Reconstructing Student Conceptions of Climate Change;
An Inquiry Approach

A DISSERTATION
SUBMITTED TO THE FACULTY OF
UNIVERSITY OF MINNESOTA
BY

J Collin McClelland

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Gillian H. Roehrig, Advisor

August 2015

Acknowledgements

The journey through my doctoral program was long and arduous, accompanied by growth beyond my expectations. Sustaining me through this journey and adding to my personal growth are many individuals to be named here. Though not exhaustive, I hope to give ample credit where it is due.

I entered this program the fall of 2009, encouraged by some graduate students in the middle of their own journey through the program. Brant Miller and Tom Meagher both spoke to me at length about what I was potentially getting into. They assured me that under the guidance of Gill Roehrig I would have a clear trajectory to success. They were right.

I will be forever grateful for the guidance and coaching offered by my adviser Gill Roehrig. She not only mapped out a clear pathway for me, she also presented me with other opportunities to grow professionally beyond what I had expected. It was a gift to be invited to participate on so many professional development teams, and explore the role of being a student teacher supervisor and methods instructor. Even more powerful for me was the realization that I could write academic works. She continually challenged me to reassess my writing and make it more academic. The product before you only exists by her persistent and ongoing feedback.

I was also blessed with a very supportive committee, which inspired me and challenged me in many ways. Fred Finley couldn't stay on due to travel duties to Thailand, but he helped me evaluate my notion of the "nature of science" and develop my inner philosopher. Frances Lawrenz introduced me to qualitative research in a way that finally made sense to me, through great readings, discussion, and "coffee shop coding". Julie Brown stepped in last minute as part of the team, challenging me with insightful questions during my defense and follow-up advice to strengthen my writing. Sarah Hobbie inspired the topic for my dissertation, training me more in global climate change content and giving me a thirst for even greater understanding.

I have had many peers that walked a journey similar to mine over these six years. They all played a support role in some capacity, by the ideas they shared during class and time spent working together. There are too many to name in this one paragraph, but two must be said. Barb Billington was an inspiration to me, the way she managed her duties as a full time instructor and graduate student. She taught me so much about teaching and mentoring student teachers. Devarati Bhattacharya was my biggest supporter at work on a regular basis. She always managed to inspire and uplift me when I was mired in the process, or at least found a way to make me laugh.

Lastly, I must credit my family for their endless support and encouragement. My journey with the University was often at the expense of time with my family. Their patience and understanding were critical to my success, as were their sacrifices. My wife Angie gave up much for me to complete this program, often pulling double duties on the home front. My daughters Eva and Anna began their school journeys as Dad began his. I am grateful for their endless hugs and kisses, reminding me that I'm forgiven from my absenteeism. I must thank them officially here.

Dedication

This work is dedicated to James Lee McClelland, my father.

Abstract

No other environmental issue today has as much potential to alter life on Earth as does global climate change. Scientific evidence continues to grow; indicating that climate change is occurring now, and that change is a result of human activities (National Research Council [NRC], 2010). The need for climate literacy in society has become increasingly urgent. Unfortunately, understanding the concepts necessary for climate literacy remains a challenge for most individuals. A growing research base has identified a number of common misconceptions people have about climate literacy concepts (Leiserowitz, Smith, & Marlon 2011; Shepardson, Niyogi, Choi, & Charusombat, 2009). However, few have explored this understanding in high school students.

This sequential mixed methods study explored the changing conceptions of global climate change in 90 sophomore biology students through the course of their participation in an eight-week inquiry-based global climate change unit. The study also explored changes in students' attitudes over the course of the study unit, contemplating possible relationships between students' conceptual understanding of and attitudes toward global climate change. Phase I of the mixed methods study included quantitative analysis of pre-post content knowledge and attitude assessment data. Content knowledge gains were statistically significant and over 25% of students in the study shifted from an expressed belief of denial or uncertainty about global warming to one of belief in it. Phase II used an inductive approach to explore student attitudes and conceptions. Conceptually, very few students grew to a scientifically accurate understanding of the greenhouse effect or the relationship between global warming and climate change. However, they generally made progress in their conceptual understanding by adding more specific detail to explain their understanding. Phase III employed a case study approach with eight purposefully selected student cases, identifying five common conceptual and five common attitude-based themes.

Findings suggest similar misconceptions revealed in prior research also occurred in this study group. Some examples include; connecting global warming to the hole in the ozone layer, and falsely linking unrelated environmental issues like littering to climate change. Data about students' conceptual understanding of energy may also have implications for education research curriculum development. Similar to Driver & While no statistical relationship between students' attitudes about global climate change and overall conceptual understanding emerged, some data suggested that climate change skeptics may perceive the concept of evidence differently than non-skeptics. One-way ANOVA data comparing skeptics with other students on evidence-based assessment items was significant. This study offers insights to teachers of potential barriers students face when trying to conceptualize global climate change concepts. More importantly it reinforces the idea that students generally find value in learning about global climate change in the classroom.

Table of Contents

List of Tables

List of Figures

Chapter I: Introduction

No other environmental issue today has as much potential to alter life on Earth as does global climate change (GCC). Scientific evidence continues to grow; indicating that climate change is occurring now, and that change is a result of human activities (Intergovernmental Panel on Climate Change [IPCC], 2014; National Research Council [NRC], 2010). A business as usual response to this issue is predicted to have dire consequences for global ecosystems and human societies which depend upon them (NRC, 2010). Despite the gravity of the situation hope exists in a belief that concerted human action toward current solutions can mitigate and minimize the effects of global climate change (Jervey, 2012; Socolow, Hotinski, Greenblatt, & Pacala, 2004).

The most comprehensive analysis of global scientific research on climate is reflected in the summary developed for world leaders and policy makers by the IPCC. In their most recent 2014 report, scientists state that, "warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen" (p. 2). The panel attributes this warming to increased greenhouse gases emitted by human activities; primarily fossil fuel combustion (IPCC, 2014). These conclusions are echoed by the National Academy of Sciences and public declarations of "all major scientific bodies in the United States whose members' expertise bears directly on the matter" (Oreskes, 2004, p. 1686). A decade's worth of scientific study of global climate change reveals that "there is a scientific consensus on the reality of anthropogenic climate change", demonstrated by an analysis of 928 peer-reviewed papers, none of which "disagreed with the consensus position" (Oreskes, 2004, p. 1686).

Many organizations are involved in educating the public on GCC, sharing web sites with updated scientific evidence on climate change, predicted consequences of social inaction, and potential solutions to alleviate this growing problem. Some of these organizations are as follows: the Union of Concerned Scientist (UCS), the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the Will Steger Foundation (WSF), and the Climate Change Science Program (CCSP). Most reflect the ideas shared by the IPCC, but in language that is less technical and more user-friendly for a mass audience. The general message is the same: climate change is occurring, humans are responsible, the consequences will impact global ecosystems and human societies in negative ways, and we have the technology and scientific knowledge necessary to respond to this issue.

