

Seventh Grade Students' Mental Models of the Greenhouse Effect

Abstract

The purpose of this study was to investigate seventh grade students' mental models of the greenhouse effect. The study was descriptive in nature and involved the analysis of 225 student drawings and explanations from three different schools in the Midwest, USA. The data were analyzed for content in an inductive manner to identify students' mental models of the greenhouse effect. Five distinct mental models were identified. Curricular and instructional implications are also explored.

Running Head: Students' Mental Models of the Greenhouse Effect

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Introduction

Although the Intergovernmental Panel on Climate Change [IPCC] (2007) has concluded that global warming is inevitable and that human activity is likely to be the main cause, only 41% of the American public believes that global warming is caused by human activity (ABC News, 2007). ABC News (2007), in a survey of the American public, reported that 33% now cite climate change as the world's top environmental issue and 84% think it is probably happening today. Furthermore, 86% believe global warming will become a serious environmental problem if not corrected and 63% think it can be reduced. Finally, 62% believe they know a moderate amount about global warming. Yet in a summary of the public's opinion about global warming Nisbet and Myers (2007) reported that only 18% agreed that every time we use coal or oil or gas, we contribute to the greenhouse effect. Thus, in reality, few individuals have a working knowledge of the greenhouse effect.

Thus, it is vital that students learn about the greenhouse effect in order to understand global warming and climate change. An understanding that is essential if future citizens are to assume responsibility for the management and policymaking decisions facing our planet (Brown, 1992; Bybee, 1993). Therefore, if science education is to promote a citizenry that is knowledgeable about global warming and climate change it is essential to identify students' mental models of the greenhouse effect (Osborne & Freyberg, 1985) in order to plan curriculum and design instruction that builds on students' models (Driver, Squires, Rushworth & Wood-Robinson, 1994).

The greenhouse effect is a scientific phenomenon that involves complex processes. Greenhouse gases in the atmosphere (troposphere) selectively absorb some of the sun's energy that is radiated by the Earth's surface and radiates this energy back toward Earth, warming the Earth. Greenhouse gases are any gases that absorb infrared radiation. Examples of key greenhouse gases include water vapor, carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O). This natural process regulates the Earth's temperature. The IPCC (2007) states that over the past century human activities, primarily the burning of fossil fuels, have enhanced the greenhouse effect by increasing the concentration of greenhouse gases in the atmosphere more than what would have occurred naturally. This increase in greenhouse gases has caused the Earth's temperature to increase, causing global warming which may cause the Earth's climate to change.

The purpose of this study was to identify seventh grade students' mental models of the greenhouse effect, add to the extant literature base on students' geoscience and environmental science learning, and provide guidance to curricular development and instructional design. Specifically, the research question guiding this study was: What are seventh grade students' mental models of the greenhouse effect?

Significance of Study

It may be argued that if earth and environmental science education is to improve citizens' understandings about global warming and climate change, students must develop mental models that are more closely aligned with scientific models. Students' mental model of the greenhouse effect grounds their understanding of global warming which guides their understanding of climate change. Thus, it is essential to grasp the constructs that students use to explain the greenhouse effect. A deeper understanding of

students' mental models of the greenhouse effect allow educators to identify potential impediments to learning (Ausubel, Novak & Hanesian, 1978) and provide insight toward planning curriculum and designing instruction that builds on students' existing mental models, and that combines with current scientific understanding, thereby allowing curriculum and instruction to be sequenced in a way that encourages curricular continuity (Driver et al., 1994).

