Seventh Grade Students’ Conceptions of Global Warming and Climate Change

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Running Head: Global Warming and Climate Change

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Abstract

The purpose of this study was to investigate seventh grade students’ conceptions of global warming and climate change. The study was descriptive in nature and involved the collection of qualitative data from 91 seventh grade students from three different schools in the Midwest, USA. These data were analyzed for content in an inductive manner to identify students’ concepts. The categories that emerged from the students’ responses reflected different degrees of sophistication or conceptualization about global warming and climate change. Based on these findings we make curricular recommendations that build on the students’ conceptions and the NRC (1996) science education standards.
Global Warming and Climate Change

Introduction

As human activities continue to add greenhouse gases—carbon dioxide, methane, and nitrous oxides—to the Earth’s atmosphere, global temperatures are expected to rise, causing the Earth’s climates to change. These climate changes may affect precipitation patterns, severe and extreme weather events, and over time environmental systems. Furthermore, human health and agriculture may be sensitive to climate change. The Intergovernmental Panel on Climate Change (IPCC) has concluded that global warming is inevitable and that human activity is likely to be the main cause. The National Research Council’s *Grand Challenges in Environmental Sciences* (NRC, 2000) identified eight "grand challenges," four of which are directly linked to climate and climate change. Thus, it is vital that students learn about global warming and climate change.

Teaching about global warming and climate change is essential for developing well rounded students, and for overcoming a critical deficiency in atmospheric science and climatology curricula (Serafin et al. 1991). Furthermore, teaching about global warming and climate change provides a natural context for studying science through personal and social applications. An understanding that is essential if future citizens are to assume responsibility for the management and policymaking decisions facing our planet (Brown, 1992; Bybee, 1993). Therefore, if science education is to promote a citizenry that is knowledgeable about global warming and climate change it is essential to determine what students’ conceptions are about global warming and climate change (Osborne & Freyberg, 1985) in order to plan curriculum and design instruction that builds on students’ conceptions (Driver et al., 1994).

The purpose of this study was to investigate seventh grade students’ conceptions about global warming and climate change, add to the extant literature base on students’ geoscience and environmental science learning, and provide guidance to curricular development. We selected
seventh grade as this is the grade level at which students begin to learn about global climate, weather, and related phenomena (e.g., hydrologic cycle), developing an understanding of the Earth as a system—the interrelationship among the physical, chemical, and biological processes that shape and change the Earth (NRC, 1996). Specifically, the research question guiding this study was: What are seventh grade students’ conceptions of global warming and climate change?

Based on these findings we make curricular recommendations that build on students’ conceptions and the National Research Council (NRC) science education standards (NRC, 1996). Furthermore our study expands on past research, providing a historical perspective on students’ conceptions as well as providing new insights into students’ conceptions about the potential environmental impact of global warming and climate change.

Background

We reviewed 14 international studies published between 1993 and 2005 that investigated secondary students’ conceptions of global warming and climate change. Because of the limited number of studies that specifically investigated seventh grade students’ conceptions of global warming and climate change; we expanded our literature review to secondary students, grades 6-12. Instead of individually describing each of the studies, we report our interpretation and categorization of the findings in tabular form (Tables 1-4). We grouped the findings from these studies into four themes and 20 categories. The four themes are: conceptions about global warming, the greenhouse effect (Table 1), causes of global warming and climate change (Table 2), environmental impact of global warming and climate change (Table 3), and resolutions (Table 4). Within each theme we identified categories that reflect the students’ conceptions. For each category we identify specific findings that make up the category along with the authors.
Table 1. Secondary students’ conceptions about global warming, the greenhouse effect