Unfortunately, a growing body of evidence indicates persistent and widespread misconceptions of global climate change (Andersson & Wallin, 2000; Boyes & Stanisstreet, 1992; Fortner, 2001; Gowda, Fox, & Magelky, 1997; Hestness, McGinnis, & Marbach, 2011; Koulaidis & Christidou, 1999; Leiserowitz, Smith, & Marlon, 2011; Meadows & Wiesenmayer, 1999; Pruneau, Gravel, Bourque, & Langis, 2003; Rebich & Gautier, 2005; Rye, Rubba, & Wiesenmayer, 1997; Shepardson, 2009). Global climate change (GCC) is a complex interdisciplinary topic requiring strong student comprehension of the implications and mitigation solutions possible for GCC, in order that well-informed decisions are made in response to this critical environmental issue.

These misconceptions extend well beyond the classroom, being shared by much of the public (Leiserowitz et al., 2011; Shepardson, Niyogi, Choi, & Charusombat, 2009). This may be due in part to a lack of GCC education in schools (Hoffman & Barstow, 2007). Recent reform initiatives call for greater inclusion of GCC education in classrooms (NRC, 2012; U.S. Global Change Research Program, 2009), and a majority of American students express interest in knowing more about this topic (Leiserowitz et al., 2011). In order to take effective steps toward mitigating this environmental problem, students will first need to have an accurate scientific understanding of the issue (Meadows & Wiesenmayer, 1999; Sadler, 2004). Teaching students explicitly about GCC, challenging their conceptions, is required. This study analyzes changes in student conceptions and attitudes of GCC through the course of an inquiry-based teaching unit on the topic.

Educational Reform Efforts

There has been a growing response to the pressing need for GCC education through a number of educational reform efforts. Early responses were rather general, with an increasing emphasis on scientific literacy, promoted by the American Association for the Advancement of Science (AAAS) in 1989 in *Science for All Americans*, then later in *Benchmarks for Science Literacy* (1993). In 1996, the National Research Council (NRC) published the national science education standards (NSES). These standards also called for a greater emphasis on developing students' scientific literacy including attention to: scientific inquiry, the nature of science, and making social decisions based on scientific knowledge and data. The NSES also state that "an important purpose of science education is to give students a means to understand and act on personal and social issues" (NRC, 1996, p. 107). These early national efforts to bolster scientific literacy provided a clear grounding for GCC education; however, they were not explicit in outlining standards and benchmarks specific to climate literacy (CL). Indeed, the NSES mentioned the word climate only nine times, but failed to once acknowledge human impacts on it (McCaffrey & Buhr, 2008). Analysis of state standards indicates that most states either ignore climate change or only touch on it indirectly in their frameworks (Hoffman & Barstow, 2007).

Recently, the NRC published *A Framework for K-12 Science Education: Practices, Cross Cutting Concepts, and Core Ideas* (2012), which serves as the framework for the *Next Generation of Science Standards* which were released in April 2013. Analysis of the NRC "*Frameworks*" revealed a much more comprehensive emphasis on climate change; referring to it 33 times across different science disciplines, explicitly connecting it to human activities, and making GCC one of four sub-strand core disciplinary ideas under Earth and Space Sciences (NRC, 2012).

In addition to the specific inclusion of GCC in the new Next Generation Science Standards, a group of researchers and educators worked with the support of NOAA, AAAS, and the National Science Teachers Association (NSTA) to craft a framework for climate literacy. This effort produced the *Essential Principles of Climate Literacy*, which provided the structure necessary for teachers to see the "explicit alignment between climate science and the National Science Education Standards" (McCaffrey & Buhr, 2008, p. 516).

The State of GCC Education

Although current reform efforts address climate literacy more comprehensively than in previous reforms, there has been a lag in implementation of GCC education in schools. Research suggests that GCC education remains a low priority in American schools, with minimal teaching of climate change and poor curricular support (Dupigny-Giroux, 2011; Leiserowitz et al., 2011; McCaffrey & Buhr, 2008). Yet, despite its minimal presence in American classrooms, GCC is an important issue to the majority of Americans and one that many feel should be taught (Fortner, 2001; Leiserowitz et al., 2011).

Most of the research on GCC education targets student conceptions. Generally the research has described the conceptions students hold in contrast to the conceptions portrayed by the scientific community. Student conceptions are typically incomplete or inaccurate (Andersson & Wallin, 2000; Boyes & Stanisstreet, 1992; Fortner, 2001; Gowda et al., 1997; Hestness et al., 2011; Koulaidis & Christidou, 1999; Leiserowitz et al., 2011; Meadows & Wiesenmayer, 1999; Pruneau et al., 2003; Rebich & Gautier, 2005; Rye et al., 1997; Shepardson, 2009). The purpose of this student misconception research has been to advise teachers in the development of curriculum that can facilitate conceptual change (Pruneau et al., 2003; Shepardson, 2009). In order to foster conceptual change, it is suggested that students should display their conceptions in some public forum, discuss in groups the variety of public conceptions, be exposed to scientific ideas through lessons which can be compared to the groups' conceptions, and have opportunities to communicate or apply their new knowledge (Hewson, 1998; Khourey-

Bowers, 2011; Posner, Strike, Hewson, & Gertzog, 1982). Inquiry-based teaching has potential to utilize the components necessary to promote conceptual change; using elements of scientific inquiry as a platform for learning science (Anderson, 2002).

Most studies on students' conceptions of GCC have been focused overseas and on younger students, leaving a research gap on secondary science students in the U.S. (Shepardson et al., 2009). Also, very few studies have been conducted on instructional approaches that challenge students' misconceptions and address students' climate literacy. There is an urgent need for research on curricular approaches that challenge students' misconceptions surrounding GCC (Andersson & Wallin, 2000; Pruneau et al., 2003; Shepardson et al., 2009).

Purpose

The focus of this study is on a secondary science classroom during the teaching of GCC. Given the recent GCC education initiatives (NOAA, 2009; NRC, 2012) and the concerns over the lack of public understanding of GCC (Dupigny-Giroux, 2010; Leiserowitz et al., 2011), the underlying goal of this study is to explore the development of students' climate literacy (CL). The following research questions guide the study:

1. To what extent and in what ways do students' conceptions change in association with an 8-week inquiry-based unit on climate change?
2. In what ways do student attitudes change in association with an 8-week inquiry-based unit on climate change?
3. How does growth in content knowledge and conceptual understanding correspond with attitudes about climate change?

