Do Earth and Environmental Science Textbooks Promote Middle and High school Students' Conceptual Development about Climate Change? : Textbooks' consideration of students' conceptions

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Abstract

The purpose of this study was to identify middle and high school students' concepts of global warming and climate change and to compare them to the concepts represented in earth and environmental science textbooks. The research questions were: 1) what does the research literature indicate regarding middle and high school students' concepts of global warming and climate change; 2) what are the concepts of global warming and climate change represented in the earth and environmental science textbooks; and 3) how do the students' concepts compare to the concepts represented in the earth and environmental science textbooks? This study analyzed 14 journal articles that researched middle and high school students' concepts of climate change and 7 most commonly used earth and environmental science textbooks for their concepts. We found that the reviewed textbooks often failed to take account of the middle and high students' concepts of global warming and climate change. Implications to curriculum development, instructional design and science textbooks are articulated.

Capsule

A considerable conceptual mismatch was found between what the earth and environmental science textbooks present and what middle and high school students know and think about climate change, suggesting a need for curriculum revision.

Introduction

With increasing public concern and media attention about climate change, students have more opportunities to learn about climate change. Media reports and the internet, however, often deliver inaccurate information or biased viewpoints (Andersson and Wallin 2000; Gowda et al. 1997). Students' misconceptions of climate change, constructed by intermittent exposures to inappropriate information, are resistant to change (Rickinson 2001). Moreover, the complexity and uncertainty of climate change science create barriers to developing scientific concepts (Boyes and Stanisstreet 1996). The research on middle and high school students' understandings of global warming and climate change has identified a number of misconceptions such as confusion of global warming with the ozone layer depletion or pollution (Andersson and Wallin 2000; Boyes et al. 1993 and 1999; Boyes and Stanisstreet 1993, 1994, 1997 and 1998; Fisher 1998; Gowda et al. 1997; Koulaidis and Christidou 1999; Österlind 2005; Pruneau et al. 2001, 2003; Rye et al. 1997). On the other hand, social awareness of the need to include climate change in school has been growing in order to promote students' scientific understandings about this current and relevant issue. Schools or board legislators in California (the U.S.A.), Ontario (Canada), London (the U.K.), New South Wales (Australia) and Philippine have included climate change in school curriculum (Chung and Kalinowski 2007; Martin 2008; McCandless 2007; Rogers 2008; Yunlong 2008; M. Lindsay, personal communication April 17, 2008). Science teachers' attitudes toward teaching global climate change in their classes are also positive (Kim and Fortner 2006).

Teachers and students largely rely on science textbooks for: teachers' source of knowledge and instructional plan, an introduction to a new topic, a resource of class activities, and a reference of new terminologies or scientific concepts (Driscoll et al 1994; Peacock and

Gate 2000; Wakefield 2006). According to the 2000 National Survey of Science and Mathematics Education, 47% of the 529 middle school science teachers and 53% of the 254 middle and high school earth science teachers surveyed across the United States indicated that they read a science textbook as a classroom activity once a week or more, and 95% of the earth science teachers and 86% of middle school science teachers considered the quality of textbooks used in their science classes to be fair or better, showing science teachers' high confidences in science textbooks (Fulp 2002; Weiss et al. 2002). Therefore, it is crucial to examine the quality of the existing science textbooks concerning climate change education and to make recommendations for the future development of educational materials.

This research reviewed some common earth and environmental science textbooks, focusing on how effectively these textbooks promote students' conceptual development about global warming and climate change. The underlying assumption is that, to guide and help students' conceptual development, it is essential for science textbooks to take account of and build on what students already know and think as meaningful learning occurs when learners make connections between prior and new science concepts and develop their existing concepts accordingly (Ausubel 1968; Driver et al. 1994; Gagne 1962; Novak 1977; Osborne and Freyberg 1985). Much research has found the effectiveness of the science teaching and learning strategies based on or actively responding to students' prior knowledge for developing students' science concepts (Bell and Barker 1982; Hewson and Hewson 2003).

Therefore, we examined the extent to which these textbooks take into account middle and high school students' prior concepts about global warming and climate change by appropriately representing scientific concepts corresponding to the students' preconceptions. The study was undertaken with support from the National Science Foundation Geo-science Education Program.

The purpose of this study was to identify middle and high school students' concepts of global warming and climate change and to compare them to the concepts represented in earth and environmental science textbooks. The research questions were:

1. What does the research literature indicate regarding middle and high school students' concepts of global warming?
2. What global warming and climate change concepts are covered in the earth and environmental science textbooks?
3. How do the students' concepts compare to the global warming concepts covered in the earth and environmental science textbooks?

