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Students' conceptions about the greenhouse effect, global warming, and climate change

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Abstract The purpose of this study was to investigate students' conceptions of the greenhouse effect, global warming, and climate change. The study was descriptive in nature and reflected a cross-age design involving the collection of qualitative data from 51 secondary students from three different schools in the Midwest, USA. These data were analyzed for content in an inductive manner to identify student's conceptions. The categories that emerged from the students' responses reflected different degrees of sophistication of students' conceptions about the greenhouse effect, global warming, and climate change. Based on these findings we make curricular recommendations that build on the students' conceptions, the IPCC Findings, the NRC (1996) science education standards, and NOAA's climate literacy framework.

1 Introduction

Climate is a component of the National Research Council's (NRC 1996) science education standards and just about every science textbook from fourth grade on addresses climate. Yet, these textbooks appear to be designed with little consideration of students' conceptions and in fact may reinforce certain misconceptions. Furthermore, students' conceptions may or may not fit current scientific perspectives

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because their conceptions are built on a combination of unique personal and social experiences (Driver et al. 1985). Consequently, there is a lack of what Driver et al. (1994) called curricular continuity, a sequence of experiences that build from students' conceptions toward scientific understanding and ultimately scientific literacy.

Research in the area of students' conceptions about geoscience phenomena is lacking (Manduca et al. 2002) and related research in environmental education tends to focus on students' factual knowledge about environmental issues and on their environmental attitudes and behaviors (Rickinson 2001). Therefore, it is essential for research in geoscience and environmental science education to continue to expand our understanding of students' conceptions about geoenvironmental phenomena and events (Payne 1998) to inform standards, curriculum, and instruction in geoenvironmental science education. The purpose of this study was to investigate students' conceptions about the greenhouse effect, global warming, and climate change, add to the extant literature base on students' geoscience and environmental science learning, and provide guidance to curricular development. Specifically, the research question guiding this study was: What are secondary students' conceptions of the greenhouse effect, global warming, and climate change?

Based on these findings we make curricular recommendations that build on students' conceptions, the scientific perspective as represented in the Intergovernmental Panel on Climate Change (IPCC), the National Research Council (NRC) science education standards, and the National Oceanic and Atmospheric Administration (NOAA) climate literacy principles.

1.1 Significance of study

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. 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 the greenhouse effect, global warming, and climate change (Osborne and Freyberg 1985) in order to plan curriculum and design instruction that builds on these conceptions (Driver et al. 1994). Furthermore our study expands on previous research by investigating U.S. students' conceptions, providing a historical perspective on changes in students' conceptions as well as providing new insights into students' conceptions about the potential environmental impact of global warming and climate change.

2 Background

Because few studies have investigated U.S. students' conceptions of global warming and climate change, we reviewed 15 international studies published between 1993 and 2008 that investigated secondary students' knowledge about the greenhouse effect, global warming, and climate change. We report a general summary of this review with the intent to show the range or diversity of students' conceptions about the greenhouse effect, global warming and climate change. The review is not an attempt to draw general conclusions about all students, but simply to show the range in the ways students understand and think about the greenhouse effect, global warming and climate change.

Students believed that air pollution causes global warming and climate change. Forms of air pollution included acid rain (Boyes et al. 1993; Boyes and Stanisstreet 1993; Pruneau et al. 2001); dust (Pruneau et al. 2001); harmful and unnatural gases (Gowda et al. 1997); and air pollution in general (Andersson and Wallin 2000; Boyes and Stanisstreet 1997; Gowda et al. 1997). Some students viewed "ozone depletion" as a cause of global warming and climate change. A commonly held idea was that the ozone hole allows more solar energy or ultraviolet radiation to reach the Earth, causing global warming and climate change (Österlind 2005; Pruneau et al. 2003; Andersson and Wallin 2000; Koulaidis and Christidou 1999; Boyes et al. 1999; Boyes and Stanisstreet 1994, 1997; Rye et al. 1997). Yet, some students believed that global warming and climate change is caused by an increase in solar radiation (Boyes et al. 1993; Boyes and Stanisstreet 1993; Pruneau et al. 2003) or because the Earth gets closer to the sun (Pruneau et al. 2003), a seasonal variation.

Most students do not consider carbon dioxide as a greenhouse gas (Boyes et al. 1993; Boyes and Stanisstreet 1993, 1997; Pruneau et al. 2001) and even when students identify carbon dioxide as a greenhouse gas they do not consider other gases such as methane, water vapor (Fisher 1998) or nitrous oxides (Boyes et al. 1993; Boyes and Stanisstreet 1993) as greenhouse gases. Furthermore, students believed that the greenhouse gases, whatever they may be, exist as a "layer" (Koulaidis and Christidou 1999; Pruneau et al. 2003) or a "lid" or "roof" (Andersson and Wallin 2000) in the atmosphere that forms a "barrier" (Andersson and Wallin 2000) that "bounces" the heat from the Earth back toward the Earth, trapping the sun's energy.

Students also have misunderstandings about the greenhouse effect. Some students do not know about the greenhouse effect (Andersson and Wallin 2000; Pruneau et al. 2001) or they make no distinction between the greenhouse effect and global warming (Andersson and Wallin 2000; Boyes et al. 1993). For some students the greenhouse effect is the trapping of solar rays by the ozone layer (Boyes and Stanisstreet 1997; Koulaidis and Christidou 1999; Pruneau et al. 2003), thus confusing stratospheric ozone with the greenhouse effect. For those students who know about the greenhouse effect their understanding is fairly simplistic. For the most part, they do not make any distinction between or they confuse the types of solar radiation, generally referring to solar radiation as "ultraviolet rays", "solar rays", "sun rays", "heat", and "heat rays" (Boyes and Stanisstreet 1997, 1998; Fisher 1998; Koulaidis and Christidou 1999; Österlind 2005). Furthermore, students often do not differentiate solar radiation from terrestrial radiation (Koulaidis and Christidou 1999).

Although some students see the consequences of global warming as causing skin cancer (Boyes et al. 1993; Boyes and Stanisstreet 1993, 1998; Pruneau et al. 2003) and higher temperatures (Gowda et al. 1997) other students see no immediate or future impact on society or humans (Pruneau et al. 2001, 2003). Students also do not understand that climate change impacts may vary by region (Boyes and Stanisstreet 1993). Students also believe that global warming and climate change cannot be stopped (Pruneau et al. 2001) or that the resolution to the problem is limiting carbon dioxide emissions, without considering the societal consequences of fossil fuel use (Andersson and Wallin 2000). More recently, students believed that planting more trees and using renewable energy would prevent or resolve global warming and climate change (Kilinc et al. 2008).