Background

In this section we provide a summary of the research on students' conceptions of the greenhouse effect, together with a general overview of the literature on mental and conceptual models. Although the research on students' conceptions reported below was conducted within schools, Rickinson (2001) noted that television serves as a major source of students' environmental information. Television provides students access to information about global warming and climate change through nature programs, documentaries, and movies. Thus, we acknowledge that students' conceptions of the greenhouse effect are likely to be influenced by television and other external sources as well as formal schooling. In fact, in our previous work (Authors, 2008) students indicated that the main source of their knowledge about the greenhouse effect came from:

- School science class/textbook 29%
- TV and video programs 20%
- Other individuals (not teachers) 6%
- Other media source 6%
- Greenhouse experience 5%

Students' Conceptions of the Greenhouse Effect

The research on students' conceptions of the greenhouse effect is rather sparse, with most studies using closed-ended response surveys. Furthermore, most studies were

conducted outside of the USA, therefore, little is known about how U.S. students conceptualize the greenhouse effect. For these reasons we reviewed 18 international studies that investigated secondary (grades 6-12) students' conceptions of global warming and climate change. We summarize the findings of these articles that pertain specifically to students' conceptions of the greenhouse effect.

Several studies found that students held no conception of the greenhouse effect (Andersson & Wallin, 2000; Pruneau, Moncton, Liboiron, & Vrain, 2001) or that students made no distinction between the greenhouse effect and global warming (Andersson & Wallin, 2000; Koulaidis & Christidou, 1999; Myers, Boyes, & Stanisstreet, 2004; Boyes, Chuckran, & Stanisstreet, 1993). Furthermore, students erroneously link the greenhouse effect with stratospheric ozone depletion. For example, some students believed that the solar rays are trapped by the ozone layer (Boyes & Stanisstreet, 1997a; Koulaidis & Christidou, 1999; Pruneau, Gravel, Courque, & Langis, 2003). Other students believed that the increased ultraviolet radiation, due to ozone depletion, results in global warming (Andersson & Wallin, 2000; Boyes and Stanisstreet 1994; Boyes & Stanisstreet, 1997a; Boyes, Stanisstreet, & Papantoniou, 1999; Kilinc, Stanisstreet, & Boyes, 2008; Koulaidis & Christidou, 1999; Österlind, 2005; Pruneau et al., 2003; Rye, Rubba, & Wiesenmayer, 1997).

The students in these studies knew little about the greenhouse effect and were not able to identify greenhouse gases beyond carbon dioxide. For example, students did not consider water vapor as a greenhouse gas (Fisher, 1998) and many did not even consider carbon dioxide as a greenhouse gas (Boyes et al., 1993; Boyes & Stanisstreet, 1993; Boyes & Stanisstreet, 1997a, 1997b; Pruneau et al., 2001). For most students air

pollutants in general are greenhouse gases (Boyes & Stanisstreet, 1997a; Koulaidis & Christidou, 1999). Students further believed that carbon dioxide or greenhouse gases form a thin “layer” or “cover” in the Earth’s atmosphere that traps the sun’s rays or heat (Kilinc et al., 2008; Koulaidis & Christidou, 1999; Pruneau et al., 2003); carbon dioxide or gases in general form a “lid,” “skin,” or “roof” over the Earth (Andersson & Wallin, 2000). Lastly, for the most part, these students did not make any distinctions between the kinds of solar energy (Boyes & Stanisstreet, 1997; Boyes & Stanisstreet, 1998; Fisher, 1998; Koulaidis & Christidou, 1999; Österlind, 2005). Therefore, many students only see solar rays from the sun as involved in the greenhouse effect; they lack the concept of terrestrial radiation (Koulaidis & Christidou, 1999) and fail to understand the Earth’s energy balance as a whole.

Mental and Conceptual Models

In order to understand the world students construct internal representations or mental models that are based on their existing knowledge and past experiences; these mental models are useful or functional in that they allow students to make predictions or explain phenomena or events (Greca & Moreira, 2000; 2001). Students are constantly revising their mental models based on new knowledge, ideas, concepts, and experiences; the students’ mental models are personal, idiosyncratic and often unstable (Greca & Moreira, 2000; 2001). Furthermore, language plays a role in the building of mental models; students’ build mental models based on what they already know about the meaning of words (Greca & Moreira, 2001).

diSessa (1993), however, viewed students’ explanations of phenomena to be spontaneous constructions based on elements of their existing knowledge structures or

what he called phenomenological primitives (p-prims). These p-prims are unconsciously used by students to make meaning of phenomena, situations, or events (diSessa, 1993). Thus in different contexts students may use different p-prims to make meaning, to explain phenomena, events, or situations. In this sense, p-prims are not mental models, but are isolated knowledge structures that students use to make sense of the world.

