Teaching Urban High School Students Global Climate Change Information and Graph Interpretation Skills Using Evidence from the Scientific Literature

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ABSTRACT

Curriculum materials designed to provide students with practice interpreting plotted evidence of global climate change were developed using graphs from the scientific literature and tested with one hundred urban high school students from a high-poverty school in a major northern city in the US. The graph interpretation lessons followed a constructivist-teaching learning cycle format. Additional activities included watching videos related to climate change and completing a graphing exercise. Students displayed motivation during the lessons along with significant improvement from pretest to posttest in graph interpretation skills and content knowledge of organisms affected by climate change. Student motivation was revealed by task commitment during the exercises as well as requests for additional activities related to investigating environmental effects on organisms and stopping global climate change. The efficacy of the lessons is attributed to the concrete, manipulative nature of the graph interpretation sets, real-world connections of the topic, the focus on interesting organisms, the opportunity for students to express their views, and the use of multi-media.

RATIONALE

Global climate change is one of the most pressing issues facing our nation and world today resulting in environmental, social, and economic problems. The American Geophysical Union (2007) provided a position statement asserting:

> The Earth's climate is now clearly out of balance and is warming… …During recent millennia of relatively stable climate, civilization became established and populations have grown rapidly. In the next 50 years, even the lower limit of impending climate change—an additional global mean warming of 1°C above the last decade—is far beyond the range of climate variability experienced during the past thousand years and poses global problems in planning for and adapting to it. Warming greater than 2°C above 19th century levels is projected to be disruptive, reducing global agricultural productivity, causing widespread loss of biodiversity, and—if sustained over centuries—melting much of the Greenland ice sheet with ensuing rise in sea level of several meters… …With climate change, as with ozone depletion, the human footprint on Earth is apparent. The cause of disruptive climate change, unlike ozone depletion, is tied to energy use and runs through modern society. Solutions will necessarily involve all aspects of society. Mitigation strategies and adaptation responses will call for collaborations across science, technology, industry, and government.

The average temperature of the Earth's surface is rising with the ten warmest years on record occurring during 1997-2008 (Goddard Institute for Space Studies, 2009). Human activities, such as the burning of fossil fuels, have led to the highest levels of carbon dioxide, a greenhouse gas, in the atmosphere in the past 650,000 years (Intergovernmental Panel on Climate Change, 2007). Deforestation makes matters worse with the loss of plants that could have transformed carbon dioxide to oxygen. Cities cover only one percent of Earth's surface, yet consume three-fourths of the world's energy and are responsible for contributing eighty percent of greenhouse gas emissions (C-40 Cities Climate Leadership Group, 2008). The need for humans, particularly city-dwellers, to work together to solve the global climate change crisis before it reaches an unstoppable tipping point is paramount.

Educating urban youth about global climate change is vital to solving the problem because they will generally continue to populate cities and the energy consumption and conservation habits they develop during their school years will most likely persist, influencing the effects of cities on global energy consumption as discussed above. Schools provide a medium for changing our society through students transferring their classroom learning to their families. Additionally, our urban youth in their teens and twenties are not only tomorrow's leaders, but represent five hundred billion dollars in purchasing power, a significant proportion that can steer consumer (and therefore manufacturer) practice in many areas (Brown and Washton, 2007). Urban students pose a challenge, however, because achievement levels are typically low in inner-city settings, even when controlling for poverty (Resnick and Glennon, 2002). A National Assessment of Educational Progress (NAEP) reading test showed only 23 percent of high-poverty urban students achieving at basic reading levels compared to 46 percent at high-poverty non-urban schools and 69 percent in non-poverty schools (Quality Counts, 1998).

This article explores the use, with urban high school students, of curriculum materials that center on interpretation of graphs displaying evidence of global climate change from the scientific literature. We ask, "In what ways (if any) are these materials effective in improving: 1) students' attitudes toward and/or knowledge of global climate change (including affected organisms), and 2) graph interpretation skills?" Additionally, the high-poverty urban school at which the current study takes place has problems of high absenteeism and has been classified, because of low test scores, as a school at risk for failure. Therefore, this challenging setting provides a strong trial for these curriculum materials. We first discuss how the lessons support national standards and constructivist teaching,

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note other existing curriculum materials in this area, present examples of the materials, and then give and discuss evidence of the efficacy of the lessons in both learning of concepts and changing of dispositions.

NATIONAL STANDARDS

Chapter 3, The Nature of Technology, of the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 2008), states that students in grades 9-12 should know the following issue of technology: "The human species has a major impact on other species in many ways: reducing the amount of the earth's surface available to those other species, interfering with their food sources, changing the temperature and chemical composition of their habitats…" The lessons discussed here support this standard by showing students scientific evidence of human impact on organisms in the environment, by providing explanations of mechanisms that cause these disturbances, and by suggesting ways to mitigate the situation.

"Evidence, models, and explanation," is one of the powerful unifying concepts of science identified in the National Science Education Standards (National Research Council, 1996, p. 104). The graph interpretation lesson activities described in this article provided students with scientific evidence for climate change in a variety of environments. The videos they watched provided scientific models for global climate change and explanations of causes and effects. Students expressed their opinions of global climate change issues prior to and after the lessons, participating in informed discussions of this current event using evidence they had just acquired.

Science Education Program Standard B (National Research Council, 1996, p. 212) states, "The program of study in science for all students should be developmentally appropriate, interesting, and relevant to students' lives; emphasize student understanding through inquiry; and be connected with other school subjects." The African American students in this urban school represented a diverse range of science ability, as quite a few students who qualified for special education services were included in the five participating classes and one class consisted of mostly honors students. To make the activities developmentally appropriate for lower-ability students, the teacher incorporated matching activities of animals to descriptions of their lifestyles and some more basic graph analysis activities into the lessons. Clearly, from the student feedback on the post-lesson survey that will be discussed in detail later (e.g., "It was fun and very interesting," "Important to know how global warming is affecting us now."), students found the activities interesting and relevant to their lives. The lessons integrated mathematics (graph interpretation) with several areas of science (biology, ecology, earth science, and climatology) and current social issues (solutions to global climate change such as reduction of fossil fuel use, recycling of paper to save forests).

