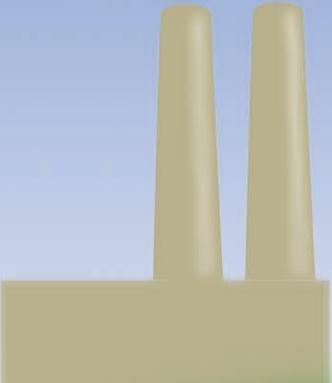


DO EARTH AND ENVIRONMENTAL SCIENCE TEXTBOOKS PROMOTE MIDDLE AND HIGH SCHOOL STUDENTS' CONCEPTUAL DEVELOPMENT ABOUT CLIMATE CHANGE?

Textbooks' consideration of students' misconceptions

BY SOYOUNG CHOI, DEV NIYOGI, DANIEL P. SHEPARDSON, AND UMARPORN CHARUSOMBAT

The reviewed earth and environmental science textbooks did not adequately address students' misconceptions about climate change, suggesting a need for revision.



One of the primary goals of climate change education is to assist students in developing a scientific understanding about the Earth's climate system (NOAA 2009). Despite an increase in supplemental educational materials and hands-on activities in science classrooms, science textbooks are still used as the general source of scientific concepts by teachers and students (Fulp 2002; Weiss et al. 2002). Students develop their understanding of scientific concepts based on their existing ideas, just as scientists rely on their existing knowledge base to acquire a better understanding about natural phenomena (Bell 2005; Duit 1991). Misconceptions, or a lack of relevant prior concepts, can hinder students from developing an understanding of scientific concepts (Duit 1991; Rickinson 2001). It is critical, therefore, that science textbook authors and publishers are aware of students' common misconceptions about climate change when developing textbooks so that their works become effective tools for facilitating students' conceptual development.

Many climate change education researchers have studied students' and teachers' conceptual understanding of climate change and the effectiveness of various teaching strategies for the teaching and learning of climate change concepts. However, few studies have focused on the representations of climate change concepts found in science textbooks. The study reported in this article sought to remedy this gap by ►

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conducting an analysis of the representations of climate change concepts found in science textbooks and examining these presentations for possible

contributions to students' misconceptions about climate change. The research questions were as follows:

TABLE 1. Middle and high school students' misconceptions of climate change. Superscript numbers indicate the following: 1: Andersson and Wallin (2000); 2: Boyes and Stanisstreet (1993); 3: Boyes and Stanisstreet (1994); 4: Boyes and Stanisstreet (1997a); 5: Boyes and Stanisstreet (1997b); 6: Boyes and Stanisstreet (1998); 7: Boyes and Stanisstreet (2001); 8: Boyes et al. (1993); 9: Boyes et al. (1999); 10: Fisher (1998); 11: Gowda et al. (1997); 12: Koulaidis and Christidou (1999); 13: Myers et al. (2004); 14: Österlind (2005); 15: Pruneau et al. (2001); 16: Pruneau et al. (2003); 17: Rye et al. (1997).