<table>
<thead>
<tr>
<th>Categories</th>
<th>Findings and Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Distinction between the kinds of radiation</td>
<td>No distinction among “ultraviolet rays,” “solar rays,” and “thermal rays or heat (coming from the sun)” (Koulaidis &amp; Christidou, 1999)</td>
</tr>
<tr>
<td>1</td>
<td>No distinction between “heat rays” and “ultra-violet rays” (Boyes &amp; Stanisstreet, 1997; Fisher, 1998; Österlind, 2005)</td>
</tr>
<tr>
<td>2</td>
<td>No distinction among “heat rays,” “ultra-violet rays,” “heat or high ambient temperature” (Boyes &amp; Stanisstreet, 1998)</td>
</tr>
<tr>
<td>The kind of radiation involved in the greenhouse effect</td>
<td>Increased ultraviolet radiation, due to ozone depletion, results in global warming (Koulaidis &amp; Christidou, 1999; Boyes &amp; Stanisstreet, 1997)</td>
</tr>
<tr>
<td>3</td>
<td>Heat or solar rays coming from sun is involved in the greenhouse effect, no concept of terrestrial radiation. (Koulaidis &amp; Christidou, 1999)</td>
</tr>
<tr>
<td>The kinds of greenhouse gases</td>
<td>Consider greenhouse gases as air pollutants and greenhouse effect as an environmental problem (Koulaidis &amp; Christidou, 1999)</td>
</tr>
<tr>
<td>4</td>
<td>Do not consider CO₂ as a greenhouse gas (Boyes et al., 1993; Boyes &amp; Stanisstreet, 1993; Boyes &amp; Stanisstreet, 1997; Pruneau et al., 2001)</td>
</tr>
<tr>
<td>5</td>
<td>Do not consider water vapor as a greenhouse gas (Fisher, 1998)</td>
</tr>
<tr>
<td>The position and distribution of greenhouse gases in the atmosphere</td>
<td>Greenhouse gases form a thin layer in atmosphere surrounding the earth (Koulaidis &amp; Christidou, 1999; Pruneau et al., 2003)</td>
</tr>
<tr>
<td>6</td>
<td>Carbon dioxide forms a “lid” or “skin” over the earth (Andersson &amp; Wallin, 2000)</td>
</tr>
<tr>
<td>7</td>
<td>Lots of gases form a “roof” over the earth (Andersson &amp; Wallin, 2000)</td>
</tr>
<tr>
<td>The definition of greenhouse effect</td>
<td>Do not know about the greenhouse effect (Andersson &amp; Wallin, 2000; Pruneau et al., 2001)</td>
</tr>
<tr>
<td>8</td>
<td>No distinction between greenhouse effect and global warming (Andersson &amp; Wallin, 2000; Boyes et al., 1993)</td>
</tr>
<tr>
<td>Erroneously involving the ozone layer in greenhouse effect</td>
<td>Greenhouse effect is that solar rays, reflected by the earth surface, are trapped by ozone layer (Koulaidis &amp; Christidou, 1999)</td>
</tr>
<tr>
<td>9</td>
<td>Sun’s rays get trapped in the ozone (Boyes &amp; Stanisstreet, 1997; Pruneau et al., 2003)</td>
</tr>
</tbody>
</table>
Table 2. Secondary students’ conceptions about the causes of global warming and climate change

<table>
<thead>
<tr>
<th>Categories</th>
<th>Findings and Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmentally harmful actions</td>
<td>Littering (Boyes &amp; Stanisstreet, 1993; Gowda et al., 1997)</td>
</tr>
<tr>
<td></td>
<td>Using environmentally harmful products (Gowda et al., 1997)</td>
</tr>
<tr>
<td>Pollution</td>
<td>Acid rain (Boyes &amp; Stanisstreet, 1993; Boyes et al., 1993; Pruneau et al., 2001)</td>
</tr>
<tr>
<td></td>
<td>Nuclear waste (Boyes &amp; Stanisstreet, 1993; Boyes et al., 1993)</td>
</tr>
<tr>
<td></td>
<td>General air pollution (Andersson &amp; Wallin, 2000; Boyes &amp; Stanisstreet, 1997; Gowda et al., 1997)</td>
</tr>
<tr>
<td></td>
<td>Chemicals, harmful and unnatural gases (Gowda et al., 1997)</td>
</tr>
<tr>
<td></td>
<td>General pollution (Fisher, 1998; Gowda et al., 1997; Pruneau et al., 2001; Pruneau et al., 2003)</td>
</tr>
<tr>
<td></td>
<td>Heat is trapped under a layer of dust created by pollution (Pruneau et al., 2001)</td>
</tr>
<tr>
<td>Ozone hole</td>
<td>Ozone depletion causes global warming (Boyes et al., 1993; Boyes &amp; Stanisstreet, 1993; Boyes &amp; Stanisstreet, 1998; Fisher, 1998; Gowda et al., 1997; Pruneau et al., 2001)</td>
</tr>
<tr>
<td></td>
<td>Ozone hole allows more solar energy to reach the earth, causing global warming (Andersson &amp; Wallin, 2000; Boyes et al., 1999; Boyes &amp; Stanisstreet, 1994; Boyes &amp; Stanisstreet, 1997; Koulaidis &amp; Christidou, 1999; Österlind, 2005; Pruneau et al., 2003; Rye et al., 1997)</td>
</tr>
<tr>
<td></td>
<td>Cool air escapes into space through the ozone hole, causing the earth to warm (Boyes &amp; Stanisstreet, 1997)</td>
</tr>
<tr>
<td>Change in solar irradiation</td>
<td>Increased penetration of solar radiation (Boyes et al., 1993; Boyes &amp; Stanisstreet, 1993; Pruneau et al., 2003)</td>
</tr>
<tr>
<td></td>
<td>Earth gets closer to the sun; sunrays hit more places on the Earth (Pruneau et al., 2003)</td>
</tr>
<tr>
<td>Barrier of gases</td>
<td>Barrier of gases bounces back the heat from the Earth and keeps it from leaving the Earth (Andersson &amp; Wallin, 2000)</td>
</tr>
</tbody>
</table>

Table 3. Secondary students’ conceptions about the impact of global warming and climate change