GLOBAL CLIMATE CHANGE CURRICULUM AND INTEGRATION OF SUBJECT AREAS

Various curriculum materials for teaching about climate change have been available for some time. The K-12 Earth Systems Education curriculum restructure effort (Mayer and Fortner, 1995) uses global climate change as a unifying theme. Two useful books of activities accompany this series: *Activities for the changing earth system* (Mayer, Fortner, and Murphy, 1993) and *Great Lakes instructional materials for the changing Earth system* (Fortner et al., 1995). More recent resources are available, including materials developed by the Environmental Protection Agency and the National Oceanic and Atmospheric Administration. The Internet provides access to many curriculum materials; Risinger (2009) and Moses (2007) reviewed many Internet sites with lesson ideas that address climate change, soil depletion, and current environmental ideas.

Global climate change issues touch many disciplines and enter into numerous pressing societal issues, making this a good overall theme for a variety of purposes. For example, Matkins and Bell (2007) showed how global climate change can effectively be used as a unitary theme in a science methods course to help preservice teachers understand the nature of science as empirically-based, tentative, requiring creativity, and influenced by society and culture.

Concepts from many fields of study, such as social studies and civics, may be integrated with science in activities related to climate change. A case in point, Sadler and Klosterman (2009) argued that students need to examine the social and political dimensions of global climate change to be better prepared as citizens to engage "intelligently in public discourse and debate about matters of scientific and technological concern" (National Research Council, 1996, p.13). They described an activity in which high school students acted as senators developing legislation for U.S. policy on global warming. Students read materials from five different special interest groups presenting different perspectives on the issues (e.g., automobile consumers' views, business leaders advocating for a strong economy, environmentalists concerned about the planet's future). Having practical actions kids can take (Bardeen, 2007) is an important follow-on for student empowerment and continuation of newly-developed interests. WebQuest projects (Dutt-Doner et al., 2001), in which students seek online information to support arguments as they take on roles as members of various groups testifying before a special senate subcommittee to decide if the Kyoto Protocol for reducing greenhouse gases should be ratified, provide another way to examine the convergence of science and politics. At the elementary school level, Lester and others (2006) investigated the effect of science content knowledge on fifth graders' social activism to halt global climate change. They found that students with adequate science knowledge expressed interest in activism more frequently.

Mathematics can be effectively integrated into global climate change lessons, helping students see real-world applications of algebra, graphing, and modeling. Carr (2008) had students calculate sea level rise from melting ice at different temperatures, taking into account sea level surface areas and ice thicknesses, to determine inundated cities. More complex models to predict sea level trends may also be used (Chen et al., 2008). Additionally, web-based data sets may be graphed to compare atmospheric gases, oxygen isotopes, and temperatures over different time spans, allowing students to analyze and interpret data (Huntoon and Ridky, 2002).

Global climate change issues provide the impetus for science inquiry. In one successful venture described in the literature (Constible et al., 2008), students, posing as public relations firm employees, created evidence-based graphic displays and arguments concerning the health-threatening effects of climate-related pollen increases caused by rising levels of atmospheric carbon dioxide. Similarly, the effects of carbon dioxide and ozone changes on aspens were investigated by other high school students who analyzed data collected by scientists at a research site in Wisconsin (Carlson, 2008). Another activity suggested for global climate study was investigating calorimetry (Burley and Johnston, 2008) in which students performed quantitative calorimetric measurements on samples of ice/water heated by light bulbs and/or convection with room-temperature, graphing the results against time to discover that not all additions of heat energy caused temperature increases; some resulted in melting of ice. In a larger unit related to the same concepts, Lueddecke and colleagues (2001) developed a secondary-to-college level curriculum for teaching about the greenhouse effect through inquiry experiments using fish tanks, heat lamps, and temperature probes, which they claimed worked well with students.

Finally, literacy and language arts can be effectively integrated into this topic area. Herreid (2005) described how he used Michael Crichton's novel with a global warming setting, *State of Fear*, in a science class to motivate students to seek and evaluate global climate change data. In a different study, Schweizer and Kelly (2005) investigated how debate could be used as a pedagogical tool in engaging students in the science concept of global warming. Students were able to analyze and utilize scientific data sets during the debates, regardless of the position their side took on the issue, making this approach effective.

EFFECTIVE TEACHING OF GLOBAL CLIMATE CHANGE

Several recent studies have been conducted to assess misconceptions related to global climate change and evaluate the efficacy of teaching materials for global climate change topics. Osterlind (2005) studied fourteen-year old students' conceptual difficulties with environment-related words that had different technical and everyday meanings, concluding that students' eventual understandings of these concepts helped them in better comprehending the broader issues. Similarly, students who are not proficient in Standard English may experience difficulty with terminology. Lee et al. (2007) examined the effects of inquiry activities that included an English language and literacy focus along with addressing students' languages and culture on fifth graders' conceptions of the greenhouse effect and global warming. They found statistically significant improvements for all diverse groups in a large urban school district except African-American and Haitian students who made no or little change respectively. Lee et al.'s study and several prior studies (e.g., Andersson and Wallin, 2000; Boyes and Stanisstreet, 1997, 1998; Boyes et al., 1999; Koulaidis and Christidou, 1998; Rye et al., 1997) indicate that students confuse the greenhouse effect with ozone depletion, ignore the natural mechanisms of greenhouse gas generation to focus only on manufacturing-environmental issues, and tend to attribute greenhouse effects to just one component of a complex system.