		Categories	Students' misconceptions
Basic notions	a	Confusion about the kind and source of radiation involved in the greenhouse effect	<ul style="list-style-type: none"> • Sun rays in general¹² • Heat or thermal rays emitted from the sun¹² • UV radiation reflecting off the Earth's surface¹² • Increase in incoming UV or total solar radiation by the ozone layer depletion^{4, 12}
	b	Confusion between UV and infrared radiation and surface temperature	<ul style="list-style-type: none"> • UV rays are "hot"^{4, 12} • No distinction between UV and infrared radiation and between heat and surface temperature^{4, 6, 10, 12, 14}
	c	Confusion about the kinds of greenhouse gases	<ul style="list-style-type: none"> • Considering air pollutants as greenhouse gases^{4, 12} • Not considering ground-level ozone or natural emissions as a greenhouse gases^{2, 7, 8} • Not considering CO₂ as a greenhouse gas^{2, 4, 8, 15} • Not considering water vapor as a greenhouse gas¹⁰
	d	Involving concepts of a gas or dust layer that traps heat inside	<ul style="list-style-type: none"> • Greenhouse gases form a thin layer around the Earth and trap heat inside^{1, 12, 16} • The greenhouse effect occurs where solar rays are trapped by the ozone layer^{4, 12, 16} • Heat is trapped under a layer of dust created by pollution¹⁵ • The atmospheric gases make a barrier bouncing back heat from the Earth¹
	e	Confusion about the definition of greenhouse effect	<ul style="list-style-type: none"> • Do not know the definition^{1, 15} • Confusion between the greenhouse effect and climate change¹ • Considering the greenhouse effect an environmental problem^{12, 13}
	f	Confusion between weather and climate	<ul style="list-style-type: none"> • Able to sense warmer temperature as an indication of climate change^{11, 16}
Causes	g	General environmentally harmful actions are not closely related to climate change	<ul style="list-style-type: none"> • Littering leads to climate change^{2, 11} • Using environmentally unfavorable products/toxin cause climate change^{2, 11}
	h	Pollution	Climate change is caused by <ul style="list-style-type: none"> • Acid rain^{2, 7, 8, 15} • Nuclear waste^{2, 7, 8} • Heat from car exhaust⁵ • Air pollution or pollutants in general^{11, 4, 10, 11, 12, 15, 16}
	i	Ozone hole	<ul style="list-style-type: none"> • Ozone holes let more solar energy to get into the Earth, causing global warming^{1, 3, 4, 9, 12, 14, 16, 17} • Ozone holes let cooler air escape out of the Earth, increasing the global average temperature⁴ • The ozone layer depletion (without further details)^{2, 6, 7, 8, 10, 11, 15}
	j	Change in solar irradiation	<ul style="list-style-type: none"> • Increase in solar energy coming into the Earth^{2, 7, 8, 16} • The Earth is getting closer to the sun¹⁶ • Solar rays hit more areas of the Earth¹⁶

- a) According to the education research literature, what common misconceptions about climate change are held by middle and high school students?
- b) How do these commonly held misconceptions about climate change compare to accepted scientific concepts?
- c) How do middle and high school science textbooks present accepted scientific concepts related to climate change?
- d) What are the relationships between common misconceptions about climate change found in the research literature and science textbooks' presentation of climate change concepts?

This study defines students' concepts as their mental representations of real world processes (e.g., the greenhouse effect) and components (e.g., carbon dioxide). We use the term "misconceptions" to refer to aspects of students' conceptions that do not reflect scientists' understandings about a natural phenomenon (Duit 1991). We identified students' misconceptions about climate change and a range of related topics, including the greenhouse effect, global warming, and consequent changes in local and regional climate.

METHODS. We conducted a literature review to identify students' common misconceptions of climate change, from which scientific concepts corresponding

to the students' common misconceptions were also identified. Both the students' common misconceptions and corresponding scientific concepts were used as a framework to review Earth and environmental science textbooks regarding their potential contribution to students' common misconceptions.

Students' misconceptions about climate change. We identified research articles pertaining to middle and high school students' concepts of climate change by searching educational research databases, including the Educational Research Information Center (ERIC), Education Full Text, OmniFile Full Text Mega, Proquest Research Library, and Google Scholar. From these articles, studies that sampled students from grades 7 to 12 (ages 12–18) were selected. This process identified a total of 17 journal articles that were reviewed to determine students' common misconceptions of climate change. We identified a total of 41 misconceptions related to climate change that were discussed in the research literature (Table 1).

The articles selected were published between 1993 and 2005, but we found no pattern of variation in students' misconceptions corresponding to the year of publication. Only two studies were undertaken in the United States; other study locations included Australia, Canada, Greece, Sweden, and the United Kingdom. We did not find any variation in students' misconceptions by study location; therefore, we

TABLE 1. Continued.