Methods

The ERIC database was searched for research articles that investigated middle and high school students' concepts of global warming and climate change. References of the retrieved articles were also used to find additional articles. From these articles, studies that sampled students from grades 7 to 12 (age 12 to 18) were selected. In cases that involved multiple age groups, only data pertaining to middle and high school students was used. A total of 14 journal articles were found and reviewed to identify students' common alternative concepts about global warming and climate change. The identified students' preconceptions were used to determine critical scientific concepts that ought to be covered in science textbooks for promoting students' conceptual development about global warming and climate change. The reviewed research articles used various approaches to identify students' concepts of global warming: a) interviews, b) questionnaires, and c) classroom observations. The sample sizes of these studies ranged from

3 to over 1,000 students. The studies were conducted in Australia, Canada, Greece, Sweden, the UK, and the U.S.A. The articles were published between 1993 and 2005.

Earth and environmental science textbooks were reviewed, as they cover more in-depth scientific concepts of global warming and climate change than other science disciplines. Five earth science and two environmental science textbooks that were considered to be most commonly used across the U.S.A were selected (Fulp 2002; Weiss et al. 2002; D. P. Shepardson, personal communication August 2007) (Table 1). Based on the identified students' concepts of global warming and climate change, the key words such as "greenhouse effect," "global warming," "ozone hole," "climate," "atmosphere," and "climate change" were used to determine the portion of the textbooks analyzed. The identified critical scientific concepts were used as criteria for analyzing the extent to which the earth and environmental science textbooks cover middle and high school students' preconceptions of global warming and climate change.

Results and Discussions

From the literature review, we identified 42 preconceptions of global warming and climate change that middle and high school students held. The identified students' prior concepts were grouped into 19 categories and 4 themes (Table 2 and Supplemental table I). Based on this, we identified 19 critical scientific concepts of global warming which need to be covered in the science curriculum for developing students' prior concepts of global warming and climate change. The 19 scientific concepts were used as criteria to review the seven earth and environmental textbooks. The textbooks' ways of presenting and organizing scientific concepts of global warming and climate change were also analyzed and three guiding principles were

determined for future educational materials promoting students' conceptual development about global warming and climate change.

1. Middle and high school students' concepts of global warming.

Table 2 shows the themes and categories of students' prior concepts of global warming and climate change. Many students were confused about the kinds and source of radiation involved in the greenhouse effect. In the Koulaidis and Christidou (1999) study, students considered sun rays without the distinction of the kinds of radiation, thermal rays emitted from the sun, or UV radiation entering or reflecting within troposphere to be involved in greenhouse effect. Some students, however, confused global warming with the ozone layer depletion, considering a growing ozone hole allows more UV or solar rays to enter the atmosphere and cause global warming (Boyes and Stanisstreet 1997; Koulaidis and Christidou 1999). In fact, many studies found that students did not differentiate the kinds of radiation or the difference between heat and temperature (Boyes and Stanisstreet 1997 and 1998; Fisher 1998; Koulaidis and Christidou 1999; Österlind 2005). These concepts together appeared to lead students to attribute global warming to an increased incoming solar radiation (Boyes and Stanisstreet 1993; Boyes et al. 1993; Pruneau et al. 2003) or a growing ozone hole (Andersson and Wallin 2000; Boyes and Stanisstrret 1993 and 1997; Boyes et al. 1999; Koulaidis and Christidou 1999; Österlind 2005; Pruneau et al. 2003; Rye et al. 1997).

Many students were also not able to identify the cause of global warming and did not have sophisticated ideas about how pollution and global warming are linked. In particular, many of the students could not identify the different kinds of greenhouse gases (e.g., carbon dioxide, ground level ozone, nitrous oxides, and water vapor) (Boyes et al. 1993; Boyes and Stanisstreet

1993 and 1997; Fisher 1998; Pruneau et al. 2001). Some considered greenhouse gases as air pollutants (Boyes and Stanisstrret 1997; Koulaidis and Christidou 1999) and thus the increase in greenhouse gases will lead to increased air pollution (Koulaidis and Christidou 1999). Many students considered greenhouse effect and global warming as synonyms (Andersson and Wallin 2000). On the other hand, some students thought air pollution or pollution in general causes global warming (Andersson and Wallin 2000; Boyes and Stanisstrret 1997; Gowda et al. 1997 Koulaidis and Christidou 1999). Some students specifically indicated acid rain or nuclear waste as a cause of global warming (Boyes and Stanisstreet 1993; Boyes et al. 1993; Pruneau et al. 2001). Further more, some students considered environmentally harmful action in general such as littering (Boyes and Stanisstreet 1993; Gowda et al. 1997) or using environmentally unfavorable products (Gowda et al. 1997) to cause global warming. In a similar way, environmental friendly actions in general were considered as a solution to the global warming issue: protecting rare species, reducing global nuclear arsenals, keeping beaches clean, using unleaded petrol (Boyes and Stanisstreet 1993; Boyes et al. 1993), reducing pollution, putting waste in a trashcan, or cleaning streets (Pruneau et al. 2003).