<table>
<thead>
<tr>
<th>Categories</th>
<th>Findings and Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>No change in my life</td>
<td>No consequence in my life (Pruneau et al., 2001; Pruneau et al, 2003)</td>
</tr>
<tr>
<td>Over estimate global warming</td>
<td>Much higher temperature estimations (Gowda et al., 1997)</td>
</tr>
<tr>
<td>Skin cancer</td>
<td>Causes skin cancer (Boyes et al., 1993; Boyes &amp; Stanisstreet, 1993; Boyes &amp; Stanisstreet, 1998; Pruneau et al., 2003)</td>
</tr>
<tr>
<td>Do not understand regional variation</td>
<td>Confusion over regional differences in that in some areas there will be more flooding and in other areas there will be more desertification (Boyes &amp; Stanisstreet, 1993)</td>
</tr>
<tr>
<td>Depletion of ozone layer</td>
<td>Greenhouse gases cause depletion of the ozone layer (Boyes et al., 1999; Boyes &amp; Stanisstreet, 1997; Boyes &amp; Stanisstreet, 1994; Gowda et al., 1997; Rye et al., 1997)</td>
</tr>
<tr>
<td>General air pollution</td>
<td>Greenhouse gases are air pollutants, increased greenhouse gases will cause air pollution (Koulaidis &amp; Christidou, 1999)</td>
</tr>
</tbody>
</table>
Theoretical and Methodological Framework

A constructivist perspective guided this study. Constructivism, as a research referent, aims to understand the meanings constructed by students participating in context-specific activities using language (Schwandt, 1994). Central to this study was the written language and drawings used by students to represent and communicate their meaning (Holstein & Gubrium, 1994; Kress, Jewitt, Ogborn & Tsatsarelis, 2001). These signs and symbols represent the students’ interests, motivation, and what they view as crucial and salient for their purpose in making the sign or symbol (Kress et al., 2001). The meanings inherent in students’ conceptions are contextualized because they represent students’ cognitive constructions at a particular point in time (Patton, 2002); that is, they reflect the unique social, educational, and cultural experiences of the students.

Similarly, the authors constructed an understanding of the language and symbols the students used to represent their conceptions of global warming and climate change—the authors created constructions about the students’ constructions. Thus, meanings were constructed by the authors within a socio-cultural context. Therefore, the codes and categories constructed by the authors are shaped and colored by their experiences and conceptions. Our interpretations of the

<table>
<thead>
<tr>
<th>Categories</th>
<th>Findings and Author</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmentally friendly action</td>
<td>Protection of rare species, reduction of nuclear arsenal, keeping beaches clean, use of unleaded petrol (Boyce et al., 1993; Boyce &amp; Stanisstreet, 1993) Pollute less, put waste in the trash, clean the streets (Pruneau et al., 2003)</td>
</tr>
<tr>
<td>Unawareness of socio-economic consequences of CO₂ control</td>
<td>Limit CO₂ emission, implying the unawareness of dependence on fossil fuel and the societal consequences of CO₂ control (Andersson &amp; Wallin, 2000)</td>
</tr>
<tr>
<td>Cannot be changed by humans</td>
<td>Cannot change/stop global warming (Pruneau et al., 2001)</td>
</tr>
</tbody>
</table>
students’ responses, then, are interpretations grounded in our experiences, conceptions, and perspectives that are grounded in both environmental education and the geosciences (Patton, 2002).

This study was descriptive in nature, involving the collection of qualitative data (i.e., student written and drawn responses). These qualitative data were then analyzed for their content in an inductive manner to identify concepts and patterns in student responses. The study was conducted with limited information about the social, cultural, and educational experiences of the students and how these might influence students’ responses. The intent was not to investigate factors influencing students’ responses but to explore their conceptions about global warming and climate change. The benefit of a survey was that it allowed us to collect data from a large number of students with varying degrees of experience, thereby providing us access to a breadth of student conceptions with different degrees of sophistication (Driver et al., 1996). This permitted the characterization of students’ concepts and allowed us to identify trends or patterns in students’ concepts and to compare these to past research.

Method

Sample and Data Collection

We employed a purposeful sampling strategy, using the classrooms of three teachers who are involved in our climate change instructional development project. We opted for a large sample size as this provided the advantage of sampling a wide range of students so as to document the similarity, diversity and/or variation in their conceptions of global warming and climate change; facilitating the comparison of the data (Patton, 2002).

An assessment instrument or survey (described below) was administered to students in the teachers’ classrooms. A total of 91 seventh grade students from the Midwest completed the
assessment. Students completed the assessment during their regularly scheduled science class. Each teacher was familiar with the assessment and its administration, and they had reviewed and critiqued the assessment. A pilot version was administered to different students and revised based on their responses. The assessment was administered by the teachers prior to any classroom instruction on global warming and climate change. It is unknown what formal or informal educational experiences these students had prior to completing the assessment.

**The Global Warming and Climate Change Assessment Instrument**

The assessment instrument consisted of five items: four open-response items and one draw-and-explain item. The instrument was designed as an idea eliciting task (Osborne & Freyberg, 1985) and based on the draw and explain protocol (White & Gunstone, 1992). Therefore, student responses were not scored as “right” or “wrong” but were analyzed for their content. The assessment used written prompts to elicit student responses. A number of researchers have used similar tasks to elicit students’ concepts about environmental and geoscience phenomena (e.g., Alerby, 2000; Anderson & Moss, 1993; Barraza, 1999; Bonnett & Williams, 1998; Payne, 1998; Simmons, 1994). The students’ written words and drawings are conceptual visualizations or representations of their understandings that contain a number of individual concepts that are embodied with meaning (Alerby, 2000; Kress et al., 2001). Thus, students’ conceptions may be constructed from their graphic representations (Vosniadou & Brewer, 1992).