3 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 symbols (drawings) used by students to represent and communicate their meaning (Holstein and Gubrium 1994; Kress et al. 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 the greenhouse effect, 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 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 and reflected a cross-age survey (Driver et al. 1996), 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 cross-age survey 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 the greenhouse effect, global warming, and climate change. The benefit of a cross-age survey was that it allowed us to collect data from a larger number of students with varying degrees of educational 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' conceptions over different age groups, and allowed us to identify trends or patterns in students' conceptions and to compare these conceptions to past research.

4 Method

4.1 Sample and data collection

We employed a purposeful sampling strategy (Patton 2002), using the classrooms of three teachers, from three different school districts, who are involved in our climate and climate change instructional development project. We opted for a larger sample size versus a smaller sample of in-depth individual interviews, 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 the greenhouse effect, global warming, and climate change; facilitating the comparison of the data (Patton 2002). A total of 51 secondary students (39 junior high school and 12 high school) from the Midwest completed the assessment. This provided us with a large age range across multiple school settings and increased the heterogeneity of the sample. The sample included a range in student academic ability from special needs students to high ability students. The sample was primarily Caucasian (about 95%) with boys accounting for roughly 54% of the sample and girls 46%. About 30% of the students were on a reduced or free lunch program. The schools were situated in small, rural communities.

The assessment instrument (described below) was administered to the students in the teachers' classroom during the month of March. Students completed the task 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 in the fall to different students and revised based on their responses and teacher feedback. Based on the pilot test two items were dropped from the instrument and the wording was changed slightly on the remaining items. The final version was viewed to be content valid by a science educator and science teacher and two climatologists. The assessment was administered by the teachers prior to any classroom instruction on the greenhouse effect, global warming, and climate change. As noted above, it is unknown what formal or informal educational experiences these students had prior to completing the assessment.

4.2 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 (Appendix A). The instrument was designed as an idea eliciting task (Osborne and Freyberg 1985) and based on the draw and explain protocol (White and Gunstone 1992). Therefore, student responses were not scored as "right" or "wrong" but were analyzed for their content (see Section 4.3 Data Analysis). The assessment used written prompts to elicit student responses and these emphasized the students' concepts. A number of researchers have used similar tasks to elicit students' concepts about environmental and geoscience phenomena (e.g., Alerby 2000; Anderson and Moss 1993; Barraza 1999; Bonnett and Williams 1998; Payne 1998; Simmons 1994). The students' written words and drawings are conceptual visualizations or representations of their understandings of global warming and climate change 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 and 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 Earth's climate if carbon dioxide levels do not increase in the future. The third item was based on the National Assessment of Educational Progress (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. Taken as a whole, the five items provide an indication of students' conceptions about the greenhouse effect, global warming, and climate change.

The five items ensured credibility (Erlandson et al. 1993) in the data collection and analysis process. It also provided synchronic reliability (Kirk and 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. Given the qualitative methodology of this study, traditional (i.e., quantitative methodological) views of assessment instrument reliability are not appropriate. Instead, the assessment instrument is viewed as dependable. Dependability is based, in part, on the context within which the assessment instrument is used and how changes in context might impact student responses. Because of the heterogeneity of the sample and the consistency in student responses we are confident in the assessment instruments ability to elicit student conceptions.

4.3 Data analysis

Data analysis involved a content analysis of students' responses resulting in the identification of students' 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 following process details the analytical procedure 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 and 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 10 randomly selected assessments. The inter-rater reliability coefficient was 0.86. Coding was monitored throughout to ensure consistency and reliability.

5 Results

We first 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 item we present examples of student responses to support our categorization. The student examples reflect the range in student responses, thus illustrating the diversity in the student responses. For each student example we list the teacher-grade–student number. We then present a visual map of the students' conceptions based on the dominate concepts for each item, to present a holistic view of the students conceptions of the greenhouse effect, global warming, and climate change.

5.1 Interpreting evidence of global warming

Most students ($n = 44$, 86%) based their response on the carbon dioxide-temperature graph. Several students ($n = 3$, 6%), however, explained the cause of global warming without reference to the graph, saying that an increase in greenhouse gas (i.e., carbon dioxide) would cause global warming. The remaining students either did not know ($n = 2$, 4%) or did not believe ($n = 2$, 4%) that the graph supported global warming. Of the 44 students who explained the graph in terms of atmospheric carbon dioxide levels and temperature (Table 1), 21 (41%) indicated that increasing carbon dioxide levels caused an increase in temperature and 4 (8%) indicated the reverse—that increasing temperature caused an increase in carbon dioxide; 7 (14%) students indicated that carbon dioxide and temperature influenced each other. The remaining students ($n = 12$, 24%) identified either increasing temperatures or increasing levels of carbon dioxide as evidence of global warming, but they did not draw a correlation between carbon dioxide levels and temperature; that is, they based their responses on the graph, but did not explicitly identify a relationship between atmospheric carbon dioxide levels and temperature (Table 1).

Table 1 Example student responses

Rising CO_2 leads to temperature increase ($n = 21, 41\%$)	These data support scientists' view that the climate is warming because everytime the carbon dioxide rises, the temperature rises also. And everytime the carbon dioxide lowers, the temperature lowers also (M-8th-3)
	This graph clearly shows that as the carbon dioxide level rise, the temperature rises with it. As the CO_2 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)
Not mentioning the correlation between CO_2 and temperature ($n = 12, 24\%$)	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)
	When you look at the chart you can see a noticeable difference along the years. You can see that temp + carbon dioxide both increase. (D-11th-2)

Although 21 (41%) of the students agreed that if there was no increase in atmospheric carbon dioxide levels there would be no change in global warming or the climate, 28 (55%) students said that our climate would change regardless of atmospheric carbon dioxide levels (Table 2). The remaining two (4%) students did not respond. The 28 students that said that our climate would change regardless of carbon dioxide levels provided a variety of reasons. Of these, 16 (31%) students thought other atmospheric gases and air pollution in general would cause the climate to change and two (4%) believed that ozone depletion would cause the climate to change. Only two (4%) students believed that the Earth's natural tilt, rotation and orbit (natural processes) would cause the Earth's climate to change. The remaining eight (16%) students had various responses.

5.2 The impact of global warming

How do students explain the potential impact of a warming climate on the Earth's oceans, weather, plants and animals, and people and society?

5.2.1 Oceans

Slightly more than half of the students expect the ocean levels to rise as a result of melting polar ice ($n = 26$, 51%) or because of increased precipitation ($n = 2$, 4%); yet seven (14%) students thought that the ocean levels would decline (Table 3). Correspondingly, 14 (27%) students stated that the oceans would get warmer. Although most students thought that global warming would have some impact on ocean levels, two (4%) students felt that the ocean levels would remain unchanged because of a balance between melting polar ice and increased ocean evaporation. For eight (16%) students global warming would result in more ocean evaporation, while five (10%) students thought there would be more ocean precipitation. These students, however, did not link these results to a change in ocean levels. The remaining three (6%) students held various ideas about the impact of global warming on the oceans' chemistry (e.g., dissolved oxygen and carbon dioxide levels and salinity). None of the students explained the potential impact of global warming on ocean life or coral reefs.