Many students held a concept of a thin layer of gases or dust around the earth as a critical component of the greenhouse effect, although the details of such concepts varied: greenhouse gases form a thin layer around the earth and trap heat inside (Andersson and Wallin 2000; Koulaidis and Christidou 1999; Pruneau et al. 2003); greenhouse effect is caused by the ozone layer trapping solar rays (Boyes and Stanisstrret 1997; Koulaidis and Christidou 1999; Pruneau et al. 2003); heat is trapped under a layer of dust created by pollution (Pruneau et al. 2001); and atmospheric gases make a barrier bouncing back heat from the earth surface (Andersson and Wallin 2000). These concepts were likely related to the concepts of the ozone layer reacting

with UV radiation. In fact, one of the most dominant concepts that middle and high school students held about global warming was the confusion between ozone layer depletion and global warming. In addition to the related concepts mentioned earlier, students believed the ozone hole lets cooler air escape from the Earth, increasing global average temperature (Boyes and Stanisstrret 1997), global warming causes skin cancer (Boyes and Stanisstreet 1993 and 1998; Boyes et al. 1993; Pruneau et al. 2003), greenhouse gases deplete the ozone layer (Boyes and Stanisstreet 1994; Boyes et al. 1999; Rye et al. 1997) or greenhouse effect causes air pollutants to go up to and deplete the ozone layer (Boyes and Stanisstrret 1997),

Related to the impacts of global warming, some students believed nothing would happen in their life time (Pruneau et al. 2001 and 2003), while others overestimated the degree of current and future global warming (e.g., about 7°F increase to date and18.4°F in the 50 years) (Andersson and Wallin 2000; Gowda et al. 1997). Many students' concepts about the impacts of global warming were limited to temperature increases, and did not consider the complexity of the feedbacks within the Earth's climate system (Boyes and Stanisstreet 1998; Gowda et al. 1997; Pruneau et al. 2001). For mitigating of global warming or climate change, students showed contrasting attitudes: some were not concerned about the dependency of human society on fossil fuels and the difficulties reducing CO_2 emissions, showing positive attitudes toward CO_2 controls (Andersson and Wallin 2000), while others considered that there is nothing people can do or people would not be willing to change their lifestyle (Pruneau et al. 2001).

2. The earth and environmental science textbooks' conceptual coverage of students' concepts of global warming

Based on the analysis and interpretation of students' prior concepts of global warming and climate change, 19 critical scientific concepts were identified that ought to be covered in science curriculum. The textbooks varied in their coverage of these 19 concepts (Table 4 and Supplemental table II)

Most of the reviewed earth and environmental science textbooks covered the concepts about basic components and mechanisms of greenhouse effect and global warming such as: distinction between weather and climate (concept 1), distinction between global warming and climate change (concept 2), distinction between greenhouse effect and global warming (concept 3), the degree of the current global temperature increase (concept 6), the major sources of greenhouse gases (concept 9), the different kinds of greenhouse gases (concept 10), the mechanism whereby greenhouse gases affect outgoing radiation and influence global warming (concept 12), how to mitigate climate change and global warming (concept 16), and distinction between incoming and outgoing solar radiation (concept 17).

About half of the 19 critical concepts of global warming and climate change that link with students' preconceptions were not covered in most of the reviewed textbooks. First, three of the textbooks did not explain that there exists different types of radiation with different radiation properties and that surface temperature is related to but is distinct from heat (concept 19). Also, four textbooks did not describe the phenomenon where atmospheric gases absorb the different kinds of radiation according to radiation wavelength (concept 18). These two concepts, however, are central to understanding the greenhouse effect and global warming by explaining why the amount of greenhouse gases in the atmosphere determines global surface temperature (i.e., why increases in greenhouse gases would lead to global warming). Without understanding these two concepts, students would not realize why they need to distinguish different kinds of

radiation by wavelength to explain the greenhouse effect (Boyes and Stanisstreet 1997 and 1998; Fisher 1998; Koulaidis and Christidou 1999; Österlind 2005) and identify the different greenhouse gases (Boyes et al. 1993; Boyes and Stanisstreet 1993 and 1997; Fisher 1998; Pruneau et al. 2001). Also, students would not be able to appropriately reason about causes, effects and control of global warming and climate change (Andersson and Wallin 2000; Boyes and Stanisstrret 1993, 1994, 1997 and 1998; Boyes et al. 1993 and 1999; Gowda et al. 1997; Koulaidis and Christidou 1999; Pruneau et al. 2001 and 2003; Rye et al. 1997).

Six of the textbooks did not clarify the distribution of greenhouse gases in the atmosphere (concept 11). As discussed above, many students commonly held the concept of a gas or dust layer surrounding the Earth and trapping heat or solar rays (Andersson and Wallin 2000; Koulaidis and Christidou 1999; Pruneau et al. 2001 and 2003). Interestingly, textbook diagrams of the greenhouse effect appear to perpetuate this misconception. In the diagrams, arrows indicate that terrestrial rays were mostly reflected back at a clearly distinguished end-line of the atmosphere surrounding the earth. An example is shown in Figure 1.

