UNDERSTANDING THE GREENHOUSE EFFECT

USING A COMPUTER MODEL

By

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A THESIS

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THESIS

ACCEPTANCE STATEMENT

On behalf of the Graduate Committee for Lisa Schultz, I affirm that this manuscript is the final and accepted thesis. Signatures of all committee members are on file with the Graduate School at the University of Maine, 42 Stodder Hall, Orono Maine.

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Dr. Molly Schauffler, Assistant Professor of Earth Sciences, August 6, 2009

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UNDERSTANDING THE GREENHOUSE EFFECT

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By Lisa Renee Schultz

Thesis Advisor: Dr. Molly Schauffler

An Abstract of the Thesis Presented
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This research investigates the effectiveness of a computer modeling program as a learning tool to understand the greenhouse effect. This study was conducted at two Maine middle-schools with 136 seventh-grade students and 11 eighth-grade students in eight classes. Students were given a pre-test that consisted of a concept map, a free-response question, and multiple-choice questions about how the greenhouse effect influences the Earth's temperature. Then students explored the Greenhouse Effect model for approximately twenty minutes with only two focus questions for guidance. After the exploration period, students were given a post-test that was identical to the pre-test. The data from these assessments were statistically evaluated using parametric tests to determine if students increased their understanding about the greenhouse effect and to assess the use of concept maps to detect students' understanding.

Results indicate middle-school students gained in their understanding about how the greenhouse effect influences the Earth's temperature after exploring the computer model for approximately twenty minutes. The magnitude of the changes in pre- and post-

test concept map and free-response scores were small compared to an expert's score, indicating that students did not gain a complete understanding of the greenhouse effect. While students gained in their understanding about the greenhouse effect, students held on to their misconceptions from the pre- to post-tests.

My research also looked at the effectiveness of using concept maps as an educational assessment tool for detecting students' understanding. The free-response question detected more of the students' understanding and misconceptions than the concept maps. There was a moderate correlation between the free-response and concept map responses, which indicates that the concept maps did detect students' understanding, although to a lesser extent than the free-response question.

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1 INTRODUCTION AND BACKGROUND

1.1 Introduction and overview

In 2002 the state of Maine implemented the Maine Learning Technology Initiative (MLTI) that provided every middle-school student a laptop computer for the purpose of increasing their technology skills and improving higher order thinking (Fairman, 2004). Although computers are available to middle-school students, reports suggest they have been underutilized, especially in science and mathematics courses (Keengwe *et al.*, 2008). Results from educational research on the effectiveness of computers as learning tools are an important resource for educators and curriculum developers who are incorporating technology into daily classroom practices.

For my thesis, I have chosen to investigate what students learn about the greenhouse effect using a computer model. One of the reasons I chose the greenhouse effect as the topic of my research was due to the learning standards adopted by the state of Maine (Maine Learning Results, 2007). The learning standards indicate that middle-school students are expected to learn specific science content, such as life, Earth and physical science, as well as “unifying themes” that prevail in all disciplines of science. The three “unifying themes” in the Maine Learning Results include systems, models, and constancy and change. When middle-school students investigate the greenhouse effect as part of the Earth's climate system using a computer to model, they are addressing the following Maine Learning Results standards:

- (A1.a): Students should be able to explain how "individual parts working together in a system… can do more than each part individually," and "how the output of one part of a system… can be the input of another part of a system."
- (A1.c): Students should be able to describe how systems can be broken down into subsystems, and be able to analyze these subsystems as part of a larger system.
- (A2. a & b): Students should be able to "use models to examine a variety of real-world phenomena… and compare the advantages and disadvantages of various models."
- (A3.b): Students should be able to describe "various cycles,… energy transformations, and human actions that affect the short-term and long-term changes to the Earth."

Complicated systems that are comprised of various hierarchical levels of knowledge and relationships can be particularly difficult for young students to understand (Hmelo-Silver & Pfeffer, 2004). Jacobson and Wilensky (2006) researched student understanding of systems and they argue that it is important for younger students to understand complicated systems that include multiple variables that work together to affect the system in various levels. In their research (Jacobson & Wilensky, 2006), one of the challenges students encountered when learning about complicated systems was that students tend to think the relationship between the size of an action and the corresponding effect is linear. Students may believe that changing something in a small way will result in only a small change in the system. The authors argue that within a complicated system, small changes can result in large effects on the system at a macro-level. They also conclude that research findings in student understanding of complicated systems will contribute to future curriculum development and development of resources for learning about complex systems.

Another reason I chose to use the greenhouse effect as a topic in my research was because the computer model I am investigating is being used as part of a teacher professional development program offered by researchers at the University of Maine. The Inquiry-based Dynamic Earth Applications of Supercomputing (IDEAS) project is funded by the National Science Foundation and is aimed at incorporating geodynamic visualization tools into existing middle-school climate curriculum. One of the computer models used in this program is the Greenhouse Effect model, which is a modified version of the NetLogo Climate Change model (Tinkler & Wilenski, 2007). The Greenhouse Effect model simulates how the greenhouse effect influences the Earth's temperature while allowing the user to modify the system variables and observe the results. Participating middle-school teachers are encouraged to include the Greenhouse Effect model as part of their climate curriculum to teach students how the greenhouse effect influences the Earth's climate system and how to use models to investigate system relationships and effects. The results from my research provided feedback to the participating teachers and the IDEAS researchers about what middle-school students may learn from exploring the model and how the model can be used as an effective learning tool in the classroom.

1.2 Purpose of study and research questions

This research investigated learning effects middle-school students experienced after exploring the Greenhouse Effect computer model. Specifically, the research questions included:

1. Did students gain a better understanding of system relationships pertaining to the greenhouse effect after using the model?
2. To what extent were students' misconceptions and difficulties congruent with previous research?
3. Are concept maps an effective assessment tool for measuring student understanding and detecting misconceptions?

To investigate the three research questions, middle-school students took pre- and post-tests that included concept maps, a free-response question, and multiple-choice questions about how the greenhouse effect influences the Earth's temperature. I wanted to research the use of concept maps as an educational assessment tool for detecting students' understanding because studies have shown that concept maps are beneficial in assessing understanding about systems because concept maps can show the relationships and effects between several concepts (Rebich & Gautier, 2005; Rye & Rubba, 1998; Novak & Gowin, 1984). Results from these assessments will be statistically analyzed to determine if students had gains in their understanding about the greenhouse effect after using the computer model for approximately twenty minutes, and whether the results of the concept maps correlate to responses from the free-response question.

2 LITERATURE REVIEW

2.1 Areas for review

This literature review focuses on three areas of inquiry: (1) current research on student ideas about the greenhouse effect, (2) the effect computer models have on student learning, and (3) using concept maps as an educational assessment tool. My research into literature relating to students' ideas about the greenhouse effect uncovered misconceptions and difficulties students have with understanding the mechanisms that drive Earth's greenhouse effect system. The results of these studies informed my design of the assessment questions used in this research. The second area of review helped me see how models have been used in teaching and how their efficacy for student learning has been assessed. For each study reviewed, I describe the type of model used, the assessment methods used to measure the effects on student learning, and researchers' claims for the learning effects due to the simulation. The third area of review informed my use of concept maps to assess students' understanding of the greenhouse effect. I wanted to review the benefits and limitations of using this type of assessment tool to assess understanding and to detect misconceptions, especially at the middle-school level.

Some find the term 'misconception' to have a negative connotation or to be insufficient to describe students' prior knowledge. Guzzetti *et al*. (1993) and Abimbola (1998) suggest that other terms, such as 'alternative conceptions' and 'alternate ideas', are more appropriate for describing students' knowledge that contains incomplete or incorrect scientific conceptual understanding. For simplicity, I am using the term 'misconceptions' similarly to what Gautier and Rebich (2005) describe as “common features of learners' prior knowledge throughout the sciences and have proven resistant to instruction" and do not appear to agree with scientific knowledge. Students often use a combination of their own observations and prior knowledge to arrive at conclusions about phenomena that are conceptually incorrect or incomplete. The authors of *Ready, Set, SCIENCE!* (Michaels *et al*., 2008) suggest that these wholly or partially incorrect ideas may inhibit students to master science concepts in meaningful ways. Although, they also claim that these misconceptions may be "necessary stepping-stones on a path toward more accurate knowledge." The misconceptions found in published research helped to focus the assessment questions used in my study, and were used to modify the NetLogo Climate Change model that will be discussed in more detail in later sections of this thesis.

2.2 Students' ideas about the greenhouse effect

Over the last few decades, scientists have come to understand more deeply the human role in affecting Earth's climate through burning fossil fuels and releasing CO_2 into the atmosphere (IPCC, 2007). Because the IPCC's findings, and those of many other climate researchers, have such great implications for global society, it has become important for teachers to incorporate understanding about climate change into their teaching goals, and to help students understand not only the mechanisms by which humans affect Earth's climate, but also how scientists study a big and complicated system such as Earth's climate system. The greenhouse effect is one factor forcing global climate change; greenhouse gases in the atmosphere, including carbon dioxide, water vapor, methane, nitrous oxide, and ozone, absorb and re-emit longwave, infrared electromagnetic energy, thus trapping heat that warms the surface of the Earth. This natural process has existed since the development of the atmosphere and has kept the Earth's temperature habitable for humans. For the first time, humans have increased the concentration of carbon dioxide in the atmosphere by about 80% between 1970 and 2004 mainly from energy production, transportation and industry emissions (IPCC, 2007). The enhanced greenhouse effect describes how humans have affected the climate due to increasing the concentration of greenhouse gases beyond natural amounts.

Inclusion of these topics into science curriculum over the last 10 – 20 years prompted educational research into what students are learning about the various phenomena that contribute to climate change, in particular what students' specifically understand about the greenhouse effect. Published studies suggest that students have common misconceptions that may deter them from achieving an accurate conceptual understanding of the physical processes involved in the greenhouse effect (Gautier *et al*., 2006; Gautier & Rebich, 2005; Papadimitriou, 2004; Cordero, 2001; Groves & Pugh, 1999; Meadows & Wiesenmayer, 1999; Koulaidis & Christidou, 1998; Rye *et al*., 1997). In this section I review three key studies that are representative of the research into students' understandings of, and misconceptions about, global climate change, the greenhouse effect, global warming, and ozone layer depletion.

Rye *et al.* (1997) interviewed 24 middle school students after they had completed a two-week Science-Technology-Science (STS) instructional unit about global warming in order to investigate students' misconceptions about the causes and mechanisms of global warming. The students' responses were analyzed to record the frequency of the misconceptions related to the nature, causation, and minimization of global warming.

Over half of the students, 54%, indicated that ozone depletion was a major cause of global warming, and half of the students mentioned that the exclusive role of carbon dioxide in global warming is that it destroys the ozone layer. The most frequent reasoning given by the students for these beliefs was that carbon dioxide in the atmosphere deteriorates the ozone layer, which allows more solar energy to heat the Earth's surface. The authors suggest that this misconception may be the result of students' intuitive knowledge that sunlight feels warm and a sunburn will make us hot. This prior knowledge interacts with their misconceptions that an increasing ozone hole would allow more sunlight to reach the Earth's surface, which would heat up the planet. The authors also suggest that another reason for the confusion about the relationship between ozone hole depletion and global warming is that these topics are typically taught in the same instructional unit.

Gautier and Rebich conducted two studies during a Mock Environmental Summit class that investigated the level of understanding and misconceptions college-age students had about climate (Rebich & Gautier 2005; Rebich *et al.* 2006). In the first study (2005) the authors assessed seventeen students' conceptual change by comparing pre- and post-course concept maps created by each student. Students' concept maps were compared with an expert's concept map and analyzed for the presence or absence of key concepts and accuracy and usefulness of the linking terms. The researchers classified the linking terms into four categories, with the lowest categories being misconceptions and weak conceptions. By the end of the undergraduate course the proportion of linking terms that included weak conceptions and misconceptions had decreased from 17% to 9%.

Rebich and Gautier (2005) identified the following undergraduate student misconceptions related to the greenhouse effect: (1) inappropriate mental models of shortwave and longwave radiative processes (e.g. not differentiating between the behavior between solar and infrared radiation), (2) mental models that attribute increasing global temperature to increasing solar input through the ozone hole, (3) belief that greenhouse gases and clouds trap solar energy, rather than infrared energy, that has been reflected off of Earth's surface, (4) and an inability to distinguish between the natural greenhouse effect and the enhanced greenhouse effect. Many students were not aware that the natural greenhouse effect keeps the Earth at a habitable temperature, but rather indicated the greenhouse effect started to occur with human civilization and the development of fossil fuels. Students had difficulty identifying specific greenhouse gases, and typically indicated that all greenhouse gases were "bad". Students who described greenhouse gases as atmospheric pollution often concluded that all types of pollution enhanced the greenhouse effect. A few students also indicated that the greenhouse gases themselves were being trapped, which the authors suggest may be due to the analogy to a greenhouse that maintains heat by preventing convection and trapping warm air inside. The authors also suggested that students do not conceive the Earth as a radiative body because longwave radiative processes were not included in any part in students' models of the greenhouse effect.

In the second study (Rebich *et al.,* 2006) the researchers interviewed eight of the undergraduate students using a set of four questions about the greenhouse effect and climate change. The first interview was conducted before the course, the second interview was done midway through the course, and the final interview was done upon the completion of the course. The interviews tracked the progress in students' mental models, and assessed the degree to which the students were able to gain new understanding and overcome misconceptions about the greenhouse effect. Students' responses were compared with a list of twenty-one concepts related to the greenhouse-effect that were compiled by a group of experts. To assess the quantity and quality of the information, the students' responses were scored on a scale of one to four, based on their accuracy and completeness. The authors also recorded the type and frequency of misconceptions held by the students for each of the interviews. They found that all eight of the students mentioned at least one misconception during the first interview, and seven of the students mentioned at least one misconceptions on the mid and post-interviews. The semi-quantitative results for this study indicated students had misconceptions concerning (1) the role and effect of ozone in the greenhouse effect process, (2) the distribution of greenhouse gases in the atmosphere (evenly distributed vs. a thin layer in the atmosphere), (3) and confusion between shortwave and longwave radiation. The number of misconceptions decreased by 20% from the initial interviews to the mid-interviews, although evidence throughout the study indicated that students had difficulty understanding how greenhouse gases are distributed in the atmosphere and differentiating between the surface heating due to incoming solar radiation and infrared radiation. The authors concluded that the students improved and deepened their understanding of the greenhouse effect, yet held on to a number of misconceptions throughout the course. The authors suggest the students may have held on to their misconceptions because they were not aware that their thinking diverged from scientific explanations and did not see a need to change their mental models. They recommend a curriculum that causes students to confront specific misconceptions so that the students would need to modify their mental models to fit with accepted scientific explanations of the greenhouse effect.

Other research related to greenhouse effect and global warming misconceptions support the above findings (Rye *et al.,* 1997; Rebich & Gautier 2005; Rebich *et al.* 2006) and have found that students (1) tend to confuse the greenhouse effect with ozone depletion (i.e. increasing the ozone hole allows more solar radiation to reach the Earth's surface, which increases the temperature), (2) attribute the greenhouse effect exclusively as an environmental problem rather than a natural process, (3) and have difficulty differentiating between shortwave and longwave radiation and the role these play in the greenhouse effect (Papadimitriou, 2004; Cordero, 2001; Groves & Pugh, 1999; Meadows & Wiesenmayer, 1999; Koulaidis & Christidou, 1998). These common misconceptions and difficulties found in previous research were used to develop the assessments used in my research in order to determine if these ideas still existed and to asses whether the computer model was able to address these issues.

2.3 Teaching with computer models

Simulations can improve students' ability to predict and explain abstract phenomena and complex systems, and can promote deep transfer of complex system principals (Zacharia, 2005; Stern *et al.*, 2008; Sengupta & Wilensky, 2009). Educational research tested how students can use those simulations to develop an accurate system understanding (Goldstone & Sakamoto, 2003; Adams *et al*., 2008a&b; Schwarz *et al*., 2007; Zacharia, 2005). Wilensky and his colleagues, in particular, have researched student understanding of systems using the NetLogo modeling program (eg. Tisue & Wilensky, 2004; Wilensky & Resnick, 1999; Wilensky, 1995 & 2003; Sengupta & Wilensky, 2009). The finding from these studies indicate students gain an understanding of systems using the NetLogo program as a simulation and modeling tool. The researchers suggest additional research about how to effectively use computer models as a learning tool in the classroom to understand the complex nature of systems. In the following sections, I review research into pedagogy that uses models such as NetLogo (or similar computer simulations) to teach some of the topics relevant to my research. Understanding how others assessed effective learning through the use of computer models, how computer simulations affect understanding at various ages, and claims of why computer simulations have been attributed to increased understanding over traditional lecture and homework based courses guided my own study design.

In this first study (Sengupta & Wilensky, 2009), researchers investigated students' understanding of electricity after using a NetLogo computer model, NIELS (NetLogo Investigations In Electromagnetism). A class of 46 undergraduate freshman at a Midwestern University participated in this study during the first three weeks of 16 week physics course. All of the students were given a written pre-test consisting of six free-response questions on the first day of class. The instructor gave a ten-minute presentation to introduce the NetLogo environment and the two models that would be relevant to the topics covered in the electricity unit. Each model included a set of activities to guide the students' exploration. The students were not required to use the models, but those students who wanted to use them were given one day to download the models. The class was categorized into two groups based on the students' voluntary decision whether to use the models: NIELS group, n = 20 (students who downloaded and used the model) and the non-NIELS group, n = 26 (students who did not use the models). The activities using the computer model were designed to cover the same content and take approximately the same time as the reading assignments and homework problems given to the non-NIELS group. The in-class instruction was the same for both groups, and was typically in a lecture format. At the end of the unit, both groups were given a post-test that was identical to the pre-test, and post-instructional interviews were conducted with five students in the NIELS group in order to get a deeper understanding of how the students were making sense of the observed phenomena depicted in the models.

The pre- and post-tests were scored by categorizing the responses as agent-perspective, aggregate-perspective, or a complimentary of both. While Wilensky was analyzing student reasoning about complex systems modeled in NetLogo, he found that students use “agent” and “aggregate” explanations (Jacobson & Wilensky, 2006). Agent-based reasoning is when “students reason from the properties and behavior of individual system elements,” and aggregate reasoning is when “students reason about the properties and rates of change of population and other macro-level structures” (Jacobson & Wilensky, 2006). The NetLogo models are designed to show how small-scale agents (NetLogo uses the term ‘turtles’) affect the macro level system. In this way, students can examine the aggregate patterns that emerge from even small changes in agent behaviors. For example, an agent-perspective response would describe the micro-level behavior and interactions of the free electrons. Whereas an aggregate-perspective response would include a description of the macro-level phenomena behavior, like current. The complimentary response would use a combination of these behaviors (micro and macro) to describe the phenomena, and are considered to be more accurate and complete than the agent or aggregate perspective responses individually.

Sengupta and Wilensky (2009) described the agent-perspective and aggregate-perspective categories as “levels”, and argued that misconceptions are generated when students inappropriately assign agent-based attributes to aggregate phenomena (or vise versa). The researchers also claimed that increased aggregate conceptual understanding is more likely to result when misapplied reasoning (misconceptions) about aggregate phenomena are correctly applied to agent-based behaviors. An example of a traffic jam is given in the article to explain this phenomenon (Sengupta & Wilensky, 2009). The cars (agents) are moving forward, yet the traffic jam (aggregate) is propagating backward. Sengupta and Wilensky indicated that subjects found this counter-intuitive because they attributed the movement of the cars to the movement of the traffic jam. The computer models used by the NIELS group were designed to specifically allow students to learn how the attributes of the agents (free electrons) would affect the aggregate patterns (current). Students predicted the interactions of the free electrons and resulting current behavior and tested those predictions by varying the model's parameters. Sengupta and Wilensky hypothesized that the patterns found in these predict-and-observe activities at the micro and macro level would increase the proportion of complimentary responses, which would indicate an increased understanding of electromagnetism.

The pre-test results indicated there were no significant differences in the performance between the groups even though they were self-selected. The post-test results indicated a significantly higher increase of the number of complimentary responses in the NIELS group compared to the non-NIELS group. The results also indicated a correlation between the student responses that failed to identify the relationships (and interactions) between the micro-level agents and attributing incorrect behaviors at the aggregate (macro) level. These results supported their claims that misconceptions are generated when behaviors from one level are attributed to another level (micro to macro or vise versa). The researchers suggest using agent-based modeling, such as NetLogo, increases understanding of micro behaviors, which will result conceptual understanding macro level behaviors. The researchers label this method of instruction as the “emergent levels-based approach”, and claim this approach can be used to teach abstract concepts in middle and high schools because agent-based reasoning builds upon common prior knowledge about micro and macro behaviors.

A study (Stern *et al.*, 2008) conducted in seventh grade classrooms in Israel evaluated the effect a computer simulation had on students' understanding of kinetic molecular theory. Three teachers each taught one control class and one experimental class consisting of approximately 23 students per class. Initially, both groups were taught same content for 30 class periods from “Into the Matter” (current curriculum), although the researchers' observations indicated that the three teachers did not present the material identically. Then, both groups were given a pre-test that contained four free response questions about the kinetic molecular theory. Next, for seven class periods both groups were taught a chapter from a highly structured unit, “Matter to Molecules”, which the researchers had found to be effective for teaching kinetic molecular theory in other studies. The experimental group also received three additional days of instruction using the computer simulations. Then both groups were given a post-test consisting of six questions that covered the same content, but were different from the original pre-test questions. The researchers indicated the time between the pre- and post-tests was short (3 weeks), and the students may have asked their teachers or parents the answers to the pre-test questions. The researchers tried to match the content and level of difficulty of the pre- and post-test questions, although direct comparison between the pre- and post-test questions were limited because of this decision. Finally, the researchers interviewed five students from each group after the post-tests were complete. During the interview, the students were asked to explain phenomena similar to one of the post-test questions.

The computer simulation in this study showed the behavior of the particles and how the particles interacted in various conditions. The students were able to modify parameters (temperature, pressure, volume, etc.) and observe how the particles responded. The students were asked to make predictions about the particles' behavior, and use the simulation to test their predictions. The researchers acknowledged that the model was limited because the model did not provide accurate spacial scaling between particles in various phases of the substance, and the model showed all particles to be the same shape and size. The researchers suggested that these limitations may contribute to a lack of understanding, although they indicated the advantages of the model addressed specific difficulties students have had in understanding this topic.

The researchers created a list of essential elements for each pre- and post-test question. The student responses were scored based upon the number of essential elements that were contained in each response. The responses were statistically analyzed using ANOVA to detect if there were statistically significant differences between (1) the pre-test scores between the groups, (2) the post-test scores between the groups, (3) the pre-test and post-test scores between each group, and (4) the pre- and post-test scores between genders for each group.