5.2.2 Weather

Not surprising, 45 (88%) of the students thought that the weather would get warmer and that this would have an impact on precipitation; with the warmer weather causing

Table 2 Example student responses

No increase in CO_2 results in no climate change ($n = 21, 41\%$)	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)
	Our climate wouldn't change, because if the carbon dioxide doesn't increase, then the temperature wouldn't change either, so therefore the climate wouldn't change (M-8th-5)
Other gases and air pollutants will cause climate to change ($n = 16, 31\%$)	Carbon monoxide, carbon trioxide might cause a change in the earths temperature (M-8th-14).
	Burning of fossil fuels, trash, polutance (D-11th-1)
	Smoke and fog or just any kind of polution (D-11th-6)

Table 3 Example student responses

Sea levels rise due to melting polar ice ($n = 26, 51\%$)	If our climate gets too warm it could melt the polar ice caps which would raise sea level greatly (M-7th-4) The oceans would overflow and cause major floods. This effect will happen because the polar ice caps would melt, and the oceans will flood (M-8th-4)
Ocean level decline because of evaporation ($n = 7, 14\%$)	The oceans decrease in size because warmer temperatures make water evaporate (M-8th-10) I think if the tempacture gets to high the water will evaporate so the oceans would drie up (T-7th 1)

less snow ($n = 13$, 25%) and rain ($n = 6$, 12%), more rain ($n = 14$, 27%), more humidity ($n = 3$, 6%), and more evaporation ($n = 2$, 4%; Table 4). Perhaps what is more interesting is that no students explained the impact on weather in terms of geographic location or regional variation. These Midwestern students did not identify the potential impact of global warming on the frequency or severity of tornados and blizzards; yet, six (12%) students believed there would be more hurricanes.

5.2.3 Plants and animals

Overwhelmingly ($n = 48$, 94%) students expect that global warming would impact plants and animals, with most describing negative impacts. Although the student responses varied, the majority of students ($n = 39$, 76%) believed that plants and animals would die or decrease in number; with 13 (25%) of these students specifically stating that hotter weather would result in more plant and animal deaths (Table 5). A few students ($n = 3$, 6%) felt that the warmer weather would benefit plants because of a longer growing season. Seven (14%) students described the impact of warmer weather on plant–animal interactions; that is, a change in plants would have an impact on animals and vice-versa. Of all of the student responses, only five (10%) responses specifically identified precipitation—less rain—as impacting plant and animal life. Thus for most students warmer weather will have the greatest impact on plants and animals. It is also interesting that none of the student responses specifically described the impact on agriculture—crops and livestock. Their responses focused only on “wild” animals and plants.

Table 4 Example student responses

Warmer weather ($n = 45, 88\%$)	Winters might be milder and the summers hotter just because the temperature will rise if it happens (T-7th-12) This would happen because the Earth would be warmer and cause us to have a more tropical climate (D-10th-1)
Change in precipitation ($n = 27, 53\%$)	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) It would rain more often, because water would evaporate more often, which would cause it to rain more (M-8th-8) There would be little snow and lots of rain because the heat will cause the water on Earth to evaporate quicker and more often (M-8th-14)

Table 5 Example student responses

Would die from warmer/ hotter weather ($n = 13$, 25%)	If these scients are correct probably some plants and animals would die, first of all because some plants and animals live in cold areas and survive in these areas and cant live in warmer climates because they arnt used to it (M-8th-3)
	The plants and animals way south and way up north will all die, mutate, or become endangered not being able to survive the warm weather (M-8th-14)
Would die from less rain ($n = 8$, 16%)	If our plants don't get the moisture they need they will eventually die and also with animals who eat plants, if there are no plants those animals will die (M-8th-2)
	The plants may die because they would dry up because of the heat index. Animals may die of thirst because all of the bodys of water would be evaporating (M-8th-10)

5.2.4 People and society

Many students ($n = 23$, 45%) did not believe that global warming would have an impact on humans or society (Table 6). These students believed that human ingenuity and technology would solve the problem. For 13 (25%) students global warming would cause humans to die; with floods ($n = 3$, 6%), heat ($n = 4$, 8%), and lack of drinking water ($n = 5$, 10%) as the main causes of human deaths. The main societal impacts included having to buy new cloths ($n = 3$, 6%), the loss of food ($n = 3$, 6%), having to move to a new location ($n = 4$, 8%), and the loss of land because of rising oceans ($n = 4$, 8%).

5.3 Understanding the greenhouse effect

A quarter of the students ($n = 13$, 25%) specifically identified carbon dioxide as a greenhouse gas and six (12%) simply described "gases" in the atmosphere; while one (2%) student identified a second greenhouse gas (i.e., water vapor). Some students ($n = 12$, 24%) represented the greenhouse gas as a layer in the atmosphere (Fig. 1) that:

> Keeps the heat in as an insulator" (M-7th-1) or that the "sun rays . . . try to escape the atmosphere but are bounced back to Earth. The CO2 levels in the atmosphere are high enough to let rays in, but not out" (M-7th-2).

Table 6 Example student responses

No impact ($n = 23$, 45%)	Nothing will change, because people and society will find ways to survive (M-8th-13)
	Things would change but I think after some readjusting people and society would get use to the changes. I think this because humans are an intelligent race that can overcome almost anything (D-10th-1)
People will die ($n = 13$, 25%)	If these scientists are correct people in our country would actually die if it gets so warm that so much carbon dioxide will be produced and we will not be able to breathe (M-8th 6)
	People will Die because the heat will dry up the water, so we have nothing to Drink (T-7th-13)

M-7th-4

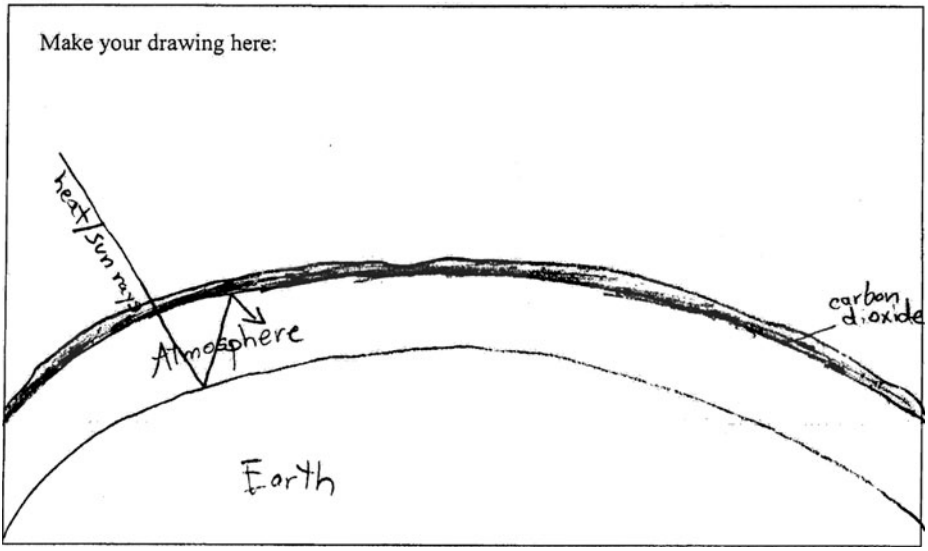


Fig. 1 Example of student drawings representing carbon dioxide as a layer in the atmosphere