On the other hand, much research found that students do not differentiate between greenhouse effect and air pollution, nor do they distinguish between greenhouse effect and global warming. Depending on the definition of pollution, the increase in greenhouse gases in the air can be considered a kind of air pollution (i.e., the abnormal accumulation of chemicals that threaten the quality of the environment). The problem, however, is that students' concepts of pollution are not as sophisticated as many science educators would expect. Once students consider greenhouse effect or global warming as a kind of pollution (Boyes and Stanisstrret 1997; Koulaidis and Christidou 1999) or as a result of pollution (Andersson and Wallin 2000; Boyes and Stanisstrret 1997; Gowda et al. 1997 Koulaidis and Christidou 1999), their concept of

the greenhouse effect or global warming seems to be fused into a simple concept of pollution (Boyes and Stanisstreet, 1996). Consequently, they are likely to consider environmentally harmful actions in general to cause global warming (Boyes and Stanisstreet 1993; Boyes et al. 1993; Gowda et al. 1997; Pruneau et al. 2001) or environmentally friendly actions in general to mitigate global warming (Boyes and Stanisstreet 1993; Boyes et al. 1993; Pruneau et al. 2003). No textbook, however, attempted to clarify students' confusion and fusion about pollution, greenhouse effect and global warming in their curriculum (concept 5).

Furthermore, several textbooks described global warming as air pollution without a clear distinction. For example, one earth science textbook describes: "*Pollutants can react with water vapor to form acid precipitation, be trapped by temperature inversion to cause thick smog, reduce the amount of ozone in the ozone layer, and contribute to global warming*" (Spaulding and Namowitz 2005, p.386). This generalized description might reinforce students' confusion and fusion about pollution, global warming and ozone layer depletion. Another similar example found in an environmental science textbook described "*The amount of carbon dioxide and other greenhouse gases in the atmosphere are rising because of the pollution caused by human activities*" (Lapinski et al. 2003, p.366) and "*Greenhouse gas pollution may result in global warming*" (Lapinski et al. 2003, p.367). Although this description is specified by showing a chemical formula whereby CO_2 is produced from combustion of a hydrocarbon (i.e., fossil fuels), students could conceptualize greenhouse gases as air pollutants and thus global warming as pollution.

Many students attributed global warming to the increased incoming solar radiation either by the Earth getting closer to the sun or by the sun's rays hitting more areas of the Earth (Boyes and Stanisstreet 1993; Boyes et al. 1993; Pruneau et al. 2003). Only one of the reviewed

textbooks clarified the probable impacts of solar irradiation change on the current global temperature change (concept 13). On the other hand, four of the textbooks did not make a clear relationship between global warming and ozone depletion (concept 7), yet many students have difficulty distinguishing the two issues (Boyes and Stanisstreet 1993, 1994, 1997 and 1998; Boyes et al. 1993 and 1999; Koulaidis and Christidou 1999; Pruneau et al. 2003; Rye et al. 1997). Seven of the textbooks did not describe that global warming is already underway and has already influenced the Earth environment (concept 8), as identified in the IPCC (2007) assessment, (e.g., increasing climatic disasters, sea level rising, and shrinking cryosphere). Thus, these textbooks reinforce the students' conception that in their life time there are no consequences of global warming (Pruneau et al. 2001and 2003).

Some students showed pessimistic attitude toward solving the global warming issue (Pruneau et al. 2001). The students appeared not to understand the links between human actions, economic versus sustainable choices and the different climatic. However, it is important for students to understand different projections of the future global temperature that change depending on the current and future human actions (e.g., IPCC scenarios), by which students will be convinced about the potential people have on mitigating climate change and global warming and also motivated to actively participate in the mitigation actions. Only one textbook discussed about the different futures people can make about global warming (concept 14). Andersson and Wallin (2000) found that students did not seriously take into account the huge dependence of modern society on fossil fuels and the probable socioeconomic barriers to limiting CO_2 emissions can cause. However, by thorough consideration and understandings about such barriers, more realistic and feasible options can be adopted. Only one textbook talked about our

society's dependency on fossil fuels and the possible difficulties cutting greenhouse gas emissions (concept 15).

4. The ways of presenting and organizing scientific concepts of global warming and climate change.

The coverage of the nineteen concepts in the science textbooks cannot guarantee the development of students' understandings about global warming and climate change, however, the ways textbooks present scientific concepts influence students' conceptual development. Especially, environmental issues such as global warming and climate change which continue to be debated amongst scientists or policy makers demand more thoroughness from science textbooks. Considering the development of the identified students' concept of global warming, three guiding principles in presenting and organizing scientific concept of global warming in science textbooks were determined.

a. *Clarify scientific concepts of global warming.* Non-specified scientific concepts in science textbooks are likely to reinforce students' existing misconception or lead to students' misunderstanding of the newly encountered science concepts. For example, making an analogy between greenhouse effect and a physical greenhouse is common in many science textbooks in an attempt to facilitate students' understandings about the greenhouse effect. If the textbooks do not clarify the differences between the greenhouse effect and a greenhouse, the concept of a thin layer of greenhouse gases over the earth will be reinforced by the analogy of the glass of a greenhouse and greenhouse gases in the atmospheric greenhouse effect. Also, this analogy might reinforce the concept in which holes in the ozone layer let cool air out of the Earth,

making the Earth warmer (Boyes and Stanisstrret 1997), like the glass of a greenhouse which keeps inside air from mixing with outside air.