The researchers found that there was no significant difference between the pre-test scores between the groups, and both groups significantly increased their pre- to post-test scores. The experimental group improvement was significantly higher than the control group (averaged 17 points higher). Also, there were no significant differences between the pre- and post-test scores between genders for either group.

Even though the researchers found that the students who used the computer simulation improved more than the control group, the overall scores were lower than expected. The researchers contributed the low overall scores to the less desired initial curriculum that failed to address students' prior knowledge and misconceptions. The misconception that particles are stationary until heated was detected in an interview response. The researchers suggested that students in the experimental group typically responded better to this topic because the computer simulation had shown particles constantly in motion.

The post-test was given to a subset of the initial students a year after the initial instruction to determine if long-term learning had occurred. The students who had used the computer simulation scored lower than those who were in the control group, and the researchers suggest that the students in the experimental group remember the uncommon experience of using the computer simulation, but that the simulation did not contribute to longterm learning. The researchers suggested that a computer simulation should be only a part of a diverse curriculum, and that more studies should be done on curriculum that incorporates simulations into inquiry activities.

Zacharia (2005) compared the effect of using an interactive computer simulation against using science textbook assignments on the nature and quality of postgraduate science teachers' explanations regarding three main physical phenomena: mechanics, waves and optics, and thermal physics. Thirteen participants enrolled in the 16-week conceptual survey in physics course, including five males and eight females with an average age of 30 years. None of the participants were physics majors, but each of them had taken at least one year of introductory physics during their undergraduate studies. Each of the three main physical phenomena were subdivided into four sub-topics (e.g. motion in one dimension and Newton's second and third laws), resulting in twelve cases to analyze. The teachers were randomly assigned either to the experimental group (those who used computer simulations) or to the control group (those who used textbook assignments). Each teacher completed half of the subtopics in the experimental group and half in the control group.

Each group used a Predict-Observe-Explain (POE) model to investigate each of the subtopics. In the Predict phase, the participants from both groups were presented with a picture taken from the computer simulation and asked to predict how the system would respond when certain variables were modified. In the Observe phase, the experimental group investigated their predictions using the computer simulation, and the control group were given relevant textbook problems that were comparable to the level of difficulty and time-on-task of the simulation. In the Explain phase, the experimental group had to reconcile any discrepancies between their predictions and their observations in the computer simulations, and the control group was given solutions to their textbook problems and asked to reconcile the differences between their answers and the solutions.

Two semi-structured interviews were conducted for each teacher and subtopic during the Predict and Explain phases. The interview data was analyzed for each of the four research questions:

1. "How does the nature of the explanation of a science teacher applying the POE model compare before and after using a simulation or textbook assignment?
2. Does the nature of the explanation differ when he/she uses a simulation as opposed to textbook problems?
3. Do science teachers, applying the POE model, generate more scientifically accurate explanations when using simulations instead of textbook problems?
4. Do science teachers, applying the POE model, have a higher degree of deepening in their explanations when using simulations instead of textbook problems?"

To determine the nature of the explanation (Questions 1 and 2), the interview responses were placed into one of four categories: everyday explanation, descriptive explanation, causal explanation, and formal explanation. The percentages of the responses in the categories were calculated for each of the subtopics and for each of the groups separately. In the Predict phase, both groups responses contained mainly *everyday* explanations. In the Explain phase, more of the experimental group responses were categorized as *formal* compared to the control group responses, which were mainly *descriptive*. These results suggest that the nature of the explanations appeared to change more when the participants used the computer simulations.

The scientific accuracy of the responses (Question 3) were analyzed using a three-level scale, where 1 is least accurate and 3 is most accurate. A rubric was created for each of the twelve subtopics in order to determine the level of accuracy. The statistical analyses of the scores indicated the nature of the experimental group explanations appeared to change more than the control group. These findings suggest the participants that used the computer simulations had a higher degree of scientific accuracy than those who used the textbook problems.

The degree to which the explanations deepened (Question 4) was assessed using a 4-level scale to compare the pre- and post-responses for each subtopic. Level 1 indicated there was no advancement, and level 4 indicated there was strong advancement. The scores were analyzed to determine if there were significant differences between the depths of explanations between the groups. The statistical analysis indicated that the simulations along with the POE model, appeared to promote more in-depth advancement.

The results of this study indicate that using the computer simulations, along with the POE model, improved the nature and quality of the participants' scientific explanations regarding physical phenomena in mechanics, waves and optics, and thermal physics. Zacharia suggests that simulations provide a medium for an interactive learning environment where the participant can test their own ideas, which gives them control over their own learning and promotes conceptual understanding. Zacharia warns that conceptual understanding is difficult to achieve, and that the reported significant results may also be attributed to the maturity level of the participants and additional physics content covered within the course. Zacharia also suggests further research should be done to include a greater number and diversity (cognitive levels) of participants to determine if computer simulations are effective learning tools.

The studies (Sengupta & Wilensky, 2009; Stern e*t al*., 2008; Zacharia, 2005) reviewed in this section suggest computer simulations can increase students' understanding about various phenomena. Each one of these studies was conducted within an instructional unit that was paired with other teaching methods (i.e. predict-and-observe, lecture, and POE), which makes me wonder to what extent do computer simulations have on students' learning with little to no guidance? Are there advantages to letting students freely exploring the model before any formal instruction? I also wonder if an agent-based simulation, such as NetLogo, is an effective learning tool for middle-school students as it was for the undergraduate freshmen (Sengupta & Wilensky, 2009).

To what degree will the middle-school students be able to detect the aggregate patterns and relate those to the agent behaviors in order to describe a complex phenomena such as the greenhouse effect?

2.4 Concept maps as assessment tools

Published studies have used concept maps to assess student understanding of system relationships and how that understanding evolves over time (Rebich & Gautier, 2005; Rye & Rubba, 1998; Novak & Gowin, 1984). Concept maps can also show how students link concepts in a system (Novak & Gowin, 1984).

A concept map is a way to graphically organize ideas to show relationships. Joseph Novak made original use of concept maps in educational research to track changes in childrens' knowledge of science (Novak & Gowin, 1984). The maps are composed of propositional phrases that can be hierarchically structured in the form of nodes and links, as seen in the expert greenhouse concept map (Figure 2.1). The nodes correspond to the important terms (concepts) of the topic, and are typically nouns (i.e. sun, Earth, and greenhouse gases). The linking terms denote the relationship between the nodes in the form of verbs (i.e. reflects and increases) or phrases (i.e. are examples of, caused when). Two nodes connected by a linking term create the propositional phrase, which make up the basic unit of the concept map.

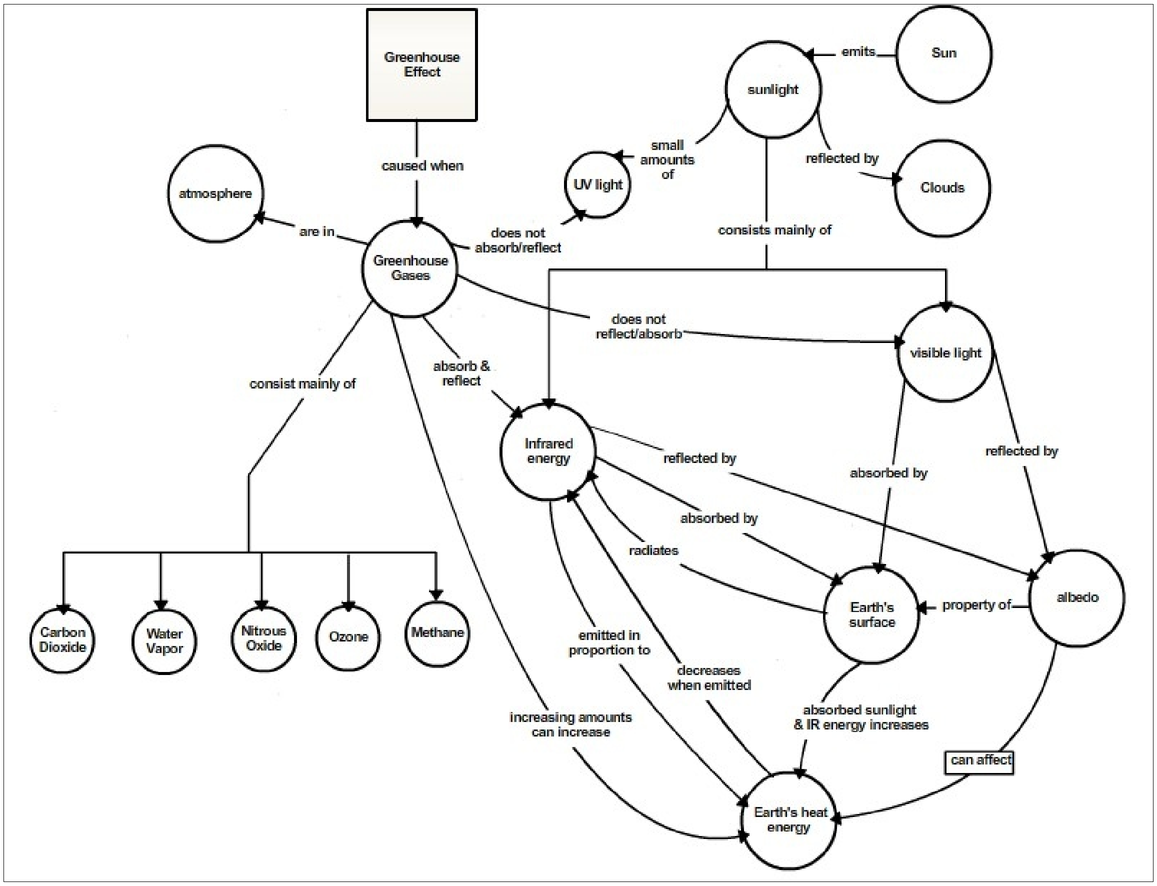


Figure 2.1. Example of expert greenhouse effect concept map. Created in collaboration with scientists and teachers.

The theory underlying the creation of concept maps came from Ausubel's theory that “learning takes place by the assimilation of new concepts and propositions into existing concept propositional frameworks held by the learner” (Novak & Gowin, 1984). That is, in the process of meaningful learning, we associate new knowledge to a prior network of knowledge using relationships. Concept maps are intended to “tap into a learner's cognitive structure and to externalize, for both the learner and the teacher to see, what the learner already knows” (Novak & Gowin, 1984). Ruiz-Primo and Shavelson

(1996) claim that concept maps are more directly related to the knowledge of facts and how concepts are related and may be limited in providing information on how students apply the knowledge to solve problems.

A greater number of studies have assessed the effectiveness of the concept mapping activity as a learning tool rather than for a formal educational assessment tool (Snead & Young, 2003, Ruiz-Primo & Shavelson, 1996). Researchers suggest the lack of education research into the effectiveness of concept maps as an assessment tool may be due to difficulties, such as scoring inter-rater reliability issues and lack of student experiences with creating concept maps (McClure et al., 1999; Ruíz-Primo, 2000; Ruiz-Primo & Shavelson, 1996, Novak & Gowin, 1984). To minimize these difficulties, participants in studies where concept mapping is part of the assessment are typically given instructions as recommended by Novak (Novak & Gowin, 1984) to promote equal and consistent map creation abilities among participants.

Students are initially given an example of a concept map to show how concepts are connected with the linking terms using directional arrows. Novak suggests giving younger students fill-in-the-blank concept maps that either have the concepts or linking terms missing, and optional word bank that contains the concepts or linking terms can be given to assist with making the maps. Older students can be given a familiar topic or a section of a textbook as a first concept map building exercise. Novak suggests comparing students' maps and giving feedback so students to help them learn to organize their knowledge. Students should be encouraged to revise their maps multiple times to clearly organize the propositional phrases in a coherent and logical manner (Novak &

Gowin, 1984). This revision process can take a considerable amount of time, which is more manageable when used as a learning tool rather than an assessment tool. (Ruiz-Primo and Shavelson, 1996).

Novak also suggests using focus questions to direct the construction of the concept maps because these questions more likely reduce the amount of erroneous data (Novak & Gowin, 1984). Ruiz-Primo and Shavelson (1996) also claim that the concept map tasks (similar to a focus question) should be chosen to elicit specific cognitive structures. Novak claims that the focus questions provide guidelines that reduce the anxiety of the person creating the concept map who may feel overwhelmed by a general topic (Novak & Gowin, 1984). For example, in my study I asked the students to create a concept map that would show how the greenhouse effect influences the Earth's temperature. This direction specifically addressed the greenhouse effect mechanisms that influence the Earth's temperature. If I had instructed the students to create a concept map about the greenhouse effect, they might have only indicated contributing factors to increased greenhouse gases, which is not what my research addresses.

The scoring of concept maps can range from formal to holistic approaches (Novak & Gowin, 1984; Snead & Young, 2003; Ruiz-Primo and Shavelson, 1996) and can be classified into three general scoring strategies: (a) scoring components of the map, (b) comparing students' maps to an expert map, and (c) using a combination of both strategies (Ruiz-Primo and Shavelson, 1996).

Novak provides an example of a formal scoring protocol, where points are assigned based upon the number of valid relationships, levels of hierachy, cross-links (linking phrases that connects two concepts across the map from different hierarchal structures) (Novak & Gowin, 1984). The points for each of these categories can be weighted based upon their perceived importance in answering the focus questions. Novak's protocol weights crosslinks the highest (10 points), followed by levels of hierarchy (5 points), and then weights valid propositions least (1 point) (Novak & Gowin, 1984). Other studies weight propositional phrases higher to focus on the concept relationships (McClure and Bell, 1990). Ruiz-Primo and Shavelson (1996) reviewed twenty-one studies that included concept mapping as an assessment tool, and suggest using scoring criteria based on the quality of the propositions rather than simply counting the number of map components because students may include extraneous information that may result in a greater number of propositional phrases (or other components), which would inflate the component-based score. When using propositional scoring, three parts of the propositional phrase are scored based on (a) whether there is a relationship between concepts, (b) the accuracy of the linking term between the concepts, and (c) the compatibility of the direction of the linking arrow and the relationship between the concepts (i.e. appropriate hierarchical or causal relationship) (McClure & Bell, 1990).

The second scoring strategy, comparing students' maps to an “expert” map, assumes that there is an ideal organization that best represents the specific knowledge. The criteria for making an “expert” map is dependent on the researchers goals. “Expert” maps might be made by scientists, teachers, and even top students. Student maps can be compared to expert maps to measure the proportion of matching propositions and the strength of the linking terms (Ruiz-Primo & Shavelson, 1996).

Ruiz-Primo and Shavelson (1996) suggest that all of the scoring strategies should be deigned to promote consistency and reliability. The researchers noted that very few studies specify the systematic methods taken to establish reliable scoring, and those that did report reliability data based their correlations on different components of the concept map. Ruiz-Primo and Shavelson suggest more studies should be done to assess how sample size, repeatability, and sensitivity to scoring affect concept map scoring reliability.

After the review of twenty-one studies that use concept maps as assessment tools, Ruiz-Primo and Shavelson (1996) offered several suggestions for educational research:

- Fill-in-the-blank tasks should not be used to measure students' knowledge because they are too restrictive.
- Hierarchal structures should not be required in the concept mapping instruction because not all content has hierarchical organization.
- Scoring of concept maps should focus on the quality of the propositions over counting the number of map components.
- Science educators and scientists should collaborate to create expert maps to determine the appropriateness of the expectation of depth of students' understanding and structure of students' maps.

The researchers (Ruiz-Primo & Shavelson, 1996) also warn that practical issues may impede large-scale implementation of concept map assessment. One issue is how to determine the instructional time necessary to train students to create maps that are useful for assessing knowledge. To what extent should the amount of concept map instruction depend upon cognitive level (i.e. grade level)? How can educational researchers know when students are prepared to create meaningful concept maps that effectively demonstrate their understanding? Ruiz-Primo and Shavelson (1996) suggest more research on these questions to increase the reliability and effectiveness of using concept mapping as assessment tools.

Concept maps have been used with some success at revealing changes in students' understanding about systems, but they are subject to logistical and reliability challenges. Several questions arose after the review of these studies: What scoring process promotes reliable data collection while determining system understanding? Are concept maps an appropriate assessment tool for middle-school students, and how much concept-map instruction time is necessary for middle-school students? Can concept maps detect system understanding better than free-response or multiple-choice questions? For my research, I have elected to combine multiple-choice and free-response questions along with concept mapping so that I can compare the effectiveness between each assessment type in detecting changes in students' understanding and misconceptions.

3 METHODS

3.1 Overview

The study was conducted in two Maine middle-school classrooms during the University of Maine's spring semester of 2009. The students from the first middle-school classroom (School 'A') were from two classes of 17 and 18 seventh-graders (Classes 1 & 2) and one class of 11 eighth-graders (Class 3). The students from the second middle-school (School 'B') were from six seventh-grade classes (Table 3.1). The teacher at School 'A' indicated that the seventh-grade students in Class 1 are grouped based upon their common higher-level math class, and are considered advanced compared to the students in Class 2 and Class 3, who are considered to be at an average level. The teacher at School 'B' indicated that students in Class 4 are considered advanced compared to the other classes that are considered average.

Table 3.1. Number of participants in the study. All classes are seventh grade except one (Bold) (* denotes "advanced" class).

	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
School 'A'	n = 17*	n = 18	**n = 11**			
School 'B'	n = 9	n = 17	n = 15	n = 25*	n = 18	n = 17

I implemented the activities and assessments for my research for each of the classes at both schools. The students from School 'A' began with a forty-minute lesson on how to make concept maps because the students had never used this type of assessment (described in Section 3.3.1). The students from School 'B' were not given this lesson because their teacher had previously used concepts maps in the classroom. Next, all students were given the same pre-test, followed by approximately twenty minutes of exploration time with the computer model, and finally a post-test that was identical to the pre-test. The pre- and post-tests consisted of three parts: (1) a concept map to explain how the greenhouse effect influences the Earth's temperature, (2) a free-response question about how the Earth's greenhouse effect works, and (3) four (School A) or five (School B) multiple-choice questions from a greenhouse effect concept inventory. The content and application of these instruments are described in detail in the following sections. Students were given approximately fifteen minutes to complete each pre- and post-test, and twenty minutes to explore the computer model. Four students from School 'A', were interviewed after the post-tests to gain a sense of how students were using the computer model to understand the greenhouse effect.

3.2 Pre-test

Students from School 'A' were instructed to complete the pre-test at the beginning of the class period, and students from School 'B' were given the pre-test as an in-class activity a day before they explored the model. All students were given approximately fifteen minutes to complete the pre-test. The pre-test included creating a concept map to explain how the greenhouse effect influences the Earth's temperature, a free-response question about how the Earth's greenhouse effect works, and four (School A) or five (School B) multiple-choice questions from a greenhouse effect concept inventory.

3.2.1 Concept maps

The students created concept maps for the first section of the pre- and post-tests. I included this type of assessment because research has indicated concept maps can measure changes in students' knowledge of complex system relationships over time

(Novak & Gowin, 1984; Ruiz-Primo & Shavelson, 1996; Rye & Rubba, 1998; Rebich & Gautier, 2005). In addition to concept mapping, I used a free-response question and several multiple choice questions to look for patterns in students' thinking and understanding. School 'A' students received a forty-minute lesson, based on Novak's suggestions, to ensure that all students were familiar with how to construct a concept map when they took the pre- and post-tests (Novak & Gowin, 1984). Students from School 'B' had prior experience with making concept maps, so they did not receive this lesson.

The instructional lesson on concept mapping for students in School 'A' began with giving the students an example of a simple concept map, unrelated to the greenhouse effect, to show them typical concepts and linking terms, and how these are graphically organized. The students were given two handouts with fill-in-the-blank concept maps; one required students to fill in missing concepts, and the other required students to fill in missing linking terms (Appendix A). The students participated in class discussions to evaluate the choice of concepts and linking terms that were used in the handouts. Then, the students worked in groups that ranged in size from three to four students to create a new concept map. The seventh-graders created maps about a favorite sport, and the eighth-graders created maps about energy because they had just completed a unit on this topic. The lesson ended with each group sharing their concept maps with the rest of the class.

The pre- and post-test concept mapping instructions were identical, and consisted of a focus question and a word bank of related greenhouse effect concepts. The instructional handout (Appendix B) indicated that students were to:

"Create a concept map that shows how the Earth's greenhouse effect works and how the greenhouse effect influences the Earth's temperature."

The students were also required to use five of the word bank concepts – sunlight, carbon dioxide, infrared light, Earth, and Earth's temperature. The instructions indicated that students could write the concept to the side of their map if they did not know how to include any of these five concepts to their maps. These five concepts were considered to be the core concepts related to how the greenhouse effect influences the Earth's temperature, and were required in the maps because I wanted to assess what the students knew about these specific concepts. Other greenhouse effect concepts (such as atmosphere and Earth's surface) were provided in the word bank, but were not required to be placed in the maps. After students completed their concept maps, they were instructed to complete the free-response and multiple choice questions.

3.2.2 Free-response question

The free-response question was intended to assess students' knowledge about the greenhouse effect. The question on the handout (Appendix C) is:

"*Explain in words how the Earth's greenhouse effect works.*"

The instructions specifically address the Earth's greenhouse effect so that responses to this question can be compared to the concept maps propositions, and to reduce the responses that may describe how a nursery greenhouse may work. Students are typically more familiar with having to complete a written response than making a concept map (Rebich and Gautier, 2005), so the information contained in the students' written responses may provide additional information about their knowledge of the greenhouse effect.

3.2.3 Multiple-choice questions

The students from School 'A' were given four multiple-choice questions (Questions 2 – 5 in Appendix D) based on a selection of questions from the Greenhouse Effect Concept Inventory (GECI) created by John Keller for his doctoral thesis research at the University of Arizona (Keller, 2006). I created a fifth question (Question 6 in Appendix D) that addressed the role of carbon dioxide in the greenhouse effect after I had noticed students from School 'A' were having difficulty in describing how the carbon dioxide molecules interacted with other variables in the system. This additional question was only given to the students from School 'B'. All of the multiple-choice questions addressed variable relationships in the model and also included common misconceptions as distracters.

Multiple-choice Question 2 asked students to predict what would occur if the concentration of carbon dioxide in the atmosphere continues to rise (Figure 3.1). There

2. Scientists have proposed that the burning of fossil fuels increases the concentration of carbon dioxide (CO_2) in the atmosphere. Which of the following is predicted to occur if the concentration of CO_2 continues to rise?

   a) Earth's surface will have increased exposure to ultraviolet rays.
   b) The average annual surface temperature will increase.
   c) Animals will be harmed by breathing the higher levels of CO_2.
   d) The ozone layer will disappear.
   e) There will be no change to the Earth's climate system.