		Categories	Students' misconceptions
Effects	k	No change in my lifetime	• Nothing would happen in my lifetime ^{15, 16}
	l	Climate change claims are exaggerated	• Overestimates of the degree of global temperature change (e.g., about 7°F increase to date and 18.4°F in 50 years) ^{1, 11}
	m	Causes skin cancer	• Global warming causes skin cancer ^{2, 6, 7, 8, 16}
	n	Not understanding different feedbacks of climate change	• The expected climate change is only limited to warming in general ^{6, 11, 15}
	o	Depletion of ozone layer	• The greenhouse gases cause ozone layer to deplete ^{3, 9, 17} • The greenhouse effect causes air pollutants to go up to higher altitudes and attack the ozone layer ⁴
	p	Increased air pollution	• Greenhouse gases are air pollutants and increased greenhouse gas concentration leads to air pollution ¹²
Resolution/ mitigation	q	Proposing pro-environmental actions in general	• Proposing pro-environmental actions not closely related to climate change as a solution (e.g., protection of rare species, reduction of the global nuclear arsenal, the use of unleaded gas, pollute less, put waste in the trashcan, clean the streets) ^{2, 7, 8, 16}
	r	Unaware of the difficulties controlling CO ₂ emissions	• Unaware of people's dependency on fossil fuel and the complexity of CO ₂ control ¹
	s	Negative attitude toward taking action regarding climate change	• There is nothing that people can do about climate change ¹⁵ • People would not be willing to change their lifestyles ^{15, 16}

considered the identified misconceptions to be representative. Eight out of the 17 studies were conducted in the United Kingdom by Boyes and Stanisstreet (1993, 1994, 1997a, 1997b, 1998, 2001), Boyes, Chuckran, and Stanisstreet (1993), and Myers, Boyes and Stanisstreet (2004). The U.K. students' misconceptions were fairly consistent with the misconceptions held by students of other countries.

We analyzed and interpreted Table 1 to develop a more structured framework to review science textbooks: we analyzed what scientific understandings students tended to lack or misunderstand and what concepts should be more explicitly taught to correct the students' common misconceptions. The specific linkages between the students' misconceptions and scientific concepts are shown in Table 2. For example, many students held the misconception of a gas or dust layer surrounding the Earth and trapping heat or solar rays (Table 1, category d). This highlights the need to teach the scientific concept that greenhouse gases are evenly distributed in the atmosphere (concept 10 in Table 2) and that the ozone layer and greenhouse gases have interactions with the different types of radiation (concept 7).

Representations of climate change concepts in science textbooks. We then reviewed seven Earth and environmental science textbooks that are considered to be commonly used across the United States¹ (Fulp 2002; Weiss et al. 2002; see also Table 2). We used the 18 scientific concepts listed in Table 2 to guide our analysis. Specifically, we analyzed each textbook for

- 1) the presence or absence of each scientific concept;
- 2) the presentation, including figures, analogies, and examples, of each scientific concept; and
- 3) the sequencing of related scientific concepts.

Finally, we examined the relationships between the misconceptions about climate change found in

REVIEWED TEXTBOOKS

S. D. Butz, *Science of Earth Systems* (2004, Delmar Learning).

F. S. Hess and Coauthors, *Earth Science: Geology, the Environment, and the Universe, Student Edition* (2005, McGraw-Hill).

A. H. Lapinski and Coauthors, *Environmental Science* (2003, Addison Wesley Longman).

R. J. Sager and Coauthors, *Modern Earth Science* (2002, Holt, Rinehart and Winston).

N. E. Spaulding and S. N. Namowitz, *Earth Science* (2005, McDougal Littell).

E. J. Tarbuck and F. K. Lutgens, *Earth Science* (2006, Pearson Education).

R. T. Wright, *Environmental Science 9th ed.* (2005, Pearson Education).

the literature and the presentation of climate change concepts in the analyzed textbooks. For example, we identified and discussed ways in which textbooks' representation of climate change concepts in textbooks may contribute to or reinforce students' misconceptions.

RESULTS AND DISCUSSIONS. Tables 1 and 2 display the 41 climate change misconceptions held by middle and high school students and the 18 corresponding scientific concepts. The next sections describe students' misconceptions identified in the literature and our analysis of textbooks' representations of climate change concepts.