Overview of Remaining Chapters

Chapter II offers an overview of literature relevant to this study, beginning with research used to shape its theoretical framework. It then outlines education research on students regarding scientific literacy, climate literacy, and scientific inquiry. Chapter III outlines the basic methodology for the study; describing the theoretical framework, study context, curriculum features, and general data collection procedures. Quantitative and qualitative data analysis and findings for the entire group are outlined in chapter IV. Chapter V reveals more in depth qualitative analysis and findings from a purposeful sample of eight students. The study concludes with chapter VI; summarizing findings, study limitations, research implications, and possibilities for future research.

Definitions

What follows are operational definitions for concepts as they apply to this study. Each is elaborated on more fully in chapter II.

Global climate change (GCC). GCC is commonly used synonymously with "global warming"; however for this study it must be clarified that these two concepts are distinctly different. GCC refers to long-term changes to Earth's climate patterns, as a whole or regionally (Conway, 2012). Global warming is one aspect of Earth's changing climate; defined as an increase in Earth's average surface temperature in response to increased concentrations of greenhouse gases (GHG's) in our atmosphere.

Scientific literacy. For the purposes of this study, scientific literacy refers in part to what students should know and be able to do following science instruction. This not only includes science content and process skills, but also having the social capabilities to use scientific knowledge and understanding to make critical decisions affecting society (AAAS 2009).

Climate literacy. This is considered a sub-concept within scientific literacy. To be climate-literate a person: 1) understands the essential principles of Earth's climate system, 2) knows how to assess scientifically credible information about climate, 3) communicates about climate and climate change in a meaningful way, and 4) is able to make informed and responsible decisions with regard to actions that may affect climate (U.S. Global Change Research Program, 2009, p. 1).

Inquiry-based instruction. Inquiry teaching involves pedagogical practices similar to those outlined by constructivists, with the teacher acting as a facilitator of knowledge construction (Anderson, 2002). Instead of telling students what they need to know, teachers help students move through conceptual change. Some elements of inquiry teaching are; helping students to process information, communicating with groups, coaching student actions, facilitating student thinking, modeling the learning process, and flexibly making use of materials (Anderson, 2002).

Scientific practices. The NRC's *A Framework for K-12 Science Education: Practices, Cross Cutting Concepts, and Core Ideas* outlines eight components of an operational definition for scientific practices: engagement in scientific questions, development and use of models, planning and implementing investigations, analysis and interpretation of data, applying mathematical and computational thinking, explanation development, evidence based argumentation, and collection and communication of ideas (NRC, 2012). Scientific practices offer a context for applying inquiry teaching, but are not a requirement for it.

Chapter II: Literature Review

This study is framed by the concepts of climate literacy and scientific inquiry. Climate literacy is a sub-set of ideas within the broad concept of scientific literacy. Scientific inquiry is also a key component of scientific literacy. What follows is a description of some of the education research on students regarding scientific literacy, climate literacy, scientific inquiry, and attitudes and learning. The chapter also describes the contextual significance of these ideas, relative to major reform efforts.

Scientific Literacy

Generally speaking scientific literacy can be defined as what students should know and be able to do upon completing their science education. The state of scientific literacy in American society has long been a source of frustration and concern. It gained special significance in the U.S. following the 1957 Soviet launch of Sputnik (Hodson, 1988; Laugksch, 2000). Soon after, reform efforts developed science curriculum to be more fun and engaging, increasing the likelihood that students would become professional scientists (Hodson 1988). Reform curricula emphasized practical process skills in conjunction with science content knowledge.

Following the 1983 publishing of *A Nation at Risk*, science became an area of emphasis in America once again. It revealed that overall U.S. students were academically falling behind other industrialized nations of the world. According to the National Assessment of Science measures, seventeen year old students showed a steady decline in science achievement scores from 1969 to 1977 (NCEE, 1983). Comparatively, many other industrialized nations were spending three times as much class time on science and math as the U.S. (NCEE, 1983). What followed was the formation of science standards to boost SL in America. In 1989, the American Association for the Advancement of Science published standard in *Science for All Americans*, then later in *Benchmarks for Science Literacy* (1993). In 1996, the National Research Council (NRC) published the National Science Education Standards (NSES). These standards called for greater emphasis on developing students' scientific literacy; particularly as it relates to scientific inquiry, the nature of science, and dealing with social decisions based on scientific findings. They also state that "an important purpose of science education is to give students a means to understand and act on personal and social issues" (NRC, 1996, p. 107).

In more recent decades national assessments on student scientific literacy indicate that student comprehension of science has generally remained stagnant (NRC, 2006). Data from the Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA) support the NRC conclusion. From 1999 to 2007, TIMSS data shows that U.S. eighth grade students were significantly below an average of 10 other industrialized nations on science measures (National Center for Education Statistics, 2012). PISA (2006) assessments reveal that U.S. fifteen year olds ranked 29th out of 40 developed countries in science, falling slightly since the previous 2003 assessment (Darling-Hammond, 2010; Organization for Economic Cooperation and Development, 2007).

More recently, the NRC published *A Framework for K-12 Science Education: Practices, Cross Cutting Concepts, and Core Ideas* (2012), which served as a template for the *Next Generation of Science Standards* released in 2013. Here the emphasis has moved toward integrating engineering into the teaching and learning of science. This becomes apparent in the following passage from *A Framework for K-12 Science Education*:

> The overarching goal of our framework for K-12 science education is to ensure that by the end of 12th grade, all students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology. (NRC, 2012)

This expands the earlier vision of scientific literacy beyond the early post-Sputnik reforms. It goes beyond just learning science content and processes necessary for development of future scientists. Instead, the vision focuses on developing a conceptual understanding of the nature of science and how it works, while working with these scientific concepts and processes in a relevant social context. These different perspectives on scientific literacy are described by Roberts (2007) in the *Handbook of Research on Science Education*, calling them Vision I and Vision II respectively (Sadler & Zeidler 2009).

For this study, scientific literacy is defined using Robert's Vision II model. This model of scientific literacy ties most closely to the NRC's broad educational goals of generating citizens capable of using scientific knowledge and understanding to make critical decisions affecting society (AAAS 2009). As scientific understanding regarding GCC and the influence of human activities increases, there is an ever-growing need for everyday citizens to understand these concepts. An accurate understanding of GCC is imperative so that citizens make well-informed personal decisions that impact our environment, politics, legal policies, and funding allocations. This broad view for scientific literacy brings greater relevance for more students.

