. What processes add carbon to the reservoir? (2 points)
Atmosphere: Respiration + Air-Sea exchange + Volcanism + Microbial Respiration/Decomposition = 30 + 59.75 + 0.03 + 30 = 119.78

Biosphere: Formation of Carbonate Shells + Photosynthesis = 0.4 + 60 = 60.4

Geosphere: Carbonate Rock Formation (from Hyd) + Carbonate Rock Formation (from Bio) + Fossil Fuel Formation + Death = 0.4 + 0.4 + 0.0001 + 30 = 30.8001

Hydrosphere: Carbonate Weathering (from Geo) + Carbonate Weathering (from Atm) + Air-Sea exchange + Seafloor dissolution = 0.17 + 0.17 + 60 + 0.3 = 60.64

4. What processes remove carbon from it? (2 points)
Atmosphere: Photosynthesis + Carbonate Weathering + Air-Sea exchange = 60 + 0.17 + 60 = 120.17

<u>Difference between inputs and outputs = 0.39</u>

Biosphere: Fossil Fuel Formation + Carbonate Rock Formation + Death + Respiration = 0.0001 + 0.4 + 30 + 30 = 60.4001

<u>Difference between inputs and outputs = 0.0001</u>

Geosphere: Carbonate Weathering + Volcanism + Microbial Respiration/Decomposition + Seafloor dissolution = 0.17 + 0.03 + 30 + 0.3 = 30.5

<u>Difference between inputs and outputs = 0.3001</u>

Hydrosphere: Carbonate Rock Formation + Air-Sea exhange + Formation of Carbonate Shells = 0.4 + 59.75 + 0.4 = 60.55

<u>Difference between inputs and outputs = 0.09</u>

5. What is the residence time of carbon in this entire reservoir? Is it gaining or losing carbon? (2 points)
Residence Times (since both fluxes are very close, they can use either one)

Geosphere – 40,005,600/30.5 = 1,311,659 years

Hydrosphere – 39,000/60.6 = 643.6 years

Biosphere – 605/60.4 = 10.0 years

Atmosphere – 760/120 = 6.3 years

Outcomes Part 2:

1. Which reservoir contained the largest amount of carbon relative to the other reservoirs? Which contained the smallest amount of carbon? (2 points)
The geosphere contained the largest amount of carbon relative to the other reservoirs. The biosphere contained the smallest amount of carbon relative to the other reservoirs.

2. Which process moves the MOST carbon within the cycle? Which process moves the lowest amount of carbon within the carbon cycle? (2 points)
Photosynthesis moves the greatest amount of carbon throughout the cycle. Fossil Fuel Formation moves the least amount of carbon throughout the cycle.

3. In which reservoir does carbon have the greatest residence time? Which reservoir has the lowest? (2 points)
The reservoir with the greatest residence time is geosphere. The one with the least is biosphere.

4. Can humans be considered carbon reservoirs? (Meaning they store carbon) If so, for how long? What living organisms are better long-term reservoirs than humans? (2 points)
Yes, humans can be considered carbon sinks. We hold carbon within us for around 80-100 years. Then when we die the carbon is absorbed into the soil. Trees are better long-term sinks, because they can live for hundreds to thousands of years.

5. Now take into consideration human activities: deforestation and fossil fuel burning. What kind of an effect do humans have on the Carbon Cycle? Is it a large or small one? (2 points)
Humans have a large effect on Carbon Cycle. Deforestation and burning of fossil fuels combined moves 8 Gt/year of carbon into the atmosphere which disrupts the natural balance.

Appendix E

Greenhouse Gases Lesson

Observing the Greenhouse Effect

Problem: The greenhouse effect is a natural process that occurs on any planet with an atmosphere. Earth, Venus and Mars all contain an atmosphere which means they all contain greenhouse effects. However, their atmospheres vary in density which means that the strength of each planet's greenhouse effect varies. Mars has a very thin atmosphere containing a small amount of greenhouse gases while Venus has a very thick atmosphere containing a very large amount of greenhouse gases. Earth's atmosphere is right in the middle in terms of thickness and amount of greenhouse gases. This "right" proportion of greenhouse gases allows the Earth to be hospitable for life while Mars and Venus are inhospitable. In this activity we will explore the relationship between the amount of one greenhouse gas, carbon dioxide, and temperature.

Learning Objectives:
Determine which gases are greenhouse gases.
Explain how the greenhouse effect works.
Demonstrate how adding a greenhouse gas will affect a model atmosphere's temperature.

Before You Begin:

1. Recall from Carbon Cycle activity, is the atmosphere gaining or losing carbon?

2. What is sunlight? Draw what you think happens when sunlight reaches the Earth

3. What do you think is meant by the phrase "greenhouse effect?"

Activity Part 1:

<u>Materials:</u>
1 high intensity lamp with a 60 to 100 watt incandescent bulb
2 thermometers or temperature probes
2- 2L soda pop bottles
Modeling clay
4 Alka-Seltzer tablets

<u>Procedure:</u>

1. Using the materials provided, design an experimental setup that compares the change in temperature between "normal" air and carbon dioxide when both are heated an hour. Write down the steps of your procedure and the data that will be collected. Hint: Make sure that the thermometer is measuring the temperature of the air inside the bottle, not the temperature of the liquid!

2. Check your setup with your instructor before starting!

Outcomes Part 1:

1. Write down your experimental design.

2. Make a prediction: Which bottle will heat up faster? Why?

3. Print the graphs.

    1. How did your prediction compare with your results? Describe the heating trend in each bottle.

    2. What is the effect of carbon dioxide on temperature?

    3. The phenomenon you just observed is called the greenhouse effect. What would the Earth would be like if the greenhouse effect didn't exist? What would the Earth be like if the greenhouse effect were much greater?

    4. Describe three ways that humans affect the carbon dioxide levels in the atmosphere and list them below

Activity Part 2:

Materials:
"The Greenhouse Effect" PhET simulation

Procedure:

1. Go to http://phet.colorado.edu/en/simulation/greenhouse and access the "Greenhouse Effect" simulation.
2. Start with the "Photon Absorption" tab, adjust the settings and keep record of how each affects your particular simulation. (Be sure to shoot ALL molecules with both types of light and see which ones "wiggle".)

   a. Create a table with a three columns: one for the name of each gas molecule, one for whether the molecule "wiggles" with infrared particles, and a third for whether the molecule "wiggles" with visible particles.
3. Answer Outcome Questions 1-3.
4. Go to the "Greenhouse Effect" tab.
   a. Create a table with two columns: one for time period/amount of GHG's and one for temperature. Use five time periods/amount of GHG's: Ice Age, the year 1750, Today, No GHG's, and Lots of GHG's.
   b. Leave the number of clouds at zero (since we are just focusing on the effect of the gases in this simulation).
   c. Make sure to change ONLY one variable at a time and leave all other variables constant to determine the effect each variable has on the simulation.
   d. Give the simulation a couple seconds to completely adjust itself to the new settings before recording.
5. Answer Outcome Questions 4-5.
   a. Then turn in questions and tables.