The first item required students to interpret a scientific graph commonly used as evidence for global warming (i.e., ice core data relating temperature and carbon dioxide). The second item probed students’ ideas about the relationship between carbon dioxide and global warming by asking students to explain what would happen to the Earth’s climate if carbon dioxide levels
Global Warming and Climate Change

do not increase in the future. The third item was based on the NAEP grade 8 released item, “Some scientists think that the Earth’s climate is getting warmer.” This item asked students to explain how a warming climate might affect the oceans, weather, plants and animals, and people and society. The fourth item required students to draw and explain the greenhouse effect. The last item probed students’ ideas about how natural processes and human activities might cause carbon dioxide levels to change and what they could do to lower the level of carbon dioxide in the atmosphere.

The five items ensured credibility (Erlandson, Harris, Skipper & Allen, 1993) in the data collection and analysis process. It also provided synchronic reliability (Kirk & Miller, 1986) in that the different items allowed us to interpret the consistency in student responses. Each item is equivalent in its content focus yet different in the manner by which it elicits students’ conceptions. This allowed students’ conceptions to be checked against each other, providing a degree of triangulation.

Data Analysis

Data analysis involved a content analysis of student responses resulting in the identification of student concepts and this process was inductive in nature. The interpretive nature of the assessment instrument required an inductive approach; that is, instead of searching for pre-determined patterns, themes were allowed to emerge from the data as the authors constructed meaning from student responses (Patton, 2002). The process followed that described by Rubin and Rubin (1995). From the first reading of the assessment, core concepts (codes) were identified. These initial codes were revised after a second reading. The codes with common/overlapping themes were grouped into categories that reflected the students’ conceptions. From these we constructed a category matrix that linked each code to a category
(Erickson, 1986) and that reflected the final categories of student conceptions. This enabled us to organize and check the data for saturation of categories and to eliminate redundant categories (Erickson, 1986; Lincoln & Guba, 1985). This process of independently constructing categories and then reaching consensus provided a degree of triangulation, reducing the influence of bias and subjectivity and increasing the validity of our analysis and interpretation of the results (Patton, 2002; Strauss, 1987). The data were also analyzed for confirming and discrepant situations in order to enhance the authenticity of the interpretations and the credibility of the findings (Patton, 2002). To ensure consistency in coding, an inter-rater reliability coefficient was calculated by comparing two of the authors’ coding of 41 randomly selected assessments. The inter-rater reliability coefficient was 0.88. Coding was monitored throughout to ensure consistency and reliability.

Results

We present the content analysis and descriptive statistics for the five items of the assessment instrument. Our presentation emphasizes the main concepts from the student responses. For each student quote we share the teacher code, grade level, and student number (e.g., M-7th-8).

Interpreting Evidence of Global Warming

Although most students (n = 68, 75%) believed that the graph supports scientists view that the Earth’s atmosphere is warming, several students (n = 15, 17%) were not sure if the data supported global warming and 6 (7%) students said such graphs help scientists understand which gases effect the Earth’s climate, but they did not indicate that a relationship existed between atmospheric carbon dioxide levels and temperature. Only two (2%) students believed that the
data (graph) did not support global warming and climate change. The remaining 4 students held various views about the graph.

Of the 68 students who explained the graph in terms of atmospheric carbon dioxide levels and temperature, 29 (32%) students indicated that increasing carbon dioxide levels caused an increase in temperature and 6 (7%) indicated the reverse—that increasing temperature caused an increase in carbon dioxide. The following student responses represent student responses that explained a relationship between carbon dioxide levels and temperature:

Because usually, when the carbon dioxide increases, the temperature increases, and when the carbon dioxide decreases, the temperature decreases or stays the same (M-7th-8).

This graph clearly shows that as the carbon dioxide level rise, the temperature rises with it. As the CO₂ drops, so does the temperature (M-7th-1).

If in the past the temperature got higher and lower as the carbon dioxide rises and falls, as carbon dioxide increases because of cars and other modern technologies the temperature theoretically should follow as it has done in the past and increase (M-7th-4).

A number of students (n = 29, 32%) did not draw a correlation between carbon dioxide levels and temperature; that is, they based their responses on the graph, but did not explicitly explain a relationship between atmospheric carbon dioxide levels and temperature. For example, this student response focused only on temperature:

I think these data supports scientists’ view that the climate is warming because it shows how the temperature is warming over time (T-7th-7).

Less than half (n = 38, 42%) of the students believed that if there was no increase in atmospheric carbon dioxide levels there would be no change in the Earth’s climate, while 47 (52%) students said that our climate would change regardless of atmospheric carbon dioxide levels. Although the students who believed that the climate would not change were similar in
their response, students who believed that the climate would change varied in their reasons, as shown in Table 5. The remaining 6 students did not respond or did not know.