Climate Literacy

To be climate-literate a person should: 1) understand the essential principles of Earth's climate system, 2) know how to assess scientifically credible information about climate, 3) be able to communicate about climate and climate change in a meaningful way, and 4) be able to make informed and responsible decisions with regard to actions that may affect climate (U.S. Global Change Research Program, 2009, p. 1). Thus far, education research has focused heavily on item one and there is a growing body of research targeting student conceptions of GCC to assess their climate literacy. Generally the research has described qualitatively the conceptions students hold in light of the conceptions portrayed by the scientific community. Student conceptions are typically incomplete or inaccurate, with respect to scientific understanding. The goal of much of this work has been to advise teachers in the development of curriculum that can facilitate conceptual change in students (Shepardson et al., 2009).

General overview. Research on student conceptions about GCC has revealed some interesting patterns of misconception. One recurring example has students believing that depletion of the ozone layer is the cause of global warming (Andersson & Wallin, 2000; Boyes & Stanisstreet, 1992; Fortner, 2001; Gowda, Fox, & Magelky, 1997; Hestness, McGinnis, & Marbach, 2011; Meadows & Wiesenmayer, 1999; Rebich & Gautier, 2005). Many students perceive the atmosphere to have a distinct boundary, like an inflated balloon, and holes in it cause more sunlight to reach Earth and warm it up (Leiserowitz et al., 2011; Meadows & Wiesenmayer, 1999). It's also common for students to believe that they can perceive a changing climate personally, misunderstanding the distinction between weather and climate (Fortner, 2001; Gowda et al., 1997; Pruneau et al., 2003). Some students cling to the notion that anything that harms the environment causes global warming; for example littering or water pollution (Fortner, 2001; Gowda et al., 1997). It is also a strongly held belief that climate science is highly uncertain, with scientists often in disagreement about whether or not climate change is occurring (Leiserowitz et al., 2011). Some studies indicate that greater uncertainty surrounding an environmental issue leads to a greater chance of student misconception (Boyes & Stanisstreet, 1992; Fortner et al., 2000; Gowda et al., 1997; Rye, Rubba, & Wiesenmayer, 1997). Without an accurate understanding of the environmental problem, students cannot be expected to see a need for or commit to actionable solutions.

Study types. Research studies in GCC education can be generally categorized into types by focus. The most prominent type already mentioned is placed in the "Conceptions" category. The other less common study types are: 1) Teaching Strategies, 2) Review & Theory, and 3) Attitudes. Teaching Strategies studies investigate the impact of a particular teaching intervention on student understanding of GCC. Review & Theory studies are not investigating the effect of any specific variable on student GCC understanding. Instead, Review & Theory studies are interested in posing theories based on current literature and offering suggestions for those who might be interested in challenging those theories. Finally, an Attitudes study investigates a person's perception of GCC to better understand it as a social and political topic.

Conceptions research. As GCC began to emerge as a significant environmental issue, educational researchers sought to better understand student conceptions surrounding the topic. Boyes and Stanisstreet (1992) used an open-form questionnaire on 60 British students (ages 13-14) to identify the most common student misconceptions. Based on those findings, they developed a closed-form questionnaire to obtain data on a larger scale. Their work reveals that most students understood some of the causes, consequences, and solutions of global warming (Boyes, Chuckran, & Stanisstreet, 1993). Beliefs that using unleaded gasoline helps reduce global warming and global warming increases the rate of skin cancer are persistent and widespread misconceptions through and beyond high school (Boyes & Stanisstreet, 1992; Boyes et al., 1993).

Gowda, Fox, & Magelky (1997) used open-ended survey questions to investigate students' conceptions and attitudes of climate change. The ninth grade student participants (n=99) were sampled from two areas, Hawaii and Oklahoma. Findings suggest that students do reveal many correct conceptions of climate change, but some prevalent misconceptions persist, echoing much of the work described by Boyes & Stanisstreet. The five misconceptions identified were: 1) student inflation of temperature estimates, 2) confusion between chlorofluorocarbons, the ozone hole, and climate change, 3) belief in the ability to perceive the changing climate firsthand, 4) the idea that all environmental harms cause climate change, and 5) confusing weather with climate (Gowda et al., 1997). The study authors assume that the sources of information are partly to blame for these misconceptions, and use some of their survey data to support greater inclusion of climate change in the classroom (Gowda et al., 1997).

Based on the persistent confusion between global warming and ozone layer depletion, Rye, Rubba, & Wiesenmayer (1997) developed open ended interview questions to better understand students' conceptions of global warming following a global warming unit. They sampled twenty-four students from four middle schools in rural Pennsylvania, each of which had a teacher who attended a Science Technology and Society (STS) Institute where curriculum on global warming was developed. Conclusions of their qualitative analysis matched previous work, outlining different types of student confusion between global warming and ozone layer depletion (Rye et al., 1997). They noted that three of the four teachers in the study taught about the ozone layer while teaching the global warming issue despite suggestions by researchers to keep the two issues separated. The study authors suggest that student conception data prior to instruction could have strengthened their study.

Research on eleven and twelve year olds in Greece took a more focused look at students' conceptions of GCC. Koulaidis & Christidou (1999) used semi-structured interviews to develop models of student conceptions of the greenhouse effect. They call attention to some very basic science concepts that students repeatedly struggled with.

These concepts underlie the larger concept of the greenhouse effect and are as follows: 1) uniform diffusion of atmospheric gases, 2) conceptual distinction between UV and other forms of solar radiation, 3) conceptual distinction between sunlight and terrestrial radiation, and 4) conceptual distinction between the role of the ozone layer and that of greenhouse gases (Koulaidis & Christidou, 1999). This indicates a need to address more basic misconceptions before tackling concepts like the greenhouse effect that requires understanding of multiple interacting concepts to understand.

Work by Andersson & Wallin (2000) began in Sweden as part of a national evaluation of some new methods and content being considered for schools. They explored students' explanations for the greenhouse effect, explanations for depletion of the ozone layer, and what they believed would happen as a result of reducing CO_2 emissions. Four hundred twenty-three 9th or 12th grade students were given open-ended prompts to write from, and their responses were categorized thematically through inductive qualitative analysis. They developed five models of how students conceptualize the greenhouse effect; each successive one building in complexity and demonstrating a higher degree of concept integration. Their data indicates continued confusion between the issue of ozone layer depletion and the greenhouse effect. A sample response to explain what the greenhouse effect is can be seen here:

> It is when poisonous gases that are let out thin the ozone layer and in this way increase the letting in of radiation from the sun and space. This makes it get warmer and the ice, especially at the north and south poles, melt (Andersson & Wallin, 2000, p. 1101).

They concluded that despite this confusion, students still have a strong understanding of the consequences of a depleted ozone layer for humans (increased skin cancer), but lack good understanding of societal consequences for drastically reducing CO_2 emissions (Andersson & Wallin, 2000).