Scientific or conceptual models, unlike mental models, are precise, complete, and simplified representations of phenomena, situations, or events based on scientifically accepted knowledge; they are external representations shared by a community of practitioners (Greca & Moreira, 2000; 2001). Conceptual models may be too simplistic or too complex for practical application or use (American Association for the Advancement of Science, 1990), which is why it is important to acknowledge students' mental models as equally valid, but alternative models of science phenomena.

Because students come to science classrooms with different cultural, educational, and personal experiences they each have different mental models (Glynn & Duit, 1995). Learning science, in part, requires students to reflect on their existing mental models and to build conceptual models (Glynn & Duit, 1995; Greca & Moreira, 2000; Libarkin, Beilfuss & Kurdziel, 2003); it involves the modification or restructuring of existing cognitive structures (Mintzes, Wandersee, & Novak, 1998). This model building process is dependent on the students' existing mental model (Greca & Moreira, 2001; Libarkin et al., 2003). Well developed and organized mental models allow students to place new knowledge into existing models while poorly developed mental models may be easily modified based on new experiences (Libarkin et al., 2003). Thus, identifying students'

mental models allows curriculum and instruction to be planned in a way that challenges students' mental models and/or that further develops students' mental models.

Theoretical and Methodological Perspective

We adopted a constructivist perspective for this study. The objective was to understand the meanings constructed by students participating in a context-specific activity using language (Schwandt, 1994). Central to this study was the written language and drawings used by the students to represent and communicate their meaning (Holstein & Gubrium, 1994; Kress, Jewitt, Ogborn & Tsatsarelis, 2001). The signs and symbols represent the students' interests and motivation for making the sign or symbol at that point in time; they reflect what the student views as crucial and salient (Kress et al., 2001). Students generate the meaning for words, in part, based on their prior experiences and existing concepts (Schollum & Osborne, 1987). These word meanings are constructed by students based on an interaction between scientific and everyday concepts; scientific concepts influence everyday concepts and everyday concepts influence scientific concepts, this interaction shapes the conceptual system students make, represent and communicate (Vygotsky, 1991). The underlying meanings in students' conceptions are contextualized because they represent students' cognitive constructions at a particular point in time (Patton, 2002); and they reflect the unique social, educational, and cultural experiences of the students.

We interpreted the drawings and writings made by the students to represent their conceptions of the greenhouse effect—that is, we created constructions about the students' constructions. Thus, meaning is not discovered in the students' written language and drawings, but constructed in the mind of the authors within a socio-cultural

context. The codes and categories are shaped and colored by our experiences and conceptions that are grounded in both environmental education and the geosciences (Patton, 2002). Our interpretations of the students' responses, then, are just that, interpretations grounded in our experiences, conceptions, and perspectives about the greenhouse effect, global warming, and climate change.

This study was descriptive in nature and reflected a survey of students (Driver, Leach, Millar, & Scott, 1996), involving the collection of qualitative data (i.e., student written and drawn responses). This qualitative data was then analyzed for its content in an inductive manner to identify concepts and patterns in student responses. Inductive analysis as a qualitative methodology involves the immersion into the details and specifics of the data in order to identify important categories and dimensions versus the imposing of preexisting expectations on the data (Patton, 2002). The benefit of a survey was that it allowed us to collect data from more students with varying degrees of experience, including school science, providing us access to a breadth of student conceptions with varying degrees of sophistication (Driver et al., 1996). This permitted the characterization of students' conceptions and allowed us to identify trends or patterns in students' conceptions. At the same time, this enabled us to compare our findings to those of other researchers; however, identifying the factors that contributed to the development of students' mental models of the greenhouse effect is beyond the scope of this study.