**Table 5. Main reasons seventh grade students gave for how carbon dioxide affects climate**

<table>
<thead>
<tr>
<th>Coding Category</th>
<th>Frequency</th>
<th>Coding Category</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>No change because of greenhouse effect</td>
<td>18 (20%)</td>
<td>Other gases will cause climate to change</td>
<td>8 (9%)</td>
</tr>
<tr>
<td>Based on temperature-CO₂ graph</td>
<td>13 (14%)</td>
<td>Air pollution will cause climate to change</td>
<td>7 (8%)</td>
</tr>
<tr>
<td></td>
<td>4 (4%)</td>
<td>Ozone layer/depletion will cause climate change</td>
<td>7 (8%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tilt/orbit of the Earth causes climate change</td>
<td>5 (5%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The Earth’s distance to the sun causes climate change</td>
<td>4 (4%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Climate changes because CO₂ has no effect on climate</td>
<td>3 (3%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Climate will cool with less CO₂</td>
<td>2 (2%)</td>
</tr>
<tr>
<td>CO₂ does not increase, no change in climate</td>
<td>13 (14%)</td>
<td>Change in Climate</td>
<td></td>
</tr>
<tr>
<td>No change because of greenhouse effect</td>
<td>18 (20%)</td>
<td>Other gases will cause climate to change</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
</tbody>
</table>

**The Impact of Global Warming**

How do seventh-grade students explain the potential impact of a warming climate on the Earth’s oceans, weather, plants and animals, and people and society? We explore student responses to this question below.

**Oceans.** Although some students expect the ocean levels to rise as a result of melting polar ice and/or increased precipitation (n = 36, 40%), a similar number of students (n= 37, 41%) believe that the ocean levels will decline because of increased evaporation. Example of student responses that reflect these categories follow:

If our climate gets too warm it could melt the polar ice caps which would raise sea level greatly (M-7th -4).

I think if the tempacture gets to [sic] high the water will evaporate so the oceans would drie up (T-7th 1).
Of the remaining students, 7 (8%) believed that the oceans would only become warmer, 5 (5%) thought there would be no change in the oceans, and 6 (7%) did not know or did not answer. None of the students explained the potential impact of global warming on ocean life or coral reefs or how the oceans affect weather (e.g. El Niño and La Niña). The students focused on the physical state of the oceans, not on the biological components or their influence on weather, perhaps a factor of living in the Midwest, which is largely landlocked.

Weather. Not surprisingly, 83 (91%) of the students thought that the weather would get warmer and that this would result in: hotter days (n = 32, 35%), shorter winters and longer summers (n = 6, 7%), less rain (n = 22, 24%) and snow (n=17, 19%), more rain (n=12, 13%), more evaporation (n=8, 9%), and higher humidity (n=7, 8%). Examples of student responses that reflect the impact of global warming on weather:

Winters might be milder and the summers hotter just because the temperature will rise if it happens (T-7th -12).

It would snow less often because most places wouldn’t be cold enough and it would probably rain more because of the warmer and more humid (because of the rise in ocean level) climate (M-7th -4).

Four students did not answer and four students had various responses. Perhaps what is more interesting is that only 1 of these Midwestern students identified the potential impact of global warming on the frequency or severity of tornados; yet, 5 students believed there would be more hurricanes. This could be a scale issue, where students think about climate change on a global scale versus on a local scale; that is, small scale changes are not affected by changes in climate.

Plants and Animals. Overwhelmingly students (n = 70, 77%) expect that global warming would have a negative impact on plants and animals, that plants and animals would die or decrease in numbers. A few students (n = 9, 10%) believed that some plants would thrive because of more sun, warmer temperatures, and longer growing season and 6 (7%) students
indicated that some plants would survive by adapting to warmer temperatures. One student believed that there would be no impact on plants or animals and the remaining 5 students did not know.

Although the student responses varied, the majority of students believed that plants and animals would die or decrease in number because of hotter temperatures (n = 27, 30%) and/or because of less rain/drinking water—drought—(n = 21, 23%); 17 (19%) students indicated that animals would die because of a loss of habitat, describing the impact in terms of plant-animal interactions: “plants die, leading to starving of herbivores”, and 4 (4%) students explained the impact of melting polar ice on animals, including polar bears. It is interesting that none of the student responses described the impact on agriculture—crops and livestock, especially given their Midwest locale. Their responses focused only on “wild” animals and plants. Although students did not describe the direct impact of global warming on crops and livestock, they did describe how global warming would impact humans by disrupting the food supply (see people and society), an indirect impact of global warming on agriculture.

People and Society. A third of the students (n = 32, 35%) believed that global warming would cause more human deaths because of heat exposure, lack of drinking water, and loss of food—both crops and livestock:

People will die because the heat will dry up the water, so we have nothing to drink (T-7th-13).

Although 30 (33%) students believed that global warming would have a negative impact on humans’ food and water supply and living space (from floods/rising oceans), they did not indicate that this would cause more human deaths. Finally, 20 (22%) students believed that there would be no impact on humans because of technological advances and/or because humans would solve the problem or adapt to the change; 9 students did not know or did not answer the question.
**Understanding the Greenhouse Effect**

From a scientific perspective, only 12 (13%) students held a more developed or scientific understanding of the greenhouse effect. These students identified carbon dioxide as a greenhouse gas and explained its role as a greenhouse gas. Even these students, however, did not identify other greenhouse gases (e.g., water vapor and methane). Half of these students (n=6) drew carbon dioxide as a layer in the atmosphere (Figure 1) versus as a dispersed gas explaining:

- Keeps the heat in as an insulator, sun rays try to escape the atmosphere but are bounced back to Earth (M-7\textsuperscript{th}-1).