Outcomes Part 2:

1. While using the "Photon Absorption" tab, which gas molecules wiggled? Which did not?

2. What does the "wiggle" represent?

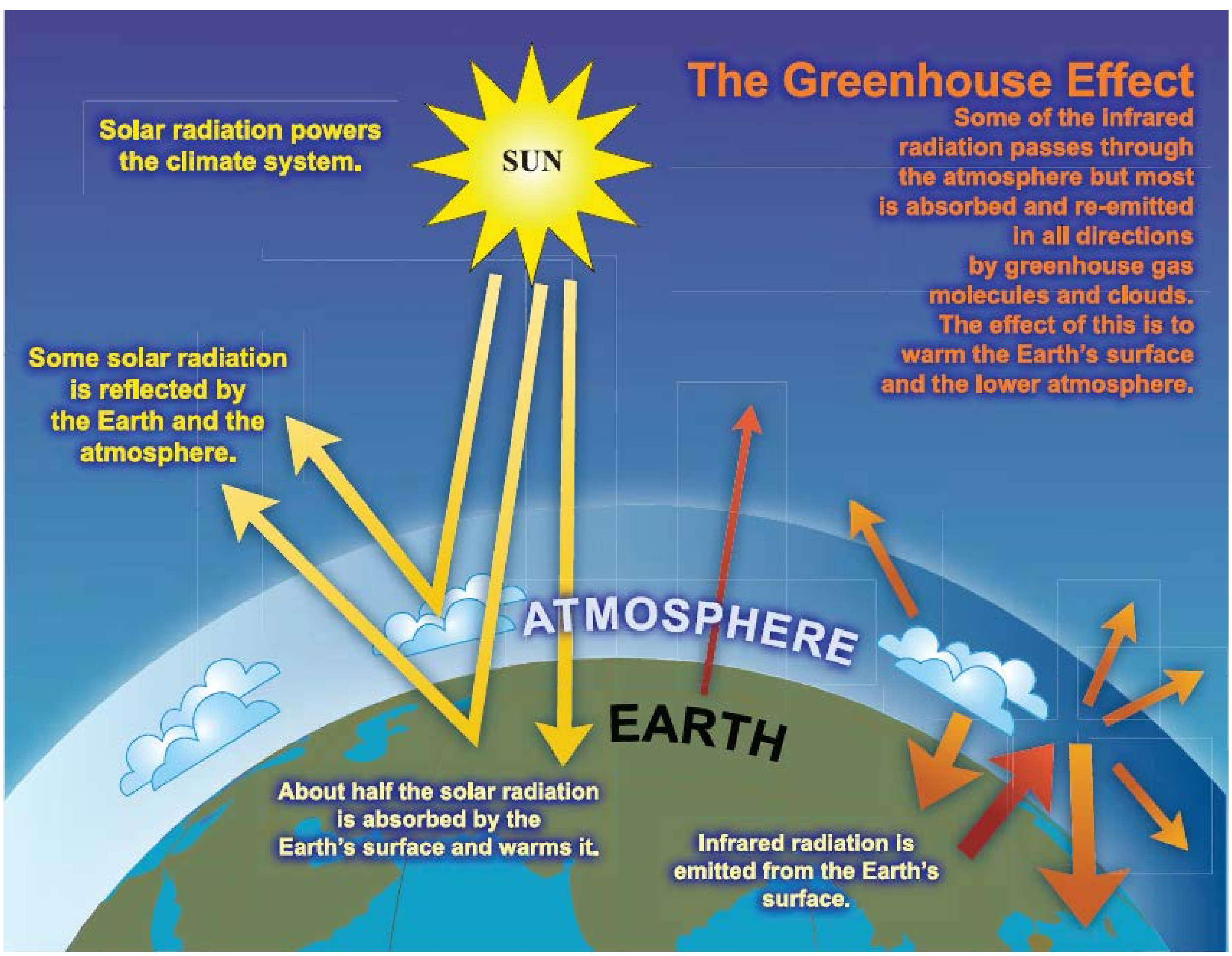
3. Which of these gases are greenhouse gases?

4. How does the amount of greenhouse gases in the atmosphere affect the atmosphere's temperature? Cite your evidence from the simulation in support of your answer.

5. What are the strengths and weaknesses of this model? How is it like what we have in the real world? How is it different than what we have in the real world?

What is the Greenhouse Effect?

Electromagnetic waves travel in various wavelengths, depending on how much energy the wave contains. This range of wavelengths has been categorized as the electromagnetic spectrum. The electromagnetic spectrum's range from longest wavelengths to shortest wavelengths is as follows: radio, microwaves, infrared light, visible light, ultraviolet light, x-rays, and gamma rays. Electromagnetic waves traveling from the Sun reach the Earth as short wavelengths, mostly as visible and ultraviolet light. Roughly one-third of the solar energy that reaches the top of the Earth's atmosphere is reflected directly back to space. The remaining two-thirds are absorbed by the surface and, to a lesser extent, by the atmosphere. To balance the incoming energy, the Earth must, on average, send out ("radiate") the same amount of energy back to space. Because the Earth is much colder than the Sun, it sends out light energy at much longer wavelengths, largely as infrared light. See figure 1. Much of this energy sent out by the land and oceans are absorbed by the atmosphere, including clouds, and then redirected ("re-radiated") back to the Earth's surface. This is called the greenhouse effect.



The glass walls in a greenhouse reduce airflow and increase the temperature of the air inside. A greenhouse is used as an analogy for how energy collects inside the Earth's atmosphere because it works to make the air inside the greenhouse hotter, however, the glass walls behave in a different fashion than the gases in the atmosphere to warm the planet.

Without the natural greenhouse effect, the average temperature of the Earth would be below the freezing point of water. Thus, Earth's natural greenhouse effect makes life as we know it possible. However, human activities have greatly intensified the natural greenhouse effect.

The two most abundant gases in the atmosphere, nitrogen (comprising 78% of the atmosphere) and oxygen (comprising 21%), exert almost no greenhouse effect. Instead, the greenhouse effect comes from molecules that are more complex and much less common. Water vapor is the strongest greenhouse gas with carbon dioxide (CO_2) as the second strongest. Methane (CH_4), nitrous oxide (NO_3), ozone (O_3) and several other gases present in the atmosphere in small amounts also contribute to the greenhouse effect. Several components of the climate system, notably the oceans and living things, affect atmospheric concentrations of greenhouse gases. A prime example of this is plants taking CO_2 out of the atmosphere and converting it (and water) into sugars and O_2 via photosynthesis.

Adding more of a greenhouse gas, such as carbon dioxide, to the atmosphere intensifies the greenhouse effect, thus warming Earth's climate. The amount of warming depends on various cycles of events that can affect one another. For example, as the atmosphere warms due to rising levels of carbon dioxide, its concentration of water vapor increases, since warmer air can hold more water vapor than cooler air, further intensifying the greenhouse effect. This in turn causes more warming, which causes an additional increase in water vapor, in a self-reinforcing cycle. This water vapor pattern may be strong enough to approximately double the increase in the greenhouse effect due to the added carbon dioxide alone.