A quarter of the students ($n = 13$, 25%) drew and explained a "greenhouse," a literal interpretation (Fig. 2): "The sun rays go inside the greenhouse and can't get out that is the greenhouse effect" (M-8th-7). A few students ($n = 4$, 8%)

M-8th-2

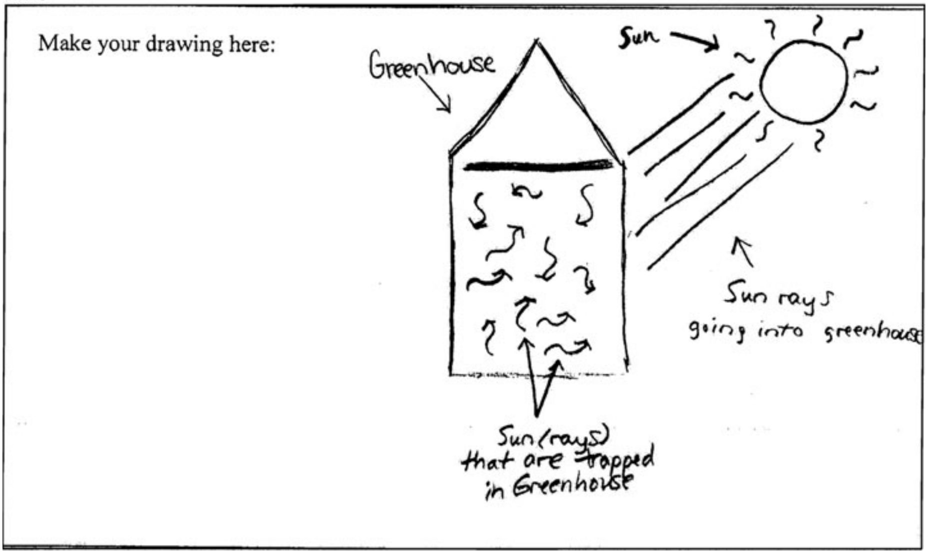


Fig. 2 Example of student drawings representing the greenhouse effect as a "greenhouse"

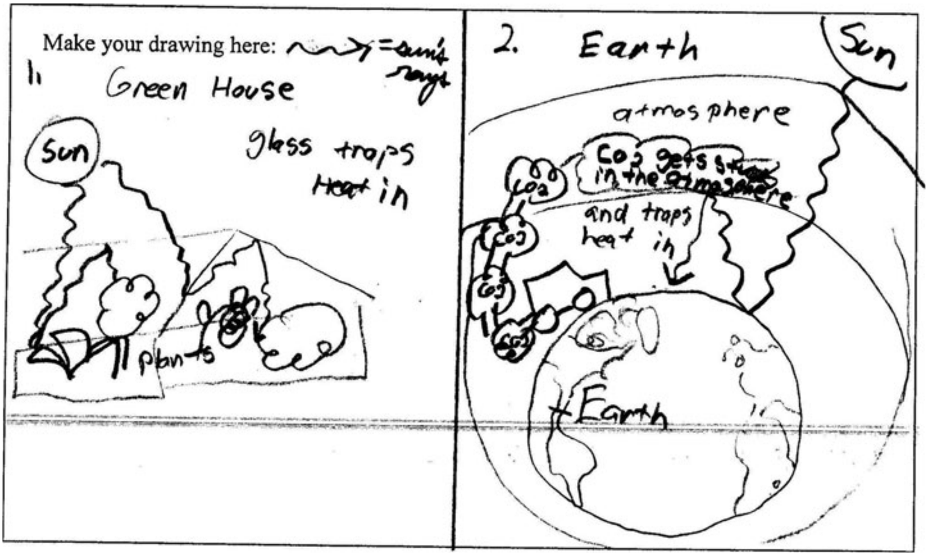


Fig. 3 Example of student drawings representing comparing the atmospheric greenhouse effect to a "greenhouse"

explained the greenhouse effect by comparing the atmospheric greenhouse effect to a "greenhouse" (Fig. 3) and four (8%) students confused ozone with the greenhouse effect. Thus, 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).

M-7th-1

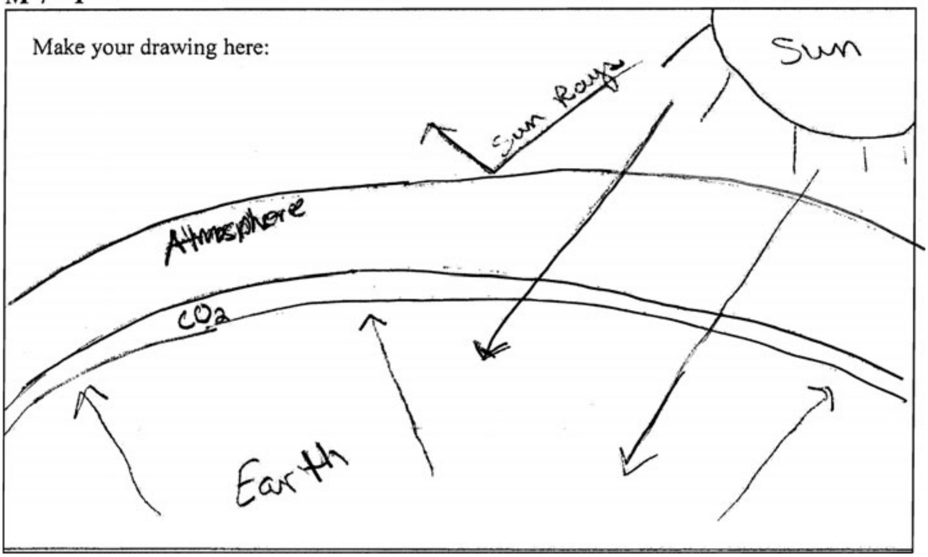


Fig. 4 Example of student drawings representing radiative forcing as "sun rays"

Table 7 Example student responses

Temperature change ($n = 12, 24\%$)	The warmth of the earth or atmosphere. Photosynthesis The warmth of the earth would cause the carbon dioxide levels to change because carbon dioxide is in the atmosphere and it rises when it gets warmer and warmer (M-8th-2)
	A rise in temperature and the rotation of the earth. Temperature makes the carbon dioxide to change so when the temperature changes the carbon dioxide changes (M-8th-10)
Volcanic eruption ($n = 9, 18\%$)	The smoke from the volcanoes can cause the $C0_2$ levels to rise The smoke molecules are replacing some of the other molecules that contain the $C0_2$ (M-8th-4)
	Volcano's send up carbon dioxide into the air and could change the carbon dioxide levels up a little but not much When a volcano erupts it send out of the vent deadly gases, and material that can put more carbon dioxide in the air (D-10th-1)

A key concept of the greenhouse effect is radiative forcing; which was described by 17 (33%) students who explained the greenhouse effect in terms of the "sun's rays" versus differentiating the radiative energy (Fig. 4). For example:

> The sun rays come down to Earth, bounce off, try to escape the atmosphere, but are bounced back to Earth (M-7th-2). Suns rays hit the earth bounce back and hit the green house gasses and stay in and heat the earth (D-11th-4).