The CO\textsubscript{2} levels in the atmosphere are high enough to let rays in, but not out (M-7\textsuperscript{th}-2).

They identified infrared radiation as being re-emitted by the Earth’s surface and clouds causing the Earth’s atmosphere to heat up, and 2 students explained that some infrared radiation escaped the Earth’s atmosphere, “keeping the earth’s heat balance”. Even these students explained the greenhouse effect in terms of the “sun’s rays” versus differentiating the radiative energy (Figure 2). For example:

- The sun rays come down to Earth, bounce off, try to escape the atmosphere, but are bounced back to Earth (M-7\textsuperscript{th}-2).

As illustrated in the above student quote, most students believed that the greenhouse gases trapped all of the heat. Four of the students identified sources of carbon dioxide emissions (e.g., cars and factories).

---------
Figure 1 about here
---------
---------
Figure 2 about here
---------
The remaining 79 (87%) students held various degrees of understanding. For example, 76 students referred to “greenhouse gas”, but did not identify a specific gas. Furthermore, only 25 (27%) of these students explained the greenhouse effect in terms of atmospheric heating. These explanations varied, but the most common explanation (n=12) was that the “sun’s rays” or “hot air” get trapped in the atmosphere. Finally, 17 students explained the greenhouse effect using a “greenhouse” analogy (Figure 3) and 8 students confused greenhouse effect, in some way, with ozone depletion and the ozone layer. Although these students’ drawing varied, 9 drew a “greenhouse gas” layer in the atmosphere and 29 drew a “greenhouse”.

In sum, most students did not understand the greenhouse effect or that carbon dioxide is a greenhouse gas or that other naturally occurring and human produced greenhouse gases exist (e.g., methane and water vapor). They lacked an understanding of infrared radiation and radiative forcing.

**Explaining the Change in Atmospheric Carbon Dioxide Levels**

Students were asked to explain how natural processes and human activities might cause atmospheric carbon dioxide levels to change and what could be done to lower carbon dioxide levels.

**Natural Processes.** The students provided a number of wide ranging explanations about natural processes that might affect atmospheric carbon dioxide levels. The four most common explanations centered on:

- animals/people, respiration (n = 27, 30%)
- volcanic eruptions (n = 15, 16%)
- number of plants, photosynthesis (n = 12, 13%)
- seasonal/weather changes (n = 7, 8%)
Human Processes/Resolutions. Again students identified a number of human activities that cause atmospheric carbon dioxide levels to rise, but overwhelmingly attributed the increase to vehicles (n = 39, 43%), air pollution (n = 31, 34%), factories (n = 29, 32%), and 9 (10%) students described deforestation. A number of different solutions were described by students, with the most common responses reflecting:

- drive less, using less energy/fossil fuels (n = 26, 29%)
- plant trees/stop cutting down trees (n = 20, 22%)
- reduce pollution in general (n = 10, 11%)
- use alternative energy, solar/hydro/electric car (n = 10, 11%)

If you live close enough to your work/school, you can ride a bike or walk to work instead of driving (M-7th -3).

None of the students associated agriculture, waste management, and landfills (methane production) as a source of greenhouse gases and that waste reduction and the re-use and recycling of materials would reduce energy use and waste production—the generation of greenhouse gases. Finally, beyond driving less, students offered general resolutions, such as use less energy or fossil fuels. They did not identify other actions they or their families could take to reduce their carbon footprint.

Discussion

These students’ conceptions about global warming and climate change in many ways are similar to previous findings. For example: these students indicated that global warming is caused by greenhouse gases (i.e., carbon dioxide) and air pollution in general (e.g., Boyes, & Stanisstreet, 1997; Gowda, Fox, & Magelky, 1997; Boyes, & Stanisstreet, 1993; Pruneau, et al., 2001) and that carbon dioxide or greenhouse gases form a layer in the atmosphere that traps and reflects the sun’s energy (Koulaidis & Christidou, 1999; Pruneau, Gravel, Courque & Langis, 2003; Andersson & Wallin, 2000). Students overwhelmingly attribute the increase in
atmospheric carbon dioxide levels to vehicles and factories. Thus, for these students solutions to
global warming involve driving or using the car less, reducing pollution in general, and reducing
the number of factories that pollute. Like Andersson and Wallin’s (2000) findings, these students
emphasized carbon dioxide emission limits, seemingly unaware of society’s dependence on
fossil fuels and the societal consequences of controlling carbon dioxide emissions.