Source: Modified from "Greenhouse Effect Lab" by Environmental Literacy and Inquiry Working Group at Lehigh University.

Appendix F

Greenhouse Gases Instructor Notes

Observing the Greenhouse Effect

Things to do before class begins:

1. Place the following agenda on the board:
    a. Announcements
    b. Finish and/or review Carbon Cycle Activity – if needed
    c. Activity
        i. Turn in all Outcomes
2. Get supplies. Per student group:
    a. White board and markers
    b. "The Greenhouse Effect" PhET simulation
    c. "What is the Greenhouse Effect" handout
3. Per two student groups:
    a. High intensity lamp with a 60 to 100 watt incandescent bulb
    b. 2 Thermometers or temperature probes
    c. 2 empty 2-liter soda pop bottles
    d. Container of modeling clay
    e. 4 Alka-Seltzer tablets

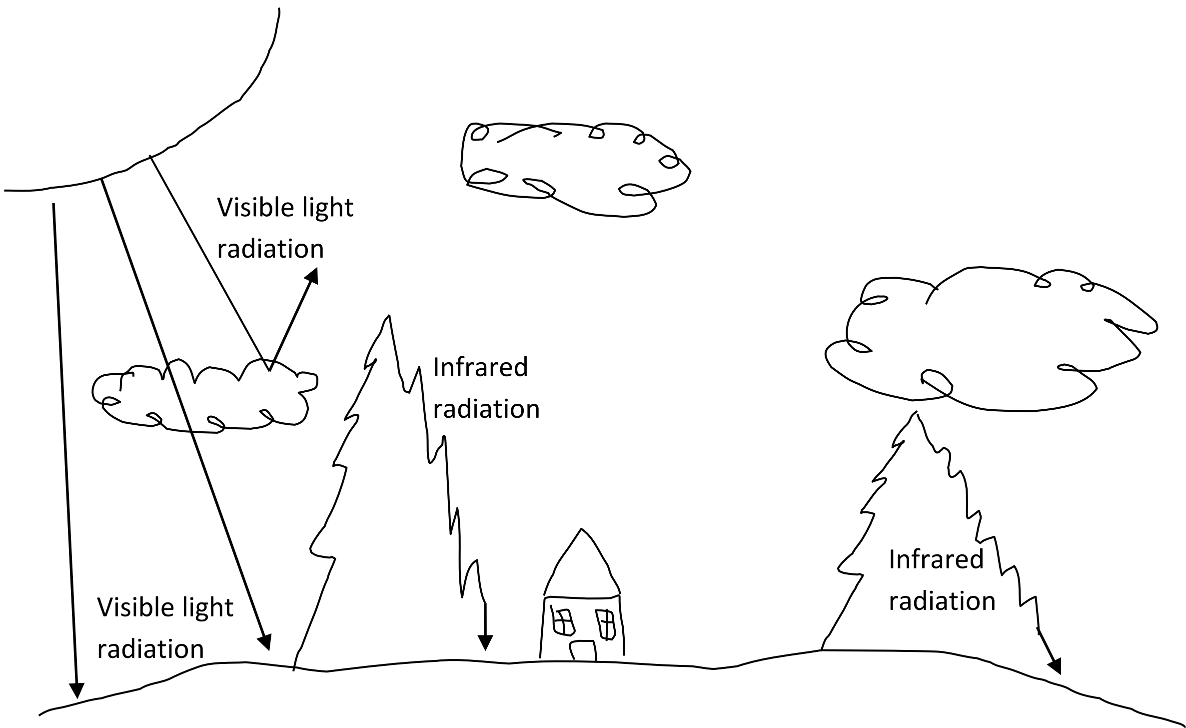
Safety Notes:

1. Remind students to be careful with and not drop the thermometers.

Order of events with approximate times to complete each task.

1. Announcements and go over daily agenda (2-5 minutes)
2. If needed – review Carbon Cycle Activity, allow students to finish jigsaw activity then discuss Carbon Cycle Activity. Allow students to revise and resubmit Outcome questions as needed. (10-20 minutes)
3. Introduce Activity. Direct students to discuss Before You Begin questions on the white boards. (5 minutes) Discuss responses as a whole class (10-15 minutes)
    a. Recall from Carbon Cycle activity, is the atmosphere gaining or losing carbon? (or this question "What is sunlight?")
        i. The atmosphere is gaining carbon. (Light from the Sun or Sunlight is the total frequency spectrum of the electromagnetic radiation that is emitted by the Sun)
    b. Draw what you think happens when sunlight reaches the Earth.
        i. Drawings may vary, an example drawing is one below.
    c. What do you think is meant by the phrase "greenhouse effect?"
        i. The "trapping" of heat energy in the Earth's atmosphere
4. Introduce the Greenhouse effect.
    a. Draw a diagram on the board to show Earth's surface, clouds, the sun, infrared and visible light rays.

Greenhouse Effect



  b. Light comes in, some is absorbed in the clouds and re-directed back into space, the rest hits the Earth's surface. After it reaches the Earth's surface it is "bounced" back into space at a different wavelength of light since the Earth is cooler than the Sun. It is "bounced" back as infrared radiation. However, most of this infrared radiation is absorbed by the atmosphere, including clouds, and then redirected back to the Earth's surface.
  c. A photon is a particle of energy, it can be of any wavelength.
5. Have students then setup Activity Part 1. (10 minutes)
  a. Supplies are limited so in setting up part 1 have two groups setup together.
  b. When setting up lab, tell students to make sure they have the same amount of gas in both bottles. (They must add the same amount of water to both.)
6. While waiting for data to be collected on Part 1, have students complete Activity Part 2 and answer Outcome questions 2. (30 minutes)
7. After students have completed Activity Part 2, have the students look at their data collected from Part 1 and answer Outcome questions 1.
  a. As circulating, make sure students understand what the "wiggling" is showing.
  b. Also, help them understand where to find each part on the simulation.

8. When all students are finished, hold a wrap-up discussion of the activity to review main points. NOTE: If class time runs short, instruct students to complete the Outcome questions. The group discussion can be held at the beginning of the next class period.
    a. What are the five gases you encountered in this activity?
        i. Methane, carbon dioxide, nitrogen, water vapor, and oxygen
    b. Which of these is the most abundant in the Earth's atmosphere?
        i. Nitrogen
    c. Which ones "wiggled" when infrared light touched them?
        i. Methane, carbon dioxide and water vapor
    d. What does it mean to "wiggle"?
        i. The energy particle is absorbed and then re-emitted out.
    e. So which of these five were greenhouse gases?
        i. Methane, carbon dioxide and water vapor
    f. What would happen if we had no greenhouse gases?
        i. The Earth would freeze and there would be no life. Mars is an example of this where there is barely an atmosphere and no life.
    g. What happens if we get too much?
        i. We get too hot. Venus is an example of this.
    h. Thinking back on the previous lab activity on the Carbon Cycle, what things do humans do that add greenhouse gases to the atmosphere?
        i. Some examples:
            1. Add carbon dioxide by deforestation
            2. Add carbon dioxide by driving cars and burning fossil fuels
            3. Add methane by raising cattle farms
9. After class, review Outcome questions in E-learning. Grade work or comment and return to students for further work as needed.