5.4 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.

5.4.1 Natural processes

The students provided a number of wide ranging explanations about natural processes that might affect atmospheric carbon dioxide levels (Table 7). The four most common explanations centered on:

- A natural change in temperature ($n = 12, 24\%$),
- Volcanic eruptions ($n = 9, 18\%$),

Table 8 Example student responses

Transportation and factories ($n = 37, 73\%$)	Driving vehicles that burn a lot of gas, or factories that burn a lot of stuff to make products. They would put more $C0_2$ in the atmosphere (D-11th-7)
	Human activities that might cause the carbon dioxide levels to change is the smoke from factories and cars and other things like these. These human activities might cause the carbon dioxide levels to change by all the nasty smoke going into the air mixing with the good carbon dioxide (D-12th-3)
General air pollution ($n = 15, 29\%$)	By the polluting air mess up the earth's atmosphere (D-11th-3)
	Car exust, warehouse exust, and other chemical pollutions in the air. The gasses would mix in the air. (D-12th-1)
	Factories, smoke, gases, pollution air spills. We burn gas which goes into the air mixing with the carbon dioxide (T-7th-13)

Table 9 Example student responses

Reduce/use care less ($n = 24, 47\%$)	If you live close enough to your work/school, you can ride a bike or walk to work instead of driving (M-7th-3)
Reduce pollution ($n = 11, 22\%$)	I can make sure that everything goes in the trash bin or is kept off the ground, and write a letter to the chemical plants requesting them to find a better way to get rid of chemicals (M-8th 4)
	Stop polluting things & start recycling (D-11th-2)

- Animal/human respiration ($n = 9, 18\%$), and
- Forest fires ($n = 7, 14\%$)

5.4.2 Human processes

Although students identified a number of human activities that cause atmospheric carbon dioxide levels to rise, they attributed the increase to vehicles ($n = 30$, 59%) and factories ($n = 25$, 49%), and eight (16%) students described deforestation (Table 8). Some students ($n = 15$, 29%) linked air pollution in general as causing atmospheric carbon dioxide levels to increase.

5.4.3 Resolution

A number of different solutions were described by students, with the most common responses reflecting (Table 9):

- The reduction in driving or using the car less, using less energy ($n = 24, 47\%$),
- Reduce pollution in general ($n = 11, 22\%$), and
- Reduce the number of factories and require "air filters" ($n = 10, 20\%$)

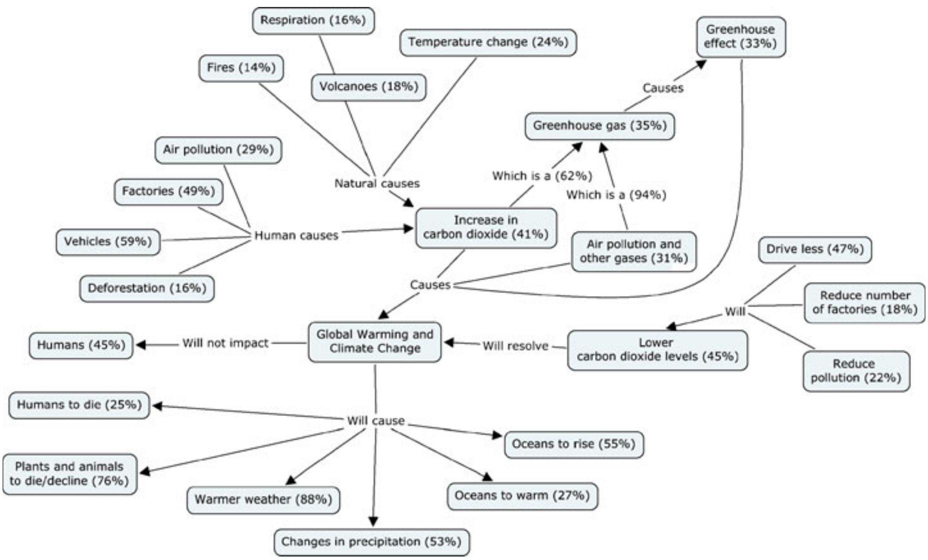


Fig. 5 Visual map of students' conceptions about global warming and climate change

5.5 Visual map of students' concepts

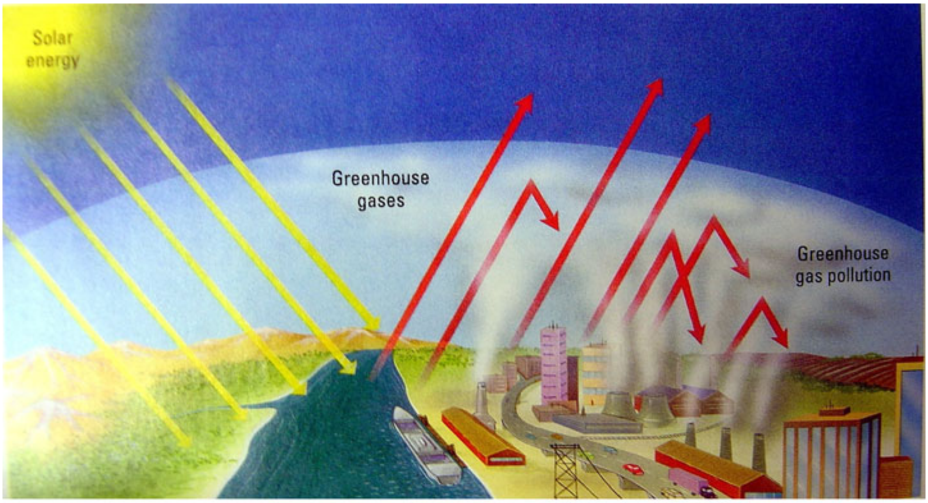
Based on the foremost student responses for each item on the assessment instrument we created a visual map of students' concepts (Fig. 5). The visual map is intended to present a holistic view of the students' conceptions of global warming and climate change. The percentages reflect the number of students who expressed that concept.