Middle and high school students' misconceptions of climate change. Table 1 displays students' misconceptions about climate change and our classification system. The literature review indicated that students were confused about the type and source of radiation involved in the greenhouse effect (Table 1, category a). For example, 27.5% of the students, studied in Koulaïdis and Christidou (1999), held the misconception that UV rays entering the Earth through the ozone hole are responsible for the greenhouse effect; other students attributed the greenhouse effect to heat from the sun (40%) or some type of solar radiation (7.5%). Such misconceptions lead students to attribute global warming to increased incoming solar radiation (Table 1, category j) or to growing ozone holes (Table 1, category i). For example, about 50% of the students studied by Boyes and Stanisstreet (2001) thought that increasing incoming solar radiation caused global warming.

¹ Quantitative data, such as annual sales and the number of schools and states that adopted the textbooks, were not available. Also, there is no intended or inferred evaluation, assessment, judgment, or promotion of any textbook's worthiness or "correctness" implied in this article. The texts were selected based solely upon their common use and their reach to varying audiences, and for various purposes, as per each text's preface.

TABLE 2. The Earth and environmental science textbooks' coverage of the scientific concepts corresponding to the students' misconceptions of climate change. Ad = Addison Wesley Longman; Pe = Pearson Education; Ho = Holt, Rinehart and Winston; MG = McGraw-Hill companies; MD = McDougal Littell; and De = Delmar Learning. N = Not covered and Y = Covered.

Scientific concepts corresponding to the students' misconceptions of climate change	The targeted students' misconceptions	Textbooks by subjects and publishers						
		Environmental science (N = 2)				Earth science (N = 6)		
		Ad	Pe	Pe	Ho	MG	MD	De
1) Distinction between weather and climate	f	N	Y	Y	Y	Y	Y	N
2) Distinction between global warming and climate change	n	Y	Y	Y	N	Y	Y	Y
3) Distinction between greenhouse effect and climate change	e	Y	Y	Y	Y	Y	Y	Y
4) The probable causes of climate change	g, h, i, and j	N	Y	Y	N	Y	Y	N
5) Distinction between pollution and greenhouse effects or climate change	h and p	N	N	N	N	N	N	N
6) The global temperature change so far	l	N	Y	Y	N	Y	Y	Y
7) Distinction between the ozone layer and greenhouse gases in terms of the interaction with radiation	d, i, m, and o	N	Y	Y	Y	N	N	N
8) Climate change is already under way	k	Y	Y	N	N	N	N	N
9) The major sources and the kinds of greenhouse gases	c and g	Y	Y	Y	Y	Y	Y	Y
10) Distribution of greenhouse gases in the atmosphere	d	N	N	N	Y	N	N	N
11) The mechanism of the greenhouse effect	a, d, and e	Y	Y	Y	Y	Y	Y	Y
12) Solar irradiation change and its possible impacts on current climate change	j	N	Y	N	N	N	N	N
13) Projections of future climate changes according to emission scenarios	s	N	Y	N	N	N	N	N
14) The dependency of human society on fossil fuel and barriers to reducing emission of greenhouse gases	r	Y	Y	N	N	N	N	N
15) How to mitigate climate change	q	Y	Y	Y	N	Y	Y	N
16) Distinction between incoming and outgoing solar radiation	a and b	Y	Y	Y	Y	Y	N	Y
17) Selective absorption of radiation in the atmospheric gases	c	N	N	Y	Y	Y	N	N
18) Distinction between the kinds of radiation and surface temperature	b	N	Y	Y	Y	N	N	Y

Over 60% of the students in Boyes and Stanisstreet (1997a) and 35% of the students in Koulaidis and Christidou (1999) considered the ozone layer (via various mechanisms) to be responsible for the increase in global mean temperature. Examples of these mechanisms included the following: the ozone hole lets cooler air escape from the Earth (Table 1, category i), ozone holes allow more solar radiation to enter the atmosphere (Table 1, category a), or the

ozone layer prohibits radiation from escaping from the atmosphere into space (Table 1, category d).

Students also held misconceptions about the types of pollution that can cause climate change. For example, about half of the students studied by Fisher (1998) and Pruneau et al. (2001) held the misconception that any kind of pollution causes global warming (Table 1, category h). Similarly, students studied by Boyes and Stanisstreet (2001) held the misconceptions

that either acid rain (37%) or nuclear waste (about 60%) cause global warming. About 40% of students considered greenhouse gases to be air pollutants and thought that the increase in greenhouse gases would lead to decreased air quality (Table 1, category c; see Koulaïdis and Christidou 1999).