Concept maps drawn by students can reveal student thinking, helping teachers identify areas that need clarification. Schuster et al. (2008) examined high school students' concept maps related to climate change, producing a baseline of science concepts. Gautier et al. (2006) and Rebich and Gautier (2005) investigated student misconceptions, finding that some students attributed rising Earth temperatures to increased sunlight through the ozone hole or thought that it was greenhouse gases or clouds themselves that were being trapped. Rebich and Gautier used pretest-posttest concept maps drawn by undergraduates to show significant increases in correct concepts about global climate change after participation in a mock summit course on global climate change. Teachers need to be aware of the common terminology and concept confusions experienced by students so that they may address them while teaching and design activities that will help students differentiate among them.

Fortner (2001) cautions educators to use curriculum materials that are of the appropriate developmental level for students so that they can truly grasp the concepts. Elementary students and many secondary students are not at a stage of cognitive development to grasp the abstract ideas of space and time encompassed by the concepts of global climate change. Seminal studies by Chiappetta (1976) along with Lawson and Blake (1976) showed that the majority of high school students and young adults function at the concrete operational stage in their understandings of science. Therefore, concrete materials should be an entry point for study of this topic. Additionally, urban students benefit from seeing connections between science and their environment (O'Connell et al., 2004). Real-world connections to the science being studied make learning more meaningful and motivate urban students.

Taking into consideration the preceding review of the literature, the current study was designed to assist urban high school students in making meaningful connections to information from the current scientific literature that has implications for Earth's climate. Mathematics (mostly as graph interpretation), literacy (a movie presenting the book, *The Lorax*, by Dr. Seuss) and student discussions of political issues were integrated into lessons that used hands-on materials to capture attention and portray concepts at a concrete level. The lessons focused mostly on biological evidence for global climate change; therefore, much of the terminology for atmospheric phenomena such as the greenhouse effect was not directly addressed.

RELEVANCE OF THE CURRENT STUDY TO EARTH SCIENCE EDUCATION

The curriculum presented in the current article, although focusing on changes to organisms' populations in various environments and tested in a high school biology course, is adaptable to other student populations and settings, including high school or middle school Earth science classes for the following reasons. 1) The sciences are becoming more integrated and interdisciplinary than traditionally taught. It is appropriate to examine biological consequences of climate change within geoscience courses and geoscience ideas within biology coursework. Few major real-world problems (such as population growth, pollution, energy resources) fit into just one subject-area and most have strong additional social studies components including economics and culture (Bralower et al., 2008). It is important that students understand the interdisciplinary nature of science so that they can tackle science problems from a broad range of approaches. 2) Extinction, adaptation, and evolution of organisms fit within the realm of paleontology in the Earth sciences. Climate changes affecting extant populations will become part of the fossil record. A major value of developing a deep understanding of the fossil record is to use these principles to comprehend and solve current issues. 3) Although the graphs from the scientific literature used in this study focused on animals, there are many other graphs available in the literature that show changes in Earth features such as ice cap or glacier size and extent of summer sea ice; cyclone or winter storm frequency and El Nino dynamics; number of natural disasters affecting a region over a time span; changes in average air or water temperatures; or fluctuations in sea level. Instructional materials have been developed for many of these non-animal graphs and are available in Rule et al. (2008).

Readers may also consider extensions of this graph-interpretation activity to the areas of mineralogy, petrology, or paleontology for both secondary and college students. One could obtain graphs from the scientific literature in these areas and prepare true and false graph interpretation statements to be sorted and discussed by students. The animal objects used in the study here could be replaced by mineral, rock, or fossil specimens in these offshoot activities. Because these materials are manipulative, visual, and concrete, they can be used with middle school and upper elementary students in addition to high school and college populations.

CURRICULUM MATERIALS AND LESSON FORMAT

The materials used in these lessons consisted of four different sets of objects, graphs, and true-false statements, each housed in a plastic shoebox that were investigated by a group of four students. Figure 1 shows an example object, while Figure 2 shows the corresponding graph and true-false cards. Additional full-size color sets of materials, many of which were used in the lessons described here, are available free on the Internet as a document at the US government Educational Resources Information Center (Rule et al, 2008) and as an appendix at the JGE website. Similar materials were used in a study with preservice elementary teachers (Rule et al., in revision). That investigation showed that preservice teachers made medium-sized gains in confidence of graph interpretation and small yet statistically significant positive changes in attitude toward taking actions in their personal lives to stop global climate change. The four different sets (of four graphs each plus objects and statements) were rotated among the groups over four days so that each student had access to all the sixteen different graphs and materials. Table 1 gives the topics of each set of materials. Each lesson was presented in the learning cycle format, sometimes called the 5E's model of engagement, exploration, explanation, expansion and evaluation, which complements constructivist learning theory (Lawson, 2001) as students construct knowledge from experience, rather than being directly instructed in concepts.