6 Discussion

It is important to stress that the conceptions described in this paper reflect the sample as a whole and not individual students. It is possible that an individual student, under a different context, might convey a different conception. The conceptions are an attempt to characterize the different conceptualizations students hold about the greenhouse effect, global warming, and climate change and to summarize these in such a way as to inform practice and to further our understanding about how students make meaning of the natural world.

These students' conceptions about the greenhouse effect, global warming, and climate change in many ways are similar to previous findings. For example: they are confused about the greenhouse effect as well as the kind of radiation involved in the greenhouse effect. They indicated that global warming is caused by greenhouse gases (i.e., carbon dioxide) and air pollution in general (e.g., Boyes and Stanisstreet 1993, 1997; Gowda et al. 1997; 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 and Christidou 1999; Pruneau et al. 2003; Andersson and Wallin 2000). These conceptions of the "greenhouse effect" are re-enforced or even built on the images and diagrams used in many secondary earth and environmental science textbooks. For example, the greenhouse effect represented in Fig. 6 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, Figs. 6 and 7 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 Fig. 8, where the greenhouse effect drawn by this student is very similar to Fig. 7; one of the few students to identify "infrared rays" in addition to "sun rays".

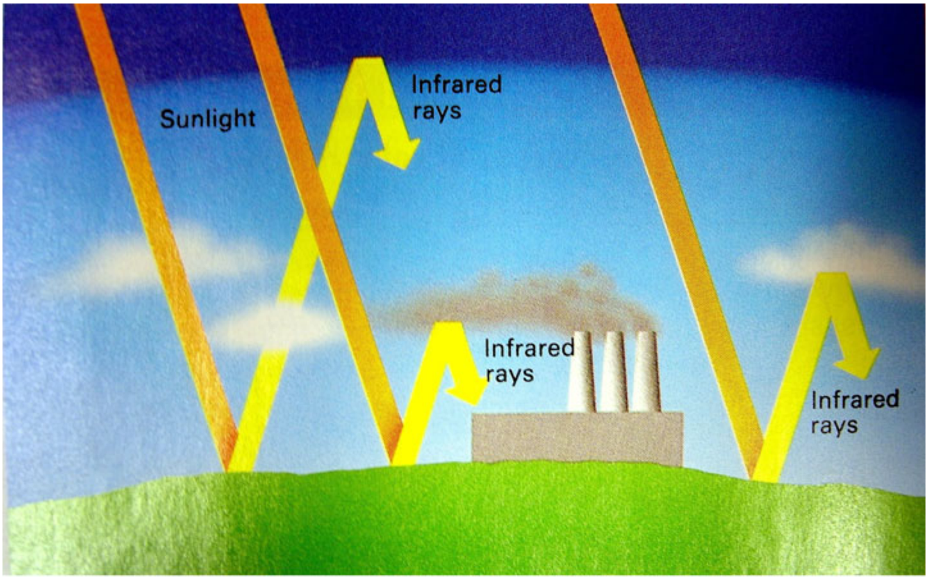
These students conceptions about the impact of global warming and climate change on humans is also similar to previous findings, where many students do not believe that global warming and climate change will have a major impact on people or society. There is no perceived consequence in the students' life (Pruneau et al. 2001, 2003). 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). Students overwhelmingly attribute the increase in atmospheric carbon



From Lapinski, A. H., Schoch, R. M., and Tweed, A. (2003) Environmental science, page 366.
Lebanon, IN: Addison Wesley Longman.

Fig. 6 Textbook representation of the greenhouse effect: greenhouse gas layer and air pollutants as greenhouse gases

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 the findings of Andersson and



From Sager, R. J., Ramsey, W. L., Phillips, C. R., and Watenpaugh, F. M. (2002). Modern earth science, page 466.
Austin, TX: Holt, Rineheart and Winston.

Fig. 7 Textbook representation of the greenhouse effect: air pollutants as greenhouse gases

D-10th-1

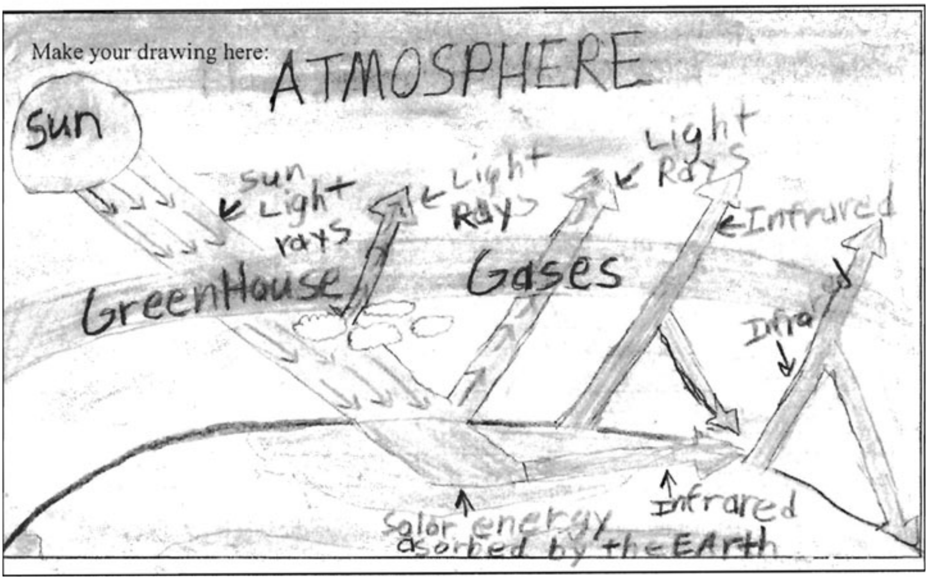


Fig. 8 Example of student drawing based on textbook diagram

Wallin (2000), these students emphasized carbon dioxide emission limits, implying an unawareness of society's dependence on fossil fuels and the societal consequences of controlling carbon dioxide emissions. The resolutions that students suggested seem to be abstract, not connected to their daily lives or actions as secondary students. In essence, these students did not relate global warming and climate change to their daily life or future activities.

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 impact plants and animals, causing plants and animals to die or decrease in number as a result of warmer weather or less precipitation. 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. They hold a simple conception of an earth climate system. An increase in the frequency and severity of weather events was not considered as a possible consequence of global warming and climate change. Geographical variation of climate change, as a result of global warming, was not considered. Similarly, these students expect that global warming will result in sea level rise as a result of melting polar ice or because of increased precipitation. Correspondingly, students stated that the oceans would warm.

Similar to the previous studies we found that although 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 both limited in scope (narrow) and simplistic (lacking complexity). Yet, the students' conceptions as a whole are similar to the IPCC findings, albeit less complex. The main student responses are compared to the IPCC findings (i.e., the scientific perspective) in Appendix B. The conceptual gap between these students and the IPCC scientific perspective calls for effective learning experiences that require a curriculum sequenced in a way that moves students toward scientific understanding—curricular continuity (Driver et al. 1994). 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.