One earth science textbook (Butz 2004) describes that the Earth's atmosphere is heated by both "*the direct absorption of short-wave radiation from the sun*" and "*absorption of long-wave radiation reradiated from the Earth's surface*" (p.259). The scientific principles explaining these two kinds of radiation absorption of atmospheric gases are not specified. Moreover, the seemingly conflicting concept is presented later: "*The greenhouse effect occurs as a result of our atmosphere's ability to allow incoming short-wave radiation from the Sun to strike the Earth's surface*" (p. 351). It is hardly expected that this description can clear up students' confusion about the greenhouse effect in terms of relations between radiation and atmospheric gases.

On the other hand, the textbook discusses the resolution of global warming in a vague and oversimplified way: "*we should attempt to lessen our impact on the Earth's systems so we do not continue to interrupt the natural balance*" (p.356). Many students indicated environmentally friendly actions in general as resolution of global warming, although those actions are not closely related to global warming (e.g., protect endangered species, stop littering, pollute less, keep beach clean, use unleaded oil (Boyes and Stanisstreet 1993; Boyes et al. 1993; Pruneau et al. 2003)). The unspecified resolutions of global warming that textbooks present are not likely to promote students' concepts about resolutions of global warming.

b. *Make connections among related scientific concepts of global warming and climate change.*

Students' alternative concepts of global warming are often likely to be made by a lack of or a failure to make appropriate connections between related science concepts. For example, students' misconceptions about radiation involved in the greenhouse effect are likely to be formed by a lack of understanding about different effects and properties of wavelengths and

selective absorption of greenhouse gases. Not surprisingly, the reviewed textbooks did not present or organize basic scientific concepts (e.g., the wavelengths and selective absorption) along with an intended scientific concept of global warming (e.g., the kinds of radiation involved in the greenhouse effect). Likewise, the scientific phenomena (e.g., global warming and the ozone layer depletion) that students have difficulties in distinguishing were not organized in a way that enables students to compare and contrast between the phenomena.

Even though students have learnt prerequisite science concepts it cannot be guaranteed that they still hold or can activate those prior concepts in order to make connections with newly encountered scientific concepts. Also, the current focus of earth science textbooks appeared to be more on weather and the relation to climate is poorly achieved, which barely provides basic concepts to understand global warming and climate change. Content in earth and environmental textbooks needs to be reorganized and designed to enable students to construct well organized conceptions where science concepts about global warming and climate change are appropriately interpreted by and connected to related basic concepts by utilizing the research findings about students' conceptions.

c. *Develop scientific literacy to deal with publicly debatable concepts of global warming and climate change.* The reviewed earth and environmental science textbooks sometimes presented concepts different from the current scientific perspectives. For example, one earth science textbook described that "*researchers are not sure exactly when, if at all, the Earth' global climate will begin to change*" (Butz 2004, p. 356), even though climate change has likely been occurring (IPCC 2007). Also, most textbooks attributed sea level rise to ice melting (e.g., "*The melting of sea ice and ice sheets will also cause a global rise in sea level*" (Tarbuck and Lutgens 2006, p.603); "*possible effects include rising sea levels due to melting polar ice caps*" (Spaulding

and Namowitz 2005, p.382)), while the IPCC (2007) reported that thermal expansion of oceans made the biggest contribution (57%) to the current sea level rising. Most of the textbooks did not represent the complexity of the Earth's climate system. For example, one earth science textbook described "*This [global temperature increase] could alter the earth's weather, cause melting at the polar icecaps, and cause sea levels to rise*" (Sager et al. 2002, p. 134). In this presentation, the chained consequences of global warming are mostly focusing on warming in general, not covering the complex feedbacks in the Earth climate system.

Global warming and climate change science is a rapidly growing science with increasing global attention. Also, some aspects about global warming and climate change continue being debatable among scientists and policy makers. This field of science shows the nature of science most dramatically (e.g., the tentativeness of scientific knowledge, scientific knowledge as a broad consensus by major scientists, and linkage between cause and effects). Therefore, it is challenging but important for textbooks to provide accurate scientific knowledge about global warming and climate change. They also need to be careful in presenting scientific concepts of global warming and climate change which might be debatable in public views (e.g., media). A desirable approach would be to: 1) present the diverse scientific perspectives on global warming and climate change in a fair and equitable manner, citing the sources of a given scientific argument; 2) explain the nature of science surrounding global warming issues; and 3) set the goals on improving students' scientific literacy (i.e., a willingness and ability to understand and make decisions about global warming issues).