More recent conceptions work on 91 seventh graders from rural Midwestern schools was done by Shepardson et al. (2009) also using an inductive approach. Students were given five open-ended prompts to respond to relating to global warming and climate change. Their data reflects some previous findings such as: 1) global warming happening because of air pollution in general, 2) greenhouse gases form a shield-like layer around Earth, and 3) global warming and climate change will not have a major impact on people or society (Shepardson et al., 2009). Most striking is how the data deviate from earlier studies. Most of the students here did not link the ozone layer depletion to global warming (Shepardson et al., 2009). They also suggest that conceptual understanding of the greenhouse effect is pivotal for developing an understanding of global warming and climate change.

Leiserowitz et al. (2011) found that relatively few American teens have a deep understanding of climate change, ranking over half as failing in their content understanding. Their data were gathered using a closed survey on a randomly selected nationally representative sample of teens (ages 13-17) during the summer of 2010. They noted a common misconception; confusing climate change with the hole in the ozone layer (Leiserowitz et al., 2011). This of course echoes most of the conceptions research to this point. The Leiserowitz et al. survey data also captured a student recognition of their own limited understanding, stating that "fewer than 1 in 5 (teens) say they are 'very well informed' about how the climate system works or the different causes, consequences, or potential solutions to global warming" (Leiserowitz et al., 2011, p. 3). More importantly, students overwhelmingly stated that they would like to know more about global warming (Leiserowitz et al., 2011).

Teaching strategies research. As it became more evident that students were not grasping the science content of GCC, research efforts sought to remedy this. Two seventh grade classes from coastal communities in Eastern Canada participated in a study that integrated climate change education over the course of a school year (Pruneau et al., 2003). Scientists and other experts were brought in to teach the climate change curriculum which emphasized experiential learning activities. Data were obtained through semi-structured interviews before and after climate change instruction. They qualitatively analyzed student conceptions of climate change, determining that students improved in their understanding but not to a high degree. The interview data also indicated that students do not believe they have power to make significant change toward mitigating climate change (Pruneau et al., 2003).

Two related studies analyzed college students' conceptions of climate change pre and post-instruction, using concept mapping (Rebich & Gautier, 2005) and open-ended essay questions (Gautier, Deutsch, & Rebich, 2006). Concept mapping scores provide evidence of "significant learning and conceptual change" based partly on percent gains in concepts and propositions (Rebich & Gautier, 2005, p. 355). Some of the students continued to manifest the misconception linking ozone depletion with global warming, even post-instruction (Rebich & Gautier, 2005). Open-ended essay data suggests the difficulty in overcoming misconceptions (Gautier et al., 2006).

Review & theory research. While some studies challenged student misconception with teaching strategies, others tried to connect current research on global climate change education and offer possible solutions to combat these misconceptions. All studies reviewed here emphasize the need to increase climate literacy by challenging recurring student misconceptions (Dupigny-Giroux, 2010; Fortner, 2001; Harrington, 2008; McCaffrey & Buhr, 2008; Meadows & Wiesenmayer, 1999; Niepold, Herring, & McConville, 2008). Two studies highlighted the importance of teacher training on GCC through professional development programs; helping teachers identify common student misconceptions and find useful tools and resources to help combat them (Fortner, 2001; McCaffrey & Buhr, 2008). There is also concern as to where GCC education belongs in schools. Repeatedly it was suggested that core GCC concepts should be integrated across disciplines, extending beyond science classrooms (Dupigny-Giroux, 2010; Fortner, 2001; Niepold et al., 2008). The teaching environment should foster peer communication that challenges and questions students' ideas against observed evidence and compares them explicitly against scientifically accurate GCC conceptions (Harrington, 2008; Meadows & Wiesenmayer, 1999).

Attitudes research. The political and social nature of the issue of GCC led to some studies trying to capture and understand the attitudes of people toward GCC. There seems to be a specific interest in the concept of uncertainty. The media often portrays the science of GCC as being very tentative, yet within the scientific community there is a nearly unanimous consensus (Oreskes, 2004). One study determined that 31% of American teens believe there is a lot of disagreement among scientists about global warming (Leiserowitz et al., 2011). The media seems to be playing a role in this perceived uncertainty (Adams, 2001; Leiserowitz et al., 2011). Other research on media uncertainty suggests a connection between the degree of perceived uncertainty in GCC and the high level of misconceptions associated with it (Fortner, Lee, Corney, Romanello, Bonnell, Luthy, Figuerido, & Ntsiko, 2000).

Inquiry-based Instruction

Inquiry has been a buzzword in science education for several decades. Amidst all the attention during this time, there is still a problem defining inquiry. It is as a key element to educational reforms in science, yet it is often not clearly defined or the definition varies from one context to another (Abd-El-Khalick 2003; Anderson, 2002). Current research on inquiry in science classrooms delineates different types of inquiry. The NSES frame an operational definition for scientific inquiry, outlining five essential features; engagement in scientific questions, giving priority to evidence, developing explanations from evidence, connecting explanation to scientific knowledge, and communicating and justifying those explanations (Asay & Orgill, 2009; NRC, 2000).

Scientific inquiry should be distinguished from inquiry teaching and learning. Inquiry teaching involves pedagogical practices similar to those outlined by constructivists, with the teacher acting as a facilitator of knowledge construction (Anderson, 2002). Instead of telling students what they need to know, teachers help students move through conceptual change. Some elements of inquiry teaching are;

helping students to process information, communicating with groups, coaching student actions, facilitating student thinking, modeling the learning process, and flexibly making use of materials (Anderson, 2002). Scientific inquiry offers a context for applying inquiry teaching, but is not a requirement for it. Inquiry learning is when students are actively engaged in identifying their current conceptions about some topic, challenging those conceptions in light of new information, and restructuring their personal conceptions into something new (Anderson, 2002).

As mentioned previously, early post-Sputnik reform efforts developed inquiry-based science curriculum with an emphasis on students doing laboratory work, with hopes of those courses being more fun and engaging with an increased likelihood that students would become professional scientists (Hodson 1988). These laboratory exercises (inquiry) were typically linear in nature, helping students develop procedural skills while confirming already known theories (Tobin, Tippins, & Gallard, 1994). Over time, it became clear that confirmatory laboratory activities did not reflect the actual practice of science and fell short of developing an accurate nature of science view, leading to the more comprehensive NSES definition.