Figure 3.1. Multiple-choice Question 2. Correct response is (b).

were five choices to choose from, and the correct response is (b) that scientists predict Earth's surface temperature would continue to rise with increasing amounts of carbon dioxide. Two of the other responses addressed the misconception students have that carbon dioxide decreases the ozone layer (answers (a) and (d)), which would allow more ultraviolet light to reach the Earth's surface, and that the greenhouse effect does not exist (answer (e)) (Rebich & Gautier, 2005). Researchers suggest this response may be due to confusion about global warming controversy. I did not find research on why students may believe increasing carbon dioxide would hurt animals, although I decided to include this choice since it was an original option from the GECI. Students have the opportunity to use the model to observe that the Earth's temperature increases when increasing amounts of carbon dioxide is added into the atmosphere.

Multiple-choice Question 3 assesses whether students know if the greenhouse effect is a naturally occurring phenomenon that has existed before human civilization (Figure 3.2). The correct response indicates the greenhouse would exist even if human civilization never developed on Earth and that the greenhouse effect is caused by

3. If human civilization had never developed on Earth, would there be a greenhouse effect?

   a) Yes, the greenhouse effect is caused by naturally occurring gases in the atmosphere.
   b) Yes, the greenhouse effect is caused by plants giving off gases during photosynthesis.
   c) No, the greenhouse effect is caused by humans burning fossil fuels and releasing pollutants.
   d) No, the greenhouse effect is caused by humans depleting ozone in the atmosphere.
   e) No, there is no conclusive evidence that a greenhouse effect exists.

Figure 3.2. Multiple-choice Question 3. Correct response is (a).

naturally occurring gases in the atmosphere. The alternate responses include the misconceptions that students believe the greenhouse effect only existed since humans began burning fossil fuels, thus increasing the amount of carbon dioxide in the atmosphere, which depletes the ozone layer. Answer (e) tests the idea that the greenhouse effect does not exist, similar to choice (e) in the previous question. I did not find research that indicated students thought the greenhouse effect is caused by gases plants give off during photosynthesis, but I decided to leave this choice since it was an original option in the GECI. Next to the buttons to increase and decrease the amount of carbon dioxide molecules in the model, carbon dioxide values are given (in parts per million) for various stages of Earth's development, such as ice-age, 1750, and today. Comparing these values could result in an observation that the greenhouse effect occurred before human civilization, although it does not specifically address where the carbon dioxide molecules come from.

Multiple-choice Question 4 assess what characteristics students think are present when a planet has a greenhouse effect (Figure 3.3). Students' have difficulty understanding the energy balance between incoming sunlight and transmitted infrared energy, which, when balanced, results in a steady-state temperature. The correct

4. A planet that has a greenhouse effect

   a) receives more ultraviolet (UV) sunlight because it lacks ozone in its atmosphere.
   b) has an atmosphere that absorbs and then gives off certain forms of energy but not all.
   c) receives more energy because it is closer to the sun.
   d) has an atmosphere that has been changed by living organisms.
   e) does not give off any energy away into outer space.

Figure 3.3. Multiple-choice Question 4. Correct response is (b).

response, (b), is that a planet that has a greenhouse effect has an atmosphere that absorbs and then gives off certain forms of energy but not all. Response (a) tests the belief that ozone in the atmosphere is deteriorated by the greenhouse effect, which would result in more UV sunlight reaching the planet. The model shows how the Earth's temperature can reach a steady-state condition when the amount of incoming sunlight is balanced with outgoing sunlight and infrared energy.

Multiple-choice Question 5 assesses what students believe to be the relationship between global warming and the greenhouse effect (Figure 3.4). Students may not distinguish between the two terms and regard them as the same phenomenon (Rebich *et al.* 2006). This can also result in confusion about whether global warming contributes to the greenhouse effect or, correctly, whether the greenhouse effect contributes to global warming. There are also choices for students who may believe global warming and the greenhouse effect does not exist or are not related. The model shows how the Earth's temperature is proportional to the amount of carbon dioxide in the atmosphere, but does

5. Which of the following best describes the relationship between the greenhouse effect and global warming?

   a) The greenhouse effect and global warming are the same thing.
   b) An increase in the greenhouse effect may be causing global warming.
   c) Global warming may be causing an increase in the greenhouse effect.
   d) The greenhouse effect and global warming are likely unrelated.
   e) There is no definite proof that either the greenhouse effect or global warming exist.

Figure 3.4. Multiple-choice Question 5. Correct response is (b).

not account for warming that may result from forcing factors other than the greenhouse effect, nor does it distinguish the *source* of the increased atmospheric carbon dioxide.

Multiple-choice Question 6 was added after I noticed students from School 'A' indicating that the carbon dioxide molecules reflected the infrared energy and solar energy (Figure 3.5). The students from School 'A' who were interviewed said that they could see the yellow and red arrows (sunlight and infrared) being reflected by the carbon

6. Increasing levels of carbon dioxide in the atmosphere will result in:

   a) A larger ozone hole that will allow more sunlight to reach the Earth's surface.
   b) More sunlight and infrared energy to be reflected down to the Earth's surface.
   c) A decrease in the Earth's temperature.
   d) More infrared energy to be reflected down to the Earth's surface.
   e) No change in the Earth's surface temperature.

Figure 3.5. Multiple-choice Question 6. Correct response is (d).

dioxide molecules. This observation was a concern because the model only shows infrared energy (red arrows) being reflected by the carbon dioxide molecules. The incorrect responses ((a), (b), (c), and (e)) include the ozone hole misconception and other incorrect ideas that I heard students pose during the study done at School 'A'. Some students said that increasing the amount of carbon dioxide would result in decreasing the Earth's temperature or no effect to the Earth's temperature ((c) and (e)). I noticed that the students that responded with either (c) or (e) had adjusted the amount of sunlight or reflectivity so low that no sunlight was being absorbed into the Earth's surface.

3.3 Exploring the model

3.3.1 Procedure

After completing their pre-test, students were given approximately twenty minutes to explore the model. All students were given a handout (Appendix D) and brief verbal instructions to explain the interface. Students received two guiding instructions to focus their exploration. The initial guiding instruction was, "use the model to determine how each of the variables affected the Earth's temperature" (i.e. Does carbon dioxide in the atmosphere cause the temperature to increase or decrease?). Once students had begun to verbally suggest how some of these variables affected the Earth's temperature, they were instructed to "determine *how* and *why* these variables affected the Earth's temperature." This second set of instructions were given to help the students focus on how each of the variables interacted with each other, and how those interactions affected the Earth's overall temperature. During this exploration period, I did not give feedback to the students indicating whether they were right or wrong about their observations or conclusions. When the students asked for confirmation, they were told to explain their observations from the model or to discuss their conclusions with a classmate. I did answer technical questions concerning how to use the model's interface or any technical issues that arose when loading the program.

3.3.2 Greenhouse effect computer model

The computer model used in this study is based on the Climate Change model currently in the 4.0.4 version of NetLogo (Wilensky, 2007). The NetLogo Climate Change model interface was slightly modified to make it more user-friendly for middle-school students and renamed the Greenhouse Effect model, which will be further referenced just as the “model” (Figure 3.6).

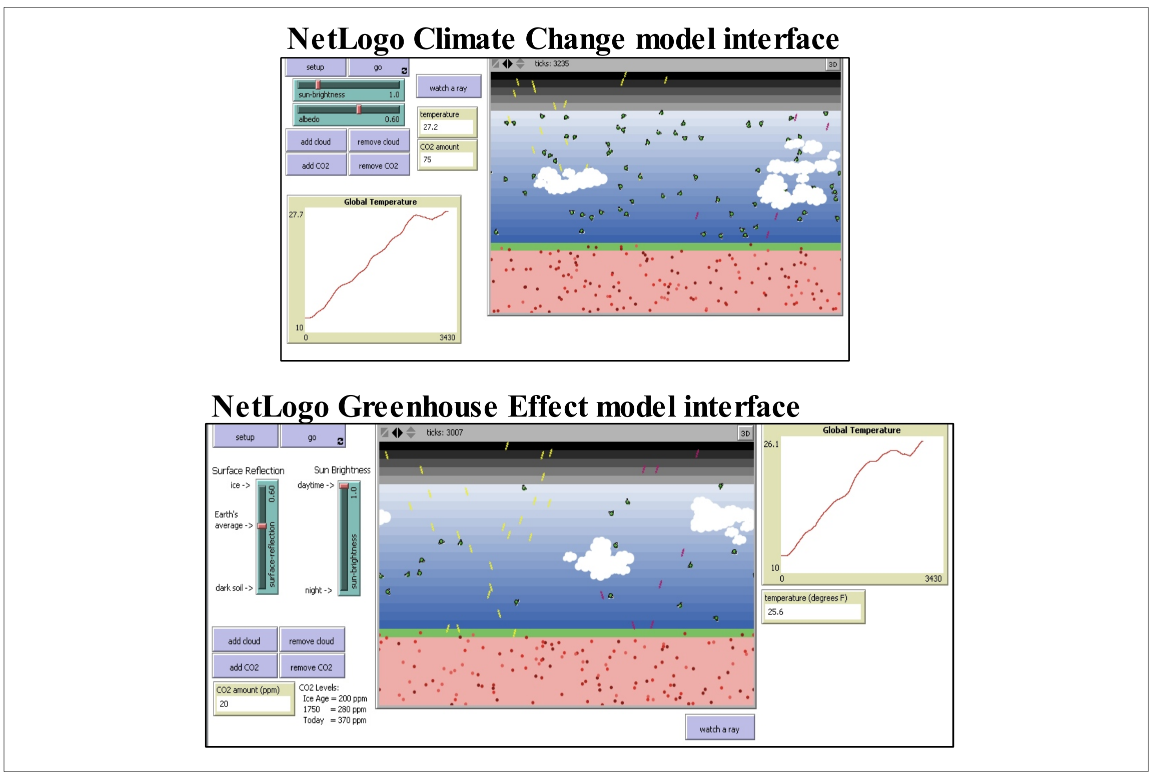


Figure 3.6. Comparison of original NetLogo Climate Change model interface (top) to Greenhouse Effect model interface (bottom) – modified to be more user-friendly.

The model's interface has buttons and sliders that allow students to modify variable parameters including surface reflection, sun brightness, amount of clouds, and amount of carbon dioxide in the atmosphere. The display portion of the interface shows a cross-section of the Earth's atmosphere and surface. The top of the atmosphere is black, which represents outer space. The blue portion represents the atmosphere where clouds and greenhouse gases may exist. The outer-most surface of the Earth is initially green representing the surface of the Earth. Below the surface is a pink area representing the Earth's mass where the Earth's heat energy is stored. The reflectivity of the Earth's surface can be modified with the surface reflectivity slider, which affects the surface color (i.e. ice is white and dark soil is black).

Once the 'setup' and 'go' buttons have been pushed, yellow arrows from space begin to head towards Earth's surface. These arrows represent sunlight, and the amount of sunlight can be modified using a slider that ranges from day to night. When the sunlight reaches the Earth's surface, some of the light is reflected back into the atmosphere, while some is absorbed into the surface depending on the surface reflectivity setting. The absorbed sunlight is represented by small red and pink dots (Earth's heat energy) under the surface, and the proportion of red dots increases as the amount of incoming sunlight increases. When the Earth's heat energy has reaches a threshold, which is determined by the model's program, the heat energy leaves Earth's surface as infrared energy (red arrows) into the atmosphere. The amount of radiated infrared energy is proportional to the heat energy of the Earth. The interface also has a graphic output that plots the Earth's heat energy, measured in degrees Fahrenheit, as time progresses. Below the temperature plot is an output box that displays the instantaneous temperature of the Earth's heat energy.

In addition to being able to modify the surface reflectivity and incoming sunlight, students can add clouds and carbon dioxide molecules to the atmosphere to investigate how these parameters affect the Earth's temperature displayed in either the graphic plot or in the instantaneous output box. The clouds reflect the sunlight and the infrared energy, but the carbon dioxide molecules reflect *only* the infrared energy. When either the solar or infrared energy is reflected back to the Earth's surface, the rays may be absorbed into the surface and increase the Earth's temperature.

3.4 Post-test

The post-test was given immediately after the students had completed the twenty-minute exploration of the model. The post-test was identical to the pre-test, and students were given approximately twenty minutes to complete the post-test. Students were allowed to use interface handout as a reference to answer the post-test questions.

3.5 Interviews

I interviewed four students individually from School 'A' after they had completed their post-tests. One male and one female, from each of the seventh-grade and eighth-grade classes (Class 1 and Class 3 from Table 3.1) voluntarily participated in the video-taped interviews after they had returned parental permission slips (Appendix E). The interviews were conducted in an empty classroom at School 'A' and lasted approximately ten minutes each.

The interview followed a scripted protocol using the following questions as a guide:

1. How did you explain how the greenhouse effect influences the Earth's temperature on the pre-test?
2. What did you try to do with the model when you first opened it?
3. What did you notice in the model when you:
   a) Changed the amount of carbon dioxide in the atmosphere?
   b) Changed the surface reflectivity?
   c) Changed the amount of sunlight?
   d) Added clouds?
4. How do you explain the changes to the Earth's temperature when those variables were changed?
5. Describe in your own words how the greenhouse effect works.
6. Do you have any suggestions to make the model better or more fun?

Students were asked to explain their responses to gain a better understanding of their thinking for each of these questions. The students had the computer model running on a laptop so that they could use the model to justify their answers. The students were asked questions related to the model's ease of use and how the students would modify the model to be more useful or fun. The responses to these latter questions will be given to the IDEAS team for future model development. The interviews were videotaped and later transcribed for analysis (Appendix F).

3.6 Data analysis

3.6.1 Overview

The student's responses to the pre- and post-assessments were scored, and the scores were entered into a Microsoft® Excel (2007) spreadsheet and analyzed using the statistical program R (2009). This chapter describes the scoring process for each assessment type, the testable research questions, and the statistical tests that were used.

3.6.2 Scoring the concept maps and free-response questions

The concept maps and free-response questions were scored based on the presence of specific propositional statements. Initially an expert concept map (Figure 2.1) was used to create an initial list of propositional statements that describe how the mechanisms simulated by the greenhouse effect computer model interact to influence the Earth's temperature. These propositional statements focused on the effects of sunlight, carbon dioxide, infrared energy, and reflectivity on the Earth's temperature. After reviewing a sample of student's concept maps and free-response answers, additional propositional statements were added to the list because some of the students' responses included part of the expert statement, but not all. For example, an expert propositional statement would be, "Earth's heat energy (temperature) increases when sunlight is absorbed into the surface." Student responses may only include part of that statement, like "sunlight affects the Earth's temperature" or "sunlight is absorbed into the Earth's surface." The list of propositions included in the final scoring guide (Appendix G) are a combination of the expert's and students' propositional statements (Table 3.2).

Table 3.2. Scored propositional phrases

Code	Propositional Phrase	Weight	Source
Greenhouse Effect			
G1	GE affects or increases Earth's temperature.	x 1	Student
G2	Greenhouse gases trap heat (energy)	x 1	Student
Sunlight			
S1	Sunlight can be absorbed into Earth's surface.	x 1	Expert
S2	Sunlight affects the Earth's temperature.	x 1	Student
S3	Sunlight is reflected by clouds.	x 1	Expert
Carbon Dioxide			
C1	Increasing CO2 increases the Earth's temperature (heat energy).	x 5	Expert
C2	CO2 affects Earth's temperature.	x 1	Student
C3	CO2 is reflects and/or absorbs infrared energy.	x 5	Expert
C4	CO2 lets sunlight through.	x 5	Expert
C5	CO2 is a greenhouse gas.	x 1	Expert
C6	CO2 is a gas in the atmosphere.	x 1	Expert
Infrared Light			
I1	IR energy is radiated from Earth's surface.	x 5	Expert
I2	Amount of IR radiated from surface is proportional to amount of heat energy.	x 5	Expert
I3	IR can be absorbed into Earth's surface.	x 1	Expert
I4	IR energy affects the Earth's temperature.	x 1	Student
Earth's Heat Energy			
T1	Earth's heat energy (temperature) increases when sunlight is absorbed into Earth's surface.	x 5	Expert
T2	Earth's heat energy (temperature) increases when IR energy is absorbed into surface.	x 5	Expert
T3	Earth's temperature decreases when heat energy is radiated to IR energy.	x 5	Expert
Reflectivity			
R1	Surface reflection affects amount of sunlight and/or IR absorbed into Earth's surface.	x 5	Expert

The propositional statements that represent a greater level of understanding of important system relationships represented in the model were given a higher weight. The weighting scheme is a way of ranking the quality of the students' responses. Common misconceptions from the literature review were also recorded on the scoring guide to track the presence of these ideas. Scores were not lowered by the presence of misconceptions because the pre- and post-scores were to be compared to detect if there were gains in understanding about how the greenhouse effect works. Even though students may have misconceptions, they may correctly understand a portion of how the greenhouse effect influences the Earth's temperature.

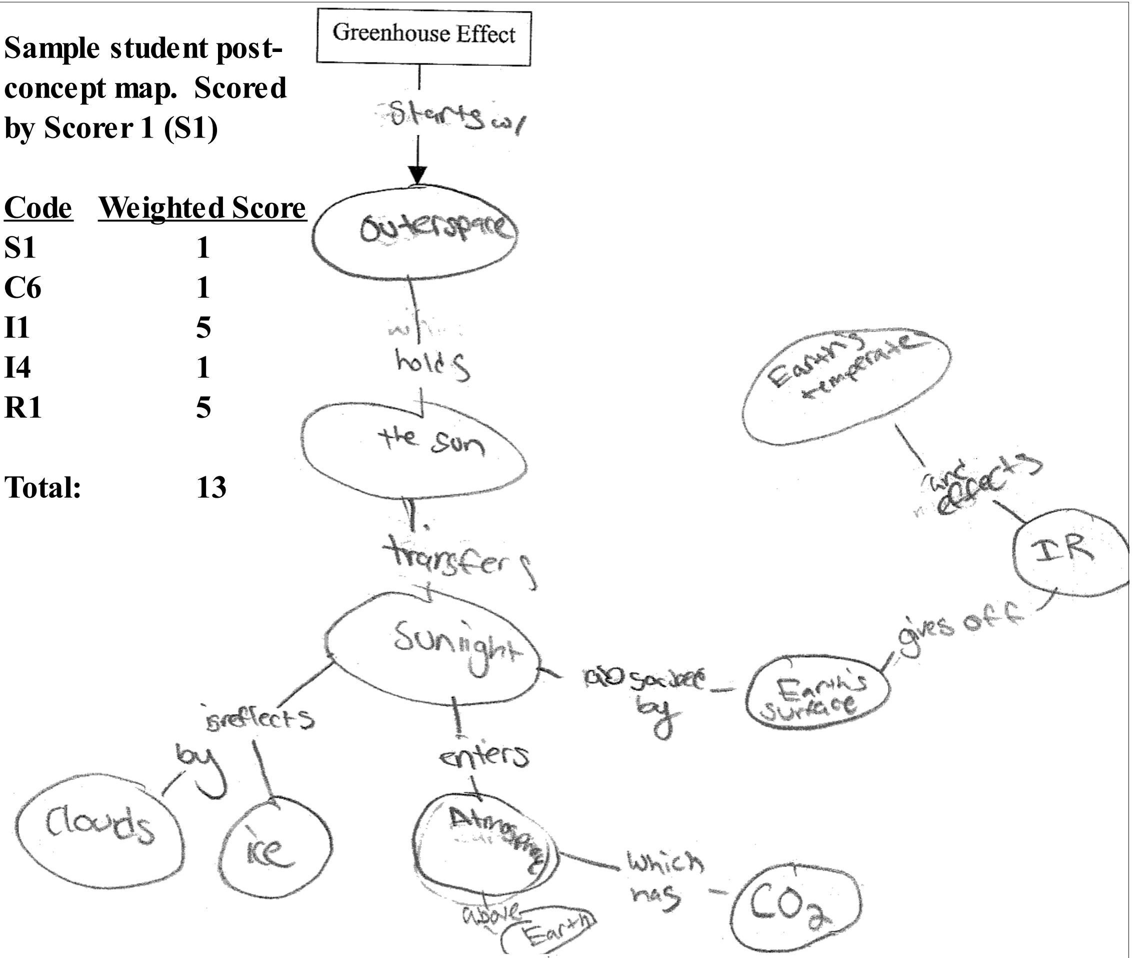
Assessing concept maps and free-response questions involves a degree of interpretation, and therefore the scores are subject to inter-reliability variability. The scoring guide was checked for scoring consistency before the final scoring of the pre- and post-responses. Ten each of the pre- and post-concept maps and pre- and post-free-response answers were scored by myself and another graduate student working on the IDEAS project. A paired two-tailed t-test of the mean scores for each pre- and post-assessment resulted in no significant differences using a confidence level of $\alpha = 0.05$ (Table 3.3), therefore I proceeded to score the remaining pre- and post-tests. Examples given in Figure 3.7).

Table 3.3. Inter-reliability data. No sig. differences between mean scores from Scorer 1 (S1) and Scorer 2 (S2) of the same sub-samples of tests. (p-values > 0.05).

	Concept Map				Free-Response			
	Pre S1	Pre S2	Post S1	Post S2	Pre S1	Pre S2	Post S1	Post S2
Mean (n = 10)	0.9	1.3	2.7	2.2	0.1	0.2	4.0	2.9
p-value	0.462		0.413		0.343		0.292	

Sample student post-concept map. Scored by Scorer 1 (S1)

Code	Weighted Score
S1	1
C6	1
I1	5
I4	1
R1	5
Total:	**13**



1. Explain in words how the Earth's greenhouse effect works.

Sunlight comes down to the Earth. It bounces off, or stays in the Earth. It then comes out as IR. It then can go into Space. If not, It bounces off of CO_2 and repeats the process until it goes into outer space

Sample of a student's post free-response question. Scored by Scorer 1 (S1)

Code	Weighted Score
S1	1
C3	5
I1	5
R1	5
Total:	**16**

Figure 3.7. Sample of a scored seventh-grade student's post- concept map (top) and seventh-grade student's post free-response question (bottom) (different students).

In addition to analyzing differences in pre- and post-mean scores for the concept maps, free-response questions, and multiple-choice questions, the gains in understanding as a result of using the model were assessed by comparing students' normalized gains for each of these assessments. Normalized gain, <g>, is the ratio of the change between the pre- and post-scores and compared to the maximum possible improvement:

$$\langle g \rangle = \frac{(\,post - pre\,)}{(\,perfect\ score - pre\,)}$$

The perfect score was based upon the score of the expert concept map, and was used for calculating the normalized gain for the concept maps and free response questions.

3.6.3 Scoring the multiple-choice questions

Students' multiple-choice responses were entered into a spreadsheet, and the sum of the correct number of responses resulted in an overall score. The students' from School A completed Questions 2 – 5, and students' from School B completed Questions 2 - 6. Because School B completed an additional question, two post-test scores were calculated for School B. One of the scores included the same questions answered by School A (2 – 5), and the other included all of the questions (2 – 6). The pre- and post-test scores were compared along with the normalized gains to determine if there were significant differences between the mean scores. In addition to an analysis of overall multiple-choice scores, the frequency of the responses for each question were tallied and compared between pre- and post-assessments.