Method

Sample and Data Collection

We employed a purposeful sampling strategy (Patton, 2002), using the seventh grade classrooms of three teachers who were involved in our climate change instructional development project. Because we were interested in identifying students' mental models, we aggregated all of the student responses from the greenhouse effect task for a total sample of 225. This provided a larger sample size and gave us the advantage of sampling a wide range of student responses so as to document the similarity, diversity and/or variation in their conceptions of the greenhouse effect (Driver et al., 1996; Patton, 2002).

The sample included a range in student academic ability from special needs students to high ability students with about 55% of the students passing the state science achievement test. The sample was primarily Caucasian (about 95%) with boys accounting for roughly 54% of the sample and girls 46%; we did not track responses by gender or ability. About 30% of the students were on a reduced or free lunch program. The schools were situated in small, rural communities in the Midwest, USA.

The Greenhouse Effect Task

The greenhouse effect task was a draw-and-explain task designed to elicit students' ideas (Osborne & Freyberg, 1985) and based on the draw and explain protocol (White & Gunstone, 1992). The task used a written prompt to elicit student responses. A number of researchers have used similar tasks to elicit students' concepts about environmental and geoscience phenomena (e.g., Alerby, 2000; Anderson & Moss, 1993; Barraza, 1999; Bonnett & Williams, 1998; Payne, 1998; Simmons, 1994). The students' written words and drawings are an active, deliberate meaning-making process and are

conceptual visualizations or representations of their understandings that contain a number of individual concepts (Alerby, 2000; Kress et al., 2001). The students' drawings, then, are representations of their mental models (Glynn & Duit, 1995) and "reveal qualities of understandings that are hidden from other procedures" (White & Gunstone, 1992, p. 99). Thus, students' conceptions may be constructed from their graphic representations (Vosniadou & Brewer, 1992). The written portion allows students to explain the drawings in their own words, and clarifies their conceptions for the authors. These written responses also allow the authors to validate meanings constructed from students' drawings.

Data Analysis

Data analysis involved a content analysis of student responses resulting in the identification of student concepts. This process was inductive in nature; that is, instead of searching for pre-determined patterns, themes were allowed to emerge from the data as we constructed meaning from student responses (Patton, 2002). The process followed that described by Rubin and Rubin (1995). From the first reading core concepts (codes) were identified. These initial codes were revised after a second reading. The codes with common/overlapping themes were grouped into categories that reflected the students' conceptions. From these we constructed a category matrix that linked each code to a category (Erickson, 1986) and that reflected the final categories of student conceptions. This enabled us to organize and check the data for saturation of categories and to eliminate redundant categories (Erickson, 1986; Lincoln & Guba, 1985). The categories were grouped into typologies that reflected the students' mental models. This process 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). To ensure consistency in coding, an inter-rater reliability coefficient was calculated by comparing two of the authors' coding of 41 randomly selected tasks. The inter-rater reliability coefficient was 0.88. Coding was monitored throughout to ensure consistency and reliability.

Results

From the inductive analysis we identified 5 typologies that reflected these students' mental models of the greenhouse effect (Table 1). The numbering of the mental models is presented as a means for distinguishing the different ways that students make sense of the greenhouse effect and are not intended to imply a hierarchy, developmental sequence, or value judgment.