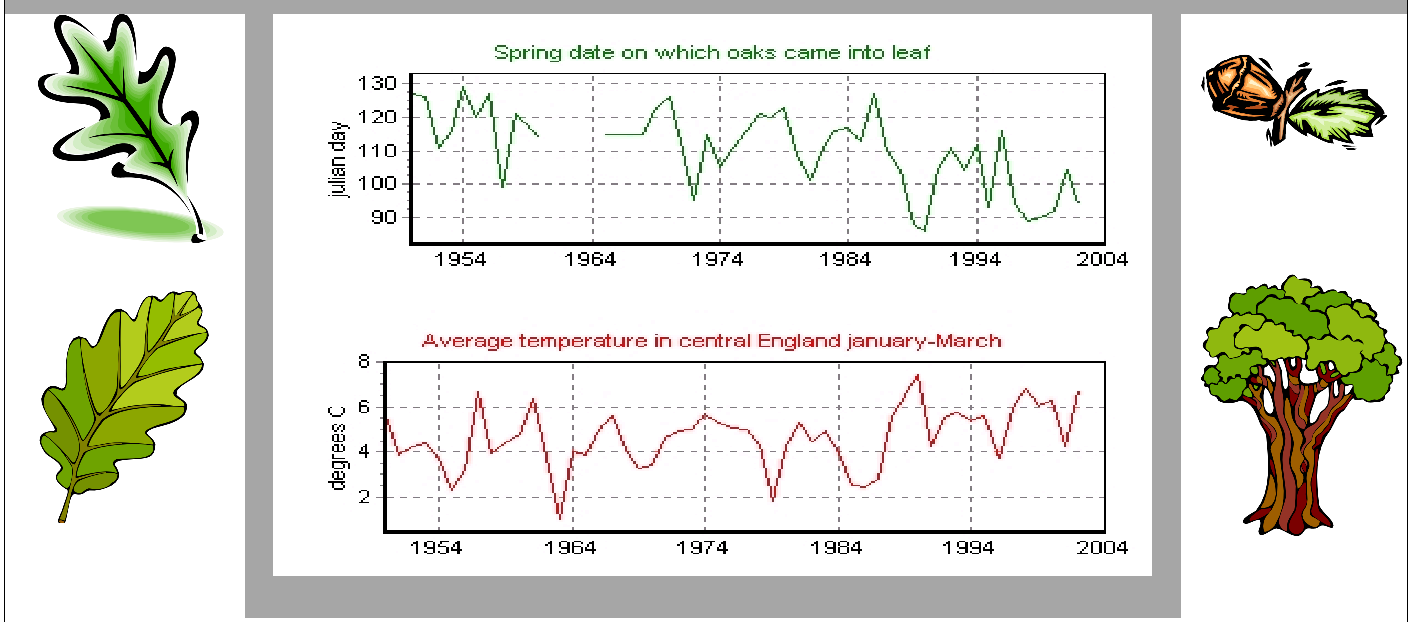
In the first, fairly brief phase of the lesson (often called the *exploration* phase), student attention (*engagement*) was focused on the learning as students examined four objects that represented evidence of global climate change and attempted to discern the connections. The teacher asked students, "Tell how each object might represent evidence for global climate change." Each object was usually a plastic model of an animal or plant wired onto a cardboard-mounted postcard-sized color photograph of the organism's environment (many objects were toy animal models or holiday ornaments). Students activated prior knowledge as they searched their memories for what they knew about global climate change and the featured animals or plants. Oftentimes, students were puzzled by this assignment as they had little experience with animal/plant-related evidence for global climate change. This uncomfortable, confused state, called *disequilibrium*, was deliberately designed into the lesson because it prompted students to pay attention and find out how these organisms were connected to global climate change so that they might return to equilibrium.

At the beginning of the second phase of the lesson (the *explanation* or concept development phase), students retrieved the colorful graphs from the box and matched them with the corresponding animal or plant objects. By reading the titles and captions of the graphs, students

FIGURE 1. Example object - oak leaves (fabric oak leaves sewn to an image of the oak).

learned how these organisms were related to evidence for climate change, thereby bringing them back to a state of equilibrium. Next, they sorted the true-false statements to the corresponding graphs (there are six statements for each graph and four graphs for a total of 24 statements) by using context clues in the statements and the process of elimination. They determined the three true and the three false statements for each individual graph by examining the plots and noting which were correct and incorrect interpretations. After the statements had all been placed

Date of Leaf Emergence of Oak Trees in Spring



Spring date on which oaks were observed to be coming into leaf in Ashtead, Surrey, shown in relation to the average temperature in Central England in January to March.

Sparks, T. H. (2002). *Date of leaf emergence of trees in spring*. Retrieved January 30, 2009 from: http://www.ecn.ac.uk/iccuk/indicators/25.htm

True Statements	False Statements
Warmer temperatures seem to be correlated to trees putting out their leaves earlier.	The warmest winter in Central England shown on the graph is 1962.
The average temperatures in Central England show a warming trend through the years on the graph.	The top graph shows the average number of days oak trees had leaves each year.
The graph shows that trees tend to put out their leaves earlier in recent years than during the mid 1950's.	The two graphs show that the warmer the winter, the later the oak trees leaf out.

FIGURE 2. Graph and true-false cards.

TABLE 1. GRAPH ANALYSIS MATERIALS USED IN THE LESSONS

SET	TOPIC	SCIENTIFIC ARTICLE OR WEBSITE FROM WHICH GRAPH WAS ADAPTED
1	Decline in breeding pairs of Emperor penguins	Figure1, page 184 of Barbraud and Weimerskirch, 2001
	Increase in elk population in a National Park	Figure 2, page 214 of Wang, Hobbs, Singer, Ojima, and Lubow, 2002
	Decrease in yolk mass of turtle eggs	Figure 1, page 848 of Willette, Tucker, and Janzen, 2005
	Increase in reported coral diseases	Figure 1, page 544 of Ward and Lafferty, 2004
2	Loss of sea ice at northern pole area	Unnumbered figure in Schliebe, 2000
	Earlier nesting of loggerhead turtles	Figure 2, page 1426 of Weishampel, Bagley, and Ehrhart, 2004
	Increase in jellyfish biomass	Figure on slide 7 of Macklin, 2000
	Forest vegetation changes	Figure 3, page 392 of Walther, Post, Convey, Menzel, Parmesank, Beebee, Fromentin, Hoegh-Guldberg, and Bairlein, 2002
3	Relationship of rainforest bird population size to temperature	Figure 4a, page 340 of Shoo, Williams, and Hero, 2005
	Moth species abundance	Figure 8, page 127 of Conrad, Woiwod, Parsons, Fox, and Warren, 2004
	Date of spring oak leaf emergence	Unnumbered figure in Sparks, 2002
	Date of spring squirrel births	Figure 1B, page 593 of Reale, McAdam, Boutin, and Berteaux, 2003
4	Relationship of cod catch to sea temperature	Figure 5, page 8 of Hannesson, 2006
	Date of flycatcher egg laying	Unnumbered figure, page 1659 of Both, et al., 2004).
	Tree ring width related to climate	Figure 2, page 483 of Bunn, Graumlich, and Urban, 2004
	Date of salmon migration	Figure 2, page 2396 of Juanes, Gephard, and Beland, 2004

under the true or false headings, students were given the answer keys to check their work. Students in each group then took turns interpreting the true statements of one of the graphs to the rest of the group, also explaining why the false statements were incorrect. During this phase, students constructed new knowledge, replacing outdated ideas they previously held, and practiced it by explaining the information to fellow students.