3.6.4 Interview data

Transcripts from the interviews were analyzed for any additional information that could provide further insight into students' responses from the other assessments. Selected excerpts from these interviews will be presented as key examples of students' reasoning about what students know about the greenhouse effect and what the students were able to learn using the model. The names of the students were changed to protect their identity. The seventh-grade students were "Jay" and "Bea", and the eighth-grade students were "Anna" and "Roger". Complete transcripts of the students' interviews are in Appendix F.

3.6.5 Testable research questions and statistical tests

The data gathered in this study were analyzed using parametric tests to evaluate significant differences between pre- and post-test scores and to determine if results correlate among the different assessments. The testable research questions are listed, along with the statistical test used, below the corresponding original research questions from Section 1.4:

1. Did students gain a better understanding of system relationships pertaining to the greenhouse effect after using the model?
   a) Were the pre-test scores between each school, grade and class equivalent for each assessment type? (Analysis of Variance)
   b) Did students' scores change significantly pre- to post-test for each assessment type? (Paired one-tailed *t*-tests and percentage of frequencies of students' responses for each question)

c) What effect did twenty minutes of exploring the model have on normalized gain for each assessment type? (Independent two-tailed *t*-test)

2. To what extent were students' misconceptions and difficulties congruent with previous research?

    a) What misconceptions did students have on the pre- and post-tests? (Percentage of frequencies of misconceptions for each question)

    b) Did the frequency of misconceptions change after using the model? (Paired two-tailed *t*-test)

3. Are concept maps an effective assessment tool to measure student understanding and detect misconceptions?

    a) Did the concept map scores correlate to the free-response scores? (Pearson's correlation coefficient and paired *t*-tests)

An additional question was posed to determine if there was a difference in understanding between genders.

4. Did gender make a difference on normalized gain and post-test scores? (Analysis of variance)

Summaries of the raw scores from each assessment type are in Appendix H.

4 RESULTS

4.1 Overview

The results for the testable questions (Section 3.6.5) are presented in this chapter to address the following research questions:

1. Did students gain a better understanding of system relationships pertaining to the greenhouse effect after using the model?
2. To what extent were students' misconceptions and difficulties congruent with previous research?
3. Are concept maps an effective assessment tool for measuring student understanding and detecting misconceptions?

Discussion of the results to the testable questions and how they relate to the research questions are included in the next chapter (Section 5).

4.2 Are the groups equivalent?

The student participants in this study came from two public middle schools – one eighth grade glass (n = 11) and eight seventh grade classes (n = 136). The first testable question asks whether there are any significant differences in the pre-test scores between schools, grade levels, and individual classes. Analysis of variance of the pre-test scores was performed between schools, grade levels and among classes for each assessment: concept maps, free-response, and multiple-choice questions. For this analysis, only the multiple-choice Questions 2 – 5 were considered for School B because students from School A did not answer Question 6. The null hypothesis for this analysis is that there is no significant difference between the groups with a confidence level of $\alpha = 0.05$.

The first analysis determined if there was a significant difference between pre-test scores between schools. Students' mean pre-test scores were not significantly different for the concept maps and free-response assessments, but were significantly different for the multiple-choice questions (Table 4.1).

Table 4.1. Comparison of pre-test scores between schools. Bold p-value indicates there was a significant difference between groups ($p < 0.05$).

	Mean Pre-test Scores (n = 147)		
	Concept Map	Free-Response	Multiple choice
School A (n = 46)	1.26	0.50	0.76
School B (n = 101)	0.76	0.85	1.15
p-value	0.111	0.203	**0.016**

The next analysis determined if there was a significant difference between the pre-test scores between grade levels. Table 5.2 shows the mean pre-test scores for each assessment and the associated p-value. Eighth-grade students scored significantly higher than the seventh-grade students for the concept maps and free-response questions, but not for the multiple-choice questions (Table 4.2).

Table 4.2. Comparison of pre-test scores between grades. Bold p-value indicates there was a significant difference between groups ($p < 0.05$).

	Mean Pre-test Scores (n = 147)		
	Concept Map	Free-Response	Multiple-choice
7^{th} Grade (n = 136)	0.71	0.66	1.03
8^{th} Grade (n = 11)	3.45	1.73	1.00
p-value	**< 0.000**	**0.028**	0.918

I was also interested to see if there was a significant difference between the pre-test scores among each of the classes. A p-value from the analysis of variance less than 0.05 indicates a significant difference between the classes, although the analysis does not show which of the classes are significantly different. Students mean scores were significantly different among classes (Table 4.3).

Table 4.3. Comparison of pre-test scores between classes. Bold p-value indicates there was a significant difference between groups ($p < 0.05$). (* indicates advanced class)

	Mean Pre-test Scores (n = 147)		
	Concept Map	Free-Response	Multiple choice
Class A1* (n = 17)	0.88	0.24	0.65
Class A2 (n = 18)	0.27	0.00	0.72
Class A3 (n = 11)	3.45	1.73	1.00
Class B1 (n = 9)	0.44	0.67	1.44
Class B2 (n = 17)	0.29	1.59	1.41
Class B3 (n = 15)	0.73	0.87	1.27
Class B4* (n = 25)	1.52	1.00	1.24
Class B5 (n = 18)	0.11	0.22	0.500
Class B6 (n = 17)	1.00	0.65	1.18
p-value	**< 0.000**	**0.0150**	**0.01179**

The analyses that compared the pre-test scores to school, grade level, and class indicated there were significant differences between the mean pre-test scores (Table 4.4).

Table 4.4. Summary of significant differences between mean scores among groups.

	Significant differences in mean scores among groups		
	School	Grade	Class
Concept map	No	Yes	Yes
Free-response	No	Yes	Yes
Multiple-choice	Yes	No	Yes

Equivalence among groups is critical in educational research studies where there is a comparison between an experimental and control group. For example, when comparing the effectiveness of an inquiry-based versus traditional curriculum, the groups should have similar levels of understanding in order to suggest the treatment was more effective. My research did not compare two treatments, but rather investigated how middle-school students' understanding changed as a result of using a computer model. Significant differences detected in students' pre-test scores among groups indicate the population of students in my study have range of abilities and prior knowledge, and the results from this study apply to a general population of middle-school students.

4.3 How did students' understanding change after exploring the model?

A paired one-tailed *t*-test was used to detect if the mean post-test scores were significantly greater than the mean pre-test scores for each assessment type. The analysis compared the scores of all students (n = 147). Only Questions 2 – 5 will be considered for the multiple choice assessment, as School A did not complete Question 6. Students scored significantly higher on the three post-test assessments (Table 4.5).

Table 4.5. Comparing pre- and post-test scores. Bold p-values indicate the post-test scores were significantly greater than the pre-test scores. ($p < 0.05$)

	Mean Pre- and Post-Test Scores (n = 147)		
	Concept Map	Free-Response	Multiple choice
Pre-Test	0.92	0.74	1.03
Post-Test	3.10	6.90	1.63
p-value	**< 0.000**	**< 0.000**	**< 0.000**

Because there were significant differences between the mean pre-test scores between the grade levels, I completed a paired one-tailed *t*-test on the pre- and post-test scores for each grade. The mean post-test scores for all of the seventh-grade assessments, and for the eighth-grade free-response questions were significantly greater than the pre-test scores (Table 4.6). The eighth-grade concept map and multiple-choice post-test mean scores were not significantly different from the pre-test mean scores.

Table 4.6. Comparing pre- and post-test scores between grades. Bold p-values indicates there was a significant difference between pre- and post-test scores. ($p < 0.05$)

	Mean Pre- and Post-Test Scores (n = 147)		
	Concept Map	Free-Response	Multiple choice
7th Grade Pre-Test (n = 136)	0.71	0.66	1.03
7th Grade Post-Test (n = 136)	2.93	7.01	1.64
p-value	**< 0.000**	**< 0.000**	**< 0.000**
8th Grade Pre-Test (n = 11)	3.45	1.73	1.00
8th Grade Post-Test (n = 11)	5.18	5.45	1.45
p-value	0.074	**0.013**	0.176

I compared the pre- and post-test scores between the students in the advanced classes (Class A1 and Class B4) and students in the remaining classes (Table 3.1). There were no significant differences between the mean pre-test scores between the advanced and the average students (Tables 4.7 – 4.9). The advanced and average students mean scores significantly increased from the pre- to post-test for each assessment type, although the advanced students increased their scores significantly more than the average students. The advanced and average students had significant normalized gains in all the assessments, but the advanced students had greater normalized gains than the average students for the concept maps and free-response assessments. There was no significant difference between the advanced and average students multiple-choice normalized gains.

Table 4.7. Comparison of concept map scores between advanced and average students. Bold p-values indicates there was a significant difference between pre- and post-test scores. ($p < 0.05$) [1]Independent one-tailed *t*-test. [2]Paired one-tailed *t*-test. [3]Independent two-tailed *t*-test.

	Concept Map Mean Scores				
	Pre	Post	p-value[2] (Same group)	<g>	p-value[3] <g> (Same group)
Advanced n = 42	1.26	5.50	**< 0.000**	0.12	**< 0.000**
Average n = 105	0.78	2.13	**< 0.000**	0.04	**0.001**
p – value[1] (Between groups)	0.066	**0.001**		**0.002**	

Table 4.8. Comparison of free-response scores between advanced and average students. Bold p-values indicates there was a significant difference between pre- and post-test scores. ($p < 0.05$) [1]Independent one-tailed *t*-test. [2]Paired one-tailed *t*-test. [3]Independent two-tailed *t*-test.

	Free-Response Mean Scores				
	Pre	Post	p-value[2] (Same group)	<g>	p-value[3] <g> (Same group)
Advanced n = 42	0.69	8.6	**< 0.000**	0.23	**< 0.000**
Average n = 105	0.76	6.22	**< 0.000**	0.15	**< 0.000**
p – value[1] (Between groups)	0.379	**0.020**		**0.016**	

Table 4.9. Comparison of multiple-choice scores between advanced and average students. Bold p-values indicates there was a significant difference between pre- and post-test scores. ($p < 0.05$) [1]Independent one-tailed *t*-test. [2]Paired one-tailed *t*-test. [3]Independent two-tailed *t*-test.

	Multiple-Choice Mean Scores				
	Pre	Post	p-value[2] (Same group)	<g>	p-value[3] <g> (Same group)
Advanced n = 42	1.00	1.71	< **0.000**	0.21	**0.001**
Average n = 105	1.04	1.59	< **0.000**	0.13	**0.002**
p – value[1] (Between groups)	0.411	0.261		0.132	

In addition to determining if there were significant differences between the pre- and post-test scores, I wanted to look qualitatively at how students' responses changed for each of the assessments. The concept maps and free-response questions were scored based upon the presence of propositional phrases (Table 3.2) related to how the greenhouse effect influences the Earth's temperature. Figure 4.1 shows the frequency of propositional responses from the pre- and post-concept maps and free-response questions.

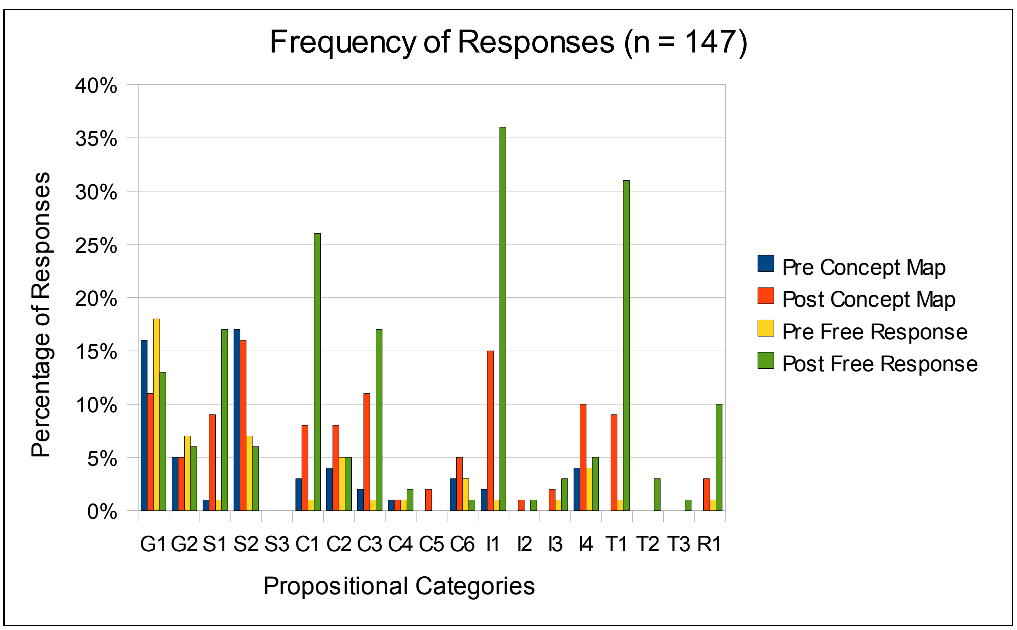


Figure 4.1. Frequency of propositional responses

The pre- and post-test responses for each of the multiple-choice questions resulted in significant increases in the frequency of the correct responses from the pre-test to the post-test for Questions 2 – 5, and indicated the presence of students' misconceptions (Table 4.10 and Figures 4.2 – 4.6). Only students from School B answered Question 6. All of the questions had five possible responses (A – E), although some students did not answer the questions or wrote, “I don't know.”

Table 4.10. Percent increase of correct responses from pre- to post-test for multiple-choice questions. Bold p-values indicate a significant increase. ($p < 0.05$)

	Question 2	Question 3	Question 4 (n = 147)	Question 5	Question 6 (n = 101)
% increase of correct response	16%	20%	14%	9%	6%
p-value	**< 0.000**	**< 0.000**	**0.001**	**0.021**	0.100

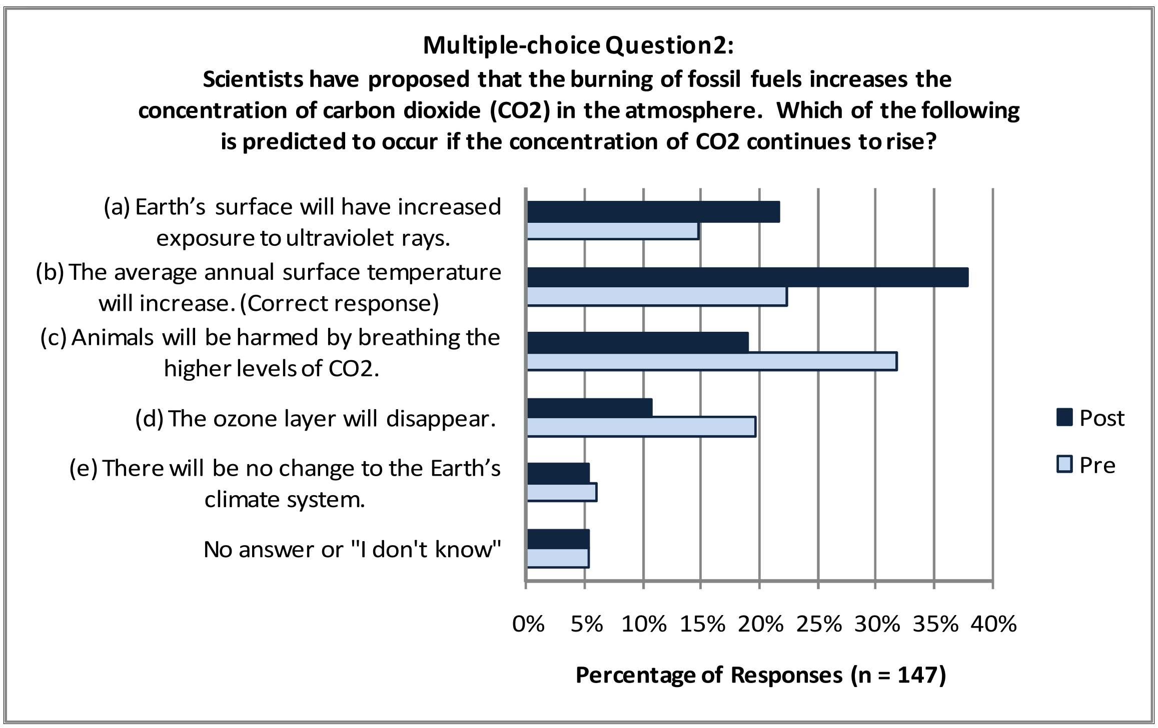


Figure 4.2. Multiple-choice Question 2. Frequency of pre- and post-test responses.

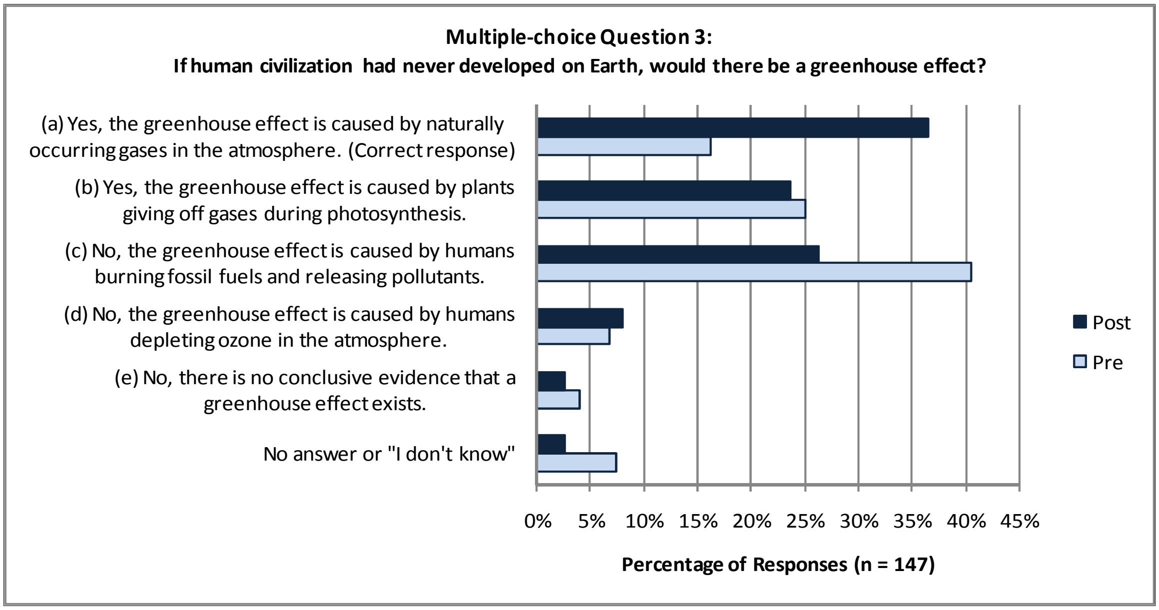


Figure 4.3. Multiple-choice Question 3. Frequency of pre- and post-test responses.

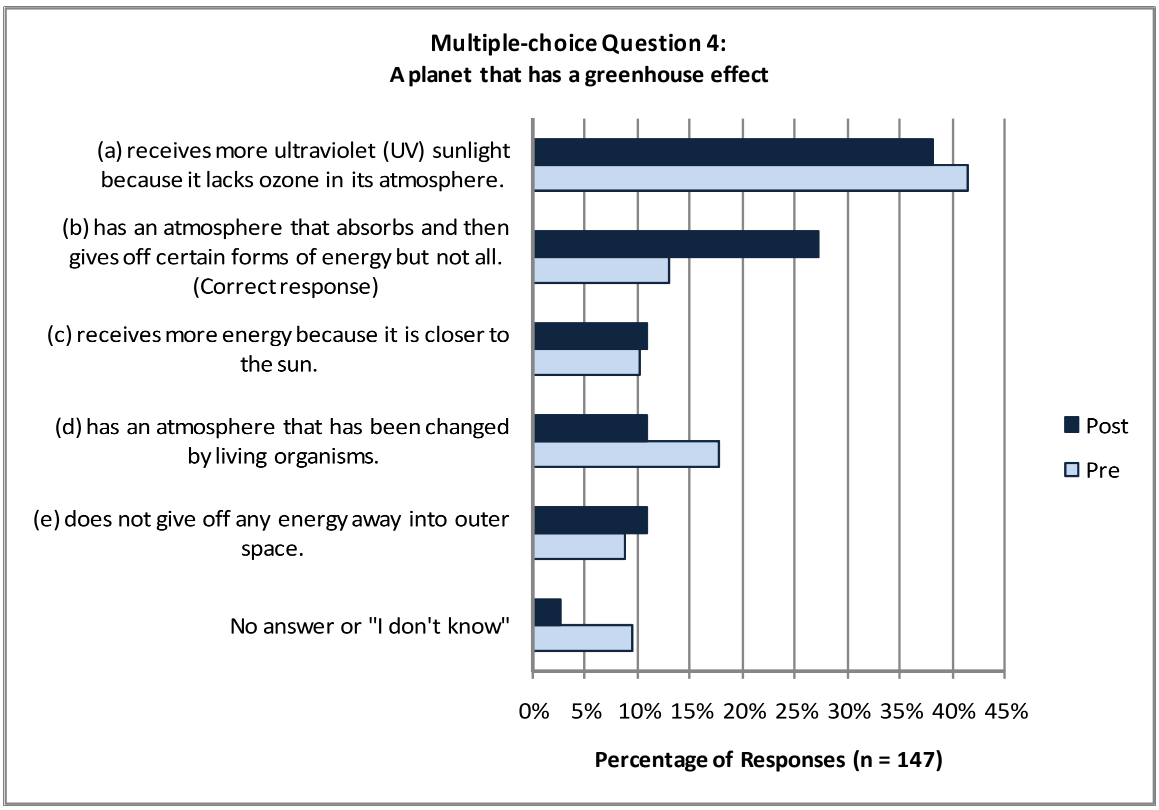


Figure 4.4. Multiple-choice Question 4. Frequency of pre- and post-test responses.