Teaching science through inquiry has produced mixed results. Some studies indicate an increase in student understanding of science within an inquiry context, while in other studies the opposite holds true, with inquiry resulting in a decrease in student understanding (Hodson, 1990). Successful implementation of inquiry seems to be rooted soundly within three realms; psychology, philosophy, and pedagogy (Duschl, 2003). Scientific inquiry should be relevant and meaningful, reflective of authentic science, and employ teaching practices that promote conceptual change. Scientific inquiry should include activities that boost student content knowledge while also developing student understanding about how science works (Schwartz, Lederman, & Crawford, 2003). A complete definition for inquiry in the classroom should be founded upon pedagogically sound methods; requiring students to engage in student-centered projects, practice hypothesis testing, solve problems, develop models, and defend their understanding, all while constructing a more scientifically accurate understanding of key scientific concepts (Schwartz et. al, 2003; Windschitl, 2001).

Research in cognitive science is beginning to show support for a teaching approach that stresses depth of understanding around focused science concepts as opposed to a broad and superficial understanding of a greater diversity of science topics (Schwartz, Sadler, & Tai, 2008). Evidence is growing in support of inquiry teaching leading to positive results (Anderson, 2002).

Attitudes and Learning

When people learn new skills, ideas, and concepts it is inevitable that some level of meaning is associated with them. That meaning links to the affective domain of learning and includes attitudes, beliefs, interests, and motivations (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956; Clark, 2000). Some argue that affect is, "a necessary condition for learning" (Koballa, 2007; Perrier & Nsengiyumva, 2003). There is no doubt that learning is linked to the affective domain, including personal attitudes. In fact some suggest that attitude as a construct includes cognitive and behavioral components as well (Simpson, Koballa, Oliver, & Crawley, 1994). Despite this link, studies on the influence of affect on learning are underrepresented in education research (Fortus, 2014; Nieswandt, 2006). Research efforts to describe the relationship between attitudes and learning present mixed findings (Mattern & Schau, 2002).

Attitudes are typically described as one's personal feelings toward some person, place, thing or idea; usually judged as positive or negative (Koballa, 2007; Zimbardo & Boyd, 1999). It could be hypothesized that the more positive a person's attitude is toward particular ideas, the easier it would be to learn them. Some research in science education suggests a positive relationship between student attitudes and science achievement (Lawrenz, Wood, Kirchhoff, Kim, & Eisenkraft, 2009; Mattern & Schau, 2002). One study struggled to measure the relationship between student attitudes toward the subject of chemistry and conceptual understanding of chemistry concepts, finding no statistically significant effects on understanding (Nieswandt, 2006). A clear understanding on how attitudes and learning interact remains elusive.

One issue raised about research into measuring attitudes is lack of consistency. Up to a quarter of the research articles measuring attitudes in three education journals over the past decade developed their own instruments, leaving some to argue for more standardization in developing attitude measurement instruments (Fortus, 2014). Different ways of operationalizing attitudes for research also presents a roadblock for clear cross-study comparison (Mattern & Schau, 2002). Consistency in how attitudes are measured and operationally defined would strengthen attitudes research, making results of different studies more comparable and increase generalizability of findings.

Mattern & Schau (2002) suggest that there is a positive relationship between students' attitudes toward a science course and achievement in science over time. However, each variable has an effect on the other. A causal link between these variables has not been determined. If increased achievement in science can lead to stronger positive attitudes toward that particular science subject, this may lead to behavioral changes. This assumption has guided research into environmental programs, aiming to improve attitudes toward an issue in hopes that it leads to actionable responses (Kraus, 1995; Primack, 1998; Thompson & Mintzes, 2002). For example growth in conceptual understanding about sharks over time seemed to correlate positively with naturalistic and ecologic attitudes toward them (Thompson & Mintzes, 2002), where students believed in the significance of sharks for maintaining stable marine ecosystem and cared about protecting them.

Belief that attitudes improve toward subjects, ideas, or issues learned which in turn results in behavioral change, frames much of the research done on environmental issues. The knowledge-deficit model is often used to describe this (Hansen, Holm, Frewer, Robinson, & Sandoe, 2003). It assumes that knowledge and attitudes operate hand-in-hand to catalyze environmentally conscious behavior. Like education research into attitude/knowledge relationships, studies exploring within the context of environmental issues have had mixed results: while some research suggests a strong conceptual understanding of environmental issues may be a predictor of subsequent actions to help those issues (Papadimitriou, 2004), others found knowledge level to be a weak predictor (Hines, Hungerford, and Tomera, 1986). Even more, studies argue that knowing much about an environmental problem or issue does not guarantee that individuals will adopt behaviors to mitigate that problem (Hwang, Kim, & Jeng, 2000; Monroe, 1993).

A study exploring the relationship between teacher attitudes and knowledge of global climate change over the course of a professional development workshop concluded that attitudes were not a strong indicator of knowledge (Liu, Roehrig, Bhattacharya, & Varma, in press). They found that teachers could have very strong conceptual understanding of global climate change and remain skeptical about a societal need to act in response. Likewise, teachers with high concern about global climate change could have poor conceptual understanding. These results cast some doubt on the knowledge-deficit model. It is likely that pro-environmental action to fight climate change will require more than just conceptual understanding of the underlying science.

Chapter III: Methodology

This chapter details the study's design and methodology used to address the research questions, restated again to help frame this chapter.

1. To what extent and in what ways do students' conceptions change in association with an 8-week inquiry-based unit on climate change?

2. In what ways do student attitudes change in association with an 8-week inquiry-based unit on climate change?
3. How does growth in content knowledge and conceptual understanding correspond with attitudes about climate change?

What follows is first, a brief overview of the study. Second, the underlying theoretical framework is elaborated upon. Third, the study setting and researcher background are detailed. Fourth, the curriculum and its linking to the overall procedural framework are described. The chapter concludes with an overview of data collection and analysis procedures. A more detailed description of analysis procedures are outlined in chapters IV (whole group) and V (cases).

Research Design

This sequential phase mixed methods study (Greene, 2007) was conducted with a group of 90 sophomore students as part of their high school biology curriculum. It involved an 8-week inquiry-based unit on global climate change (GCC), outlined in Appendix A. The unit duration was based in part on research by Clark & Linn (2003), which demonstrated a significant link between instructional time on a topic and increased "knowledge integration" (stronger conceptual understanding) around complex concepts.

Work by Schwartz, Sadler, & Tai (2008) also influenced the choice to study GCC in depth. All participating students were assessed before and after instruction to measure quantitative changes in content understanding and attitudes; using a pretest-post-test pre-experimental design (Cohen, Manion, & Morrison, 2000). Student artifacts including concept maps, journal entries, mid-unit survey responses, prompted essays, inquiry projects, and open-ended assessment question responses were then analyzed qualitatively from a smaller sub-sample of participants. This process led to the formation of a group of eight purposefully selected students. Each of these eight students granted a post-unit interview. The study design reflects convergence described by Greene (p. 122) similar to Creswell & Clark's convergent parallel design (Greene, 2007; Creswell & Clark, 2011).