Table 1. Student Mental Models of the Greenhouse Effect

| Greenhouse Effect Model | Totals (n=225) |
|---|-------------------|
| Model 5. Sun's rays are "bounced" or reflected back and forth between the Earth surface and greenhouse gases, heating the Earth (may or may not identify specific greenhouse gases) | 30 (13%) |
| Model 4. Greenhouse gases "trap" the sun's rays, heating the Earth (may or may not identify specific greenhouse gases) | 78 (35%) |
| Model 3. Greenhouse gases, but no heating mechanism; simply gases in the atmosphere | 38 (17%) |
| Model 2. Greenhouse gases cause ozone depletion or formation, causing the Earth to warm | 14 (6%) |
| Model 1. "Greenhouse" for growing plants | 65 (29%) |

We describe each of the models in detail below. In addition, several elements cut across students' mental models (Table 2). For example, 16% of the students explicitly described carbon dioxide as a greenhouse gas. The ability to identify carbon dioxide as a greenhouse gas was more prevalent in Models 4 and 5, but some students who held

Models 2 and 3 also identified carbon dioxide as a greenhouse gas. Only students (3%) who held Model 5 identified other greenhouse gases, such as methane and water vapor. Also, students (44%) who held Models 4 and 5 tended to describe the greenhouse gases or carbon dioxide as existing as a layer in the Earth's atmosphere, and students who held Model 2 tended to identify an ozone layer. In general, students who held Model 3 tended to describe air pollution as a greenhouse gas (10%) and were more likely to identify fossil fuels as a source of greenhouse gases (8%). Students who held Models 2 and 5 identified the process of sun rays reflecting from the Earth's surface before being re-radiated by greenhouse gases.

Table 2. Core Concepts or Elements of Mental Models 2, 3, 4, and 5

| Concept/Element | Model 5 | Model 4 | Model 3 | Model 2 |
|--|---------|---------|---------|---------|
| Carbon dioxide as a greenhouse gas | X | X | X | X |
| Greenhouse gases | X | X | X | X |
| Other greenhouse gases: methane, water vapor | X | | | |
| Sun's rays or heat | X | X | | X |
| Greenhouse gas/carbon dioxide layer | X | X | | |
| Energy reflected "bounced" from Earth surface | X | | | X |
| Energy reflected "bounced" back by greenhouse gases/carbon dioxide | X | | | |
| Sun's energy "trapped" by greenhouse gases | | X | | |
| Air pollutants as greenhouse gases | | | X | X |
| Ozone layer reflects/traps sun's energy | | | | X |
| Fossil fuels as source of greenhouse gas | | | X | X |

It should be noted that no students explained in detail why a gas, such as carbon dioxide, was considered to be a greenhouse gas. That is, students did not explain why some gases absorb the sun's energy and why other gases do not. Also, regardless of the mental model, all of the sun's energy is retained within the Earth's atmosphere, that is,

none of the energy escapes to space. Although a few students (<1%) who held mental models 2, 4, and 5, explained that some of the incoming “sun’s rays” or solar radiation is reflected by the Earth’s atmosphere or clouds, most students did not incorporate clouds or aerosols in their models, in essence all of the sun’s rays reach the Earth’s surface. Thus these students do not conceptualize the greenhouse effect as a process within the Earth’s energy or radiation balance.

Description of Model 5

Students (13%) who held mental model 5 explained the greenhouse effect as the reflection of the sun’s energy by the Earth and by the greenhouse gases. Students who held this model may or may not identify specific greenhouse gases such as carbon dioxide. Thus, greenhouse gases are the “gases” that cause the greenhouse effect. They explained that the “sun’s rays” or energy passes through the atmosphere and greenhouse gases and is “bounced” or “reflected” by the Earth and then “bounced” or reflected back toward Earth by the greenhouse gases, preventing the sun’s energy from escaping the Earth’s atmosphere, warming the Earth (Figure 1). For example:

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

A few students (<1%) explained that not all of the sun’s energy reaches the Earth; these students explained that the Earth’s atmosphere and clouds reflect some of the sun’s energy back toward space (Figure 1): “Some of the sun’s rays are bounced back to the sun” (T-7th-23).