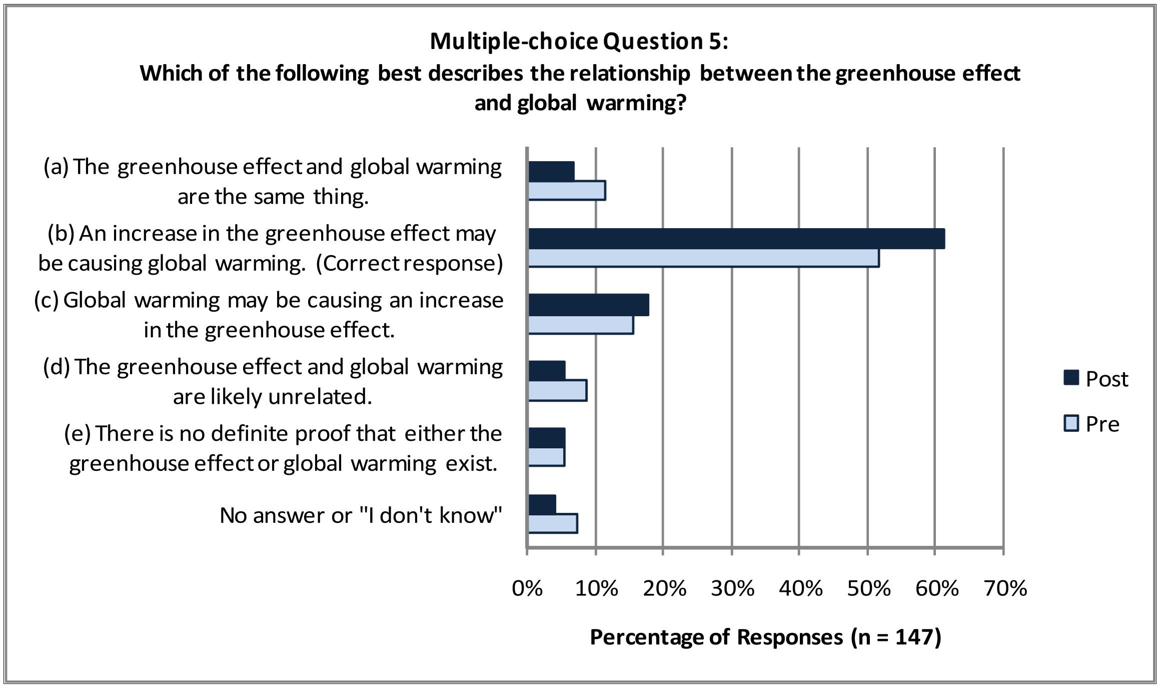


Figure 4.5. Multiple-choice Question 5. Frequency of pre- and post-test responses.

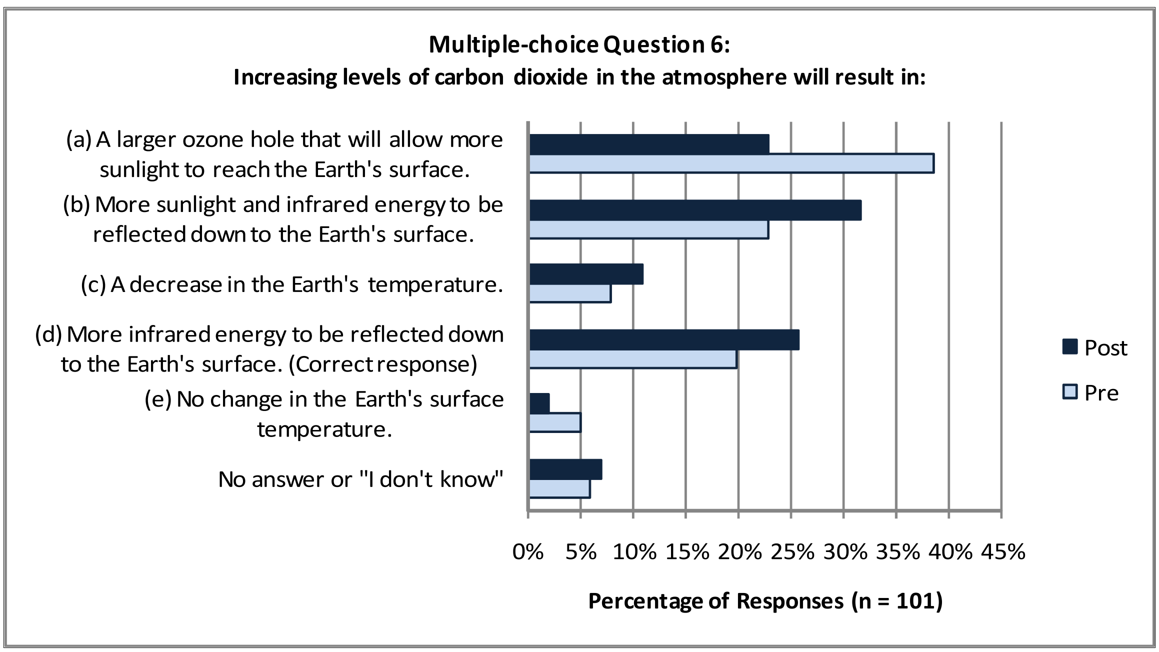


Figure 4.6. Multiple-choice Question 6. Frequency of pre- and post-test responses.

4.4 Normalized gain

Normalized gain, <g>, is a ratio of the change from pre- to post-test score compared to the maximum possible improvement. This measurement indicates the change in understanding because it takes into account prior knowledge. Normalized gain ranges from -1 to 1, where zero indicates no change from pre- to post-test. An independent one-tailed *t*-test was performed on the <g> values for each assessment type with the null hypothesis that the mean of the <g> values is zero. All of the mean <g> values are positive and significant, indicating students' gained understanding between the pre- and post-tests (Table 4.11).

Table 4.11. Mean normalized gain between pre- and post-tests. Bold p-values indicate <g> scores are significant. ($p < 0.05$)

	Mean Normalized Gain <g> (n = 147)	
	Mean <g>	p-value
Concept Map	0.06	**< 0.000**
Free-Response	0.18	**< 0.000**
Multiple-Choice	0.16	**< 0.000**

Because the pre-test scores differed between the grade levels, I wanted to determine if there was a significant difference between the normalized gain between these two groups. The null hypothesis is that there is no significant difference in normalized gain scores between grades with a confidence level of $\alpha = 0.05$. The p-levels were greater than 0.05, thus the normalized gain scores between grades are not significantly different (Table 4.12).

Table 4.12. Comparison of mean normalized gain scores between grades. No significant differences between scores were detected. ($p < 0.05$)

	Mean Normalized Gain <g>		
	Mean 7th <g> (n = 136)	Mean 8th <g> (n = 11)	p-value
Concept Map	0.06	0.04	0.6473
Free-Response	0.18	0.10	0.1435
Multiple-Choice	0.17	0.00	0.2032

4.5 How well do concept maps assess understanding?

To answer this question, I initially performed a Pearson's correlation analysis between the concept map and free-response scores to determine the degree of association between responses to the two assessments. The Pearson's coefficient, ρ, represents the degree of correlation between two variables and ranges from +1 to -1. The strength of the correlation is interpreted based upon the magnitude of ρ (Table 4.13).

Table 4.13. Interpreting strength of Pearson's correlation coefficient (Urdan, 2001).

Correlation Strength	Negative ρ	Positive ρ
Weak	-0.2 to 0	0 to 0.2
Moderate	-0.5 to -0.2	0.2 to 0.5
Strong	-1 to -0.5	0.5 to 1.0

A perfect positive ρ coefficient of +1.00 indicates a high score on one variable is related to a high score on the other variable. A perfect negative ρ coefficient of -1.00 indicates that a high score on one variable is related to a low score on the other variable. A ρ coefficient of zero indicates there is no correlation between the variables. The definitional formula for Pearson's correlation is the sum of the z scores for each paired variable divided by the number of paired scores (Table 4.14).

Table 4.14. Formula for Pearson correlation (Urdan, 2001).

$$\rho = \frac{[\Sigma z_x z_y]}{N}$$

ρ = Pearson's correlation coefficient

z_x = a z score for variable X

z_y = a paired z score for variable Y

N = the number of pairs of X and Y scores

The ρ values calculated between the pre-concept map and free response scores indicate a moderate positive correlation (Table 4.15).

Table 4.15. Pearson's correlation coefficient between mean pre- and post- concept map and free-response scores. Results indicate a moderate positive correlation.

	Correlation between mean scores (n = 147)	
	Pre-concept map and free response	Post-concept map and free-response
ρ value	0.40	0.38

A paired t-test was performed to compare the mean scores for the concept maps and free-responses. The null hypothesis is that there is no significant difference between the pre- or post-test scores between the assessment types with a confidence level of α = 0.05. The mean post-test scores for the concept maps and the free-response question were significantly different from each other, but the pre-test scores were not significantly different from each other (Table 4.16).

Table 4.16. Comparison of mean pre- and post-test scores between concept maps and free-response assessments. Bold p-value indicates significant difference between post-test scores. ($p < 0.05$)

	Concept map	Free-response	p-value
Mean pre-test scores (n = 147)	0.92	0.74	0.242
Mean post-test scores (n = 147)	3.1	6.9	**< 0.000**

I also wanted to know if concept maps were effective at detecting misconceptions. The concept map and free-response scoring guide (Appendix G) contained eight categories of misconceptions about the greenhouse effect. There were a total of 87 instances where misconceptions were detected in these eight categories by the pre- and post-tests from both assessment types (Figure 4.7).

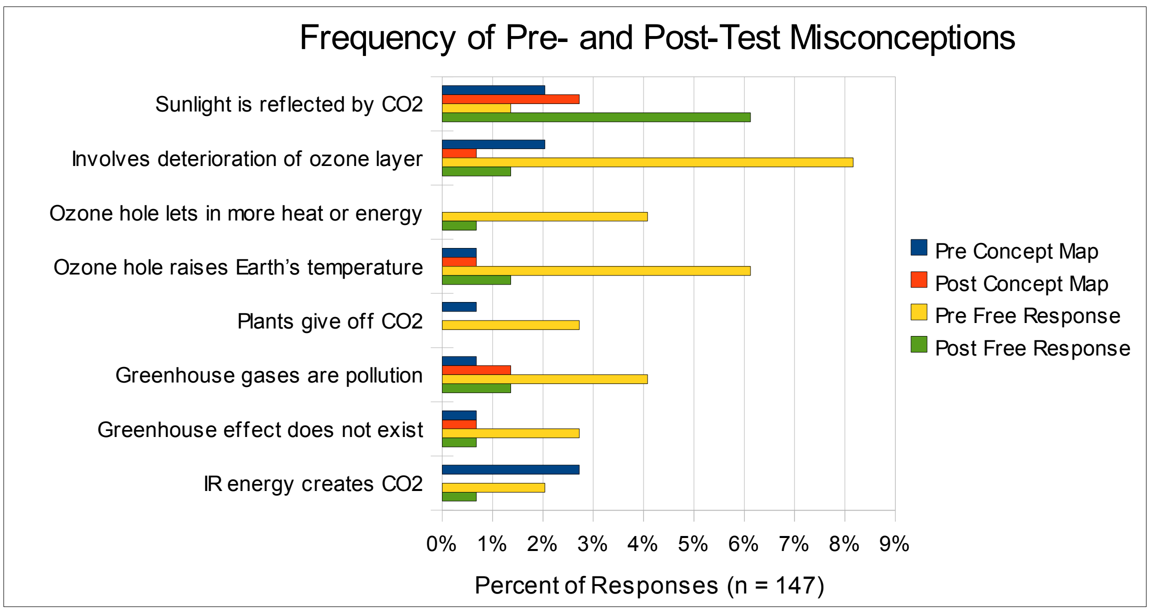


Figure 4.7. Frequency of pre- and post-concept map and free-response misconceptions.

The free-response questions detected more misconceptions in the pre- and post-tests than the concept maps did (Table 4.17).

Table 4.17. Amount of misconceptions detected in pre- and post-test concept maps and free-response questions.

	Pre-test		Post-test		Pre- and Post-Test	
	Amount	%	Amount	%	Amount	%
Concept map	14	23%	9	33%	23	26%
Free-response	46	77%	18	67%	64	74%

4.6 Did students hold misconceptions on any pre- or post-tests?

I wanted to know if the common misconceptions about the greenhouse effect (Section 2.2) appeared within the students' responses. The frequency of students' misconceptions in the eight categories indicates these misconceptions are held by middle-school students (Figure 4.7). In the pre-test the highest frequency of misconceptions was detected in the free-response question where 8% of the students indicated the greenhouse effect involved the deterioration of the ozone, and 6% indicated an increased ozone hole would increase the Earth's temperature (Table 4.18). In the post-test, 6% of students indicated sunlight is reflected by carbon dioxide.

Table 4.18. Frequency of misconceptions in pre- and post-concept maps and free-response questions. Bold values indicate highest values. ($p < 0.05$) (CM: Concept Map, FR: Free-Response)

	Pre-Test		Post-Test	
	CM	FR	CM	FR
Sunlight is reflected by CO_2	2%	1%	3%	**6%**
Involves deterioration of ozone layer	2%	**8%**	1%	1%
Ozone hole lets in more heat or energy	0%	4%	0%	1%
Ozone hole raises Earth's temperature	1%	**6%**	1%	1%
Plants give off CO_2	1%	3%	0%	0%
Greenhouse gases are pollution	1%	4%	1%	1%
Greenhouse effect does not exist	1%	3%	1%	1%
IR energy creates CO_2	3%	2%	0%	1%

The multiple-choice questions also targeted these misconceptions (Figures 4.2 – 4.6). The data gathered from these questions indicate students have misconceptions about the greenhouse effect in the pre- and post-tests (Table 4.19).

Table 4.19. Frequency of misconceptions from pre- and post-multiple-choice questions. (Questions 2 - 5: n = 147. Question 6: n = 101)

		Pre-Test	Post-Test
Question 2 Misconceptions: Which of the following is predicted to occur if the concentration of CO2 continues to rise?			
A.	Increasing CO_2 results in increased UV rays.	15%	22%
C.	Animals will be harmed by increased CO_2.	32%	19%
D.	Increasing CO_2 deteriorates the ozone layer.	20%	11%
E.	Increasing CO_2 will not change Earth's climate system.	6%	5%
Question 3 Misconceptions: If human civilization had never developed on Earth, would there be a greenhouse effect?			
B.	No, the greenhouse effect is caused by plants giving off gases during photosynthesis	25%	24%
C.	Yes, the greenhouse effect is caused by humans burning fossil fuels and releasing pollutants.	41%	26%
D.	Yes, the greenhouse effect is caused by humans depleting ozone in the atmosphere.	7%	8%
E.	There is no conclusive evidence that a greenhouse effect exists.	4%	3%
Question 4 Misconceptions: A planet that has a greenhouse effect			
A.	receives more ultraviolet (UV) sunlight because it lacks ozone in its atmosphere.	41%	38%
C.	receives more energy because it is closer to the sun.	10%	11%
D.	has an atmosphere that has been changed by living organisms.	18%	11%
E.	does not give off any energy away into outer space.	9%	11%
Question 5 Misconceptions: Which of the following best describes the relationship between the greenhouse effect and global warming?			
A.	The greenhouse effect and global warming are the same thing.	12%	7%
C.	Global warming may be causing an increase in the greenhouse effect.	16%	18%
D.	The greenhouse effect and global warming are likely unrelated.	9%	5%
E.	There is no definite proof that either the greenhouse effect or global warming exist.	5%	5%
Question 6 Misconceptions: Increasing levels of carbon dioxide in the atmosphere will result in:			
A.	A larger ozone hole that will allow more sunlight to reach the Earth's surface.	39%	23%
B.	More sunlight and infrared energy to be reflected down to the Earth's surface.	23%	32%
C.	A decrease in the Earth's temperature.	8%	11%
E.	No change in the Earth's surface temperature.	5%	2%

4.7 Gender differences in understanding

Analysis of variance was used to determine if there were significant differences between the mean pre- and post-test scores and the normalized gains, <g>, between genders. The null hypothesis is that there is no significant difference between pre- and post-test scores or normalized gain between genders – that boys and girls gain equally. The p-values calculated for each of the pre- and post-tests and normalized gains were greater than 0.05, so the null hypothesis is accepted with a confidence level of $\alpha = 0.05$ (Table 4.20).

Table 4.20. Pre- and post test scores and normalized gain between genders. No significant differences were detected between genders for each assessment type. (CM: Concept Map, FR: Free Response, MC: Multiple-choice)

Mean Pre- and Post-Test Scores and Normalized Gain Between Genders								
Females (n = 68)								
Pre-Test Mean Scores			Post-Test Mean Scores			<g>		
CM	FR	MC	CM	FR	MC	CM	FR	MC
0.93	0.63	1.1	2.74	6.19	1.68	0.05	0.15	0.15
Males (n = 79)								
Pre-Test Mean Scores			Post-Test Mean Scores			<g>		
CM	FR	MC	CM	FR	MC	CM	FR	MC
0.91	0.84	0.96	3.41	7.51	1.58	0.08	0.19	0.14
p-values								
0.9589	0.4298	0.3489	0.4157	0.1893	0.5714	0.2070	0.1698	0.7254

5 DISCUSSION

The results from my research indicate that students gained in their understanding about the greenhouse effect after exploring the model for approximately twenty minutes. In this section, I discuss to what extent the Greenhouse Effect model (modified NetLogo Climate Change model) may have increased students' understanding and how the model addressed students' misconceptions. In addition, I will discuss the benefits and limitation of using concept maps as educational assessment tools to detect students' understanding.

5.1 The greenhouse effect model

The model used in this research simulates how the greenhouse effect influences the Earth's temperature, and allows the user to manipulate the variables to observe the effects. Computer models, in general, simplify the phenomenon being modeled to focus on a subset of specific factors, which may mean the models do not exactly represent the phenomena. The Greenhouse Effect model used in this study focuses on how sunlight, carbon dioxide, surface reflectivity, and clouds affect the amount of heat and infrared energy produced and, thus, Earth's temperature. Although the model reasonably represents the relationship between these variables, it does have some limitations.

First, the solar energy that Earth receives from the sun is made up of a combination of infrared, visible, and ultraviolet electromagnetic energy. The model shows the incoming solar radiation as yellow arrows that behave as if they are only in the visible part of the spectrum (i.e. it does not get absorbed or reflected by carbon dioxide in the atmosphere). In fact, approximately 23% of the incoming solar energy is absorbed by clouds, aerosols, water vapor and ozone (Keller, 2006). The modeled behavior of the solar radiation may confuse or mislead students that all of the solar radiation is transmitted through the atmosphere.

Second, the model excludes the other greenhouse gases including water vapor, which is the most abundant greenhouse gas in the atmosphere. I suggest that carbon dioxide was the only greenhouse gas included in the model because humans have been increasing the amount of carbon dioxide in the atmosphere at an increased rate through the use of fossil fuels, and the model seeks to emphasize this. The model's focus on carbon dioxide may contribute to an idea that carbon dioxide is the only and most abundant greenhouse gas. Further instruction may be required to give students the opportunity to discover that there are other greenhouse gases.

Third, the model shows that carbon dioxide molecules reflect infrared energy and not sunlight, but does not show why this happens at a molecular level. Knowledge about the energy levels and wavelengths associated with the electromagnetic spectrum and changes in energy levels between visible light and infrared light would need to be discussed in more detail for a more precise understanding of why Earth heats up when carbon dioxide molecules reflect infrared energy. These concepts are included in the Maine Learning Results, which specify that middle-school students should understand "the relationship between visible light and the electromagnetic spectrum" and the "properties of solar radiation and its interaction with objects on Earth." Addressing these concepts may decrease difficulties students may have distinguishing between solar and infrared energy behaviors. This confusion was detected by multiple-choice Question 6 given to students at School B (n = 101). After using the model, 32% of the students indicated that sunlight and infrared radiation would be reflected by carbon dioxide compared to 26% of the students who indicated infrared radiation would be the only type of energy reflected by carbon dioxide. The free-response results show that 29% of the students (n = 147) indicated Earth's temperature would increase when sunlight is absorbed into the surface, but only 3% said that Earth's temperature would increase when infrared energy is absorbed into the surface.

5.2 Students' understanding of the greenhouse effect

The pre- and post-test results suggest middle-school students gained in their understanding about the greenhouse effect after they explored the model for approximately twenty minutes. The concept map mean scores significantly increased from 0.92 to 3.1 out of a possible score of 48, and the free-response mean scores significantly increased from 0.74 to 6.9, although these gains seem small compared to an expert's score of 48. The mean number of correctly answered multiple-choice questions significantly increased from 1.03 to 1.63 out a maximum score of four.

The frequency of the propositional phrases in the pre- and post-concept maps increased in several categories (Figure 4.1). The categories with the highest increases for the pre- and post-concept maps are included in Table 5.1. These increases in propositional phrases were also detected with the free-response question (Table 5.2), although the increases were typically higher, except for I3 (infrared energy can be absorbed into the Earth's surface).

Table 5.1. Propositional phrase increase in concept maps.

Propositional Phrase	% Increase (n = 147)
(I1): Infrared energy is radiated from the Earth's surface	13%
(C3): CO_2 reflects/absorbs infrared energy	9%
(T1): Earth's temperature increases when sunlight is absorbed into the surface.	9%
(S1): Sunlight can be absorbed into the Earth's surface.	7%
(I4): Infrared energy affects Earth's temperature.	6%
(C1): Increasing CO_2 increases Earth's temperature.	5%

Table 5.2. Propositional phrase increase in free-response question.

Propositional Phrase	% Increase (n = 147)
(I1): Infrared energy is radiated from the Earth's surface	35%
(T1): Earth's temperature increases when sunlight is absorbed into the surface.	29%
(C1): Increasing CO_2 increases Earth's temperature.	25%
(S1): Sunlight can be absorbed into the Earth's surface.	16%
(C3): CO_2 reflects/absorbs infrared energy	16%
(I4): Infrared energy affects Earth's temperature.	1%

5.2.1 Students' understanding of infrared energy

The increase in the number of propositional statements concerning infrared energy may be due to students starting with little or no knowledge about what infrared energy is before they used the model. Also, while using the model, students would be able to observe infrared energy radiating from the surface. The data from the free responses show that only 1% of the students indicated that the amount of infrared energy radiated is dependent upon the Earth's temperature, and only 3% indicated that Earth's temperature increased when infrared energy is absorbed into the Earth's surface. Although, the concept map responses show that 6% of the students indicated infrared energy affected the Earth's temperature.

5.2.2 Students' understanding of the effects of carbon dioxide

The free-responses also show that there was an increase in understanding about the role carbon dioxide in the atmosphere plays in determining the Earth's temperature. The data showed a 16% increase in the number of students who indicated correctly that carbon dioxide reflected infrared energy, and a 25% increase in the number of students who indicated that increasing the amount of carbon dioxide in the atmosphere would increase the Earth's temperature. Responses to multiple-choice Question 2 also show a 16% increase in the number of student who indicated Earth's temperature is predicted to rise with increasing levels of carbon dioxide in the atmosphere. While students may indicate a better understanding about the effects of increasing carbon dioxide in the atmosphere, I hesitate to make any claims that students understand why carbon dioxide reflects infrared energy. In the interviews, "Jay" said the "*temperature went up*" when the amount of carbon dioxide molecules were increased, but could not explain why this happened. The results from multiple-choice Question 6 show a 9% increase in the number of students who indicated that both sunlight and infrared energy would be reflected to the surface by carbon dioxide.