Many students also consider actions such as littering or the use of products containing chlorofluorocarbons (CFCs) or other environmentally harmful chemicals to cause global warming (Table 1, category g) and hold the belief that abstaining from these actions will help to reduce the potential for global warming (Table 1, category q). For example, Boyes and Stanistreet (2001) found that students thought using unleaded gasoline (50%) or engaging in general conservation efforts such as protecting rare species (30%) to be a solution to global warming.

Most of the reviewed studies reported that many held the misconception that the greenhouse effect is caused by a thin layer of dust or gases in the atmosphere (Table 1, category d). For example, over 60% of students studied by Koulaïdis and Christidou (1999) included a thin layer of greenhouse gases or the ozone layer in the greenhouse effect mechanism. Examples of related misconceptions included the belief that there is a thin greenhouse gas layer or a layer of dust or pollution around the Earth that traps heat inside, and that atmospheric gases make a barrier that bounces back the heat from the Earth's surface. Figure 1 visualizes examples of the pathways by which students understand the greenhouse effect and global warming that were discussed above.

The literature showed a large variability in students' understanding of the impacts of climate change. Many students' concepts about the impacts of climate change were limited to temperature increases, and did not consider the complex feedbacks within the Earth's climate system (Table 1, category n). While only 7.1% of the students studied by Pruneau et al.

(2001) thought that global warming is already serious, students studied by Gowda et al. (1997) *overestimated* the degree of current and future global warming (e.g., on an average, students estimated about 7°F increase to date and 18.4°F by 2050; see Table 1, categories l and k).

Studies have also sought to assess students' concepts about socioscientific aspects of climate change issues (Table 1, categories r and s). About half of the students studied by Andersson and Wallin (2000) were not concerned about the dependency of human society on fossil fuels and showed extremely positive attitudes toward the implementation of CO₂ controls. Conversely, students studied by Pruneau et al. (2001) believed that there is nothing people can do (about 5% of students) or that people would not be willing to change their lifestyle (about 70%) to control CO₂ emissions.

Middle and high school level textbooks' coverage of the 18 scientific concepts. The textbooks analyzed varied in their presentation of the climate change concepts (Table 2). Most of the reviewed textbooks included basic scientific concepts about the greenhouse effect and climate change, such as the distinction between the weather and climate (Table 2, concept 1), between global warming and climate change (Table 2, concept 2), and between the greenhouse effect and global warming (Table 2, concept 3); the degree of the current global mean temperature increase (Table 2, concept 6); the major sources and types of greenhouse gases (Table 2, concept 9); the mechanisms of the greenhouse effect (Table 2, concept 11); possible climate change mitigation strategies (Table 2, concept 15); and the distinction between incoming and outgoing solar radiation (Table 2, concept 16).

However, about half of the 18 scientific concepts of climate change were absent in the majority of the reviewed textbooks. Three of the textbooks neither distinguished among the types of radiation nor clarified how surface temperature is related to and distinct from infrared radiation (Table 2, concept 18). Four textbooks did not describe the phenomenon of selective absorption of radiation in the atmosphere (Table 2, concept 17). If students

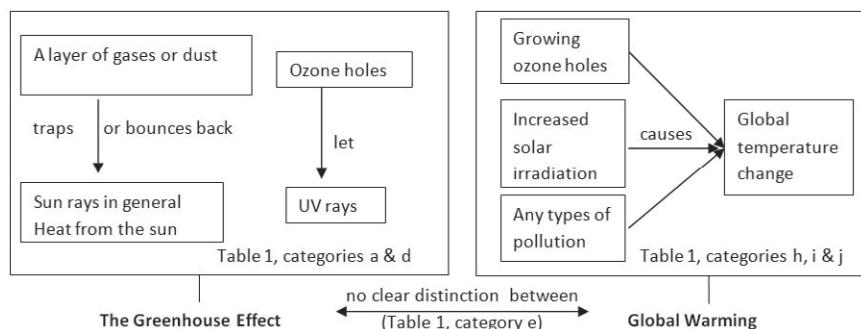


FIG. 1. Visualization of students' misconceptions of the greenhouse effect and global warming.

have misconceptions about these two concepts, they may not recognize either the need to distinguish among different types of radiation to explain the greenhouse effect (Table 1, categories a and b) or why they need to identify the kinds of greenhouse gases (Table 1, category c).