For most of these students the Earth retains all of the sun’s energy; the sun’s energy is unable to escape the Earth’s atmosphere because the greenhouse gases act as an

“insulator” or form a “layer” that “bounces” or reflects the sun’s energy or heat back toward the Earth, heating the Earth (Figure 1):

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

Insert Figure 1 about here

As illustrated in the above student drawings and quotes (Figure 1), these students explained that the sun’s energy or “rays” is “bounced” or “reflected” by the Earth. There is no conception that the sun’s rays are absorbed and radiated by the Earth or that the terrestrial radiation is absorbed by the greenhouse gases and radiated warming the atmosphere. The model is built upon the concepts of bouncing and reflecting the sun’s rays or energy. Only two students explained that some of the sun’s energy escapes the Earth’s atmosphere, “keeping the earth’s heat balance” (M-7th-10). Furthermore, most students explained the greenhouse effect in terms of the “sun’s rays” or “heat from the sun” versus differentiating the radiative energy involved. For these students the heating mechanism or radiative forcing is caused by a “greenhouse gas layer” or “carbon dioxide layer” in the atmosphere. This “layer” “bounces” or “reflects” the sun’s energy or “heat” back toward the Earth, warming the Earth. Thus, in addition to the “bouncing” concept, students built their mental model on the “layer” concept. The greenhouse gases are not viewed as being uniformly distributed in the atmosphere, but existing as a layer in the atmosphere.

Description of Model 4.

The major difference between students who held Model 4 and Model 5 is the heating mechanism. Students (35%) who held Model 4, like Model 5, identified

greenhouse gases or carbon dioxide as atmospheric gases that cause the greenhouse effect, but unlike Model 5, Model 4 students explained that the “sun’s rays”, “heat”, or energy is “trapped” in the atmosphere (Figure 2). The sun’s rays are “trapped” by the greenhouse or carbon dioxide layer or gases in the atmosphere, preventing them from escaping the Earth. They do not explain that the sun’s energy is “bounced” or “reflected” by the Earth or by the greenhouse gases or carbon dioxide, the sun’s energy is simply “trapped” by greenhouse gases or carbon dioxide. The greenhouse gas layer functions as a barrier that prevents heat from escaping the Earth’s atmosphere. A few students (<1%) explained that not all of the “sun rays” reach the Earth (Figure 2).

Insert Figure 2 about here

Description of Model 3

Students (17%) who held Model 3 were aware of greenhouse gases but not the greenhouse effect; they did not explain a heating mechanism or the radiative forcing involved in the greenhouse effect (Figure 3). Students simply identified gases in the atmosphere. A small number of students (8%) identified fossil fuels (e.g., cars and factories) as the source of the greenhouse gases or carbon dioxide. Many of these students identified air pollution in general as the source of greenhouse gases and some identified carbon dioxide as a greenhouse gas. In essence, students who held Model 3 emphasized the source or type of greenhouse gas rather than the greenhouse effect, they focused on air pollution emitted by human activity.

Insert Figure 3 about here

Description of Model 2

Students (6%) who held Model 2 comingled concepts of the greenhouse effect with ozone depletion or the ozone hole and the ozone layer. Students with this mental model believed that ozone depletion or the ozone hole causes the Earth to warm because more of the sun's energy reaches the Earth or that the ozone layer prevents the sun's rays from escaping (Figure 4). In fact, the greenhouse gases (e.g., carbon dioxide) either "tear up" the ozone layer causing the ozone hole or result in the formation of the ozone layer which prevents the sun's rays from escaping (Figure 4). These students' mental model was similar to students who held Models 4 and 5 in that the sun's energy is "trapped" or "stuck" (Model 4) or is reflected (Model 5) by the ozone layer. These students also build their mental model using the "layer" concept, albeit a layer of ozone.

Insert Figure 4 about here

Description of Model 1

Students (29%) who explained the greenhouse effect as a "greenhouse" were categorized as holding Model 1 (Figure 5). These students created a literal representation of the word "greenhouse." These students likely do not understand the greenhouse effect, thus they represent the concept based on their everyday experience with and knowledge about a "greenhouse". They connect the word "greenhouse" to a concrete object they are familiar with; their meaning is shaped by the everyday concept of "greenhouse". Thus, everyday language guided these students' meaning-making (Duit, 1991) and how they represented their mental model of the greenhouse effect.