The last phase of the lesson (the *expansion* phase) allowed students to practice their newly-acquired learning by applying it to different situations. During this time, students watched videos related to different aspects of ecology and global climate change. By watching and discussing the videos, students confirmed their learning and made more connections between it and previous knowledge, allowing them to easily access this information from memory in the future. After students had cycled through all four sets of materials and had viewed the videos, they took the posttest evaluation and survey to determine what they had learned.

PARTICIPANTS

African-American students in five diverse high school biology classes (containing honors students, students with cognitive disabilities, and typical students from an urban neighborhood in a large northern US city) taught by the same instructor participated in the lessons. Only students who took both the pretest and posttest were included in the study resulting in 100 participants. The sex and grade level make-up of the participant population was as follows: 56 female, 44 male; 18 ninth graders, 65 tenth graders, 10 eleventh graders, and 7 twelfth graders. Internal Review Board approval (#08-0295) was obtained from the University of Northern Iowa for use of data from human subjects in this study.

EXPERIMENTAL SET-UP

This study had a simple pretest-intervention-posttest design to investigate the efficacy of using hands-on graph analysis materials based on graphed data related to the effects of global climate change on different organisms from the scientific literature. Table 2 shows the two-week sequence of activities for ten 55-minute class periods.

The pretest and posttest were identical instruments. The graph interpretation part of the test consisted of seven multiple choice graph interpretation questions that accompanied a set of four related graphs showing tufted puffin hatch dates, growth rates, sea surface temperatures and fledgling success rates (from Figure 3 of Gjerdrum et al., 2003). The organism/ habitat part of the test consisted of 15 matching items in which students matched organism names and descriptions of habitat to models of the organisms.

Additionally, students responded to a survey at the end of the lessons that asked them to tell three things that they enjoyed, three new things they learned, and three things they would change to improve the activities. Students also responded to five statements about global warming by placing stickers on a graph to indicate their level of agreement, both as a pre-and post- activity.

RESULTS AND DISCUSSION

A paired, two-tailed t-test was computed for the pre- and posttest scores of participants with the pretest score acting as the control for the posttest. This calculation showed a significant difference between pre- and posttest scores on the graph analysis section, the section on organisms affected by global climate change, and the test as a whole. The pooled standard deviation was determined using the original standard deviations, as

TABLE 2. LESSON ACTIVITIES

DAY	LESSON ACTIVITY
1	Students take pretest of graph analysis and organism questions. They also place stickers on charts to express their views (strongly disagree, disagree, agree, strongly agree) concerning statements related to global climate change.
2	Students work in small groups of four students each. Each group receives a plastic shoebox with 4 organism objects, four graphs, and true-false statement cards. After completing the activity, they check their work with answer keys.
3	Students complete an exercise focusing on a yeast cell population, construct a data table, plot a graph, and interpret the results.
4	Students work in small groups with another set of objects, graphs, and true-false statements.
5	Students watch video, The Eruption of Mount St. Helens! (Graphic Films Corporation, 1997), showing plant and animal succession in areas affected by the eruption. This video provided students with information on ecosystems.
6	Students work in small groups with the third set of graphs.
7	Students watch and discuss video: An inconvenient Truth featuring Al Gore (Bender, David, et al., 2007)
8	Students work in small groups with the fourth set of graphs.
9	Students watch and discuss video: The Lorax – Dr. Seuss (Pratt, 1972), which describes problems of deforestation.
10	Posttest of graph analysis and organism questions. Students place stickers on charts to express their views of statements about global climate change.

suggested by Dunlop (1996) and used to determine the effect size as Cohen's *d* (Cohen, 1988). This gives an effect size that is not artificially magnified by the correlation between the paired scores. The effect size from pre- to posttest was small to medium for the graph interpretation assessment, but large for the section on organisms affected by climate changes and for the test as a whole.

Tables 4 through 7 provide additional data on the efficacy of the lessons. On the questions addressed by Tables 4-6, students were asked to give three items for each question. However, some students supplied more and some provided less. Additionally, some students who were absent during the pretest answered these surveys, making the number of respondents larger than 100. The categorized data in Table 4 reveal the aspects of the lessons students enjoyed. In general, many students found the exercises fun and interesting. They particularly liked studying the animals in their environments and learning the causes and effects of global warming. Students took pleasure in expressing their feelings about the global warming statements and learning the views of classmates. They also liked the graph interpretation activities and believed they had increased their skills through this work. Group interactions were motivating to students. Many remarked that they liked handling the animal/plant models that were mounted on a colored image of the organism's environment and sorting the true-false statements. Several commented that they were glad to finally understand what global warming was all about and benefitted from the thought-provoking lessons. Only a few stated that they did not enjoy the activities. The classroom teacher reported that motivation was often a problem during other classes, but students' attitudes and task commitment were good during these lessons.

Table 5 shows what students said they learned from the unit. The most frequent response was that they were surprised to learn how animals are affected by global climate change. The second-most frequent comment was that new graph interpretation skills were acquired through this work. This finding supports the small to medium effect size change seen on the graph analysis portion of the pretest-posttest. Students also revealed that they learned the immediacy of the climate change problem from their work during this unit. Students noted their surprise that plants, as well as animals are affected. Students' interests in animals and their environments came through as many students told specific facts they had learned about unfamiliar animals. Students remarked on their new knowledge of the human-caused perils of global warming, including dangers to humans. They expressed surprise that some organisms might be favored by the changing conditions.