A good example that deals with the global warming issues was found in an earth science textbook (Tarbuck and Lutgens 2006): in an inquiry activity, "*Global Warming: Fact or Fiction?*" (p.587). Here, students select one of the suggested global warming issues and

investigate the conflicting viewpoints using credible web sources. Students evaluate the credibility of each viewpoint, make a decision, and write a letter to convince their state senators of their argumentation. This textbook also invites students to interpret graphical data (e.g., the time series of global temperature change, and CO_2 concentration and emission change), rather than presenting the authors' or the major scientists' interpretations. Also, one earth science textbook discussed the uncertainty and complexity of computer model based prediction of global warming and climate change (Spaulding and Namowitz 2005, p.476).

Conclusion

This research found that the textbooks often failed to consider students' concepts. If science education is to promote students' conceptual development, it is essential to determine students' concepts of global warming and climate change (Osborne and Freyberg 1985) in order to plan curriculum and design instruction that builds on students' concepts (Driver et al. 1994). When science textbooks are designed to better respond to students' concepts and ways of thinking, the textbook will be more successful in capturing students' interests in subject matter, motivate learning, and guide their conceptual development. Developers of climate change educational materials should know about and consider students' concepts of global warming and climate change in curriculum development.

As per IPCC (2007), global warming and climate change will likely become more serious with time. Educating about climate change is important to preparing students to become environmentally literate citizens. As society increases its demands for educating students about climate change, more and better teaching and learning materials on global warming and climate change will need to be developed. In this regard, this study synthesized the research on students'

concepts of global warming, providing an essential resource for science educators, science teachers, and textbook publishers that inform curriculum development and instructional design. Finally, this study made an original and initial contribution to the research on science textbooks by analyzing science textbooks for their coverage of global warming and climate change and comparing this coverage to the concepts held by students.

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Figure and Table Captions

Supplemental Tables

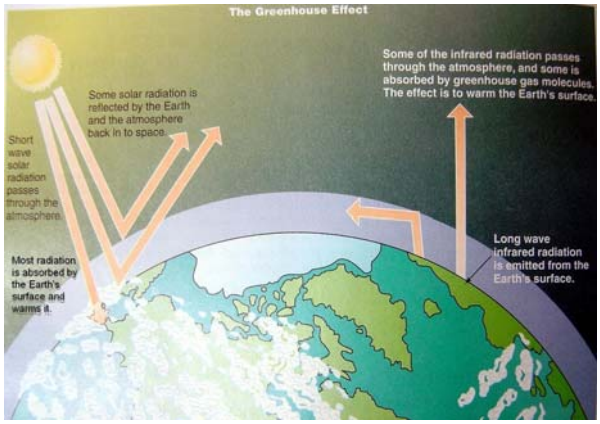
Earth Science	Butz, S. D. (2004). Science of earth systems. Clifton Park, NY: Delmar Learning. Hess, F. S., G. Kunze, S. A. Leslie, S. Letro, C. Millage, L. Sharp, and T. Snow, 2005: Earth science. Columbus, OH: The McGraw-Hill companies. Sager, R. J., W. L. Ramsey, C. R. Phillips, and F. M. Watenpaugh, 2002: Modern earth science. Austin, TX: Holt, Rineheart and Winston. Spaulding, N. E., and S. N. Namowitz, 2005: Earth science. Evanston, IL: McDougal Littell. Tarbuck, E. J., and F. K. Lutgens, 2006: Earth science. Upper Saddle River, NJ: Pearson Education.
Environmental Science	Lapinski, A. H., R. M. Schoch, and A. Tweed, 2003: Environmental science. Lebanon, IN: Addison Wesley Longman. Wright, R. T. 2005: Environmental science (9th ed.). Upper Saddle River, NJ: Pearson Education

Theme	Categories
Basic concepts	• Radiation wavelengths involved in the greenhouse effect • Distinction of the kinds of radiation and their properties • The kinds of greenhouse gases • A gas or dust layer traps heat inside • The definition of greenhouse effect • Confusion between climate and weather
Cause	• Environmentally harmful action in general • Pollution • Ozone hole • Change of incoming solar radiation
Effect	• No change in my life time • Exaggerated global warming claim • Skin cancer • Not understanding the different aspects of climate change • Depletion of ozone layer • Increased air pollution
Resolution/ Mitigation	• Environmentally friendly actions in general • Pessimistic attitude toward stopping global warming • Unaware of the difficulties controlling CO_2 emissions