Six textbooks did not specifically mention that greenhouse gases are distributed in the atmosphere (Table 2, concept 10). A common misconception of many students is that a thin gas or dust layer surrounding the Earth traps heat or solar rays (Table 1, category d). The textbook diagrams of the greenhouse effect appear to perpetuate this misconception. In the diagrams, arrows indicate that terrestrial rays were reflected back at a single layer or point in the atmosphere (Fig. 2).

Andersson and Wallin (2000) found that students neither differentiated between the greenhouse effect and air pollution, nor distinguished between greenhouse effect and climate change. Under some definitions, 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). However, students' concepts of pollution are often not sophisticated enough to differentiate between the disparate effects of traditional air pollutants, such as soot and other particulates and greenhouse gas pollutants. Once students consider the greenhouse effect or climate change as a kind of pollution (the first misconception in Table 1, category c; the third misconception in Table 1, category e) or as a result of pollution (Table 1, category h), their concept of the greenhouse effect or climate change 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 climate change (Table 1, category g) and environmentally friendly actions in general to mitigate climate change (Table 1, category q). No textbook appears to clarify the relationships between pollution, greenhouse effect, and climate change in their treatment of these processes (Table 2, concepts 3 and 5). In fact, textbooks' juxtaposition of these concepts may encourage students to equate these processes, as in the following:

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 (McDougal Littell 2005, p. 386).

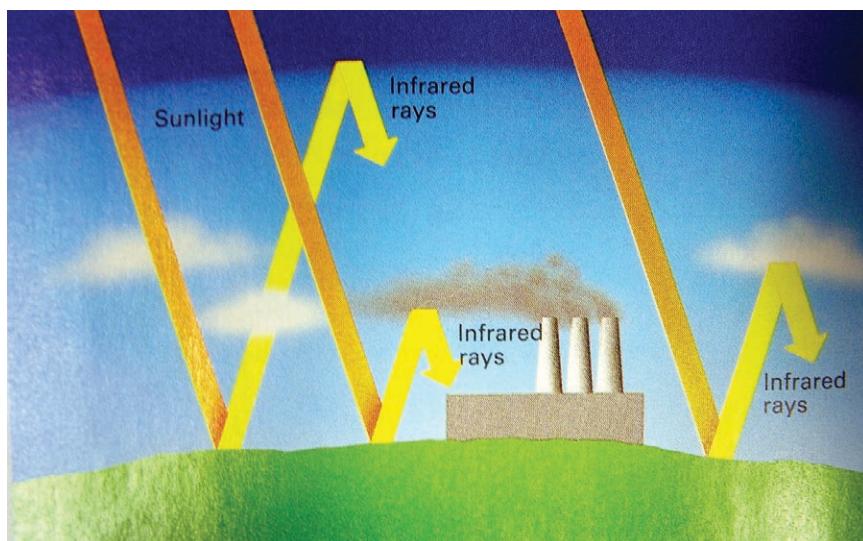
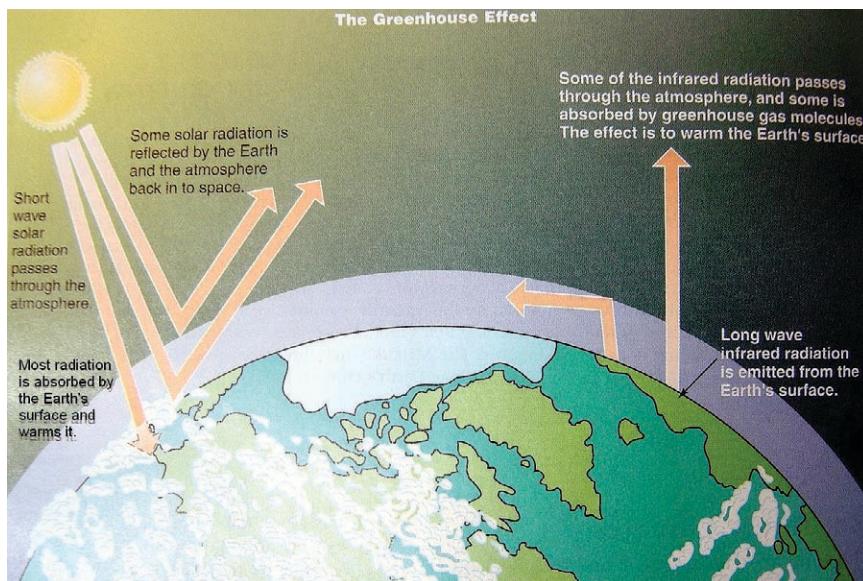