TABLE 3. PRETEST AND POSTTEST RESULTS

DESCRIPTION	GRAPH ANALYSIS PART OF TEST	ORGANISM AFFECTED BY CLIMATE CHANGE PART OF TEST	COMPLETE TEST
Number of Students	100	100	100
Pretest mean in percent correct	55.6	58.6	57.1
Posttest mean in percent correct	61.4	77.8	69.6
p from Two-tailed paired student T-test	0.003	<0.0001	<0.0001
Effect size: Cohen's *d*	0.30	0.95	0.78
Effect size interpretation	Small to medium	Large	Large

Table 6 lists suggestions given by students for improvement of the activities. An exciting theme of these student responses was now that they knew the causes and consequences of global climate change, they wanted to do something to stop it. The most frequent suggestion was having a conservation or ecology project in which they could be involved. This finding shows the impact of the lessons in motivating students to action, something that is sorely needed and difficult to accomplish. The second-most-frequent response given by students was not to change anything about the lessons because they were enjoyable and effective as presented. However, some students thought that the lessons could be made somewhat easier to complete, which may be influenced by the large range of student abilities taught by the teacher – naturally, some students would find the lessons on the difficult side while others found them easy. Students indicated their fascination with learning about animals and their habitats when they suggested that additional animals (with representative models as objects) be used in the lessons. More time spent on learning about global climate change with in-depth discussion and more details were requested.

Student dispositions toward global warming were measured before and after the lessons by having students place a sticker on a graph to indicate their agreement or disagreement with a given statement. Students thoroughly enjoyed both placing the stickers to indicate their feelings and viewing the sticker placements of others. Pretest to posttest attitude changes were small and not statistically significant for four of the statements. However, there was a significant change (2-tailed t-test, p =.008) in thought expressed for the fifth statement, "Global climate change will have a bad effect on all animals and plants." After

TABLE 4. STUDENT RESPONSES TO, "TELL THREE THINGS THAT YOU ENJOYED ABOUT THE GLOBAL CLIMATE CHANGE ACTIVITIES.

FREQUENCY	GENERAL CATEGORY FOLLOWED BY EXAMPLES
31	**Fun, interesting, and easy activities:** That it is fun by doing the graphs; It wasn't very hard; It was really interesting to me.
28	**Studying the animals and their environments:** I enjoyed learning facts about all of the animals; learning the temperatures animals like to be in; it showed us how animals live in their environments.
28	**Finding out the causes and effects of global warming:** Learning how it affects us and plants and animals; How global warming happens to the planet; Learning ways to stop it.
25	**Expressing and examining student feelings about global warming:** I liked it because I could tell how I felt about it; I could really see how people felt about global warming; Writing how I felt about global warming and how it will affect the animals.
25	**Doing the graph analysis activities:** I enjoyed graphing; I liked working with the animal graphs; The graphs helped you learn.
24	**Acquiring skills of graph interpretation:** Helped me to understand graphs a lot more; Learned to plot and make sure I read graphs; Talking about strategies of interpreting graphs.
20	**Working as a team or group:** It was fun working in a group; Doing teamwork; Working with other students.
18	**Matching/sorting the true or false statements:** Finding the true and false statements about the animals; It was fun to match up the true-false statements; I enjoyed the true or false cards.
18	**Learning something new I didn't know before:** I learned something new about it everyday; We learned lots of new things; I like the knowledge it gave.
15	**Using creative, visual, tactile materials with animal models:** It was a hands-on thing- not just writing; The pictures were nice and creative; How creative the activity was; Getting the feel of the animal objects.
11	**Watching movies and videos about global warming:** The man in the movie talked about a lot of things I had never heard of; The movie-it was interesting; Watching global warming videos.
11	**Learning exactly what global climate change is:** Taking notice on what global warming really is; I never really knew much about global warming but now I do.
11	**Participating in challenging and thought-provoking activities:** I liked it because it gives you something to think about; The graph activity had me thinking about the temperature in our city now; It was challenging and keeps your mind guessing.
9	**Learning to identify new animals:** I enjoyed matching up the animals with its picture; Matching the names and the animals.
8	**Did not like the activity:** Nothing; I don't like them.
8	**The fact that this is a real-life current event activity:** Being active in what's going on in the world; You can put yourself in the events that go on; I enjoyed this because it is true.
7	**Using the answer key to check answers:** Finding out whether our predictions were true of false; I liked it when the answers showed I got it right; I learned what I did wrong so next time I could get it right.
7	**This was a good experience:** It was enjoyable; It was set up nice; This was a good experience for me.
6	**Putting stickers on the graphs:** The stickers; Putting stickers on the graphs.

participating in the lessons, during which some examples of organisms benefitting from warmer conditions were presented, students tended to agree less with the statement. Significant movement on this question probably occurred because it was one statement that goes counter to the general feeling that global climate change will have all negative effects.

SUGGESTIONS FOR IMPLEMENTATION

Our students were very excited by the graph analysis activities and requested additional activities to learn more details of organisms affected by global climate change. They also expressed the desire to work together to do something about the dangerous situation our planet is facing. Unfortunately, there was no time for in-class continuation of this topic, as the teacher was required to move on to other parts of the curriculum. Hopefully, the next time the teacher presents this topic, there will be time for students to develop action plans and organize to carry them out. Some possible activities include: making posters to inform other students in the school about global climate change issues, organizing recycling campaigns, presenting skits on energy conservation to the elementary school PTA, producing a brochure that explains steps urban citizens can take to halt global climate change, or becoming involved with one of the international organizations trying to stop global climate change.