Scoring guide to Outcome questions (20 points):

Outcomes Part 1:

1. Write down your experimental design.

Each group should have a control over the amount of air in both, a seal so that the gas doesn't escape and adding the Alka-Seltzer to both.

2. Make a prediction: Which bottle will heat up faster? Why?
Responses will vary. As long as there is a valid reason it should be fine.

3. Print out your graphs.

a. How did your prediction compare with your results? Describe the heating trend in each bottle.
   Responses will vary. Both bottles heated up, however the bottle with added CO2 heated up faster and to a higher temperature.

b. What is the effect of carbon dioxide on temperature?
   The more CO2, the higher the temperature.

c. The phenomenon you just experimented on is called the greenhouse effect. Describe what the Earth would be like if the greenhouse effect didn't exist? What if the greenhouse effect were much greater?
   If it didn't exist the Earth would be too cold for life.
   If it were much greater, depending on how much greater, the Earth would be warmer and possibly inhabitable.

d. Describe three ways that humans affect the carbon dioxide levels in the atmosphere and list them below.
   Deforestation, Burning fossil fuels, Respiration, Driving cars

Outcomes Part 2:

1. While using the "Photon Absorption" tab, which gas molecules wiggled? Which did not?
Carbon Dioxide, methane and water vapor all wiggled. Nitrogen and oxygen did not wiggle.

2. What does the "wiggle" represent?
The "wiggle" represents the molecule absorbing the infrared radiation and then re-emitting it back out.

3. Which of these gases are greenhouse gases?
Carbon dioxide, methane and water vapor are greenhouse gases.

4. How does the amount of greenhouse gases in the atmosphere affect the atmosphere's temperature? Cite your evidence from the simulation in support of your answer.
The more greenhouse gases in the atmosphere, the higher the atmosphere's temperature. As we increased the number of greenhouse gases from the year 1750 to Today, the temperature got warmer. When we eliminated all the greenhouse gases in the "None" scenario, the temperature got very cold.

5. What are the strengths and weaknesses of this model? How is it like what we have in the real world? How is it limited?

These are just a few examples:

Strengths: Demonstrates visually the effects greenhouse gases have in the atmosphere, shows which gases are effected by visible and infrared photons.

Weaknesses: Didn’t show a drastic temperature difference between the maximum amount of greenhouse gases and today’s amount of greenhouse gases, small scale simulation which don’t pertain to every location on Earth,

It is a computer simulation with only a few variables so it is limited with respect to showing all aspects of the real world since climate is a product of multiple factors, however it can show the general effect of increasing greenhouse gases at a fictional location.

Appendix G

Weather and Climate Lesson

Determining Global Temperature Averages with Google Earth

Problem: To determine the temperature, wind speed, air pressure, and other current weather conditions, scientists use various equipment to record and study the weather. What is the difference between weather and climate? Does weather change? Does climate change? What is meant by the term “yearly average”? How was that yearly average calculated?

Learning Objectives: Compare and contrast the difference and relationship between climate and weather. Determine how yearly average temperature data is calculated.
Note: this activity was modified from “Investigating Weather and Climate with Google Earth” http://www.ei.lehigh.edu/eli/cc/

Before You Begin:

1. What do you think weather is?

2. What do you think climate is?

3. Do you think Kalamazoo’s climate has ever been different from what it is now?

Activity Part 1

Materials:
Temperature graph of one day in January and July in St. Louis, Missouri
Temperature graph over one year in Kalamazoo, Michigan
Google Earth Temperature graph of Allentown, Pennsylvania

Procedure:
1. Examine the three paper graphs and the graph on Google Earth.
2. Answer the following questions.

Outcomes Part 1:
1. In the July St. Louis, Missouri graph, what is the minimum temperature? What is the maximum temperature? What is the average temperature?

2. In the January St. Louis, Missouri graph, what is the minimum temperature? What is the maximum temperature? What is the average temperature?

3. How does temperature vary throughout a winter and summer day? What is the average temperature difference between a winter and summer day? Cite the data from the graphs in support of your answer.

4. The Kalamazoo, Michigan graph shows the average daily temperature over the course of a year. What are the small up and down fluctuations in this graph?

5. What overall pattern do you see in the Kalamazoo, Michigan graph? Approximately what are the average temperatures in the summer and winter months? What is the approximate average temperature for the whole year?

6. Look at the 10-year period of 1960-1970 on the Allentown, Pennsylvania graph on Google Earth. What do the up and down fluctuates over this 10-year period represent? What was the warmest year in this period? What was the coldest year in this period? What is the approximate average temperature over this 10-year period?

7. Compare the 10-year period of 1960-1970 to the period of 1990-2000 on the Allentown, Pennsylvania graph on Google Earth. Which period was warmer? What in the graph is leading you to think this way?

8. Compare the patterns of temperature on the two 10-year periods (1960-1970 and 1990-2000) on this graph with the overall 50-year period. How are they alike and different? Which period, 10-year or 50-year, best represents the climate of this city? Why?

Activity Part 2 – Around the World in 50 Years

<u>Materials:</u>
Computer with Google Earth and E-learning access

<u>Procedure:</u>
1. Go to GEOS 2900 folder and open the **weatherandclimate.kmz** Google Earth file.
2. Refer to the Google help document if you need it.
3. Visit the cities marked by pins in Google Earth.
    a. Specified by your instructor: three groups will gather data for cities 1-6, while the other three groups will gather data for cities 7-13.
4. Create a table that records the city name, latitude/longitude, min/max temp, and amount of warming for each city. Note that temperatures are recorded in Celsius for this part of the activity.
    a. Share data will another group who has the other 6/7 cities to complete the rest of your table.
5. Use the data to answer the questions below.

Outcome Questions Part Two
1. Hand in your table.

2. Create a graph showing the magnitude of temperature change over 50 years for each city.

3. Which city has the highest maximum average annual temperature? The lowest?

4. Which two cities have had the greatest amount of climate change over the last 50 years? The least amount?

5. What does the trend line on each average annual temperature graph represent? Why do we use this trend line and not the minimum and maximum temperatures for each city in determining climate change?

6. Based on the data you've collected describe any global climate trends in the past 50 years. Scientists have concluded that polar regions have experienced more warming over the past 50 years than equatorial regions, can you support this conclusion using your data? What limitations exist with this data set? What additional information would you need?