Theoretical Framework

A constructivist view of learning framed this study. Constructivism assumes that people's knowledge is built up based upon their social interactions and experiences with the world (Hewson, 1992). Learning is an active process, requiring engagement of the learner with material to be learned. According to Piaget, cognitive understanding of the world develops "through the coordination and internalization of a person's actions on the world" (Driver, Asoko, Leach, Mortimer, & Scott, 1994, p. 6, Piaget, 1970). This cognitive understanding evolves with personal experiences, constructed "in ways that to them are coherent and useful" (Hewson, 1992, p.7). In formal learning environments, it becomes evident that students' conceptual understanding often conflicts with that of the greater scientific community. These conflicting views are often termed alternative conceptions or misconceptions (Hewson, 1992).

To address student misconceptions in the classroom, this study made use of the model for conceptual change (CCM) outlined by Posner, Strike, Hewson, and Gertzog (1982). It considers learners' conceptual ecology; involving prior knowledge, social setting, epistemological beliefs, awareness and degree of satisfaction regarding one's own understanding, and motivation (Gautier, Deutsch, & Rebich, 2006; Hewson, 1992; Posner, Strike, Hewson, & Gertzog, 1982). Within their conceptual ecology, learners determine if new concepts to be learned are intelligible, plausible, and fruitful (Hewson, 1992, Posner et al., 1982). When those conditions around a new concept are met, learning occurs without difficulty.

Under circumstances where the CCM conditions are not met, there is a resistance to internalizing the new concept. This is especially true when the new concept conflicts with a learner's existing conceptions (Hewson, 1992). The three CCM conditions cannot be met until the learner becomes dissatisfied with their current understanding (Hewson, 1992; Driver et al., 1994). Learning the new concept then requires a restructuring of existing conceptions or replacing the old with the new.

Setting

The study took place in a small rural community in Minnesota. It tends to lean politically conservative, with sixty percent registered Republicans. Students are primarily of Caucasian descent, many having grown up with an agricultural background. They were high school students ranging from 15-16 years of age and enrolled in general biology, a required course for all sophomores. The participating students were divided among five sections, broken down for display in Table 3.1. Their most recent formal encounter with climate-related concepts in school was during their 8th grade Earth Science course.

Table 3.1

Class Period Timing, Student Numbers, and Gender Breakdown

Class Period	Time	Number of Males	Number of Females	Class Total
1st	8:19-9:14	10	7	17
2nd	9:18-10:06	7	12	19
4th	11:02-11:50	6	9	15
6th	1:15-2:03	11	10	21
7th	2:07-2:55	12	6	18

The researcher was also the classroom teacher. On one hand, this allowed prolonged opportunity to build trust and gain firsthand understanding of the classroom culture (Creswell, 2007). However, the dual role also presented some unique challenges to the study. Priority one was teaching students, tending to the day to day responsibilities of the classroom. As such, the research process was hindered, particularly timing of analysis and the ability to be fluid as a researcher in response to student data.

The study began during the fall semester of 2012. Time during the preceding Nature of Science teaching unit was used to establish familiarity with inquiry teaching and assessment practices. The eight week study unit spanned October 25 through December 20, concluding as Holiday break began.

The Curriculum

Much of the curricular content information was derived from two sources; lesson plans from the Will Steger Foundation (*Global Warming 101 & Minnesota's Changing*

Climate) and reading excerpts from Tim Flannery's book *We are the Weather Makers* (2006). Discussion questions were developed from the Flannery excerpts to highlight and reinforce concepts framing the GCC unit. Curriculum notes for class discussion were developed as a scaled down version of those taken by the teacher during a university course titled "The Science and Policy of Global Climate Change". These notes were reflective of ideas outlined in *Climate Literacy: The Essential Principles of Climate Science* developed by the U.S. Global Change Research Program. For a summary outline of the curriculum see Table 3.2.

Table 3.2

Curriculum Concepts and Scientific Practices Developed by Week of Study Unit

Week	Scientific Practices	Key Concepts
1	Analyzing and Interpreting Data; Evaluating and Communicating Information; Developing Models; Using Mathematics	MN's climate parameters for various biomes; Distinguishing between weather and climate; Longitudinal data trends in MN
2	Analyzing and Interpreting Data; Asking Scientific Questions; Constructing Explanations	Proxy data used by climate scientists; Abiotic factors influencing pond water ecosystems
3	Obtaining, Evaluating, and Communicating Information; Developing Models; Analyzing and Interpreting Data	Climate trends of Earth's past & impacts on biological communities; The Greenhouse Effect
4	Obtaining, Evaluating, and Communicating Information; Analyzing and Interpreting Data	Connecting the Greenhouse Effect to Global Warming; Greenhouse Gas Sources; Climate Determiners
5	Engaging in Argument from Evidence; Obtaining, Evaluating, and Communicating of Information; Planning & Carrying out Investigations; Asking Scientific Questions	Climate Determiners; Current evidence of Climate Change; Global Predictions; Possible Solutions
6	Obtaining, Evaluating, and Communicating of Information; Analyzing and Interpreting Data; Engaging in Argument from Evidence	More evidence of Climate Change; Impacts of Climate Change in today's biological communities (including humans)
7	Obtaining, Evaluating, and Communicating of Information; Analyzing and Interpreting Data; Engaging in Argument from Evidence	Climate Models and Predictions; Corroborative Evidence & Predicted Impacts of Climate Change on MN
8	Obtaining, Evaluating, and Communicating of Information; Engaging in Argument from Evidence	Solutions; Concepts Review

Teaching science through inquiry required a non-traditional approach to curriculum design and lesson implementation. Traditional lecture was replaced by discussion; leading with questions to guide students toward science content objectives (Trowbridge, 2004). Students were engaged in collaborative small group work each week, and regularly asked to communicate their understanding orally, in writing, and by using diagrams. The scientific practices outlined in the NRC's *A Framework for K-12 Science Education: Practices, Cross Cutting Concepts, and Core Ideas* were also incorporated; engagement with scientific questions, development and use of models, planning and implementing investigations, analysis and interpretation of data, applying mathematical and computational thinking, explanation development, evidence based argumentation, and collection and communication of ideas (NRC, 2012). For a more detailed look at these scientific practices, see Appendix B.

Data Collection

Assessment measures focused on content understanding of global climate change and attitudes toward the topic. The content knowledge assessment and attitude survey were combined as part of one assessment instrument based on the format presented by Leiserowitz et al. (2011). Student classroom artifacts and post-unit interview transcripts were also gathered for analysis. Further detail about the data collection instrument is provided later in the quantitative data collection and analysis section.