Two aspects of the materials that particularly appealed to students were their tactile and visual nature. All graph materials were printed in vibrant color and mounted on heavy white presentation board. The "objects" were interesting animal figures or realistic artificial plants wired or sewn to postcard-sized cardboard -mounted photographs of their environments. We

TABLE 5. STUDENT RESPONSES TO, "TELL THREE NEW THINGS THAT YOU LEARNED FROM THE GLOBAL CLIMATE CHANGE ACTIVITIES."

FREQUENCY	GENERAL CATEGORY FOLLOWED BY EXAMPLES
56	**Animals are affected by global climate change:** Global warming affects polar bears and penguins; I learned that animals are dying off because of global warming; I learned that lots of animals will lose their homes and will die.
37	**Skills for interpreting, making, and answering questions about graphs:** How to get a better understanding of the graph; How to carefully look at graphs and pay more attention to it; How to read different graphs.
31	**Global warming is actually occurring now:** Global warming definitely affects the climate; It's in effect now; Earth's climate is getting warmer.
29	**Plants are affected by global warming:** I learned that plants are also affected; Wetter warmer weather is good for tree life; It makes some plants grow faster.
29	**Natural history and ecology of animals:** I learned what a flycatcher bird looks like; How animals live and hunt their food; How animals live in their environment.
25	**Extinction or bad effects for humans are possible because of global warming:** We may or may not be able to survive global warming; Will affect us badly because it could change population for so many things that we may need; If global warming is not stopped, we may die.
22	**What global warming is all about:** Global warming is about temperature and massive heat; I learned how global warming occurs; I learned what makes global warming.
14	**Worldwide and all-inclusive nature of global warming:** Global warming is affecting everyone and everything; Global warming is a world-wide issue; How many different things are affected.
14	**Ways to stop global warming:** I learned that there are ways we can stop it; Chopping down trees to make paper hurts the ecosystem; Stop using up so much energy that we don't need.
13	**Greenhouse gases from burning fuels contribute to global warming:** Greenhouse gases are oiling up; The radiation from the sun is trapped; I learned that pollution plays a big part in global warming.
12	**Some organisms are favored by global warming, whereas others fail:** I learned that global warming will destroy some animals' lives while others won't be affected as much; It could or could not be bad for animals; That some animals may get help from global warming.
10	**Changes occurring because of global warming are dangerous:** That global warming is more serious than I thought; Global warming is dangerous; Things may not be as they seem.
9	**Opinions of classmates related to global warming**: Many people feel the same way about global warming and agree with a lot of things I disagree with; That different people can have similar feelings.
8	**Ice at the poles and in glaciers is melting:** Global warming is melting a lot of the glaciers; I learned that the arctic will truly be affected because of how the ice caps and glaciers will melt..
5	**Humans are the cause of global warming**: We are the cause of global warming; Humans are the cause of global warming.
4	**Scientific evidence tells us what is happening:** There is scientific evidence that Earth's climate is getting warmer.
2	**Human diseases increase as global warming occurs:** Global warming gives heat illnesses; It causes humans to get sick.
2	**How to work better in a group:** I learned how to work better in a group.

recommend that teachers replicate the hands-on nature of the materials and not translate them into paper worksheets, as handling and arranging the objects, graphs, and statements was an important attention-maintaining and motivating part of the activities.

IMPLICATIONS AND CONCLUSION

In this article, we have presented evidence for the motivating effects on urban high school students of using hands-on graph interpretation materials stemming from graphs reported in the scientific literature. Evidence for the usefulness of the lessons is threefold: 1) increases in graph analysis skills and knowledge of organisms and their habitats from pretest to posttest; 2) student survey responses showing their enthusiasm for the work; and 3) students survey responses indicating that students would like to continue with more lessons and activities related to global climate change because they consider it important. Our positive results are significant, as another study reporting the results of a large-scale intervention on global climate change concepts that included diverse groups of fifth-grade students (Lee et al., 2007) showed no gains for African-American students.

It is difficult to directly compare our study with that of Lee et al. (2007). Although the general topic area was the same (global climate change), the interventions, data collections, and grade levels of students were different. Our study focused on graph interpretation skills, attitudes, and knowledge of climate-affected organisms of high school students after the interventions of examining

TABLE 6. STUDENT RESPONSES TO, "TELL THREE THINGS YOU WOULD CHANGE TO IMPROVE THE ACTIVITIES?"

NO.	GENERAL CATEGORY FOLLOWED BY EXAMPLES
37	**Conservation/ ecology project for students to help stop global warming:** We should work on keeping the environment clean; Clean up around us and conserve energy; Recycling and cleaning the places you're at.
30	**Keep the activity the same:** I wouldn't change the activities that were organized; Leave it as it was; It does not need to be improved.
27	**Fun, easy, interesting aspects should be increased:** Make it more fun so people can get an even better understanding; It would be more fun if it wasn't so hard; Make it more interesting.
25	**More and different animals/plant objects should be added each time:** By adding different or more objects every time; I probably would have had a bigger variety of animals; I would use more land animals than sea animals.
20	**Spend more time studying this topic with additional activities:** Make it so we have to do this topic for a whole week; Just to have more things to include in it; Do more activities dealing with global warming.
19	**Take more time for discussing or writing about global warming:** There would be more talking about global warming; I would talk about more things that will affect us as humans; Discussing moreover the subject.
17	**By having more or different or larger, more colorful graphs and charts:** Do better graphs with more information; Make the graph bigger in the activity; Use different colors on the graphs.
15	**Questions should be changed or made harder:** Make it smarter; Harder questions; I would make the questions really difficult so you can think about it better; Give multiple choice questions.
14	**Details and more features should be added so that students learn more:** Give more details so I can learn more about it; They could have put more information on the graph; I would rather have more ideas.
12	**Provide more pictures of the animals and ecosystems:** I would show more pictures; Provide more pictures and information about the organisms; Show more real pictures.
11	**Extra project, work with live animals, or field trip on global warming or animals should be added:** Add a project on global warming to do; Add some real animals to the activity; I wish we could have worked with animals as they are in their environments; We could have a field trip.
11	**Allow students to choose their own groups and increase group cooperation:** Let people pick their groups; Don't have the same people in the same group all the time; More teamwork or team effort.
9	**Watch more videos or make movies about global climate change:** Watch more movies, then do another graph about the movie; Watching more tapes or videos on the subject; Make a movie about global warming.
8	**Provide more images and predictions of what will happen as global warming proceeds:** Bring pictures of predictions of what the earth will look like in 2050; How long will it be before the worst global warming happens; Bring some pictures of Antarctica in 1920 and 2005.
8	**Have more true/false statements to sort:** Add more statements to decide if true or false.
7	**Involve others in making changes to stop global warming:** Try to get people active in order to change; Try to inform more people about global warming; Just take actions and get involved.
6	**Sticker activity of graphing opinions should be improved**: I would give each class a different kind of sticker and then each class would be able to compare their data; I would buy better stickers.
6	**Make a competition or fun game of it:** Have teams and have a competition between the teams; Make it into a game show; Maybe changing it into a game.
4	**Hints and answer keys should be provided more often:** Give us little hints; Have more keys to help understand the graphs; Give kids more answers.