FIG. 2. Examples of typical textbook diagrams indicating the greenhouse effect. [From Butz 2004 and Sager et al. 2002 respectively.]

The amount of carbon dioxide and other greenhouse gases in the atmosphere are rising because of the pollution caused by human activities . . . Greenhouse gas pollution may result in global warming (Addison Wesley Longman 2003, 336–367).

Although this final description of greenhouse gas pollution includes a chemical formula whereby CO₂ is produced from combustion of a hydrocarbon (i.e., fossil fuels), the use of the generic term pollution may encourage students to attribute the properties of particulate air pollution to greenhouse gases and, thus, consider global warming and climate change to be a result of particulate air pollution.

Many students attributed global warming to an increase in incoming solar radiation, the Earth getting closer to the sun or the sun's rays hitting more areas of the Earth (Table 1, category j). Only one of the reviewed textbooks clarified the probable impacts of changes in incoming solar radiation on the global mean temperature (Table 2, concept 12). Four textbooks did not clarify the distinction between climate change and ozone depletion (Table 2, concept 7), even though many students had difficulty distinguishing the two issues (Table 1, categories i, m, and o). Seven textbooks did not describe that climate change is already underway and has already influenced the Earth environment (Table 2, concept 8). Thus, these textbooks could reinforce the students' misconceptions that in their life time there will be no consequences of climate change (Table 1, category k).

Students appeared to have a highly diverse view regarding our ability to control climate change impacts (Table 1, category s). It could be illustrative for students to understand the different projections of future global temperature changes depending on the current and future human actions [e.g., Intergovernmental Panel on Climate Change (IPCC) scenarios]. This could help the students appreciate the potential impact that humans have on climate change and possible mitigation strategies. Only one textbook discussed the different climate change scenarios (Table 2, concept 13) and only one textbook sought to address the issue of society's dependence on fossil fuels and the complexity of CO₂ control (Table 2, concept 14).

LIMITATIONS AND IMPLICATIONS. We recognize the nature of this study has the following several inherent limitations: i) science textbooks are only a part of climate change educational tools that are available for middle and high school instruction of climate change; ii) the quantitative data to qualify the representativeness of the reviewed textbooks were not

available; iii) the scientific concepts corresponding to the students' misconceptions represent the authors' interpretations only; iv) we used the IPCC Fourth Assessment Report (Solomon et al. 2007) as a basis of climate change knowledge, but the textbooks were published prior to the fourth assessment. Considering the last point, it is impractical to consider that textbooks can adapt to the knowledge base that evolves with every IPCC assessment. Therefore, digital materials, Web portals, and teacher training programs should supplement textbook materials, which can allow for more readily available updates.

The writing and reviewing process of science textbooks should involve the careful consideration of students' common misconceptions of climate change when making decisions about how and what concepts should be presented. Scientists, science educators, and publishers should actively create and take opportunities to communicate with each other about their knowledge of and perspectives on climate change science and pedagogically appropriate educational approaches. Future development of climate change modules and materials should involve a systematic assessment process in which scientists and science educators collaborate. Guidance for educators and learners regarding the choice of science textbooks, climate change portals, and educational materials from both the meteorological/climatological and science educational research community is important. The study also implies the importance of teacher training to equip teachers with sufficient scientific understandings about climate change so that science teachers can be in a better position to guide students' learning. Science teachers can apply the findings and implications of this study to build their teaching of climate change based on students' prior knowledge.