6.1 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 C). Developing students' conceptions of global warming and climate change requires a curriculum that integrates the disciplines. Unfortunately, many teachers and school administrators inappropriately view the NRC standards as a curriculum and as an instructional guide for teaching content—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. Add to this mix the necessity to build from students' conceptions and you have an even more daunting task of developing conceptually rich and personally relevant learning experiences.

The interdisciplinary nature of climate promotes curricular linkages within the NRC (1996) science education standards as shown in Appendix C. Although the appendix presents a condensed version of the K-12 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 10). This

Table 10 The relationship between the NRC system standards and climate

NRC system concepts	Climate concepts
Structure	Different climatic regions and weather events
Function	Distribute energy (heat) and water, plant and animal life
Feedback/equilibrium	Hydrologic cycle, biogeochemical cycles, ocean currents, atmospheric circulation
Boundaries	Geographic, topographic (relief/elevation), oceans, scales of time and space
Components	Atmosphere, hydrosphere, biosphere (including humans), lithosphere
Resources (inputs/outputs)	Radiative energy, water, pollutants

systems-based perspective is in line with the Earth Science Literacy Initiative [ESLI] (2009) that states "Earth is a complex system of interacting rock, water, air, and life" (p. 4). Thinking about climate and other natural phenomena 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.

> 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 (National Oceanic and Atmospheric Administration 2007, p. 1).

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). Teaching and learning about global warming and climate change in the context of a system, requires that students think about how the radiation 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. To support educators in their efforts to plan a climate system based curriculum, National Oceanic and Atmospheric Administration (2007) has developed, *Climate Literacy: Essential Principles and Fundamental Concepts* that identifies seven essential principles (Table 11) and their fundamental concepts that educators can draw from to build a conceptual framework for developing a

Table 11 Essential principals of climate literacy (National Oceanic and Atmospheric Administration 2007)

Life & climate	Essential Principle: Life on Earth has been shaped by, depends on, and affects climate
How do we know	Essential Principle: We understand the climate system through observing and modeling
Sun drives earth system	Essential Principle: The Sun is the primary source of Earth's energy
Complex interactions	Essential Principle: Earth's weather and climate system are the result of complex interactions between land, ocean, ice and atmosphere
Natural variability & change	Essential Principle: Earth's weather and climate vary over time and space
Human activities and change	Essential Principle: Recent climate change is primarily caused by human activities
Making decisions	Essential Principle: Earth's climate system is influenced by human decisions which are complex and involve economic costs and social values

curriculum grounded in system-based learning. This provides educators and climatologist the opportunity to develop climate literate individuals:

> Your are climate literate if you understand the influence of the climate on you and society—and your influence on climate (National Oceanic and Atmospheric Administration 2007, p 1).

Similarly, *Earth Science Literacy Principles* developed by the ESLI (2009), suggest that an Earth science literate individual understands the fundamental concepts and principles of climate and climate change. For example, that the:

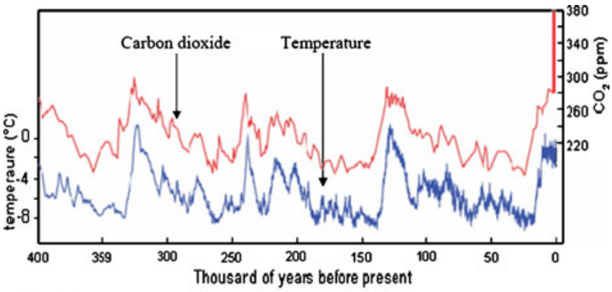
> 3.8 Earth's climate is an example of how complex interactions among systems can result in relatively sudden and significant changes (p. 5)
>
> 6.8 Life changes the physical and chemical properties of Earth's geosphere, hydrosphere, and atmosphere (p. 8)
>
> 9.3 Humans cause global climate change through fossil fuel combustion, land-use changes, agricultural practices, and industrial processes (p. 11).

Ultimately it is the responsibility of superintendents, principals, science teachers, science educators, and scientists to utilize the NRC standards, the NOAA and ESLI documents, and the research on students' conceptions to develop curriculum that informs classroom practice and that nurtures Earth science and climate science literacy.

Appendix A: The global warming and climate change assessment instrument

Conceptualizing Climate and Climate Change Assessment Instrument (spaces removed for publication)

1. The graph below shows the change in temperature and atmospheric carbon dioxide (CO_2) over the past centuries. The left axis shows temperature and the right axis shows carbon dioxide. The bottom axis shows years from the present (0) to the past. Scientist often use these data to talk about global warming and climate change. How do you think these data support scientists' view that the climate is warming?



The top red line is carbon dioxide (CO_2)
The bottom blue line is temperature

2. If there were no increase in carbon dioxide (CO_2) levels, would our climate change?_____
   (a) If yes, what other factors besides carbon dioxide would cause our climate to change?
   (b) If no, why wouldn't our climate change?
3. Some scientists think that the Earth's climate is getting warmer.
   (a) If these scientists are correct what will happen to the oceans? Explain why you think this would happen.
   (b) If these scientists are correct what things about the Earth's weather will change? Explain why you think this would happen.
   (c) If these scientists are correct what will happen to plants and animals? Explain why you think this would happen.
   (d) If these scientists are correct what will happen to people and society? Explain why you think this would happen.
4. Draw your understanding of the greenhouse effect; you can also use words to label parts of your drawing. In the space below your drawing, explain your drawing and explain how you know this.

Make your drawing here:

Write your explanation here:

____

____

____

____

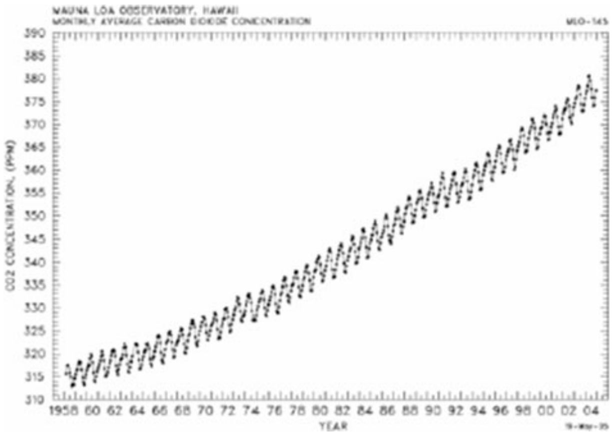
Explain how you know this:

____

____

____

5. The graph below shows the change in carbon dioxide (CO_2) levels at the Mauna Loa Observatory in Hawaii. Answer the following questions based on this data.



(a) List the natural processes that might cause the carbon dioxide (CO_2) levels to change?
(b) Explain how these natural processes might cause the carbon dioxide levels to change.
(c) List the human activities that might cause the carbon dioxide levels to change?
(d) Explain how these human activities might cause the carbon dioxide levels to change?
(e) What could you do to lower the level of carbon dioxide in the atmosphere?