Nineteen critical scientific concepts of global warming and climate change (that ought to be covered in curriculum for students' conceptual development)		Textbooks by subjects and publishers						
		Environ (N=2)		Earth science (N=6)				
		A[a]	P[b]	P[b]	H[c]	T[d]	M[e]	D[f]
1	Distinction between weather and climate	N	Y	Y	Y	Y	Y	N
2	Distinction between global warming and climate change (i.e., climate change means more than warming)	Y	Y	Y	N	Y	Y	Y
3	Distinction between greenhouse effect and global warming	Y	Y	Y	Y	Y	Y	Y
4	The probable causes of global warming that scientists have debated on	N	Y	Y	N	Y	Y	N
5	Distinction between pollution and greenhouse effects or global warming	N	N	N	N	N	N	N
6	The degree of the global temperature change so far	N	Y	Y	N	Y	Y	Y
7	Distinction between the ozone layer and greenhouse gases in terms of radiation changes and impacts	N	Y	Y	Y	N	N	N
8	Global warming and climate change is already underway and influencing the Earth's environment and climate variability	Y	Y	N	N	N	N	N
9	The major sources of greenhouse gases	Y	Y	Y	Y	Y	Y	Y
10	The different kinds of greenhouse gases	Y	Y	Y	Y	Y	Y	Y

11	Greenhouse gases are well mixed within the Earth's atmosphere	N	N	N	Y	N	N	N
12	The mechanism whereby greenhouse gases affect outgoing radiation and influence global temperatures	Y	Y	Y	Y	Y	Y	Y
13	Solar irradiation change and its possible impacts on current global warming	N	Y	N	N	N	N	N
14	Different possibilities and linkages between future climate and human actions or choices	N	Y	N	N	N	N	N
15	The dependency of human society on fossil fuel and barriers that we may face when trying to decrease greenhouse gas emission	Y	Y	N	N	N	N	N
16	How to mitigate climate change and global warming	Y	Y	Y	N	Y	Y	N
17	Distinction between incoming and outgoing solar radiation	Y	Y	Y	Y	Y	N	Y
18	Selective absorption of atmospheric gases	N	N	Y	Y	Y	N	N
19	Distinction between the different kinds of radiation by wavelength in relation to surface temperature	N	Y	Y	Y	N	N	Y

A[a] = Addison Wesley Longman. P[b] = Pearson Education. H[c] = Holt, Rineheart and Winston. T[d] = The McGraw-Hill companies. M[e] = McDougal Littell. D[f] = Delmar Learning. N = Not covered. Y = Covered.



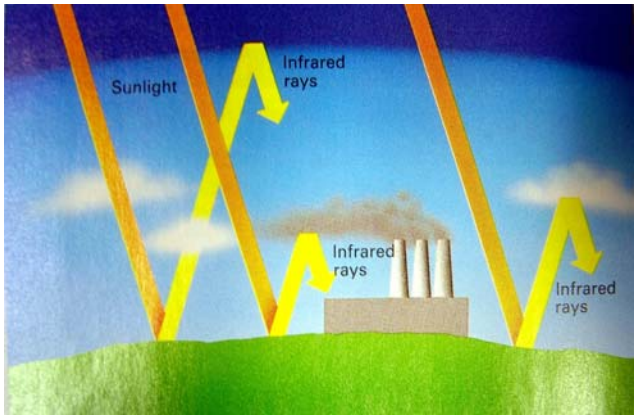


Figure from Butz (2004) and Sager et al. (2002).

	Categories	Students' Concepts
Basic notions	Radiation wavelengths involved in the greenhouse effect	• Sun rays in general (10). • UV radiation reflects off the earth surface (10) • Heat or thermal rays emitted from the sun (10) • Increase in incoming UV or total solar radiation by the ozone layer depletion (4 and 10).
	Distinction of the kinds of radiation and their properties	• Solar radiation involved in global warming (10) • UV rays are "hot" (4 and 10) • No distinction between UV and infrared radiation and between heat and surface temperature (4, 5, 8, and 11)
	The kinds of greenhouse gases	• Considering greenhouse gases as air pollutants (4 and 10) • Not considering ground-level ozone or natural emssions as a greenhouse gas (2 and 6). • Not considering CO_2 as a greenhouse gas (2, 4, 6, and 12) • Not considering water vapor as a greenhouse gas (8)
	A layer of greenhouse gases, ozone gases or dust trapping heat.	• Greenhouse gases form a thin layer around the earth and trap heat inside (1, 10, and 13). • Greenhouse effect is where solar rays are trapped by the ozone layer (4, 10, and 13). • Heat is trapped under a layer of dust created by pollution (12) • The atmospheric gases make a barrier bouncing back heat from the earth (1)
	The definition of greenhouse effect	• Do not know the definition (1, 12) • Confusion between greenhouse effect and global warming (1) • Considering greenhouse effect as an environmental problem (10)
	Confusion between climate and weather	• Able to sense warmer temperature as a surrogate for climate change (9 and 13)
Causes	Environmentally harmful	• Littering (2 and 9)