7. What effect on animals and humans do you think the change in climate over the past 50 years will have?

Appendix H

Weather and Climate Instructor Notes

Determining Global Temperature Averages with Google Earth

Things to do before class begins:

1. Place the following agenda on the board:
    a. Announcements
    b. Finish and/or review Greenhouse Gases Activity – if needed
    c. Activity
        i. Turn in all Outcomes
2. Get supplies. Per student group:
    a. White board and markers
    b. Temperature graph of one day in January and July in St. Louis, Missouri
    c. Temperature graph over one year in Kalamazoo, Michigan
    d. Google Earth

Order of events with approximate times to complete each task.

1. Announcements and go over daily agenda (2-5 minutes)
2. If needed – review previous Activity (Greenhouse Gases) allow students to revise and resubmit Outcome questions as needed. (10-20 minutes)
3. Introduce Activity. Direct students to discuss Before You Begin questions on the white boards. (5 minutes) Discuss responses as a whole class (10-15 minutes)
    a. What do you think weather is?
        i. Current, short term conditions.
        ii. Weather is a product of temp., wind, air pressure, precip., humidity, and cloud cover. However for this activity we will just be focusing on temperature.
    b. What do you think climate is?
        i. Conditions over longer periods of time.
    c. Do you think Kalamazoo's climate has ever been different from what it is now?
        i. Responses may vary, however, Kalamazoo's climate has changed multiple times in Earth's history.
4. Ask the students, "What is the transition between weather and climate? How long do we need to look at in order for it to be considered climate?"
    a. Usually the cutoff is at least 30 years of weather data to be considered a climate trend.
5. At what temp does water freeze in the Celsius and Fahrenheit scales?
    a. Celsius – 0
    b. Fahrenheit – 32
6. At what temp does water boil in the Celsius and Fahrenheit scales?
    a. Celsius – 100
    b. Fahrenheit – 212

7. To get an idea for temperature comparison,
    a. 0-5 degrees C ~ 30-40 degrees F
    b. 5-10 degrees C ~ 40-50 degrees F
    c. 10-15 degrees C ~ 50-60 degrees F
    d. 15-20 degrees C ~ 60-70 degrees F
    e. 20-25 degrees C ~ 70-80 degrees F
    f. 25-30 degrees C ~ 80-90 degrees F
8. One degree in which scale will represent a greater amount of temperature change?
    a. Celsius
9. Have students complete Activity Parts 1 and 2 (60 minutes) and turn in Outcome questions.
    a. NOTE: Let students know that some graphs are in degrees C while others are in degrees F.
    b. Circulate among the groups as they complete each part of the activity to help clarify thinking and answer questions.
    c. For part 2, have 3 groups of students do cities 1-6, have other 3 groups of students do cities 7-13.
        i. Once completed students get information from table across from theirs to fill in the rest of the table.
    d. For part 2, check and make sure students are not just taking the maximum minus minimum to find amount of warming.
    e. For part 2 Outcome question 3, the highest average temperature is a bit confusing.
        i. Imagine two cities:
            1. City one is 70-80 degrees F all year
            2. City two varies from 30-70 degrees F within the year
                a. City two has a greater change (40 degrees) but has lower average annual temperature.
10. When all students are finished, hold a wrap-up discussion of the activity to review main points. NOTE: If class time runs short, instruct students to complete the Outcome questions. The group discussion can be held at the beginning of the next class period.
    a. Ask the class, what is the cutoff for climate?
        i. At least 30 years of weather data.
    b. What did you look at in this activity?
        i. Day->Year->Decades
        ii. We averaged day then put that on the year scale
        iii. We averaged year then put that on the decadal scale
    c. Did you see evidence of global warming?
        i. On average about 1 degree Celsius of warming
11. After class, review Outcome questions in E-learning. Grade work or comment and return to students for further work as needed.

Scoring guide to Outcome questions (20 points):

Outcomes Part 1:

1. In the July St. Louis, Missouri graph, what is the minimum temperature? What is the maximum temperature? What is the average temperature?

82 degrees F is the minimum temperature. 96 degrees F is the maximum temperature. 89.2 degrees F is the average temperature. (All temps added = 2141 degrees, 2141degrees/24hours = 89.2)

2. In the January St. Louis, Missouri graph, what is the minimum temperature? What is the maximum temperature? What is the average temperature?

2 degrees F is the minimum temperature. 28 degrees F is the maximum temperature. 15.6 degrees F is the average temperature (All temps added = 374 degrees, 374degrees/24hours = 15.6)

3. How does temperature vary throughout a winter and summer day? What is the average temperature difference between a winter and summer day? Cite the data from the graphs in support of your answer.

In a winter day, the temperature varies about 26° F throughout the day, with very cold temperatures late at night and early in the morning and the warmest temperatures in the afternoon. In a summer day, the temperature varies about 14° F, again with the warmest temperatures in the afternoon. To find these varied temperatures, we took the minimum temperature of the day and subtracted it from the maximum temperature. The graphs show that there is a bigger range of warming and cooling in the winter day than there is in a summer day.

4. The Kalamazoo, Michigan graph shows the average daily temperature over the course of a year. What are the small up and down fluctuations in this graph?

The small fluctuations in the Kalamazoo graph are the changes in the average temperature from day to day.

5. What overall pattern do you see in the Kalamazoo, Michigan graph? Approximately what are the average temperatures in the summer and winter months? What is the approximate average temperature for the whole year?

The patterns of the Kalamazoo graph shows that the temperatures gradually increase as the season change from winter into spring and summer, and then the temperatures gradually decrease during the fall and winter seasons. An average temperature for the summer months is 70 degrees F. An average temperature for the winter months is 28.5 degrees F. The average for the whole year is 50 degrees F.

6. Look at the 10-year period of 1960-1970 on the Allentown, Pennsylvania graph on Google Earth. What do the up and down fluctuates over this 10-year period represent? What was the warmest year in this period? What was the coldest year in this period? What is the approximate average temperature over this 10-year period?

Each up and down fluctuation represents the average temperature for each year in this decade. It appears that 1960 had the highest average of about 11.5° C. The lowest average was the year of 1967 with a low average of 9.5° C. The average was about 10° C.

7. Compare the 10-year period of 1960-1970 to the period of 1990-2000 on the Allentown, Pennsylvania graph on Google Earth. Which period was warmer? What in the graph is leading you to think this way?

The 10 year period from 1990-2000 was significantly warmer than the 1960-1970 period. The coldest year of the 1990-2000 period was almost as warm as the warmest year of the 1960-1970 period. And the warmest year in the 1990-2000 period was almost an entire degree warmer than the 1960-1970 period.

8. Compare the patterns of temperature on the two 10-year periods (1960-1970 and 1990-2000) on this graph with the overall 50-year period. How are they alike and different? Which period, 10-year or 50-year, best represents the climate of this city? Why?

The two 10 year periods that we looked at both had drastic fluctuations in temperatures where the overall 50-year period did not always have that. But over the 50-year period, the temperatures gradually increase, which is consistent with each 10 year period.
The 50-year period best represents the climate of the city, because the entire graph fluctuates less than the two 10 year periods we viewed. Also the 50-year period account for more average temperatures and is not as easily effected by abnormally hot or cool periods.