As stated before, there is no intended or inferred evaluation, assessment, judgment, or promotion of any one textbook's worthiness or correctness implied in this article. The texts were selected based solely upon their common use and their reach to varying audiences, and for various purposes, as per each text's preface.

CONCLUSIONS AND RECOMMENDATIONS. This study reports on the analysis of the representations of climate change concepts found in science textbooks and an examination of these presentations for possible contributions to students' misconceptions about climate change. We hope this study will assist textbook publishers and authors in revising textbook treatment of climate change con-

cepts to minimize possible creation or reinforcement of students' misconceptions. When science textbooks are designed based on a careful consideration of students' misconceptions and actively respond to them, the textbooks will be more successful in engaging students and guiding their conceptual development. In this spirit, we make three primary recommendations for future treatment of climate change concepts in science textbooks, discussed below.

Clarification of scientific concepts of climate change. Scientific concepts that are explained in generic terms or terms with multiple interpretations are likely to reinforce students' existing misconceptions or lead to the formation of misconceptions by students. For example, in an attempt to facilitate students' understandings about the greenhouse effect, making an analogy between the greenhouse effect and a physical greenhouse is common in many science textbooks [e.g., Earth Science by Delmar Learning (2004, 268–269) and Environmental Science by Addison Wesley Longman (2003, p.366)]. If the textbooks do not clarify the limitations of this analogy, the misconception that a single layer of gas or dust is responsible for the greenhouse effect (Table 1, category d) may be reinforced. Simple and familiar analogies and descriptions are pedagogically useful and appropriate for younger students; however, without careful clarification, these helpful analogies and simple explanations can hinder, rather than help, students' conceptual development.

Connecting and differentiating scientific concepts. Students' misconceptions about climate change are often due to an inability to connect interrelated science concepts. For example, students' misconceptions about the types of radiation involved in the greenhouse effect and the causes of global warming are likely formed by a lack of understanding about selective absorption of radiation by different atmospheric gases. The reviewed textbooks did not make a link between these related basic scientific concepts (e.g., the wavelengths and selective absorption in the atmosphere) and the greenhouse effect. Problems such as global warming and the ozone layer depletion that students have difficulties in distinguishing between were not organized in a way that enables students to compare and contrast them. We recommend careful organization of content in earth and environmental textbooks to assist students in developing well-organized and articulated concepts of climate change.

Presenting the nature of climate change science. The presentation of climate change concepts by the reviewed Earth and environmental science textbooks sometimes differed from current scientific perspectives. For example, one Earth science textbook stated that “researchers are not sure exactly when, if at all, the Earth' global climate will begin to change.” Also, most textbooks attributed sea level rise to ice melt [e.g., “The melting of sea ice and ice sheets will also cause a global rise in sea level,” Earth Science by Pearson Education (2006, p.603); “possible effects include rising sea levels due to melting polar ice caps,” Earth Science by McDougal Littell (2005, p. 382)]. Most of the textbooks did not represent the complexity of the Earth's climate system. For example, one Earth science textbook notes “This [global temperature increase] could alter the earth's weather, cause melting at the polar icecaps, and cause sea levels to rise” (Holt, Rinehart and Winston 2002, p. 134). Most of the reviewed texts described the impact of climate change in terms of global warming and did not address the likely variability of impacts on regional scales.

The field of climate change science is a dramatic demonstration of the nature of science. Climate science assumes that there are principles governing Earth's climate system and that the principles can be understood through thorough and systematic scientific studies. Scientific claims are established based on evidence. Climate science accepts the uncertainty of scientific knowledge in which existing knowledge can be challenged and changed by new observation. Scientists in climate change science participate in social decision making by providing up-to-date scientific knowledge and insight into matters of public concern. Thus, we suggest that future texts should consider i) explaining the nature of climate change science explicitly, ii) presenting scientific perspectives with the information on the assessed likelihood (e.g., by IPCC, see Solomon et al. 2007), and iii) setting the goal to develop students' ability to judge the credibility and validity of diverse perspectives on climate change.

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