There was also a 5% increase in the number of students who indicated in their post-free-response questions that sunlight was reflected by carbon dioxide. Students responses in the interviews also supported these results.

Roger: *"Then I started to add CO_2, and the more that you add, the more it reflects the sunlight that's not only coming down to Earth, but also reflecting it out."*

Interviewer: "*How does the carbon dioxide interact with the sunlight and infrared?"*

Roger: *"Well, what I noticed is that it seems to let in sunlight a lot more than is blocks it back out."*

When students indicated in the classroom that sunlight was being reflected by carbon dioxide, I asked them to explain to me why they thought that or to have them show me in their model. Typically students responded that they were seeing sunlight in the model being reflected by clouds or students did not differentiate between the red arrows (infrared energy) and the sunlight (yellow arrows).

5.2.3 Students' understanding of the effects of sunlight

Students indicated in the pre- and post-tests that sunlight affected the Earth's temperature. There was an increase of 26% of the students that indicated in the post-free-response data that Earth's temperature increased when sunlight is absorbed into the surface. In the pre-concept maps, 17% of the students indicated that sunlight affected Earth's temperature, although only 1% (both pre-concept map and free-response) of students said that sunlight was absorbed into the surface or Earth's temperature was affected when sunlight was absorbed into the surface. I suggest that initial responses about how sunlight affects the Earth's temperature may be due to the everyday experience of feeling warm from sunlight or from noticing that it is warmer during the day than at night. The results from the post-test data suggest that more students understood that the energy from the sunlight is absorbed into the surface to increase the heat energy (red dots in the model), which also increases the Earth's temperature.

5.2.4 Students' understanding about the natural greenhouse effect

Results suggest students gained in their understanding that the greenhouse effect is a naturally occurring phenomenon. There was an increase of from 14% to 36% of the students that indicated the greenhouse effect was caused by naturally occurring gases in the atmosphere (multiple-choice Question 3). The pre-test results from this question showed that 41% of the students thought that the greenhouse effect was caused by humans burning fossil fuels and releasing pollutants. I suggest this increase in understanding may be because the model interface included carbon dioxide levels from different time periods (i.e. the ice-age). Students may have recognized that carbon dioxide was in the Earth's atmosphere even before humans began burning fossil fuels, and so the greenhouse effect would still have existed even without human civilization. Although none of the students indicated this reasoning in their concept maps or free-response answers.

5.2.5 Comparison of gender in understanding

The pre- and post-responses from the concept maps, free-response question, and multiple choice questions indicates there is no significant difference in mean test scores when analyzed for gender differences (Table 4.18). This suggests that the model was equally effective for males and females in learning greenhouse effect concepts. Both girls and boys were actively engaged during the twenty-minute exploration time with the model, although it appeared that more boys were involved in a competition to get the most carbon dioxide molecules in the model's atmosphere. In the interviews “Jay” said “*I pushed go and then I added like a thousand* CO_2*...cause it looked like fun.”* The competition to add the most carbon dioxide molecules was observed in every class, and was not discouraged. Students were periodically reminded of the focus questions to keep them on the task of determining how the model's variables affected the Earth's temperature. Effectiveness between genders is an important aspect in developing any curriculum, and should be considered for models developed as learning tools.

5.2.6 Comparisons between advanced and average students

There were no significant differences between the pre-test scores between the advanced students (Classes A1 and B4) and the remaining students in each of the assessments, which indicates that all of the students began with a similar understanding of the greenhouse effect. The advanced students and the average students significantly improved from their pre-test to post-test mean scores in each of the assessments, although the advanced students increased their scores significantly more than the average students for the concept map and free-response assessments. The multiple-choice post-test scores were not significantly different between the advanced students and the average students. These results suggest that computer models can be effective learning tools for the advanced and average students.

5.2.7 Overall normalized gains

The data from the pre- and post-tests and the normalized gains suggest students gained an increased understanding about some of the system relationships that are involved with the greenhouse effect after using the model, especially infrared behavior. Although, I do not suggest that these results show that students have a complete or expert level of understanding. One of the core concepts pertaining to the greenhouse effect is that Earth's surface is held at a relatively steady-state temperature because of the balance of energy that is absorbed and transmitted from the atmosphere. The computer model shows that this balance is affected by the atmospheric composition, amount of sunlight, infrared radiation, and surface reflectivity. Question 4 from the multiple-choice test assesses whether students understand that a planet that has a greenhouse effect has an atmosphere that absorbs and gives off certain forms of energy but not all. Students' responses to this choice increased from 13% to 27%, but increased understanding was not indicated in the other assessments. The relatively low post-mean scores from the concept map and free-response assessments (compared to an expert's score) suggests that students are aware of some of the variable behaviors and their effects, but do not have a complete understanding of how all the variables interact to make the steady-state condition.

5.3 Misconceptions

One of the most common misconceptions about the greenhouse effect in the literature (Rye *et al.,* 1997; Rebich & Gautier 2005; Rebich *et al.* 2006) is that students believe the greenhouse effect deteriorates the ozone layer, which creates a hole for more sunlight or ultraviolet rays to pass through and heat up the surface. This misconception was detected in each of the assessments, although it was more prevalent in the multiple-choice responses.

The multiple-choice Question 2 asked students to indicate what was predicted to occur if the concentration of carbon dioxide continued to increase. Two of the choices were based on the deteriorating ozone layer misconception. Choice “A” said that the Earth would be exposed to more ultraviolet rays, and choice “D” said the ozone layer would disappear. Students' responses increased from 15 to 22% for choice “A”, and decreased from 20% to 11% for choice “D” indicating that although some students changed their answers, most continued to hold a misconception about how the greenhouse effect affects incoming ultra-violet light and the ozone layer. This misconception was also evident in 8% of the pre-free-response answers. Question 4 had students indicate the characteristics of a planet that had a greenhouse effect. Choice “A” says that the planet would receive more ultraviolet sunlight because it lacks ozone in its atmosphere. Students that responded with this choice slightly decreased from 41% to 38% from pre- to post-test. The misconception about ozone layer depletion was also found in the interviews.

> Interviewer: “*What did you think the greenhouse effect was...before we played with the model?*”
>
> Roger: “*Really I just thought it was sunlight coming down to the Earth and then all the emissions from the fossil fuels and everything else that we are burning is just getting caught up in the atmosphere and depleting the ozone layer.*”

Due to the presence of the deteriorating ozone layer misconception throughout the pre- and post-tests, I suggest this model does not help students understand why this is a misconception. This claim is not surprising because the model does not include an ozone layer, so the students did not have the opportunity to confront or test this idea. The model may be able to address this misconception if future iterations included a representation of the ozone layer where students could see that carbon dioxide did not effect the ozone layer or the amount of sunlight that was allowed to reach the surface.

Another common misconception is that the sole source of greenhouse gases is from human pollution and are not naturally occurring atmospheric gases (Rebich and Gautier, 2005). On the pre-test multiple-choice Question 3, 41% of the student indicated the greenhouse effect would not exist if human civilization had never developed because the greenhouse effect is caused by humans burning fossil fuels and releasing pollutants. The frequency of this response decreased by 14% after students used the model. In Section 6.3 I suggested that the decrease in this response, and the increase in the correct response may be because the model shows there was carbon dioxide in the atmosphere before human civilization.

Other misconceptions were present in each of the assessment types. Thirty-two percent of students indicated on the pre-test that animals would be harmed if the level of carbon dioxide increased (multiple-choice Question 2). Twenty-five percent said in the pre-test that the greenhouse effect is caused by plants giving off carbon dioxide (multiple-choice Question 3). Twelve percent said in the pre-test that global warming and the greenhouse effect are the same thing, and 16% indicated that global warming was causing the greenhouse effect (multiple-choice Question 4). Although, about half of all of students did initially correctly indicate that an increase in the greenhouse effect may be causing global warming (multiple-choice Question 4), which may indicate students associate the greenhouse effect with global warming even if they do not understand the phenomenon. More research should be done to determine what factors could be added to this model or instruction to address these misconceptions.

5.4 Concept maps as assessment tools

I decided to include concept maps as an assessment tool for my research because I wanted a method of understanding how students' linked concepts together in a system. I included other forms of assessment in order to compare the results and determine the benefits and limitations in using concept maps for assessment of students' understanding. The Pearson's correlation analysis indicated there was a moderate correlation between the pre-concept map and free-response tests ($\rho = 0.40$) and the post-concept map and free-response tests ($\rho = 0.38$). The free response question generally detected a higher number of propositional phrases and misconceptions, respectively (Figure 4.7 and Table 4.12).

I attribute this moderate correlation for a few reasons. First, the students from School A had only made concept maps during the instructional period prior to the pre-test. Novak (1984) indicates that the skill of concept mapping takes practice, especially to organize the concepts in a hierarchical fashion. Second, even though the students from School B had prior experience with concept mapping, there were many maps that included concepts but no linking terms. The scoring procedure used in my research required a linking term between concepts to ensure the student understood how those two concepts were related. Third, it was challenging to determine the appropriate number of concepts that students were required to include in their concept maps. I wanted to be able to compare specific concepts and their relationships, but I also did not want to overwhelm the student with too many concepts. These difficulties may be different for other grade levels. While I was student teaching a physics course in the Spring of 2009, I gave the same concept map instructions to a conceptual physics class, and asked the students to complete a concept map that described the sound concepts they had learned about in the previous unit. These students developed concept maps for the first time that had over forty concepts with appropriate linking terms. While I used this exercise as a learning tool instead of as a formal assessment tool, I did observe their maps were much more complex than the middle-school maps. Although, this also may be due to the physics students recently completing a unit on sound, where the middle-school students had no prior knowledge of the greenhouse effect.

I suggest that future research should investigate how to use concept maps as effective assessment tools for educational assessment. Even though my research did not show that concept maps were as effective as the other types of assessment, I think concept maps could become a valuable tool once strategies are developed to increase students' concept mapping skills and to standardize scoring procedures.

6 CONCLUSIONS

The results of my study indicate middle-school students had gains in their understanding about how the greenhouse effect influences the Earth's temperature after exploring the computer model for approximately twenty minutes. The magnitude of the changes in pre- and post-test concept map and free-response scores were relatively small compared to an expert's score, indicating that students did not gain a complete understanding of the greenhouse effect. The results of the multiple-choice questions indicated that students gained in their understanding that the greenhouse effect is caused by natural gases in the atmosphere and that the Earth's atmosphere absorbs and gives off certain forms of energy. The three areas in the concept maps and free-response question where students gained in understanding the most included:

- Infrared energy is radiated from the Earth's surface.
- Earth's temperature increases when sunlight is absorbed into the surface.
- Increasing carbon dioxide in the atmosphere increases the Earth's surface temperature.

While students gained in their understanding about the greenhouse effect, the results indicate students held on to their misconceptions from the pre- to post-tests. The misconception that was detected the most in all three pre- and post-assessments was that the greenhouse effect deteriorates the ozone layer so that more ultra-violet light will hit the Earth's surface, which results in the Earth's temperature increasing. Students also indicated in the pre- and post-tests that the greenhouse effect is caused by humans burning fossil fuels and plants giving off carbon dioxide gas instead of from naturally occurring gases in the atmosphere. Results indicated that students increased in their misconception that carbon dioxide molecules reflect both sunlight (visible light) and infrared light. Although the computer model does not show sunlight being reflected by carbon dioxide molecules, it does show sunlight being reflected by clouds. Students may have thought the sunlight and the infrared rays were the same thing or they may have thought the sunlight was being reflected by carbon dioxide when, actually, the sunlight was being reflected by the clouds.

The results indicate that the Greenhouse Effect computer model is an effective learning tool for understanding the relationships between the system variables, although the model should be used with additional guidance and curriculum to gain a higher level of understanding of the phenomenon. Students should be encouraged to isolate variables so they can determine the effects on the system. In my classroom observations I noticed that students increased all the variables at the same time and had difficulty determining which variable was causing changes in the Earth's temperature. Students should also be encouraged to ask questions about the behaviors of the variables. For example, why do the carbon dioxide molecules only reflect infrared light? These types of questions may not be answered directly by the model, but can be used as a segue for further investigations. Once students become more familiar with the greenhouse effect, students can critically analyze the limitations of the model and give suggestions to improve the way the model represents the phenomenon, like including other greenhouse gases. Since some of the misconceptions about the greenhouse effect are not directly addressed by the computer model, students should be given additional opportunities to confront their ideas.

My research also looked at the effectiveness of using concept maps as an educational assessment tool for detecting students' understanding. The results indicate that the free-response question detected more of the students' understanding and misconceptions than the concept maps. This difference may be a result of students' lack of experience of making concept maps or that complex concept maps are too difficult to make for middle-school students. There was a moderate correlation between the free-response and concept map responses, which indicates that the concept maps did detect students' understanding, although to a lesser extent than the free-response question.

The results from this study prompt further research opportunities. In what way can the computer model be used with additional inquiry curriculum to increase student understanding about the greenhouse effect? What modifications to the computer model could decrease students' misconceptions about the greenhouse effect? Would using concept maps as a learning tool instead of an assessment tool increase students' understanding about the greenhouse effect system relationships? Are concept maps an effective assessment tool at higher grade levels? The results from my study and these further areas of research may increase the effectiveness of computer models in the classroom.

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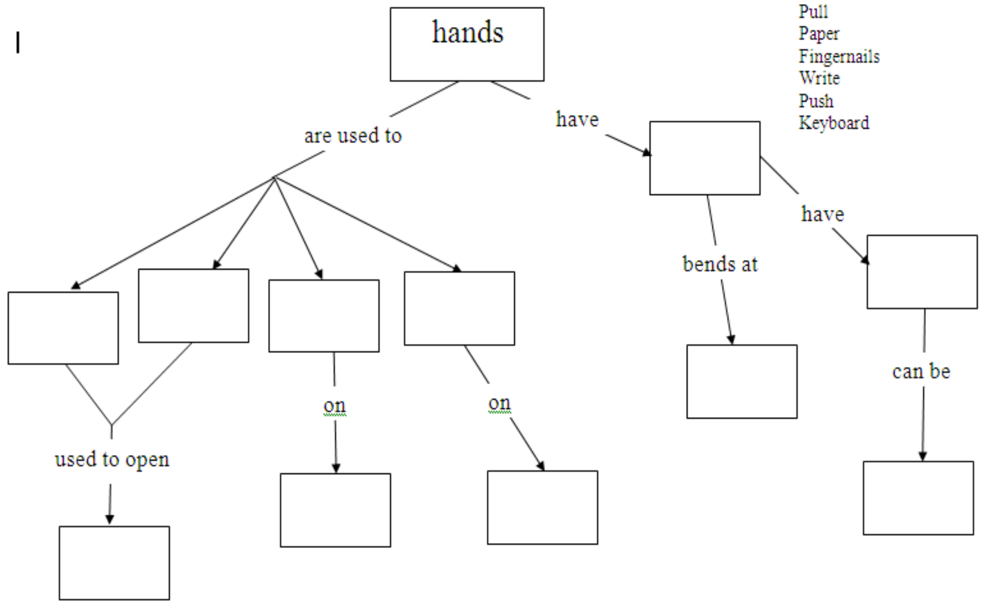
APPENDICES

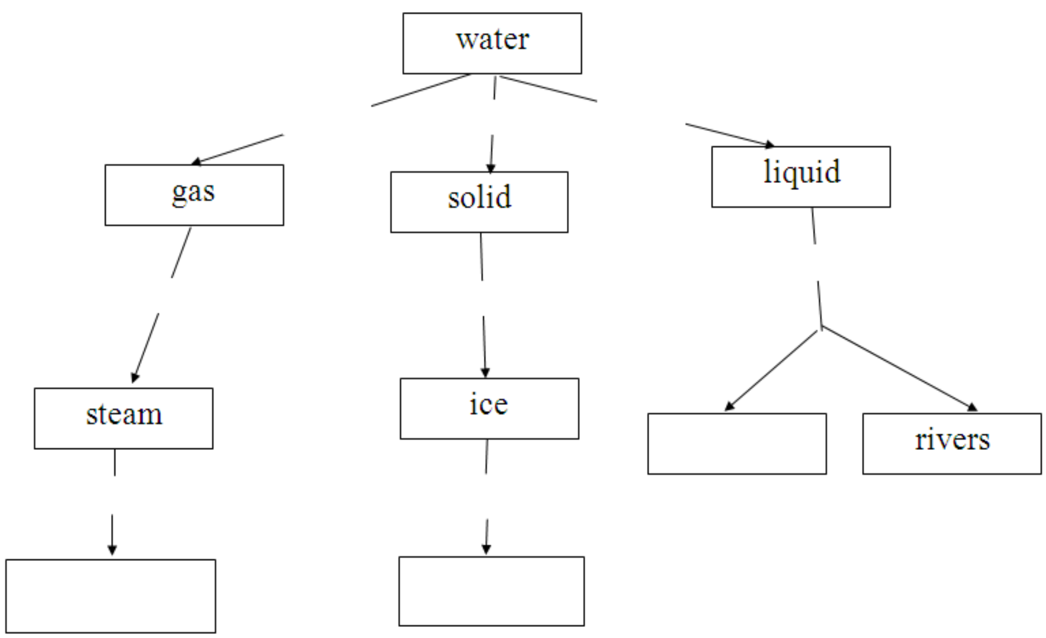
Appendix A: Concept map worksheets

Directions
Fill in the concept map using the given concepts OR your own concepts.

Five fingers
Type
Painted
Doors
Knuckle
Pull
Paper
Fingernails
Write
Push
Keyboard



Directions
Fill in the linking terms between the concepts.



Appendix B: Concept map assessment instructional handout

Greenhouse Effect Concept Map

Directions:

Create a concept map that **shows how the Earth's Greenhouse Effect works and how the Greenhouse Effect influences the Earth's temperature.**

You must include the following five concepts in your concept map. If you do not know how to connect any of these concepts or do not know what they mean, just draw a circle around the concept and put it to the side of your concept map.

1. Sunlight
2. CO_2 (carbon dioxide)
3. Infrared light (IR)
4. Earth
5. Earth's temperature

Below are more concepts that you may find useful for creating your concept maps, but they are not required:

- Sun
- Atmosphere
- Greenhouse gases
- Clouds
- Heat Energy
- Outer Space
- Earth's Surface

Remember:

- Your concepts need to be connected with a linking term.
- Be sure your concept map shows:
    - how the Earth's Greenhouse Effect works AND
    - how the Greenhouse Effect influences the Earth's temperature

Appendix C: Free-response and multiple-choice assessments

1. Explain in words how the Earth's greenhouse effect works.

2. Scientists have proposed that the burning of fossil fuels increases the concentration of carbon dioxide (CO2) in the atmosphere. Which of the following is predicted to occur if the concentration of CO2 continues to rise?
   a) Earth's surface will have increased exposure to ultraviolet rays.
   b) The average annual surface temperature will increase.
   c) Animals will be harmed by breathing the higher levels of CO2.
   d) The ozone layer will disappear.
   e) There will be no change to the Earth's climate system.

3. If human civilization had never developed on Earth, would there be a greenhouse effect?
   a) Yes, the greenhouse effect is caused by naturally occurring gases in the atmosphere.
   b) Yes, the greenhouse effect is caused by plants giving off gases during photosynthesis.
   c) No, the greenhouse effect is caused by humans burning fossil fuels and releasing pollutants.
   d) No, the greenhouse effect is caused by humans depleting ozone in the atmosphere.
   e) No, there is no conclusive evidence that a greenhouse effect exists.

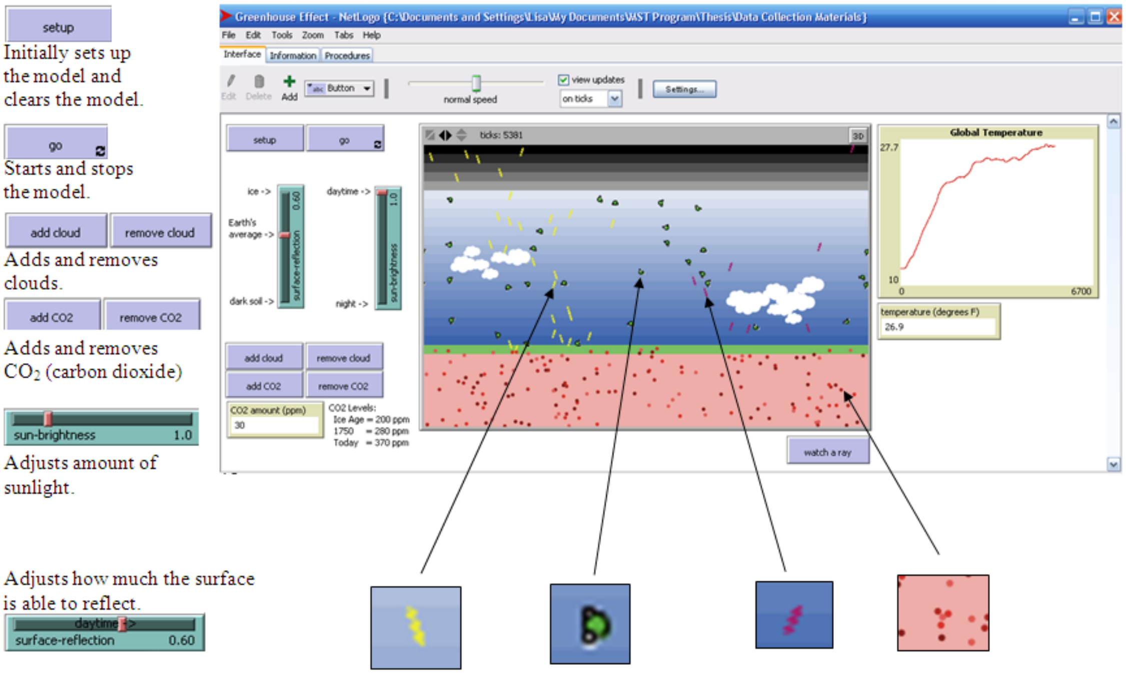
4. A planet that has a greenhouse effect
   a) receives more ultraviolet (UV) sunlight because it lacks ozone in its atmosphere.
   b) has an atmosphere that absorbs and then gives off certain forms of energy but not all.
   c) receives more energy because it is closer to the sun.
   d) has an atmosphere that has been changed by living organisms.
   e) does not give off any energy away into outer space.

5. Which of the following best describes the relationship between the greenhouse effect and global warming?
   a) The greenhouse effect and global warming are the same thing.
   b) An increase in the greenhouse effect may be causing global warming.
   c) Global warming may be causing an increase in the greenhouse effect.
   d) The greenhouse effect and global warming are likely unrelated.
   e) There is no definite proof that either the greenhouse effect or global warming exist.

6. Increasing levels of carbon dioxide in the atmosphere will result in:
   a) A larger ozone hole that will allow more sunlight to reach the Earth's surface.
   b) More sunlight and infrared energy to be reflected down to the Earth's surface.
   c) A decrease in the Earth's temperature.
   d) More infrared energy to be reflected down to the Earth's surface.
   e) No change in the Earth's surface temperature.