Outcomes Part 2:

1. Hand in your table.
2. Create a graph showing the magnitude of temperature change over 50 years for each city.

3. Which city has the highest maximum average annual temperature? The lowest?

The highest maxium average annual temperature is Aswan with 30.2 degrees C. The lowest is Vostok with -58 degrees C.

4. Which two cities have had the greatest amount of climate change over the last 50 years? The least amount?

Greatest amount of climate change: Beijing and Prince Albert; least amount of climate change: Vostok and Aswan (Alice Springs and Akureyi also experienced very little change)

5. What does the trend line on each average annual temperature graph represent? Why do we use this trend line and not the minimum and maximum temperatures for each city in determining climate change?

The trend line on each average annual temperature graph represents the overall change in climate over the past 50 years. The trend line does a better job of representing the overall change of the climate rather than simply using the minimum and maximum temperatures which would only represent the difference between two years not the entire period.

6. Based on the data you've collected describe any global climate trends in the past 50 years. Scientists have concluded that polar regions have experienced more warming over the past 50 years than equatorial regions, can you support this conclusion using your data? What limitations exist with this data set? What additional information would you need?

We cannot support the conclusion that the polar regions have experienced more climate warming because one of our regions that experienced the least amount of change was Vostok on the south pole, and the other one was Aswan which is fairly close to the equator. Also, the two cities that have experienced the most warming are Prince Albert at 53° N and Beijing at 40° N which are about midway between the poles and the equator. We noticed that most of the data sets were from locations in the middle latitudes area which would cause all of these cities to have similar data. There was only one location from the poles and only one location relatively close to the equator. This is a limitation because we our data cannot support the conclusion regarding the difference in warming rates between equatorial locations and locations on the poles. In order to investigate this conclusion, we would need to collect more data from equatorial and polar locations.

7. What effect on animals and humans do you think the change in climate over that past 50 years will have?

Responses will vary, this is an example response: The change in climate could have a major effect on humans in relation to glaciers melting because this will cause an excess of water in continental areas and extreme flooding. It can also have a major effect on animal species that are not able to sustain in warmer temperatures. Species that depend on a colder climate in order to live will not be able to survive in the warmer climate unless they are able to adapt quickly enough to changes in their environment.

Appendix I

Paleoclimate Lesson

Using a Proxy (Ice Cores) to Determine Past Climate

Problem: We have learned that the average temperature of various locations throughout the Earth has changed over the past 50 years. What does this mean? Is this a large enough sample of data to make a conclusion about the Earth's climate? What was the Earth's climate like 1,000 years ago? What about 10,000 years ago or 100,000?

To get a better picture of Earth's past climate we will use a climate proxy. A climate proxy possesses physical characteristics that were generated in the past and have been preserved over time. These preserved physical characteristics can be substituted for direct measurements when making direct measurements is not possible (as is the case in investigating the climate of the distant past). An example of a climate proxy are tree rings. By looking at the width of tree rings you can determine the amount of growth a tree experienced during a certain year in its life. From that growth you can determine what the climate conditions of that year was like.
For the purpose of this lab, we will be looking at ice core data. Ice cores are used as a climate proxy for past temperatures. As ice forms atmospheric air can become trapped in ice as gas bubbles. To extract these gas bubbles, engineers first need to drill into the ice, which produces long thin cores of ice. Then scientists use an instrument called a mass spectrometer to measure the types and amounts of gases that exist in the air bubbles trapped within the ice. This trapped gas in the ice cores can help climate scientists determine what past climates were like.

Learning Objectives:
Verify the relationship between the Milankovich Cycles and carbon dioxide concentration in the Earth's atmosphere.
Interpret findings, communicate results and make judgments based on ice core data.

Before You Begin:

1. How has climate changed globally over the past 50 years?

2. How do you think the climate record will change if you look back 350,000 years?

3. Describe some natural, non-human processes that can cause climate to change.

Activity Part 1

<u>Materials:</u>
Colored pencils
Graphs

<u>Procedure:</u>

1. Methane (CH_4) is another greenhouse gas. Examine the two graphs: Carbon dioxide vs. gas age, and Methane vs. gas age. On each graph:

   a. Identify periods of time where the gas concentration is high and where it is low on each graph. Your periods of time should be on the order of about 20,000-80,000 years.
   b. Recall the relationship from the greenhouse gas activity between greenhouse gas concentrations and temperature.
   c. Color the graphs such that the warm periods are one color and the cooler periods are a different color.
   d. Answer the outcome questions.
2. Compare your graphs to the PPT slide

Outcomes Part 1:

1. Turn in your colored graphs.

2. What is the relationship between greenhouse gas concentration and temperature? Why do you think this relationship exists?

3. Describe the patterns that you see in the graphs. For example, how are the warm and cool periods distributed through time? What are the durations of the warm and cool periods?

4. Propose two explanations for why the earth's temperature has changed in this pattern over the past 350,000 years.

5. How do the warm and cool periods on your graphs compare to the scientific classification of warm and cool periods over the past 350,000 years? What might account for any differences you observe between your results and the scientific results?

Activity Part 2

<u>Materials:</u>
Computer with internet access

<u>Procedure:</u>

1. Go to http://www.sciencecourseware.org/eec/
   Click on "Global Warming".
   Then "Tutorials"
   Lastly, click on "Milankovitch Cycles"

2. Follow the prompts and then answer the outcome questions.

Outcomes Part 2:

1. What happens to the shape of the Earth's orbit over a 100,000 year cycle? What is this phenomenon called?

2. What happens if the tilt (obliquity) of the Earth is 0 degrees? Why?

3. On what time scale does the Earth's obliquity vary? And by how many degrees?

4. What is the Earth's precession? On what time scale does the Earth's precession vary?

5. Why is it important to understand these three Milankovich cycles?

Activity Part 3:

<u>Materials:</u>
Vostok Ice Core graphs

<u>Procedure:</u>

1. Examine the full set of graphs and answer the Outcome questions.

Outcomes Part 3:

1. Compare the three Carbon dioxide graphs with the overlays of precession, obliquity, and eccentricity. What patterns do you see?

2. Which Milankovich cycle best matches with the patterns observed in the carbon dioxide record? Why?

3. You will notice that the Milankovich cycles do not exactly match the fluctuations in carbon dioxide. Why do you think this? What other phenomena might explain changes in carbon dioxide concentration in the past 350,000 years?

4. The “Real Paleoclimate Data” graph compares the last 150,000 years of ice core data from Vostok with ice and salt core data from three other locations. Note that instead of reporting carbon dioxide concentrations, the graph is showing temperature differences at each location relative to today. Based on the four ice core/salt core graphs, how well do the warm and cool periods match?

5. Look at the most recent period on these graphs. Does the carbon dioxide level follow the “natural trend” you would expect to see based on the Milankovitch cycles or does it vary from the expected trend? If it varies from the expected trend, what could cause this?