These conceptions of the “greenhouse effect” are re-enforced or even built on the images
and diagrams used in many earth and environmental science textbooks. For example, the
greenhouse effect represented in Figures 4 and 5 implies the existence of a “greenhouse gas”
layer above the Earth’s surface that traps and reflects the sun’s energy. Thus, greenhouse gases
cause the Earth’s temperature to rise. At the same time, Figures 5 and 6 represent factories
discharging smoke (air pollutants) into the “greenhouse gas” layer of the atmosphere. Therefore,
air pollution in general is a greenhouse gas and factories in particular are the major source of
“greenhouse” gas. These diagrams put forward the notion that in order to resolve global warming
humans need to pollute the air less, build fewer factories, or require factories to use “filters”.

The impression that science textbook diagrams can have on students may be seen in the students’
drawing (Figures 1, 2, & 3), where the greenhouse effect drawn is very similar to the textbook
diagrams (Figures 4, 5, & 6).
These students conceptions about the impact of global warming and climate change on humans is also similar to previous findings, where many students do not believe that global warming and climate change will have a major impact on people or society. There is no perceived consequence in the students’ life (Pruneau et al. 2001 & 2003). Many students believed that humans would develop new technologies or that people would find ways to survive or adjust to the environmental changes caused by global warming and climate change. For some students, however, global warming would cause human deaths as a result of floods, heat, and the lack of drinking water (drought).

Unlike previous studies, however, most of these students did not link the ozone hole (stratospheric ozone depletion) to global warming and climate change, suggesting that students are becoming more knowledgeable about the difference between global warming and stratospheric ozone depletion. Furthermore, students in this study expect that global warming would cause plants and animals to die or decrease in number as a result of warmer weather or less precipitation, drought conditions. Most students, however, did not consider the impact of global warming and climate change on the complex interdependence of plants and animals. The impact on agriculture—crops and livestock—was not considered; the students focused only on “wild” animals and plants. For the most part, these students thought that global warming and climate change would only affect temperature and precipitation. Few students considered the possibility that global warming and climate change would cause an increase in the frequency and severity of weather events. In essence, these students hold a simple conception of an earth climate system. Geographical variation of climate change, as a result of global warming, was not considered. Similar to past studies, about a third of the students expect that global warming will result in sea level rise as a result of melting polar ice or because of increased precipitation.
Unlike other studies, however, about a third of the students expect the oceans to contract because of increased evaporation. The impact of global warming on the world’s oceans (e.g., El Niño and La Niña) and weather or climate were not identified or explained.

Although these students held rudimentary concepts about global warming and climate change they lack a rich conceptualization of the issue. Fundamentally their conceptions of global warming and climate change are limited in scope (narrow) and simplistic (lacking complexity). Designing a curriculum based on students’ conceptions that builds toward a scientific perspective is essential (NRC, 1996) if students are to become more knowledgeable about global warming, climate change and environmental health in general. Educators, administrators and legislators would do well to heed the notion that, “central ideas related to health, populations, resources and environments provide the foundation for students’ eventual understanding and actions as citizens” (NRC, 1996, p.138).

**Designing a Climate Science Curriculum**

Although the National Science Education Standards (NRC, 1996) do not explicitly identify global warming and climate change, planning curriculum and designing instruction contextualized within the issue of global warming and climate change addresses a number of NRC standards (Appendix A). Developing students’ conceptions of global warming and climate change requires a curriculum that integrates the science disciplines.

Climate is an ideal interdisciplinary, integrating theme for education. Beginning with simple concepts and observations of weather and water, and building increasingly complex inquiries and investigation into the physical, chemical, biological, geographical, social, historical and even technological dimensions of climate, students and citizens have the opportunity to better comprehend the interconnectedness of this important topic and make use of this knowledge in their lives and in their communities (NOAA, 2007, p. 1).
Unfortunately, many teachers and school administrators inappropriately view the NRC standards as a curriculum—the preverbal standards-based instruction. Simply following the NRC standards as a curriculum, however, leads to a discipline-based and conceptually fragmented program of science learning. Planning curriculum and designing instruction is a difficult and challenging process made even more taxing by the scientific complexity of global warming and climate change and the necessity to build from students’ conceptions. This presents an even more daunting task of developing conceptually rich and personally relevant learning experiences. Based on the results of this study and others, it would appear that a curriculum built from students’ conceptions would need to be sequenced to address the following topics:

**Carbon Cycle and the Greenhouse Effect**

- Carbon cycle and energy, the burning of fossil fuels
- Greenhouse effect, radiative forcing (infrared radiation) and the earth’s temperature balance
- Greenhouse gases (e.g., water vapor, carbon dioxide, methane)
- Human sources of greenhouse gases and personal solutions and actions

**Global Warming and Climate Change**

- Weather and climate
- Global warming and climate change
- Earth’s tilt/orbit and relationship to Earth’s temperature and climate, seasonal and natural variation

**Climate Change Impacts**

- Impact on oceans, sea level rise, ocean life and weather (e.g., El Niño and La Niña)
- Severe weather events (e.g., tornados, thunderstorms, blizzards, hurricanes)
- Climate change and water cycle changes, drought/floods
- Climate and biomes, plant and animal distribution, migration, and plant-animal interactions, ecosystem impacts
- Societal and agricultural impacts of climate change

For example, students’ understanding of the carbon cycle and its connection to the greenhouse effect form the foundation from which students build a conception of global
warming. Students’ understanding of global warming provides the basis for conceptualizing climate change. Students’ conceptualization of climate change progresses to understanding the impacts of climate change on weather, oceans, and the biosphere. At the same time, the interdisciplinary nature of climate promotes curricular linkages within the NRC (1996) science education standards as shown in Appendix A. Although the appendix presents a condensed version of the 5-8 science standards, it demonstrates that the development of a curriculum grounded in climate science can provide opportunities for students and teachers to explore and analyze the natural world from a systems-based perspective rather than in isolated segments (Table 6). Teaching students about global warming and climate change provides an ideal context for introducing students to complex and messy systems of the real world (Dahlberg, 2001). Thinking about climate in such a holistic manner creates a more meaningful context for learning and doing science because it requires that students use and apply concepts from the science disciplines.