Appendix B: Comparison of student responses and IPCC findings

Question	Main student responses	Summary of IPCC[a] findings
Interpreting evidence of global warming and changes in carbon dioxide	Rising CO_2 leads to temperature increase (41%) Climate changes regardless of carbon dioxide levels (55%) Other gases and air pollutants cause warming (31%)	Carbon dioxide is the most important anthropogenic greenhouse gas. The atmospheric concentration of carbon dioxide by far exceeds the natural range as determined from ice core data Warming of the climate is evident from increases in global average air and ocean temperatures, melting of snow and ice, and rising global sea levels Continued greenhouse gas emissions will cause further warming and climate change
The impact of global warming: ocean	Sea levels rise due to melting polar ice; warming oceans (51%)	Sea-level rise Costal flooding and erosion Loss of costal wetlands, salt marshes and mangroves Coral bleaching

Question	Main student responses	Summary of IPCC[a] findings
		Land use relocation, population, and infrastructure
The impact of global warming: weather	Warmer weather (88%) Change in precipitation (53%)	Increase in drought-affected areas and extent Increase in heavy precipitation events with localized flooding Increased tropical cyclone intensity
The impact of global warming: plants and animals	Plants and animals would die from warmer/hotter weather (25%) or from less rain (16%)	Earlier leaf-unfolding, bird migration and egg-laying Poleward/upward shifts in plant and animal species Earlier spring planting of crops Alterations in forest disturbances from fires and pests Plant and animal extinctions
The impact of global warming: people and society	No impact (45%) Humans would die (25%) from floods, hot weather, increased CO_2, and lack of drinking water.	Increased heat mortality and infectious disease, and death as a result of floods, storms, fires, and droughts Increased mortality from water stress
Understanding the greenhouse effect	Carbon dioxide as a greenhouse gas (25%) Greenhouse gas as a layer in the atmosphere (24%) Sun's rays are emitted by the Earth's surface or clouds back into space; the atmosphere reemits it back towards the Earth (33%)	Changes in atmospheric greenhouse gases and aerosols, in solar radiation and in land surface properties alter radiative forcing and the energy balance of the climate system
Explaining the change in atmospheric carbon dioxide levels: natural processes	Natural temperature change (24%) Volcanic eruption (18%)	Volcanic and anthropogenic aerosols have offset some warming that would otherwise have taken place Prior to 1950, a significant fraction of the Northern Hemisphere temperature variability is likely attributable to volcanic eruptions and changes in solar irradiance
Explaining the change in atmospheric carbon dioxide levels: human processes	Transportation and factories (73%) Not identifying any specific kinds of greenhouse gases (75%) Indicating only carbon dioxide as a greenhouse gas (24%)	Increases in carbon dioxide due primarily to fossil fuel use and land-use change Increases in methane are primarily due to fossil fuel use and agriculture and waste production Nitrous oxides are primarily due to agriculture Tropospheric ozone (nitrogen oxides, carbon monoxide, and hydrocarbons) Changes in surface albedo, due to land-cover change
Explaining the change in atmospheric carbon dioxide levels: resolutions	Reduce/use car less (47%) Reduce pollution (22%)	Fuel switching from coal to gas, nuclear and renewable More fuel efficient and hybrid vehicles, shift to mass transit

Question	Main student responses	Summary of IPCC[a] findings
		Efficient lighting and electrical appliances, improved insulation, passive and active solar design
		Landfill methane recovery, waste incineration, composting, waste recycling and reduction

[a]IPCC (2007), contribution of working groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

Appendix C: Example of NRC standards that relate to global warming and climate change

Grade	Standard	Standard excerpt
K-4	Earth and Space Science	The sun provides the light and heat necessary to maintain the temperature of the earth.
		Weather changes from day to day and over the seasons. . .
	Life Science	The behavior of individual organisms is influenced by . . . external cues (such as change in the environment)...
		Humans depend on their natural and constructed environment. Humans change environments in ways that can be either beneficial or detrimental for themselves and other organisms.
	Science in Personal and Social Perspectives	Changes in environments can be natural or influenced by humans. Some changes are good, some are bad, and some are neither good nor bad. Pollution is a change in the environment that can influence the health, survival, or activities of organisms, including humans.
		Some environmental changes occur slowly, and others occur rapidly. Students should understand the different consequences of changing environments in small increments over long periods as compared with changing environments in large increments over short periods.
5–8	Physical Science	Heat moves in predictable ways, flowing from warmer objects to cooler ones...
		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.
	Life Science	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 . . .
	Earth and Space Science	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" ...
		The atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor. ...

Grade	Standard	Standard excerpt
		Clouds formed by the condensation of water vapor, affect weather and climate.
		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.
		Living organisms have played many roles in the earth system, including affecting the composition of the atmosphere ...
		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. . . .
	Science in Personal and Social Perspectives	Causes of environmental degradation and resource depletion vary from region to region and from country to country.
		Human activities also can induce hazards through resource acquisition, urban growth, land-use decisions, and waste disposal. Such activities can accelerate many natural changes.
9–12	Physical Science	Chemical reactions may release or consume energy. Some reactions such as the burning of fossil fuels release large amounts of energy by losing heat and by emitting light. Light can initiate many chemical reactions such as photosynthesis and the evolution of urban smog.
		A large number of important reactions involve the transfer of either electrons (oxidation/reduction reactions) or hydrogen ions (acid/base reactions) . . . . In other reactions, chemical bonds are broken by heat or light to form reactive radicals . . . Radical reactions control many processes such as the presence of ozone and greenhouse gases in the atmosphere, burning and processing of fossil fuels . . . .
	Life Science	Human beings live within the world's ecosystem. . . . Human destruction of habitats through direct harvesting, pollution, atmospheric changes, and other factors is threatening current global stability . . . .
	Earth and Space Science	Heating of earth's surface and atmosphere by the sun drives convection within the atmosphere and oceans, producing winds and ocean currents.
		Global climate is determined by energy transfer from the sun at and near the earth's surface. This energy transfer is influenced by dynamic processes such as cloud cover and the earth's rotation, and static conditions such as the position of mountain ranges and oceans.
		The earth is a system containing essentially a fixed amount of each stable chemical atom or element. . . . Each element on earth moves among reservoirs in the solid earth, oceans, atmosphere, and organisms as part of geochemical cycles.
	Science in Personal and Social Perspectives	Natural ecosystems provide an array of basic processes that affect humans. Those processes include maintenance of the quality of the atmosphere, generation of soils, control of the hydrologic cycle, disposal of wastes, and recycling of nutrients. Humans are changing many of these basic processes, and the changes may be detrimental to humans.
		Materials from human societies affect both physical and chemical cycles of the earth.

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