Appendix J

Paleoclimate Instructor Notes

Using a Proxy (Ice Cores) to Determine Past Climate

Things to do before class begins:

1. Place the following agenda on the board:
    a. Announcements
    b. Finish and/or review previous Determining Global Temperature Averages using Google Earth Activity – if needed
    c. Activity
        i. Turn in all Outcomes
2. Get supplies. Per student group:
    a. White board and markers
    b. Gas Age vs. Carbon Dioxide graph
    c. Gas Age vs. Methane graph
    d. Internet access to Milankovitch Cycles Tutorial on www.sciencecourseware.org/eec/
    e. Vostok Ice Core graph: Precession vs. Carbon Dioxide
    f. Vostok Ice Core graph: Obliquity vs. Carbon Dioxide
    g. Vostok Ice Core graph: Eccentricity vs. Carbon Dioxide
    h. "Real Paleoclimate Data for the Past 16,000 years" handout
3. Get supplies for the class to share:
    a. Colored pencils
4. Get supplies for class demonstration/discussion
    a. PowerPoint slide of cool and warm periods with respect to the correlation between carbon dioxide and temperature levels.
    b. PowerPoint slide of combined effects of all Milankovitch Cycles.

Order of events with approximate times to complete each task.

1. Announcements and go over daily agenda (2-5 minutes)

2. If needed – review Determining Global Temperature Averages with Google Earth Activity, allow students to revise and resubmit Outcome questions as needed. (10-20 minutes)

3. Introduce Activity. Direct students to discuss Before You Begin questions on the white boards. (5 minutes) Discuss responses as a whole class (10-15 minutes)

    d. How has climate changed globally over the past 50 years?
        i. Students should be recalling the previous lab activity with their responses to this. The climate has increased globally by about 1 degree Celsius over the past 50 years.
    e. How do you think the climate record will change if you look back 350,000 years?

    i. Responses will vary. The climate record will have temperatures oscillate up and down throughout the past 350,000 years.

  f. Describe some natural, non-human processes that can cause climate to change.
    i. Take note all student responses, however, some of their responses could be things that occur due to climate changing. Three natural, non-human processes that can change climate are tilt of the Earth, solar flares, and volcanoes.

4. Go over with students climate proxies and how we can use them to determine Earth's past climate.
  g. Ask the students, "Can we hold out a thermometer and see what the weather used to be like here in Kalamazoo?"
    i. No
  h. Actual weather measurement records only go back about 150 years but the Earth is 4.6 billion years old…so in order to determine what the area's climate used to be like scientists use a climate proxy, which is a substitute that allows us to indirectly measure the climate conditions of the past.
    i. Examples of climate proxies are tree rings, fossils, and rocks.
      1. Tree rings – fat -> warmer/wetter period
         thin -> cooler/dryer period
         Oldest tree is 4,000 years old in California
      2. Lake sediment – varves
      3. Ice cores
        a. To get a more accurate measurement, lots of cores are taken from multiple places
        b. To determine a time period's climate we look at multiple cores and make inferences.
          i. In this activity we will be looking at data of carbon dioxide gas levels in ice cores.

5. Have students complete Activity Part 1 (45 minutes) and Outcome questions Part 1.

6. After students have completed Part 1, put the PowerPoint slide of "cool and warm periods with respect to the correlation between carbon dioxide and temperature levels" on the screen for the students to compare their colored graphs to.

7. Discuss with groups their findings and how their graphs compared.
  i. How does your group's breakdown into cool and warm periods compare with the scientists' periods of time?
  j. How do your graphs compare to how other groups broke down the data into cool and warm periods?

8. Have students complete Activity Parts 2 and 3 and Outcome questions Parts 2 and 3.
  k. Circulate among the groups as they complete the activity to help clarify thinking and answer questions.

i. Make sure students take note of most recent section of graphs in part 3. Have them think about what could be causing the carbon dioxide levels to continue to rise while if it were still following the path from the Milankovitch cycles it should be dropping.

ii. Make clear to students that climate change creates a change in the seasons, not just “having different seasons throughout the course of a year”.

9. When all students are finished, hold a wrap-up discussion of the activity to review main points. NOTE: If class time runs short, instruct students to complete the Outcome questions. The group discussion can be held at the beginning of the next class period.

10. Go over the three Milankovitch Cycles with the class. Ask for the names of each, what it is and how long of a period each one has.

l. Eccentricity – “stretchiness” of Earth’s orbit with a period of 300,000 years

m. Obliquity – “tilt” of Earth’s orbit with a period of 40,000 years

n. Precession – “wobble” of Earth’s rotation, with a period of 26,000 years

i. Explain to the students that all three of these are like waves that depending on how they meet up they can either cancel each other’s effect out or amplify each other’s effect.

ii. Put the PowerPoint slide of “combined effects of all Milankovitch Cycles” on the screen.

11. After class, review Outcome questions in E-learning. Grade work or comment and return to students for further work as needed.

Scoring guide to Outcome questions (20 points):

Outcomes Part 1:

1. Turn in your colored graphs.

2. What is the relationship between greenhouse gas concentration and temperature? Why do you think this relationship exists?

When the greenhouse gas concentration is high the temperature increases, and when the greenhouse gas concentration is low the temperature decreases. This happens because if there are more greenhouse gases the infrared rays are absorbed and re-emitted in the Earth’s atmosphere.

3. Describe the patterns that you see in the graphs. For example, how are the warm and cool periods distributed through time? What are the durations of the warm and cool periods?

Responses will vary, here is an example response: The patterns on the graph are distributed as warm and cool time periods that last about 50,000 years. Starting about 350,000 years ago we begin to see more warming and cooling periods that do not last for any extended period of time. As time progresses towards the recent, we see less change between cooler and warmer periods lasting for approximately 90,000 years.

4. Propose two explanations for why the earth's temperature has changed in this pattern over the past 350,000 years.

Increase in greenhouse gases, the eccentricity of Earth's orbit, the tilt of Earth's axis, and the wobble of Earth as it rotates.

5. How do the warm and cool periods on your graphs compare to the scientific classification of warm and cool periods over the past 350,000 years? What might account for any differences you observe between your results and the scientific results?

Responses will vary depending on how large or small the students made their warm and cool period time intervals.

Outcomes Part 2:

1. What happens to the shape of the Earth's orbit over a 100,000 year cycle? What is this phenomenon called?

The shape of the Earth's orbit stretches and retracts in size every 100,000 years. This is called eccentricity and is one of the Milankovitch cycles.

2. What happens if the tilt (obliquity) of the Earth is 0 degrees? Why?

If the obliquity of the Earth is 0 degrees there will be no seasons because there will be no change in the amount of sunlight that each area of the earth will be receiving. Everywhere on earth will always be receiving the same amount of sunlight.

3. On what time scale does the Earth's obliquity vary? And by how many degrees?

The earth's obliquity varies on a 40,000 year cycle from a minimum of 22.1 degrees to a maximum of 24.5 degrees.

4. What is the Earth's precession? On what time scale does the Earth's precession vary?

Earth's precession is the "wobble" of the earth on its axis. It is a 26,000 year cycle.