	action in general	• Using environmentally unfavorable products (9)
	Pollution	• Acid rain (2; 6 and 12) • Nuclear waste (2 and 6) • Air pollution or pollutants in general (1, 4, 8, 9, 10, 12 and 13)
	Ozone hole	• The ozone layer depletion in general (2, 5, 6, 8, 9, and 12) • Ozone hole lets more solar energy to get into the earth, causing global warming (1, 3, 4, 7, 10, 11, 13 and 14). • Ozone hole lets cooler air escape out of the Earth, increasing global average temperature (4).
	Change in solar irradiation	• Increase in solar energy coming into the Earth (2, 6 and 13) • The Earth is getting closer to the sun (13) • Solar rays hit more areas of the Earth. (13)
Effect	No change in my life time	• Nothing would happen in my life time (12 and 13)
	Exaggerated global warming claim	• Over estimates of the degree of global warming (e.g., about 7°F increase to date and18.4°F in the 50 years) (1 and 9)
	Skin cancer	• Global warming causes skin cancer (2, 5, 6 and 13)
	Not understanding different aspects of climate change	• The expected climate change is limited to warming in general (5, 9 and 12)
	Depletion of ozone layer	• The greenhouse gases cause ozone layer to deplete (3, 7 and 14) • The greenhouse effect causes air pollutants to go up higher and deplete the ozone layer (4)
	Increased air pollution	• As greenhouse gases are air pollutants, increased greenhouse gases will cause air pollution (10)
Resolution / Mitigation	Pessimistic attitude toward stopping global warming	• Indicating specific pro-environmental actions, not closely related to global warming (e.g., Protection of rare species; Reduction of the global nuclear arsenal; Keeping beaches clean, The use of unleaded petrol) (2 and 6) • Pro-environmental action in general (e.g., pollute less; put waste

		in the trashcan; clean the streets) (13)
	Unaware of the difficulties controlling CO_2 emissions	• Showing radically positive attitude to limit CO_2 emissions, implying the limited understandings of dependence of human society on fossil fuel and the huge socioeconomic consequences of CO_2 control (1)
	Negative attitude toward taking action regarding global warming	• There is nothing people can do (12) • People would not be willing to change their lifestyle (12)

N.B. Numbers indicate the following citation: 1. (Andersson and Wallin 2000). 2. (Boyes and Stanisstreet 1993). 3. (Boyes and Stanisstreet, 1994). 4. (Boyes and Stanisstreet 1997). 5. (Boyes and Stanisstreet 1998). 6. (Boyes et al 1993). 7. (Boyes et al 1999). 8. (Fisher1998). 9. (Gowda et al. 1997). 10. (Koulaidis and Christidou 1999). 11. (Österlind 2005). 12. (Pruneau et al. 2001). 13. (Pruneau et al. 2003). 14. (Rye et al. 1997).

Nineteen critical scientific concepts of global warming and climate change (that ought to be covered in curriculum for students' conceptual development)		Textbooks by subjects and publishers						
		Environ (N=2)		Earth science (N=6)				
		A[a]	P[b]	P[b]	H[c]	T[d]	M[e]	D[f]
1	Distinction between weather and climate	N	541[g]	476	455/ 523	359	466	N
2	Distinction between global warming and climate change (i.e., climate change means more than warming)	368	555	603	N	380	382	354
3	Distinction between greenhouse effect and global warming	367	547	487	467/ 542/ 134/ 467	375- 376/ 725	373	352/ 353
4	The probable causes of global warming that scientists have debated on	N	545	600- 601	N	371 376	474- 476	N
5	Distinction between pollution and greenhouse effects or global warming	N	N	N	N	N	N	N
6	The degree of the global temperature change so far	N	544	603	N	725	381/ 476	354
7	Distinction between the ozone layer and greenhouse gases in terms of radiation changes and impacts	N	548	477- 478	464- 465	N	N	N
8	Global warming and climate change is already underway and influencing the Earth's environment and climate variability	368	552	N	N	N	N	N
9	The major sources of greenhouse gases	366	548- 551	602	467	377/ 380/ 725	376/ 381/ 476	353
10	The different kinds of greenhouse gases	366	548- 551	487	466- 467	375	376/ 381	243/ 269/

								353-354
11	Greenhouse gases are well mixed within the Earth's atmosphere	N	N	N	456	N	N	N
12	The mechanism whereby greenhouse gases affect outgoing radiation and influence global temperatures	366	546	487	466	276 375	372	268-269/ 351
13	Solar irradiation change and its possible impacts on current global warming	N	548	N	N	N	N	N
14	Different possibilities and linkages between future climate and human actions or choices	N	554-558	N	N	N	N	N
15	The dependency of human society on fossil fuel and barriers that we may face when trying to decrease greenhouse gas emission	371	N	N	N	N	N	N
16	How to mitigate climate change and global warming	371	560	603/ 610	N	377/ 725	382	N
17	Distinction between incoming and outgoing solar radiation	366	542/ 546	485/ 487	464/ 466	276	N	252 257 268
18	Selective absorption of atmospheric gases	N	N	485	464 466	276	N	N
19	Distinction between the different kinds of radiation by wavelength in relation to surface temperature	N	547/ 564	483-484	463	N	N	252 264

A[a] = Addison Wesley Longman. P[b] = Pearson Education. H[c] = Holt, Rineheart and Winston. T[d] = The McGraw-Hill companies. M[e] = McDougal Littell. D[f] = Delmar Learning. [g]Page References. N = Not covered.