Table 6. The relationship between the NRC system standards and climate

<table>
<thead>
<tr>
<th>NRC System Concepts</th>
<th>Climate Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>Different climatic regions and weather events</td>
</tr>
<tr>
<td>Function</td>
<td>Distribute energy (heat) and water, plant and animal life</td>
</tr>
<tr>
<td>Feedback/Equilibrium</td>
<td>Hydrologic cycle, biogeochemical cycles, ocean currents, atmospheric circulation</td>
</tr>
<tr>
<td>Boundaries</td>
<td>Geographic, topographic (relief/elevation), oceans, scales of time and space</td>
</tr>
<tr>
<td>Components</td>
<td>Atmosphere, hydrosphere, biosphere (including humans), lithosphere</td>
</tr>
<tr>
<td>Resources (inputs/outputs)</td>
<td>Radiative energy, water, pollutants</td>
</tr>
</tbody>
</table>

Teaching and learning about global warming and climate change in the context of a system, requires that students think about how the heat from the sun is absorbed and transferred by the Earth’s land surface and oceans, how the sun’s energy and water are distributed and how climate and local weather events impact the distribution of plant and animal life, including
humans. How different geographic regions have different climates because of topography and oceans. It requires students to think about how the hydrologic and biogeochemical cycles are influenced by humans and climate and how climate shapes the atmosphere, hydrosphere, biosphere, and lithosphere. It requires students to think in terms of scales of time and space.
References


National Research Council (2000a) *Grand Challenges in Environmental Sciences,* Committee on Grand Challenges in Environmental Sciences, Oversight Commission for the Committee
on Grand Challenges in Environmental Sciences, National Academy Press, Washington DC.


## Appendix A: The 5-8 NRC Standards that Relate to Global Warming and Climate Change

<table>
<thead>
<tr>
<th>Standard</th>
<th>Standard Excerpt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Science</td>
<td>Heat moves in predictable ways, flowing from warmer objects to cooler ones…</td>
</tr>
<tr>
<td></td>
<td>The sun is a major source of energy for changes on the earth’s surface. . . . A tiny fraction of that light reaches the earth, transferring energy from the sun to the earth. The sun’s energy arrives as light with a range of wavelengths, consisting of visible light, infrared, and ultraviolet radiation.</td>
</tr>
<tr>
<td>Life Science</td>
<td>The number of organisms an ecosystem can support depends on the resources available and abiotic factors, such as quantity of light and water, range of temperatures … Lack of resources and other factors, such as predation and climate, limit the growth of populations . . .</td>
</tr>
<tr>
<td>Earth and Space Science</td>
<td>Water, which covers the majority of the earth’s surface, circulates through the crust, oceans, and atmosphere in what is known as the “water cycle” …</td>
</tr>
<tr>
<td></td>
<td>The atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor. …</td>
</tr>
<tr>
<td></td>
<td>Clouds formed by the condensation of water vapor, affect weather and climate.</td>
</tr>
<tr>
<td></td>
<td>Global patterns of atmospheric movement influence local weather. Oceans have a major effect on climate, because water in the oceans holds a large amount of heat.</td>
</tr>
<tr>
<td></td>
<td>Living organisms have played many roles in the earth system, including affecting the composition of the atmosphere …</td>
</tr>
<tr>
<td></td>
<td>The sun is the major source of energy for phenomena on the earth’s surface, such as growth of plants, winds, ocean currents, and the water cycle. . . .</td>
</tr>
<tr>
<td>Science in Personal and Social Perspectives</td>
<td>Causes of environmental degradation and resource depletion vary from region to region and from country to country.</td>
</tr>
<tr>
<td></td>
<td>Human activities also can induce hazards through resource acquisition, urban growth, land-use decisions, and waste disposal. Such activities can accelerate many natural changes.</td>
</tr>
</tbody>
</table>
Figure 1. Example of student drawings representing carbon dioxide as a layer in the atmosphere.
Figure 2. Example of student drawings representing radiative forcing as “sun rays”.

Make your drawing here:
Figure 3. Example of student drawings representing the greenhouse effect as a “greenhouse”.

Make your drawing here:
Figure 4. Textbook representation of the greenhouse effect: Greenhouse gas layer.

Figure 5. Textbook representation of the greenhouse effect: Greenhouse gas layer and air pollutants as greenhouse gases.

Figure 6. Textbook representation of the greenhouse effect: Air pollutants as greenhouse gases.