Insert Figure 5 about here

Discussion

It is important to stress that the mental models of the greenhouse effect described in this article 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 mental model. The typologies are an attempt to characterize the different mental models students hold about the greenhouse effect 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.

The students' mental models of the greenhouse effect contain similar concepts found in previous findings. For example: these students indicated that air pollutants in general are greenhouse gases (Boyes & Stanisstret, 1997a; Koulaidis & Christidou, 1999) and that carbon dioxide or greenhouse gases form a layer in the atmosphere that traps the sun's energy (Andersson & Wallin, 2000; Kilinc et al., 2008; Koulaidis & Christidou, 1999; Pruneau, et al., 2003). Similarly, few students made a distinction between the types of solar energy, with most referring only to "solar rays" or "sun rays" (Boyes & Stanisstreet, 1997; Boyes & Stanisstreet, 1998; Fisher, 1998; Koulaidis & Christidou, 1999; Österlind, 2005). Like Koulaidis and Christidou (1999) most students did not specifically identify terrestrial radiation, but simply that the suns rays are "bounced" back by the Earth. Although students in many studies (Andersson & Wallin, 2000; Boyes and Stanisstreet 1994; Boyes & Stanisstreet, 1997a; Boyes, Stanisstreet, & Papantoniou, 1999; Kilinc, Stanisstreet, & Boyes, 2008; Koulaidis & Christidou, 1999; Österlind, 2005; Pruneau et al., 2003; Rye, Rubba, & Wiesenmayer, 1997) confused the

ozone layer or ozone depletion with the greenhouse effect, only a small number of students from this study explained the greenhouse effect in terms of stratospheric ozone.

Based on the mental models identified it is apparent that these students lacked a clear understanding of the greenhouse effect. At best 48% of the students realized that the greenhouse gases, what ever they may be, cause the greenhouse effect and that the sun's energy is either "trapped" by or "bounced" back to the Earth by the greenhouse gas layer. On the other end of the spectrum, 29% of the students lacked an understanding of the greenhouse effect. On the bright side, students who hold mental models 3, 4, and 5 and probably students who hold mental model 2 have fairly well developed mental models that are likely easily modified with the appropriate curriculum and instructional experiences.

Because most students' mental model lacked a concept of solar energy, a distinction needs to be made between ultraviolet radiation, visible light, infrared radiation, and other forms of solar energy; that is, sunlight as a spectrum of different bands of radiation. It is also essential to address the notion that different greenhouse gases and atmospheric gases absorb electromagnetic radiation at different wavelengths, explaining why some gases absorb the sun's energy (e.g., water vapor and carbon dioxide) and others do not (e.g., nitrogen and oxygen). At the same time, none of the students' mental models dealt specifically with the Earth's absorption and radiation of the sun's energy, the notion of terrestrial radiation. The role of clouds and aerosols or particles in reflecting or absorbing solar radiation is also lacking in the students' mental models. Addressing these concepts is likely to foster the development of a more conceptual model of the greenhouse effect. In essence, developing students' mental

models where the greenhouse effect is part of the Earth's energy balance. The narrow emphasis on anthropogenic sources of greenhouse gases suggest that students also need to be exposed to other human, as well as natural, modifiers of greenhouse gases such as animal waste, landfills, forest fires, and land cover and land use changes.