TABLE 7. STUDENT DISPOSITIONS TOWARD FIVE STATEMENTS ABOUT GLOBAL WARMING

STATEMENT	TIMING	NUMBER OF STUDENTS REPORTING THIS DISPOSITION				MEAN SCORE
		STRONGLY DISAGREE = 1	DISAGREE = 2	AGREE = 3	STRONGLY AGREE = 4	
1. There is a lot of scientific evidence that Earth's climate is getting warmer.	Pretest	17	17	30	36	2.9
	Posttest	17	9	23	51	3.1
2. I believe that global warming/global climate change is happening now.	Pretest	11	12	27	50	3.2
	Posttest	15	11	16	58	3.2
3. Global warming/climate change will not affect animals and plants much at all.	Pretest	46	22	15	17	2.0
	Posttest	44	25	12	19	2.0
4. Global climate change will have a good effect on many animals and plants.	Pretest	31	17	18	34	2.6
	Posttest	32	19	17	32	2.5
5. Global climate change will have a bad effect on all animals and plants.	Pretest	7	12	29	52	3.3
	Posttest	20	17	20	43	2.9

models of organisms, reading information, and sorting graph interpretation statements, among other activities. Lee, Lester et al.'s study examined fifth grade student conceptions of the greenhouse effect and global warming as revealed in response to writing prompts following a simulation of the greenhouse effect using sand in covered and uncovered containers heated by a lamp and watching an eco-public service announcement.

Our lessons were effective for the following reasons: 1) the materials consisted of interesting animal or plant models and small cardboard-mounted true-false statements that could be touched and manipulated, thereby focusing student attention; 2) the graphs represented real-world data from the scientific literature, presenting meaningful evidence for world climate changes happening now; 3) the activities focused on interesting animals and plants in their native habitats, many of which were new to the students and engendered feelings of empathy; 4) students expressed their views of agreement or disagreement with statements about global warming and participated in many informal discussions of the topic; and 5) a variety of sources of information were presented, including graphs from the scientific literature, videos, and classroom graph exercises.

The urban audience for the lessons made significant gains in graph interpretation skills and appreciated the format and content of the lessons. This population often poses a challenge to teachers because of high rates of absenteeism, poor achievement, and low motivation. The students in our study, however, displayed considerable motivation during the lessons and expressed interest in delving deeper into the topics. This is encouraging for both changing the low achievement levels of inner-city students and for mobilizing urban citizens to make lifestyle changes to halt global climate change.

Our materials may have succeeded with this urban population because of motivating factors of the materials: their very appealing, concrete nature and the perceived "ease" of manipulating and sorting the graph interpretation statements. The empathy-engendering animal figures accompanied by compelling evidence of endangerment captured student attention, encouraging students to want to learn the concepts. Students saw the activities as "easy" because the statements were supplied, allowing them a straightforward way to respond to the activity (note the number of students who made comments to this effect in Table 4), but in reality, they were challenging graph interpretation exercises. The evidence for this is teacher observation of student work: many students took time puzzling over where to place the statements, discussing ideas with peers, and many statements were initially incorrectly categorized. Additionally, although there was significant positive movement from pretest to posttest on the graph interpretation questions, the posttest mean of 61.4% indicates that students still have much room for improvement. Student beliefs in the ease of the activities may have allowed them to feel confident enough to delve into them. The self-checking nature of the activities (when students used the answer keys) allowed students to note their errors without drawing undue attention to their mistakes. The fact that students recognized their improvement in graphing skills (See second row in Table 5) shows that they valued the activities – another factor in motivation. Student statements of wanting to learn more about additional animals and to become involved in actions to halt global climate change attest to the appeal of the materials and activities along with student recognition of their authentic real-world application (as noted by O'Connell et.al., 2004).

Students learned several aspects of the nature of science through these activities as they examined empirical evidence for global climate change and considered social and cultural influences on climate. They also learned of the tentative nature of scientific knowledge as Earth's climate has clearly been warming for decades, yet only in recent years have scientists become united in recognizing this. We concur with the findings of Matkins and Bell (2007), that global climate change is an excellent overarching theme to study the nature of science.

Our planet is facing the growing crisis of global climate change. It is imperative that we identify effective science activities that teach important content from the standards (animal adaptations for habitat, human effects on the environment) and skills (such as graph interpretation) while at the same time addressing current events that require social action. Others (Rule et al., in revision) have shown these materials were effective with preservice elementary teachers; we have presented evidence that high school students can also benefit from their use.

An online supplement to this article, with additional figures and images, is available at http://www.journalofgeoscienceeducation.org/

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