Appendix D: Greenhouse model interface handout

NetLogo Greenhouse Effect Interface



Appendix E: IRB Proposal

Human Subjects Application
November 4, 2008
Submitted by: Lisa Schultz, MST Graduate Student, UMaine
Advisor: Molly Schauffler PhD, Center for Sci & Math. Ed. Research

1. Summary of Proposal

The purpose of this study is to learn about how middle school students understand the greenhouse effect, and how their understanding changes when they use the NetLogo Climate Change model. The information learned in this study will be used to inform members of the IDEAS project (Inquiry-based Dynamic Earth Applications of Supercomputing) that are currently developing an ice-sheet modeling program for the middle school classroom. The data will also give insight on what middle school students know about the greenhouse effect and how they use technology as a learning tool. The specific research questions that Lisa Schultz will be investigating are:

- How do middle school student currently understand the greenhouse effect?
- In what way does the NetLogo Climate Change model affect their understanding of the greenhouse effect system?
- How do middle school students use the NetLogo Climate Change model interface to investigate the greenhouse effect?

The study will consist of two parts. The first part will be thirty-minute individual interviews with up to six middle school students. During these interviews the students will be asked to answer two free response questions about the greenhouse effect and create a pre-concept map of what they know about the greenhouse effect. The free response questions are:

- Explain in words what the greenhouse effect is.
- If the concentration of greenhouse gases significantly increased, would the Earth's surface temperature increase, decrease, or stay the same? Explain your answer.

Then the student will be asked to "play" with the NetLogo Climate Change model. After having some experience with the model, the student will be asked to make a post-concept map by either modifying their previous concept map or by creating a new concept map based on their experiences with the modeling program. The interviewer will ask the student to explain the process of how they created each of their concept maps and how they used the modeling program to determine greenhouse effect relationships. The student will also be asked about their experiences with the modeling interface. The student will be asked to answer the same free response questions after they have completed their modified concept map. The data for the first part of the study will consist of the video taped interview that will be later transcribed, the two written pre and post free response questions, and the concept maps created in the interview.

The next part of the study will consist of going into various middle school classrooms where the students will be asked to answer the two free response questions, and then work in pairs to create a pre-concept map of what they know about the greenhouse effect. As with the individual interviews, the students will be instructed to "play" with the NetLogo Climate Change model and then asked to make a post-concept map by modifying their previous concept map or by creating a new concept map based on their experiences with the model. The data for this part of the study will consist of the two written pre and post free response questions and concept maps created by the students and notes taken by an observer. These classroom studies may take one or two class periods depending on the length of the class period.

The following items will be included at the end of the application:

- Consent form for the student's parents
- Script to inform the student about the research and risks
- Website of the NetLogo Climate Change model
- Interview protocol

The data for this study will be collected at various times throughout November 2008 and August 2009. Specific dates will be determined based on the participating student and teacher schedules.

2. Personnel

Lisa Schultz, MST graduate student
Molly Schauffler, PhD, Center for Sci & Math. Ed. Research (581-2707)

3. Subject Recruitment

The subjects for this study will be 7th and 8th grade students from a variety of schools around Maine. The teachers of these students were part of the IDEAS workshop series that occurred during the summer of 2008. Lisa Schultz is involved in the evaluation of the IDEAS workshop series and formed relationships with the participating teachers. These teachers are especially interested in the resulting data because they hope to use the ice-sheet model that is currently being developed by the IDEAS project group.

Lisa Schultz has contacted these teachers and requested student recommendations for the interviews and time in their classrooms to gather additional data. There will be up to three girls and three boys participating in the interviews. The teachers are requested to recommend average ability students so that we can study what a typical student would understand. The observed classroom will be from a subset of the teachers that participated in the IDEAS workshop series. The number and range of students will depend on the participating teachers, but all of the students will be either in 7th or 8th grade.

Since this study will be conducted at a variety of Maine schools, the necessary permissions will be gained depending on each school policy in addition to parental consent forms and student assent script.

4. Informed Consent

All the middle school students will be informed of the research methods, goals and any risks that are involved with participating with the study. A sample student assent script will be included at the end of the application. Written parental consent forms will be given to the students that will be interviewed and to the students participating in the classroom-wide study (if needed). A sample of this consent form will also be included at the end of the application. Appropriate permissions and consent will be gained from the school administration, teachers, parents, and student before performing any study.

5. Confidentiality

All data will be kept confidential either by changing student names or by assigning identity codes. Any references to students in summaries, research papers, or discussions will ensure student confidentiality.

The data that will be taken during the interview studies will consist of a video recording of the interview that will later be transcribed, written free response questions, and the greenhouse effect concept maps created by the students. The video recording of the interview will only be accessible to the personnel listed in this application and will be kept in the investigators locked office at the University of Maine. Sections of the video may be reviewed by faculty and other graduate students in the Center of Science and Mathematics Educational research to assist with the transcription and evaluation of the interview data. The students' names will be changed when referring to them in the videos, transcripts, and reports in order to protect their identity. The concept maps will be coded in order to associate them with the free response data and the proper video or transcript data. The video recordings will be kept for a maximum of two years after their recorded date to ensure enough time for transcription, and after that time they will be permanently deleted. The investigator will keep the transcription data, free response data, and concept maps indefinitely.

The data that will be taken during the classroom activity will consist of pre and post free response questions and concept maps about the greenhouse effect. These concept maps will be coded so that the pre and post free response questions and concept maps can be coupled at a later time. Lisa Schultz will be taking written notes about student comments and activities. Names of students will be changed while taking these notes and in any summary of these data. The investigator will keep the observational notes, free response data, and concept maps indefinitely.

6. Risks to Subjects

There are few risks associated with this study because the methods used to get the data closely resemble common classroom activities. The students that are interviewed may be uncomfortable answering questions while being video taped. Each student will be informed of the measures to keep their identity confidential, and they will be given the option to not participate or stop participating in the study at any time. Other than time and inconvenience, there are no other risks to participating in this study.

7. Benefits

The data collected from this study will assist with student understanding of the greenhouse effect system and how the students interact with a computer model as a learning tool. This will directly assist the IDEAS group with their ice-sheet model development that will be implemented into the middle school classrooms as soon as next summer. This data can assist teachers with curriculum development around climate change systems and assessment of student understanding using concept maps. The data will also help expand the educational research concerning middle school students understanding of the greenhouse effect, how middle school students use computer models, and the use of concept mapping as an assessment tool for understanding student ideas about systems.

Parental Consent Form

Your daughter or son has been invited to participate in an educational research project being conducted by Lisa Schultz, a graduate student in the Center of Science and Mathematical Educational Research at the University of Maine. The purpose of this research is to better understand middle school student understanding of the greenhouse effect system and how these students use computer models as an educational tool.

What will your child be asked to do?

If you decide to let your child participate in this study, Lisa Schultz will interview them up to thirty minutes about their understanding of the greenhouse effect system. She will also be having the student use a program called NetLogo that is currently installed on their school laptop computers. This program has a simulation of the greenhouse effect, and your student will be asked to use this program to try and explain how the greenhouse effect works. Your child will be asked to answer some written questions as well as asked to explain their ideas during the interview. The video-tape of the interview will be kept in a locked office located at the University of Maine, and will only be used for educational purposes.

Risks

There are few risks associated with this study because the methods used to collect information closely resemble common classroom activities. The students who are interviewed may be uncomfortable answering questions while being video taped. Each student will be informed of the measures to keep their identity confidential, and they will be given the option to not participate or stop participating in the study at any time. Other than time and inconvenience, there are no other risks to participating in this study.

Benefits

The collected information from this study will assist with student understanding of the greenhouse effect and how the students interact with a computer model as a learning tool. This will directly assist the IDEAS (Inquiry-based Dynamic Earth Applications of Supercomputing) group, at the University of Maine, with their ice-sheet computer model development that will be implemented into the middle school classrooms as soon as next summer. This information can assist teachers with curriculum development around climate change systems and assessment of student understanding using concept maps. The information will also help expand the educational research concerning middle school students understanding of the greenhouse effect, how middle school students use computer models, and the use of concept mapping as an assessment tool for understanding student ideas about systems.

Confidentiality

Your child's name will not be on any collected documents. A code number will be used to protect their identity, and all data will be kept in a locked office at the University of Maine. Your child's name or any other identifying information will not be reported in any publications. The videotape portion of the data will be kept for up to two years for evaluation and transcription, and after will be permanently deleted. The key linking your child's name to the data will be deleted after the data analysis is complete. The investigator will keep the transcript of the interview and the concept maps created in the interview indefinitely.

Voluntary

Participation in this study is voluntary. You may choose at any time to not have your child participate in the study. Your child will also be informed of the study method, goals, and risks prior to the start of the interview. They may choose to stop at any part of the study or skip any questions during the interview process.

Contact Information

If you have any questions about this study, please contact me (207-217-2116, Lisa.R.Schultz@umit.maine.edu). You may also reach the faculty advisor on this study, Molly Schauffler (207-581-2707, Molly.Schauffler@umit.maine.edu). If you have any questions about your rights or your child's rights, please contact Gayle Anderson, Assistant to the University of Maine's Protection of Human Subjects Review Board, at 581-1498 (or e-mail gayle.anderson@umit.maine.edu).

Your signature below indicates that you have read and understand the above information. You will receive a copy of this form.

______________________________ _______________________

Signature Date

Script for Child's Assent

Hello, my name is Ms. Schultz and I am a graduate student at the University of Maine. Today we are going to do an activity that will help me understand what you know about a climate system. I don't expect that you will have all the right answers. What I want is for you to try your best.

I'm going to have you answer two written questions and then do an activity called a concept map. If you have never done one before, then I can show you how to do one and we can practice until you feel comfortable. After that I will give you a few exercises using concept maps that will help me understand what you are thinking about a specific climate system.

It is normal for you to feel a bit weird because you are being interviewed and that we are going to be video taped. You can tell me at any time if you don't want to answer a question or if you want to stop the interview. You can also ask me questions at any point.

I'm going to use the information in this interview to help scientists develop computer simulation tools that will help students like you learn. It's kind of like when video game companies test out their new games to see how kids use them. When you are doing the activities I will be asking you what you are thinking and how you are using the computer model. All of your comments and questions will be really useful in helping me understand what you are thinking.

I also want you to know that all the information that you give me today will be confidential. That means that your name will not be connected to the comments or concept maps that you give me. Also, the video of this interview will only be viewed by a select group of people in my school. It won't be posted on the web or be shown to any of your classmates. And after I'm done analyzing the video, I will delete it after two years.

Do you have any questions or concerns about doing this interview? Would you like to start the interview?

NetLogo Climate Change model:
http://ccl.northwestern.edu/netlogo/models/ClimateChange

This program is also currently installed on the student's MLTI computer as part of the standard software.

Interview Protocol

1. Students will be given the two free response questions to complete in written form.

2. Students will be asked to create a pre-concept map about that would show how the greenhouse effect works. During this time the interviewer will ask these questions:

   a) Can you explain how your concept map shows how the greenhouse effect works?
   b) What concepts in your concept map effect the Earth's temperature?
   c) Can you explain the relationship between _______ and ________ (depends upon the students' map).
   d) Are there any differences between your written response and your concept map in describing how the greenhouse effect works? If so, explain why they are different.
   e) Have you ever used a NetLogo computer model before today? If yes, please describe your experiences.

3. The student will be directed to open the NetLogo Climate Change model and given 5-10 minutes to 'play' with the model.

4. The student will be asked to check, modify, or create new concepts and relationships in their concept map about the greenhouse effect. They may choose to start from scratch if desired.

5. The interviewer will ask these questions while the student is creating the post-concept map:

   a) Are there any new concepts that you added to your concept map? If yes, why did you decide to add that concept?
   b) Can you explain to me why you added / changed / removed the relationship between _______ and _______? (depends upon students' map)
   c) Can you explain the relationship between _______ and ________ (depends upon the students' map).
   d) Can you explain (or give an example of) the process you are using to determine relationships between concepts using the NetLogo model?
   e) Are there any parts of the model that you find confusing? Do you have any suggestions that would make it less confusing?
   f) How would you modify the concepts in the model to maximize the Earth's temperature?

g) Are there any concepts on your concept map that are not included in the model? If yes, can you think of a reason why they may not be included in the model?
h) What aspects of the model interface do you like? Why?
i) What aspects of the model interface do you not like? Why?

6. The student will be asked to answer the free response questions again. They will have access to their post-concept maps and NetLogo model for reference.

7. The data collection portion of the interview will then end.

8. The student will be given an opportunity to ask any questions concerning the events and topics covered in the interview.

Appendix F: Interview transcripts

Student 1: 7th Grade, Male, School A - "Jay"

I: Do you remember when you first came into class what you knew about the greenhouse effect?
J: I knew nothing.
I: You knew nothing, okay. So when you open the program, do you remember what was the first thing you tried to do?
J: I saw the button that said go, then I pushed go and then I added like a thousand CO2.
I: A thousand CO2?
J: Yep.
I: Why did you do that?
J: Cause it looked like fun.
I: Yeah?
J: Cause they looked like turtles.
I: And what did you notice when you added the CO2?
J: That the temperature went up.
I: The temperature went up.
J: And there is more red bumps in the pink (motions to the pink area on the screen).
I: So, if someone were to ask you right then what the greenhouse effect was, would you understand?
J: Maybe a little bit, but not fully on how it works, but...
I: So how would you say that carbon dioxide influences the Earth's temperature?
J: Um, I don't know. Like the more you have, the more sunlight comes down, and then it gets – ah hot, hotter... the temperature rises.
I: So the temperature rises when you add more carbon dioxide?
J: Yeah.
I: And how did you know that?
J: Cause we were, I just kept pushing that and then [teacher name] told us to see how, check the temperature, and I checked the temperature, and it went up faster when I added more carbon dioxide.
I: You mean looking at the graph over there?
J: Yeah. And looking at the temperature right there (pointing at the instant temperature read-out) and that went up, and sometimes it would go down and then up.
I: So when the sunlight came in, how did that affect the Earth's temperature?
J: It azorb... it, it.. can't even say that word. It azorb...
I: absorbed?
J: absorbed into the ground. And then it got hot.
I: So did the CO2 affect the sunlight?
J: Uh, no – not really. It, uh – no.
I: So how would you explain adding CO2 would raise the Earth's temperature?
J: Um, I don't know.

I: Okay. You just know that putting more CO2 in makes the graph go up?
J: Yep.
I: Okay.
J: And then the temperature goes up.
I: Okay. And what are some of the buttons you pushed over there (indicating to the model's interface) or things that you changed?
J: Um, there was an add CO2 button. I pushed that and then that put ten more of the little thingies. And then if you push add a cloud, that will go in there, but when there is a cloud it will reflect the sunlight, and it will shoot the sunlight back up into the sky, so I don't use clouds. And you can make it daytime or nighttime. You can have normal soil, ice, or dark soil. And you can watch one of the sun rays.
I: What did you notice changing when you changed the surface reflection?
J: When it went to ice it didn't allow much sunlight to go into the, into the ground. It would just, all of the sunlight would bounce off and go back to the sky.
I: And how does the Earth's temperature respond when that happens?
J: It gets colder.
I: Colder?
J: Like when it's on this (indicating ice setting), all the sunrays will bounce back up, but when it's on dark soil, it will absorb all of them.
I: So also on here I see some red arrows. Do you know what those are from?
J: That's from some of the heat that, infrared light or heat that would rise up and it would leave, but then it will hit the CO2, and the CO2 will change its direction, and sometimes it will hit it back into the ground, so it warms the...
I: So what would you say were the sources of energy?
J: The sun.
I: Sun.
I: So, if you were to try to figure out how adding carbon dioxide increases the Earth's temperature, how do you think you would try to do that?
J: Um, I would probably test it on this without carbon dioxide, and then to see how high it will go and how fast it will get that hot and up in temperature. And then I would put CO2 in there and see how high [unintelligible].
I: So by doing that you are seeing, you're just looking at the temperature, right?
J: Yeah.
I: And you said before that without C02 its cooler than when it has C02.
J: Yeah.
I: So you kinda know that, that when you add C02 it adds...
J: heat
I: heat, right?
J: Yeah.
I: So how would you describe, in your own words, how the greenhouse effect works?
J: Um – ah – it shows the temperature of the Earth, cause it has to do with global warming, and it will show you the temperature on the graph, and like I said, add C02 or clouds and change the soil and make it night or day.
I: Okay.

J: And you can write down here at the bottom [unintelligible].
I: Okay.
I: If you had any suggestions to someone who was making one of these models, to make it easier to use, what would you tell them?
J: Um, probably just use this, depending on what they are trying to figure.
I: So you felt like it was pretty easy to use?
J: Yeah.
I: Yeah. Do you have any questions for me?
J: No, not really.
I: Okay, then we're done.

Interview 2: 7th Grade, Female, School A, "Bea"

I: Okay, just to start off, do you remember, like when I gave you those first sheets, what you put on there when I asked you what you knew about the greenhouse effect before we started looking at it?
B: Um, I didn't put anything down because I didn't know – I had no idea what the greenhouse effect was.
I: Okay. That's fine. So when you opened the program, do you remember what you started – what you first started doing?
B: Um, I think I started adding a lot of clouds and CO2 and stuff. And then I found the go button.
I: Oh (laughing)
B: and then I pressed go (laughing). And then the temperature went up, so – then I started changing the Earth's average temperature and stuff (pointing at the surface reflection slider).
I: So when you were changing things, was there anything in particular that you were looking at?
B: I was looking at the temperature and I was looking at the little red dots underneath the soil line...
I: Okay.
B: And seeing how those were multiplying.
I: Okay.
B: And decreasing when there was ice.
I: Oh, so you noticed that the red dots got less when there was ice.
B: (nodding)
I: So do you know how the red dots related to the temperature that was graphed over here?
B: Um, I think the sunlight came down through the little green line, and then it got trapped in [pink area].
I: Okay.
B: So the temperature goes up.
I: Okay, so when there is red dots over here, the temperature goes up?
B: Yep.

I: Okay. So – you can start playing around with it if you want –
B: And I found out that the CO2 or the sunlight gets reflected off the clouds so it doesn't go down [unintelligible].
I: So when you add CO2, does the overall temperature go up or go down?
B: Goes up.
I: Can you explain to me why you think it goes up? Like, what makes it go up?
B: Um, the CO2... I don't really know... I think it reflects the stuff down back into the Earth.
I: What kind of stuff do you think it reflects back down?
B: It reflects the heat particle thingies.
I: So, show me on here (pointing to the screen). What are you seeing here?
B: The stuff gets bounces up here and it bounces back down, and the sunlight gets down here it gets trapped into a little red dot and the sunlight is reflected off the clouds. So it goes back up into the atmosphere and [mumbles].
I: (laughs) So you were saying, I'm just going to go back on each of those variables there – so when you changed the surface, from ice to dark soil, what did you notice about the Earth's temperature when you did that?
B: I noticed that when it was ice it, the temperature went, it stayed the same, it stayed at 12. And when I did the dark soil, the heat was absorbed into the dark soil, so the temperature went up a lot faster.
I: So it went up a lot faster?
B: Yep.
I: Okay. And how about the sun brightness? When you changed that – did you change that from daytime to nighttime?
B: Yeah I did. Um, it doesn't really get warm cause there's no sunlight coming down. So it doesn't really change that much, but the CO2 still does [mumbles].
I: Okay. And you said you added clouds. What do the clouds do?
B: They reflect some of the sunlight and they trap some of the CO2 sometimes, and then it gets hot. And then it's like only half the sunlight gets down [mumbles].
I: So are you saying it reflects the sunlight back out to outer space. Do they do anything to the stuff coming up?
B: What do you mean?
I: Like the sun rays and the infrared rays coming up. Do you notice it affecting those at all?
B: Um, not really.
I: Okay. So, let's see. We've talked about surface reflection, sun brightness, clouds, and the CO2 you said when add CO2, the temperature goes up.
B: (nodding)
B: So we were in a competition and we had over 2000 CO2's.
I: You did?
B: Yeah. It was pretty cool.
I: Okay, so how would you explain, um, I don't have your paper in front of me, but how would you explain how the – if someone were to ask you what is the greenhouse effect – how does it work – what would you tell them?

B: I would tell them that Earth's temperature rises because the CO2 traps the heat under the ground, and the infrared light – the CO2 makes – I don't remember, but something to do with infrared light.
I: Okay. Great. So if you were able to tell a scientist or a researcher, like they were making stuff like this (pointing at model), like models like this – what, could you make any suggestions to make it easier to use or more fun to use, or anything like that?
B: I guess it would be more fun if it had different levels so we had to do different things.
I: So almost like a game?
B: Yeah.
I: Okay.
B: Cause we did that in [mumbles] and it was fun.
I: So a little more interesting to try to get to different places?
B: Yeah.
I: Okay, great. Do you have any questions for me?
B: Um, not really.
I: Okay, we're done.

Interview 3: 8th Grade, Female, School A, "Anna"
(Note: A fan was running in the background, making it difficult to transcribe the video.)

I: So first off, before you started using the program, what did you think the greenhouse effect was?
A: I thought it was something [mumbles]
I: Okay, and so when you first opened the program what – can you explain to me what you did?
A: Well, we first pressed setup, which came up with a [mumbles] sky, and then you pressed go, and it simulated sun rays going down into the Earth [mumbles], and then from there you can just play around with the CO2, clouds, [mumbles] the surface reflection of the sun.
I: And what were some of the things you noticed that changed the Earth's temperature?
A: The surface reflection. The dark soil is the best to keep the heat – ice pretty much blocks the sun rays, and [mumbles] – CO2 increases the temperature.
I: And, so you were talking about how the surface reflection wouldn't – you said ice it blocks the sun rays. What do you mean by that?
A: It like stops the heat from the sun from getting into the Earth.
I: Okay. So you said when you add CO2 it increased the Earth's temperature.
A: Yes.
I: How does it do that?
A: Well there's – you mean like on the computer?
I: Yeah, like what did you see happening?
A: Well, the more CO2 you added – the more CO2 you add – the temperature starts increasing.
I: And can you explain by what's going on in the screen why you think that is going up?
A: Because, I think, the sun's rays are allowed to get in, but the heat is not allowed to

escape from the CO2. So the heat stays [mumbles].
I: Okay, and did you see that when you increased the CO2?
A: Yeah
I: So what was the heat that wasn't able to get back out?
A: [mumbles]
I: You mean the red [mumbles]
A: You are getting some of the CO2.
I: Getting some of the CO2. Okay, and did you play with the clouds at all?
A: Yeah, but I didn't see how they affected the temperature.
I: Okay. And – okay, so, I haven't looked at your sheet yet or anything, but if you were to have to explain what is the greenhouse effect, what would you – how would you explain that to a friend?
A: I would say the greenhouse effect is increasing the CO2 in the atmosphere, which lets the sunlight come in, but traps the heat in [mumbles].
I: Okay. If you had... I'm working with scientists and researchers who are making models like this for your age group right now [mumbles] – if you were able to give them advice or give them suggestions about how to make a model like this fun and easier to use, what would you – are there any suggestions you would give to them?
A: Um, well you have the handout, but if someone was to find this somehow, they wouldn't know what exactly the sun rays or the CO2 or the – heat trapped in the Earth [mumbles] what they would be.
I: So a little more clear [mumbles]. How about the buttons and the sliders? Where they easy to use?
A: Yeah, they were pretty easy to use.
I: Okay, do you have any questions for me?
A: No, not really.
I: Okay, that's it.