Table 3. The NRC 5-8 Standards

| Standard | Standard Excerpt |
|---|--|
| Physical Science | <p>Heat moves in predictable ways, flowing from warmer objects to cooler ones...</p> <p>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.</p> |
| Earth and Space Science | <p>The atmosphere is a mixture of nitrogen, oxygen, and trace gases that include water vapor. ...</p> <p>Living organisms have played many roles in the earth system, including affecting the composition of the atmosphere ...</p> <p>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. . . .</p> |
| Science in Personal and Social Perspectives | <p>Human activities also can induce hazards through resource acquisition, urban growth, land-use decisions, and waste disposal. Such activities can accelerate many natural changes.</p> |

Planning curriculum and designing instruction is a difficult and challenging process made even more taxing by the necessity to build from students' mental models. Based on the results of this study and previous findings it would appear that a curriculum built from students' mental models would need to address the following concepts, which link to the NRC 5-8 science education standards (Table 3):

- Carbon cycle, fossil fuels (energy), and greenhouse gases

- Other human and natural sources of greenhouse gases (e.g., forest fires, animal waste, landfills, land use)
- Greenhouse gases (e.g., water vapor, carbon dioxide, methane, nitrous oxide)
- Uniform distribution of greenhouse and atmospheric gases
- Absorption and radiation of energy—energy transfer
- Greenhouse effect, radiative forcing (infrared radiation) and the Earth's energy balance
- Distinction between types of solar radiation and solar and terrestrial radiation
- Greenhouse gases and ozone depletion
- The greenhouse effect and global warming
- Natural versus human sources of greenhouse gases and personal solutions and actions

Many of the students' mental models of the greenhouse effect are re-enforced or even built on the concepts displayed in the diagrams found in most earth and environmental science textbooks. For example, the greenhouse effect represented in Figure 6 implies the existence of a "greenhouse gas layer" above the Earth's surface that traps and reflects the sun's energy. In Figure 7 the "sunlight" is transformed into "infrared rays" that are reflected by the atmosphere. At the same time, Figures 6 and 7 represent factories discharging smoke (air pollutants) into the "greenhouse gases" layer of the atmosphere. Therefore, air pollution in general is a greenhouse gas and factories in particular are the major source of "greenhouse" gases. Thus, the greenhouse effect is conveyed as an anthropogenic phenomenon versus a natural process. The impression that science textbook diagrams can have on students may be seen in the students' drawings where the greenhouse effect drawn is very similar to the textbook diagrams.

Insert Figure 6 about here

Insert Figure 7 about here

When designing instruction science educators need to take care not to reinforce student conceptions that the greenhouse effect “traps” all of the sun’s energy and that carbon dioxide is the only greenhouse gas or that air pollution in general is a greenhouse gas. For example, the typical “greenhouse” demonstration is not an exact physical model of the Earth’s greenhouse effect and must be cautiously presented to students, stressing the limitations of the model. Failure to address these limitations may reinforce students’ mental models, especially students that hold Models 3 and 4, whereby the glass prevents heat loss or “traps” all of the heat. Students need to realize that the elements of the physical model do not necessarily correspond to elements in reality (Greca & Moreira, 2001). By addressing students’ mental models of the greenhouse effect and designing curriculum and instruction that builds from students’ mental models and that moves toward a scientific perspective, science educators develop the foundation from which an understanding of global warming and climate change may be anchored.

Once students have developed a more sophisticated mental model of the greenhouse effect and the Earth’s energy balance a stronger connection to global warming and climate change may be made. Solar radiation and the Earth’s energy balance are important modulators of Earth’s climate. One way human’s change the Earth’s energy balance is through changing the atmospheric concentration of greenhouse gases which alters the longwave radiation being absorbed and radiated back toward Earth, thus warming the Earth—global warming (Le Treut et al., 2007). As the Earth warms its climates change and so do weather phenomena such as an increase in the frequency and severity of heat waves and heavy rains and a decrease in the frequency and intensity of cold events (Le Treut et al., 2007). A warming climate also causes more

snow and ice to melt, revealing darker land and water surfaces that in turn absorb more of the sun's energy, causing more warming; amplifying the warming caused by the increase in greenhouse gases (Le Treut et al., 2007). Thus changing one aspect of the climate system affects changes in other aspects of the climate system. Therefore, in order for students to understand climate change they must also understand climate as a coupled system.

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