5. Why is it important to understand these three Milankovitch cycles?

Reponses may vary, but here is an example: Milankovitch cycles result in long term fluctuations in the energy that reaches the Earth that influences the Earth's climate.

Outcomes Part 3:

1. Compare the three carbon dioxide graphs with the overlays of precession, obliquity, and eccentricity. What patterns do you see?

Responses will vary, but here is an example: The precession line shows the least amount of correlation to CO2 levels. The obliquity line seems to show that when the Earth is at its smallest degree of tilt, the CO2 levels are at its lowest.

2. Which Milankovich cycle best matches with the patterns observed in the carbon dioxide record? Why?

The eccentricity best matches the carbon dioxide record, because when the carbon dioxide peaks the eccentricity peaks and when the carbon dioxide falls the eccentricity falls.

3. Why do the Milankovich cycles not exactly match the fluctuations in carbon dioxide? Why do you think this? What other phenomena might explain changes in carbon dioxide concentration in the past 350,000 years?

They do not exactly match the fluctuations in carbon dioxide because all three of the cycles are happening at once and so each cycle individually isn't creating the carbon dioxide concentration record. The record is due to the combined effects of all three as well as other phenomena that are affected the carbon dioxide levels. Other things that could effect the carbon dioxide concentrations over the past 350,000 years would be solar flares, volcanic eruptions, plate tectonics and human activity.

4. The "Real Paleoclimate Data" graph compares the last 150,000 years of ice core data from Vostok with ice and salt core data from three other locations. Note that instead of reporting carbon dioxide concentrations, the graph is showing temperature differences at each location relative to today. Based on the four ice core/salt core graphs, how well do the warm and cool periods match?

The warm and cool periods of Antartica and Greenland from the ice core data are very similar and seem to have the same ups and downs of temperature periods. It is harder to compare these with the two sets of data from salt cores in California and Chile because the temperature scales are different and the data does not reach back as far. But it does seem like the one from California is very similar to the data in the ice cores, while the date from Chile is not similar and does not seem to follow a pattern.

5. Look at the most recent period on these graphs. Does the carbon dioxide level follow the “natural trend” you would expect to see based on the Milankovitch cycles or does it leave that path? If it varies from the expected trend, what could cause this?

Based on our data, the current period of global warming seems to be caused by an outside force, possibly human activities, because there is a major spike in carbon dioxide in recent years while all of the “natural cycles” seem to be dropping. Further in the past the eccentricity cycle seemed to follow the same pattern and increase and decrease at the same rate as the carbon dioxide levels which is not occurring in recent years.

Appendix K

Student Surveys

Name: ______________________________

GEOS 2900 Feedback Form

1) Did you have enough prior understanding to complete this activity?

2) Do you have confidence in this topic to teach it to your own set of K-8 students?

3) What part of the activity best helped you learn this topic?

4) What was your least favorite part of this activity? How could it be improved?

Appendix L

Content Assessment Test

Name

GEOS 2900 Global Change

1) Which statement best describes the consensus of most climate scientists?

a. Changes in the sun's energy output is the main cause of climate change.
b. Cyclical changes in Earth's tilt and orbit is the main cause of climate change.
c. Earth's climate has stopped warming over the past decade.
d. The recent (over last 100 – 120 years) warming trend is caused by human activity.
e. The recent warming trend is no more than natural variability of climate.

2) How has the concentration of carbon dioxide in Earth's atmosphere changed since the industrial revolution?

a. It has remained approximately the same.
b. It has increased by approximately 10%
c. It has increased by approximately 20%
d. It has increased by over 30%

3) What do most scientists think is causing the current warming trend?

a. Holes in the ozone layer allow more solar radiation to reach Earth.
b. Warm air from the increased number of cars on the road.
c. An increase in greenhouse gases.
d. An increased number of greenhouses.
e. The carbon cycle breaking down, and heat related by natural chemical breakdown.

4) Indicate if the process increases, decreases, varies (could increase or decrease), or has no effect on the concentration of carbon dioxide in the atmosphere. (**Circle your choice**)

Process	**Effect on Carbon Dioxide** **Circle your response.**
a) Burning of fossil fuels	Increase Decrease Varies No Effect
b) Decomposition and decay	Increase Decrease Varies No Effect
c) Deforestation	Increase Decrease Varies No Effect
d) Deposition of carbonate in sediments	Increase Decrease Varies No Effect
e) Dissolution of carbonate in ocean water	Increase Decrease Varies No Effect
f) Earth's tilt on axis and orbit	Increase Decrease Varies No Effect

g) Air-sea exchange	Increase Decrease Varies No Effect
h) Photosynthesis	Increase Decrease Varies No Effect
i) Respiration	Increase Decrease Varies No Effect
j) Solar intensity	Increase Decrease Varies No Effect
k) Volcanic eruptions	Increase Decrease Varies No Effect

5) The definition of climate involves all of the following EXCEPT ____________.
   a. Averages and variability of weather conditions over decades.
   b. Conditions of the atmosphere due Earth's position relative to the sun.
   c. Extremes in weather events over decades.
   d. The state of the atmosphere at some particular place and time.

6) The sun's radiant energy is mostly at which of the following wavelengths?
   a. infrared
   b. radio
   c. ultraviolet
   d. visible

7) Which of the following *greenhouse gases* are the most abundant in Earth's atmosphere?
   a. Carbon dioxide and methane
   b. Carbon dioxide and water vapor
   c. Carbon dioxide and ozone
   d. Carbon dioxide and oxygen
   e. Nitrogen and oxygen

8) The natural greenhouse effect is geologically a(an) _______________.
   a. Old process, caused by gases selectively absorbing and emitting infrared radiation.
   b. Old process, caused by the buildup of the ozone layer in the atmosphere.
   c. Old process, caused naturally by volcanic eruptions and changes in solar activity.
   d. Recent process, caused by burning of fossil fuels, deforestation, and other human activity
   e. Recent process, caused naturally by volcanic eruptions and changes in solar activity.

9) The greenhouse effect is best described as ____________.
   a. A buildup of the ozone layer due to excess greenhouse gases.
   b. Greenhouse gases becoming trapped by carbon dioxide.
   c. Greenhouse gases absorbing and re-emitting infrared radiation.
   d. Infrared radiation absorbing and trapping greenhouse gases.

10) Which of the following statements best describes the relationship between the greenhouse effect and global warming?

    a. As the concentration of greenhouse gases increase, global mean temperature increases.
    b. Global warming causes an enhanced greenhouse effect.
    c. The greenhouse effect and global warming are basically the same phenomenon.
    d. The greenhouse effect is manmade and global warming is part of a naturally occurring cycle.

11) Give three ways you can reduce the amount of greenhouse gases entering the atmosphere and explain how each way would reduce the amount of greenhouse gases.

12) What's the difference between climate and weather?

13) The Earth's climate changes gradually over long periods of time.
    a. Explain two natural mechanisms that cause climate to change

    b. Explain one human activity that can cause climate to change