Interview 4: 8th Grade, Male, School A, "Roger"
(Note: A fan was running in the background, making it difficult to transcribe the video.)

I: Okay, so before today, like on those sheets that you gave me earlier, what did you think the greenhouse effect was, like before we played with the model?
R: Really I just thought it was sunlight was coming down to the Earth and then all the emissions from the fossil fuels and everything else that we are burning is just getting caught up in the atmosphere and depleting the ozone layer and keeping [mumbles].
I: Okay, so you might need to press setup – there you go. Okay, when you opened the program, can you describe to be what you first started doing to look at it?
R: Well when I first opened it up, I guessed to put the dark soil, and I saw it starts to keep that in, and I was wondering why it keeps bouncing things out, so I looked over it says surface reflection. If you turn it up, it turns into ice, which will reflect basically every kinds of light and stops the temperature from rising. But when you put it down to darker soil, it will absorb more and more as it goes down. And I was playing around with the sunlight, because basically right here it fires down a lot of sunlight, but closer to the night

setting, it gives off less and less, eventually it gets to none.
I: Okay, so that is sort of where you went first – to see
R: what the sliders did
I: what the sliders did. And, so when you – did you add clouds or CO2 eventually?
R: That was the next thing I started doing. I was wondering what clouds did, so I added those in, and I saw it reflects the light that's coming down along with what's going up. Then I started to add CO2, and the more that you add, the more it reflects the sunlight that's not only coming down to Earth, but also reflecting it out. So it will just bring it back down to Earth and that's when I started figuring it out that it was the CO2 that's keeping everything trapped in.
I: Okay. So what would you say – I know we kind of talked about this in class, but when you increase the CO2, how does that affect the Earth's temperature?
R: Well, it basically stopped – it lets a lot more of the sunlight in than it lets out, so it will just keep the sunlight in, which will keep the temperature constantly increasing. And it basically keeps it a lot warmer – doesn't really cool off much. So that will affect the global warming.
I: Okay, and how would you explain how the infrared rays are produced?
R: I'd say that after the sunlight comes in [mumbles] within the Earth, and while it's releasing, it's releasing the infrared.
I: Okay, and how does the carbon dioxide interact with the sunlight and the infrared?
R: Well, what I noticed is that it seems to let in sunlight a lot more than it blocks it back out. But while it's trying to come back out from the Earth, it keeps it back down and lets very little out. And if it does let any of it out, it bounces around the field for a little while.
I: And is that for the sunlight and the infrared?
R: Yeah, cause like right there, some of the sunlight is bouncing up, but not half as much as what is actually going in.
I: Okay, so if you now were to be asked by a friend how the greenhouse effect work, how would you explain it to him?
R: I would explain it to them as the sunlight comes down, well obviously from the sun, and the CO2 will reflect some of it back up into space, but it let a lot more down. And while it's trying to come back out, the CO2, which is from us burning all kinds of fossil fuels and coal and stuff, it will bounce it back down keep all the heat within the Earth, and not let much out. And it keeps just building up, and the Earth's temperature will gradually increase. And also that the clouds will both reflect most sunlight out if it blocks where the sunlight is coming in, and it also brings the infrared back down.
I: In the very beginning you mentioned something about the ozone layer. Do you remember what you said about that at all?
R: I think I said that all the emissions from us burning fossil fuels and coal is depleting the ozone layer, while we're – well, burning the fossil fuels, which we can't exactly get rid of, so we just got to let it happen and cut back the best we can.
I: So scientists and researchers are trying to make these kinds of models for students to use. Do you have any suggestions or requests to make it more fun and easy to use?
R: I think to make it easier to use they should – you should be able to move around the clouds because as you add them in, they seem to just clump together instead of being a bit

spaced out more. So it will basically keep all the sunlight out for a long time until those clouds pass [mumbles]. Whereas, really, the clouds are a bit more spaced out.
I: Okay.
R: So I think it would just make it easier to use if you could move the clouds around.
I: Is that because you think that the reaction isn't what you really expect?
R: Yes, because if they were more spread out, more sun would come through and it would seem a lot more realistic than a bunch of clouds grouped in one spot, and having a big open space where no heat will get through.
I: Okay, that's it. Thank you.

Appendix G: Concept map and free-response scoring guide

Table G.1. Scoring Guide

	Student ID:	Concept Map					
		Pre	Weight	Total	Post	Weight	Total
	Greenhouse Effect						
G1	GE affects or increases Earth's temperature.		x 1			x 1	
G2	Greenhouse gases trap heat (energy)		x 1			x 1	
	Sunlight						
S1	Sunlight can be absorbed into Earth's surface.		x 1			x 1	
S2	Sunlight affects the Earth's temperature.		x 1			x 1	
S3	Sunlight is reflected by clouds.		x 1			x 1	
	Carbon Dioxide						
C1	Increasing CO_2 increases the Earth's temperature (heat energy).		x 5			x 5	
C2	CO_2 affects Earth's temperature.		x 1			x 1	
C3	CO_2 is reflects and/or absorbs infrared energy.		x 5			x 5	
C4	CO_2 lets sunlight through.		x 5			x 5	
C5	CO_2 is a greenhouse gas.		x 1			x 1	
C6	CO_2 is a gas in the atmosphere.		x 1			x 1	
	Infrared Energy (Light)						
I1	IR energy is radiated from Earth's surface.		x 5			x 5	
I2	Amount of IR radiated from surface is proportional to amount of heat energy.		x 5			x 5	
I3	IR can be absorbed into Earth's surface.		x 1			x 1	
I4	IR energy affects the Earth's temperature.		x 1			x 1	
	Earth's heat energy (temperature)						
T1	Earth's heat energy (temperature) increases when sunlight is absorbed into Earth's surface.		x 5			x 5	
T2	Earth's heat energy (temperature) increases when IR energy is absorbed into surface.		x 5			x 5	
T3	Earth's temperature decreases when heat energy is radiated to IR energy.		x 5			x 5	
	Reflectivity						
R1	Surface reflection affects amount of sunlight and/or IR absorbed into Earth's surface.		x 5			x 5	
	Total:						
	Misconceptions						
M1	Sunlight is reflected by CO_2.						
M2	Involves deterioration of ozone layer.						
M3	Ozone hole lets in more heat or energy.						
M4	Ozone hole raises Earth's temperature.						
M5	Plants give off CO_2						
M6	Greenhouse gases are pollution.						
M7	Greenhouse effect does not exist.						
M8	IR energy creates CO_2						

Table G.1 Continued

	Student ID:	Free Response					
		Pre	Weight	Total	Post	Weight	Total
	Greenhouse Effect						
G1	GE affects or increases Earth's temperature.		x 1			x 1	
G2	Greenhouse gases trap heat (energy)		x 1			x 1	
	Sunlight						
S1	Sunlight can be absorbed into Earth's surface.		x 1			x 1	
S2	Sunlight affects the Earth's temperature.		x 1			x 1	
S3	Sunlight is reflected by clouds.		x 1			x 1	
	Carbon Dioxide						
C1	Increasing CO_2 increases the Earth's temperature (heat energy).		x 5			x 5	
C2	CO_2 affects Earth's temperature.		x 1			x 1	
C3	CO_2 is reflects and/or absorbs infrared energy.		x 5			x 5	
C4	CO_2 lets sunlight through.		x 5			x 5	
C5	CO_2 is a greenhouse gas.		x 1			x 1	
C6	CO_2 is a gas in the atmosphere.		x 1			x 1	
	Infrared Energy (Light)						
I1	IR energy is radiated from Earth's surface.		x 5			x 5	
I2	Amount of IR radiated from surface is proportional to amount of heat energy.		x 5			x 5	
I3	IR can be absorbed into Earth's surface.		x 1			x 1	
I4	IR energy affects the Earth's temperature.		x 1			x 1	
	Earth's heat energy (temperature)						
T1	Earth's heat energy (temperature) increases when sunlight is absorbed into Earth's surface.		x 5			x 5	
T2	Earth's heat energy (temperature) increases when IR energy is absorbed into surface.		x 5			x 5	
T3	Earth's temperature decreases when heat energy is radiated to IR energy.		x 5			x 5	
	Reflectivity						
R1	Surface reflection affects amount of sunlight and/or IR absorbed into Earth's surface.		x 5			x 5	
	Total:						
	Misconceptions						
M1	Sunlight is reflected by CO_2.						
M2	Involves deterioration of ozone layer.						
M3	Ozone hole lets in more heat or energy.						
M4	Ozone hole raises Earth's temperature.						
M5	Plants give off CO_2						
M6	Greenhouse gases are pollution.						
M7	Greenhouse effect does not exist.						
M8	IR energy creates CO_2						

Appendix H: Raw concept map, free-response, and multiple-choice scores

Table H.1. Raw student total scores for concept maps, free-response question, and multiple-choice questions.

				Multiple-Choice Scores			Concept Map Scores			Free-Response Scores		
ID	School	Grade	Class	Pre	Post	<g>	Pre	Post	<g>	Pre	Post	<g>
JC701	A	7	1	1	1	0.00	1	1	0.00	0	2	0.04
ML702	A	7	1	1	1	0.00	4	2	-0.04	3	2	-0.02
JA703	A	7	1	0	0	0.00	0	1	0.17	1	10	0.24
RY704	A	7	1	0	0	0.00	0	5	0.00	0	5	0.12
CC705	A	7	1	0	0	0.00	0	7	0.02	0	1	0.02
TT706	A	7	1	2	2	0.00	0	0	0.00	0	5	0.12
ER707	A	7	1	0	1	0.25	0	0	0.12	0	5	0.12
JB708	A	7	1	1	1	0.00	5	11	0.04	0	5	0.12
NM709	A	7	1	1	0	-0.33	0	0	0.00	0	5	0.12
FB710	A	7	1	1	0	-0.33	1	2	0.00	0	0	0.00
CS711	A	7	1	0	2	0.50	0	0	0.12	0	5	0.12
JS712	A	7	1	0	1	0.25	0	0	0.00	0	5	0.12
BB713	A	7	1	0	0	0.00	0	0	0.07	0	1	0.02
MP714	A	7	1	1	2	0.33	1	1	0.00	0	0	0.00
MR715	A	7	1	2	1	-0.50	1	6	0.04	0	5	0.12
NH716	A	7	1	0	2	0.50	1	3	0.00	0	5	0.12
KK717	A	7	1	1	1	0.00	1	1	0.04	0	5	0.12
KG720	A	7	2	0	0	0.00	1	1	0.00	0	11	0.30
MG721	A	7	2	0	1	0.25	0	1	0.00	1	6	0.12
KS722	A	7	2	1	2	0.33	0	5	-0.02	0	0	0.00
SW723	A	7	2	1	1	0.00	1	1	0.00	1	12	0.31
CS724	A	7	2	1	0	-0.33	0	0	0.21	2	8	0.15
JW725	A	7	2	1	0	-0.33	0	0	0.15	1	2	0.02
RT726	A	7	2	0	0	0.00	0	0	0.02	0	2	0.04
MI728	A	7	2	0	0	0.00	0	0	-0.04	1	1	0.00

Table H.1. Continued.

NS729	A	7	2	1	3	0.67	1	4	0.00	1	0	-0.02
NB730	A	7	2	2	1	-0.50	1	3	0.02	0	11	0.30
MO731	A	7	2	1	2	0.33	0	0	0.00	2	6	0.10
JB732	A	7	2	2	3	0.50	0	2	0.00	0	21	0.78
KK733	A	7	2	1	3	0.67	0	0	0.00	3	12	0.25
AC734	A	7	2	0	2	0.50	0	2	0.26	5	10	0.13
DR735	A	7	2	0	2	0.50	0	0	-0.02	1	6	0.12
LS736	A	7	2	0	2	0.50	0	0	0.00	0	5	0.12
BW737	A	7	2	0	2	0.50	0	0	0.00	0	0	0.00
LI738	A	7	2	2	1	-0.50	1	1	0.00	0	6	0.14
RA802	A	8	3	2	2	0.00	6	6	0.17	0	10	0.26
AP803	A	8	3	3	1	-2.00	10	12	0.00	0	1	0.02
CC804	A	8	3	1	1	0.00	6	9	0.00	5	1	-0.09
AP805	A	8	3	1	1	0.00	2	2	0.00	0	1	0.02
JE806	A	8	3	0	2	0.50	0	0	0.04	0	10	0.26
GB808	A	8	3	0	1	0.25	7	6	0.04	0	16	0.50
TG809	A	8	3	1	2	0.33	2	2	0.31	1	16	0.47
CJ810	A	8	3	1	2	0.33	2	2	-0.02	1	6	0.12
TD812	A	8	3	0	1	0.25	2	10	0.00	1	5	0.09
KB813	A	8	3	1	1	0.00	1	7	0.12	1	15	0.42
AE815	A	8	3	1	2	0.33	0	1	0.04	1	11	0.27
JP101	B	7	1	1	2	0.33	2	0	0.07	1	7	0.15
AW102	B	7	1	1	2	0.33	0	0	0.24	1	10	0.24
GJ103	B	7	1	0	1	0.25	0	16	0.00	1	5	0.09
DW104	B	7	1	2	1	-0.50	0	0	0.39	2	20	0.64
MN105	B	7	1	2	1	-0.50	0	0	0.00	0	11	0.30
SS106	B	7	1	1	1	0.00	1	2	0.00	0	0	0.00
LA107	B	7	1	2	2	0.00	0	0	0.00	1	1	0.00
SC108	B	7	1	2	1	-0.50	1	0	-0.02	0	0	0.00
BD109	B	7	1	2	2	0.00	0	0	0.00	0	2	0.04

Table H.1. Continued

SV201	B	7	2	0	0	0.00	3	22	0.02	1	18	0.57
JR202	B	7	2	1	1	0.00	0	1	0.24	0	0	0.00
TL203	B	7	2	2	1	-0.50	0	0	0.31	0	0	0.00
ET204	B	7	2	3	3	0.00	0	0	-0.13	0	12	0.33
KM205	B	7	2	0	1	0.25	1	0	0.00	3	6	0.07
DF206	B	7	2	4	3	0.00	0	0	0.00	0	6	0.14
WC207	B	7	2	2	1	-0.50	0	15	0.00	0	0	0.00
GP208	B	7	2	1	2	0.33	1	0	0.00	0	5	0.12
KC209	B	7	2	0	1	0.25	0	16	-0.02	0	10	0.26
KF210	B	7	2	2	2	0.00	0	0	0.09	1	10	0.24
LZ211	B	7	2	1	2	0.33	0	0	0.00	0	10	0.26
KP212	B	7	2	0	3	0.75	0	0	0.14	0	11	0.30
JI213	B	7	2	1	2	0.33	0	0	0.00	0	0	0.00
DR214	B	7	2	1	2	0.33	0	0	0.02	0	5	0.12
AH215	B	7	2	2	3	0.50	0	10	0.12	0	1	0.02
JO216	B	7	2	2	3	0.50	0	0	0.00	0	1	0.02
TB217	B	7	2	2	3	0.50	0	10	0.16	0	15	0.45
NI301	B	7	3	2	2	0.00	0	6	0.00	0	0	0.00
DI302	B	7	3	1	3	0.67	0	0	0.00	0	0	0.00
MK303	B	7	3	2	2	0.00	3	2	0.00	0	5	0.12
ZS304	B	7	3	1	1	0.00	6	1	0.00	0	0	0.00
BD305	B	7	3	1	3	0.67	1	1	0.02	0	0	0.00
BW306	B	7	3	1	2	0.33	0	0	0.00	0	0	0.00
KA307	B	7	3	2	2	0.00	0	0	0.00	0	1	0.02
CM308	B	7	3	1	3	0.67	0	0	0.00	0	0	0.00
MJ309	B	7	3	1	3	0.67	0	0	0.00	0	0	0.00
DE310	B	7	3	0	1	0.25	0	7	0.04	0	0	0.00
ML311	B	7	3	3	2	-1.00	0	0	0.00	0	0	0.00
MH312	B	7	3	2	2	0.00	0	0	0.00	0	5	0.12
KL313	B	7	3	0	1	0.25	0	0	0.00	0	0	0.00

Table H.1. Continued

TC314	B	7	3	1	2	0.33	1	0	0.06	7	11	0.11
KS315	B	7	3	1	1	0.00	0	2	0.08	1	5	0.09
CS401	B	7	4	4	3	0.00	1	16	0.00	3	2	-0.02
JM402	B	7	4	0	2	0.50	1	8	0.00	2	1	-0.02
JS403	B	7	4	2	3	0.50	5	20	0.00	1	11	0.27
NF404	B	7	4	1	2	0.33	0	7	0.00	0	10	0.26
AM405	B	7	4	0	1	0.25	0	2	0.50	1	1	0.00
ZS406	B	7	4	1	2	0.33	6	12	0.00	1	6	0.12
RR407	B	7	4	2	2	0.00	2	13	0.00	0	0	0.00
PL408	B	7	4	1	4	1.00	2	18	0.02	1	15	0.42
RM409	B	7	4	1	2	0.33	1	10	-0.02	0	15	0.45
EG410	B	7	4	1	2	0.33	7	6	0.00	1	11	0.27
BM411	B	7	4	3	2	-1.00	0	0	0.73	12	23	0.44
EH412	B	7	4	1	4	1.00	0	0	0.00	1	16	0.47
HB413	B	7	4	0	3	0.75	1	15	0.00	1	16	0.47
RH414	B	7	4	1	2	0.33	1	6	-0.02	1	15	0.42
AW415	B	7	4	1	2	0.33	1	6	0.45	0	15	0.45
SH416	B	7	4	1	3	0.67	0	2	-0.02	0	5	0.12
MB417	B	7	4	1	1	0.00	0	3	0.50	0	16	0.50
CF418	B	7	4	1	3	0.67	2	2	0.00	0	10	0.26
JK419	B	7	4	0	2	0.50	1	10	0.00	0	15	0.45
JK420	B	7	4	2	2	0.00	1	8	0.00	1	1	0.00
MR421	B	7	4	0	2	0.50	2	11	0.00	1	15	0.42
MM422	B	7	4	1	1	0.00	0	0	0.26	0	12	0.33
NC423	B	7	4	1	1	0.00	1	1	0.14	1	7	0.15
CT424	B	7	4	2	2	0.00	1	0	0.00	0	10	0.26
KS425	B	7	4	3	4	1.00	2	15	-0.11	5	11	0.16
RO501	B	7	5	1	1	0.00	0	0	0.00	0	1	0.02
JL502	B	7	5	1	2	0.33	0	0	0.00	0	15	0.45
TS503	B	7	5	0	2	0.50	0	0	-0.02	1	5	0.09
LM504	B	7	5	0	0	0.00	0	0	0.47	5	16	0.34

Table H.1. Continued

MD505	B	7	5	0	0	0.00	0	0	0.18	2	6	0.10
KS506	B	7	5	0	2	0.50	0	0	0.54	0	20	0.71
AS507	B	7	5	0	3	0.75	0	0	0.17	0	11	0.30
BC508	B	7	5	0	1	0.25	0	0	0.17	1	1	0.00
RG509	B	7	5	1	2	0.33	0	0	0.53	0	5	0.12
MR510	B	7	5	0	3	0.75	1	0	0.24	2	10	0.21
DZ511	B	7	5	2	1	-0.50	0	0	0.00	0	10	0.26
KB512	B	7	5	0	1	0.25	0	0	0.42	0	15	0.45
AM513	B	7	5	0	0	0.00	1	0	0.12	1	15	0.42
CK514	B	7	5	1	2	0.33	0	0	0.00	2	21	0.70
RB515	B	7	5	1	2	0.33	0	0	0.18	1	15	0.42
SY516	B	7	5	1	1	0.00	0	1	0.24	1	21	0.74
CH517	B	7	5	0	0	0	0	0	0.00	0	7	0.17
BC518	B	7	5	1	2	0.33	0	0	-0.02	0	10	0.26
ST601	B	7	6	1	2	0.33	2	11	0.00	0	0	0.00
MA602	B	7	6	1	2	0.33	0	0	0.00	0	1	0.02
CD603	B	7	6	1	3	0.67	6	1	0.00	0	0	0.00
KO604	B	7	6	2	1	-0.50	1	12	0.00	1	10	0.24
JM605	B	7	6	0	1	0.25	0	0	0.00	0	10	0.26
BG606	B	7	6	0	1	0.25	6	0	0.00	0	0	0.00
ES607	B	7	6	1	2	0.33	0	0	0.00	0	0	0.00
DW608	B	7	6	1	1	0.00	0	0	-0.02	0	11	0.30
LA609	B	7	6	2	4	1.00	0	0	0.00	1	5	0.09
AR610	B	7	6	3	2	-1.00	0	0	0.00	0	1	0.02
JD611	B	7	6	1	0	-0.33	0	0	0.00	0	1	0.02
TR612	B	7	6	3	3	0.00	1	0	0.00	0	0	0.00
HM613	B	7	6	0	0	0.00	1	5	0.00	1	11	0.27
AK614	B	7	6	2	3	0.50	0	0	-0.11	6	15	0.27
AC615	B	7	6	1	0	-0.33	0	6	0.00	0	0	0.00
VT616	B	7	6	1	0	-0.33	0	0	0.00	0	6	0.14
BE617	B	7	6	0	0	0.00	0	0	0.00	0	10	0.26

BIOGRAPHY OF THE AUTHOR

Lisa Renee Schultz was born and raised in Oakdale, California. She graduated from Oakdale High School in 1994 and attended Abilene Christian University in Abilene, Texas for two years before transferring to the University of California, Davis where she received her Bachelors of Science in Mechanical Engineering. She was a manufacturing mechanical engineer at Agilent Technologies in Santa Rosa, California for five years, and then worked at various start-up companies for another three years before deciding to move to the east coast.

While in Maine, Lisa decided to pursue a teaching career and entered the Center for Science and Mathematics Education Research graduate program at the University of Maine in Orono in 2007. She is in the process of receiving her teaching certification and is planning on teaching science starting in the fall of 2009 at Old Town High School in Old Town, Maine. Lisa is a candidate for the Master of Science in Teaching degree from The University of Maine in August, 2009.