Timeline. Figure 3.1 below outlines the basic timeline for the study; preparing students for participation, the global climate change teaching unit, and follow-up analysis resulting in further data collection. During week one of the school year, the research study was explained to students and consent forms distributed. The first eight weeks of the school year students were engaged in an introductory nature of science (NOS) unit.

During this acclimatization time students became familiar with various scientific practices and assessment formats prior to the global climate change study unit. Piloting of the study assessment instruments occurred during week one of the school year with another section of high school science students.

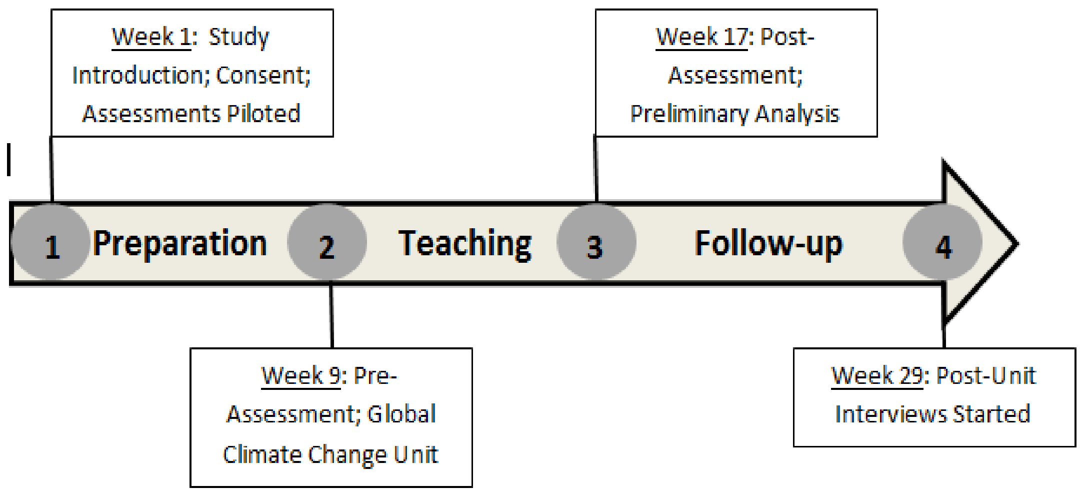


Figure 3.1. Timeline overview outlining unit preparation, teaching unit, and follow-up analysis leading to further data collection

The global climate change unit followed the Nature of Science unit. Students took a concept mapping assessment on day one. Day two, students took the attitude and content knowledge assessment. Over the course of the study unit, students participated in a variety of lessons; many of which resulted in student artifacts. Those artifacts with high potential to express students' changing understanding and attitudes were taken as supplementary artifacts for qualitative analysis. These classroom artifacts are outlined on Table 3.3. The teaching unit concluded with two days of post-assessment, using the same instruments as day one and two. Preliminary analysis of the data resulted in a decision to develop follow-up interview questions and request student volunteers.

Table 3.3

Student Artifacts, Descriptions, and Collection Times

Student Artifact	Description	Collection Times
Concept Map	List of climate change concepts to be connected with propositions	Day 1 and Day 38
Open-Ended Content Knowledge Assessment Responses	Explanatory; describing understanding of the greenhouse effect, global warming vs. climate change, and proxy data	Day 2 and Day 37
Mid-Unit Survey Question Responses	Open-ended responses to questions about the value of learning about climate change in the classroom	Day 16
Predictive Essay	Describing the predicted climate trends of MN and how that would impact them personally	Day 31
Open Inquiry Project	Development of a study to a) measure the impact of behavior changes on emissions, or b) study the impacts of different temperature settings on organisms	Day 38
Post-Unit Journal Entry	Open-ended responses to questions about GHE, GW, and CC, predicted consequences, possible solutions, and unit critique	Day 37
Interview Transcripts	Six open-ended face-to-face interview questions about conceptual relationships (GHE, GW, CC), evidence of GW & CC, scientific consensus, personal changes in viewpoint and value in learning about CC, and most interesting or useful lesson from unit	3 to 6 months after teaching unit

Data Collection and Analysis

The study followed a three-phase analysis: 1. Quantitative analysis of content and attitude surveys from all participants (n=90), 2. Qualitative analysis of content and attitude assessments (n=50), and 3. Qualitative analysis of eight student cases.

Phase I: Quantitative Data Collection and Analysis. The content knowledge assessment and attitude survey responses were initially used for quantitative analysis of all ninety student participants. The combined assessments were primarily closed-survey questions developed using Google.doc forms. Students were given a question and then asked to determine which answer(s) they believed to be true or which description best fit their own view. The questions and format were modeled after Leiserowitz et al.'s instrument outlined in *American Teens' Knowledge of Climate Change* (2011). The content knowledge items were scored relative to the correct scientific answer. Attitude-based survey items were compared using frequency tables. These tables outlined the percentage of students expressing particular beliefs assumed by their answer selection choice. Attitude survey items are also discussed in detail and displayed in chapter IV. The complete assessment instrument can be viewed in Appendix C.

Pre and post assessment scores were matched samples, analyzed using a paired t-test to measure the statistical significance of gains in content knowledge. The assessments were piloted prior to the study, using junior and senior students taking the General Science elective. Piloting helped identify formatting errors and ruled out inconsistency issues for the instruments prior to application to the study. Ninety students were deemed a large enough sample to demonstrate statistical significance comparing pre-post assessment scores.

Following the study unit, quantitative analysis began with descriptive statistics of the study population to verify it represented a normally distributed population. Next, a statistical test was run to determine if student growth in content understanding was statistically significant following the teaching unit. Pre-post attitude survey results on the belief that global warming is happening were used to develop three categories of students labeled: skeptics (SK), open-skeptics (OSK) and opens (OP). The categorization process is detailed in chapter IV. One-way ANOVA was used to compare content knowledge scores of these three categories of students. Frequency tables were developed to compare and identify trends among these three groups, outlining content knowledge responses and attitude survey responses. In-depth details for quantitative analysis and results are also outlined in chapter IV.

Phase II: Qualitative Data Collection and Analysis. This portion of the study made use of a sub-sample of fifty student participants, examining student language expressing conceptual understanding, attitudes and beliefs. For this qualitative phase, representatives from each of the three previously mentioned student categories (SK, OSK, OP) were included.

Participant Sampling. For qualitative analysis, it was important to get rich descriptive data from participants. Therefore, certain engagement criteria were considered when determining whether students would become part of the phase II sample for qualitative data analysis. Four questions helped frame these criteria: 1) Did the students take their work seriously? 2) Were they actively engaged in classroom discussion? 3) Were they active participants in lesson activities? 4) Did their work demonstrate substantial effort and expression of deep thought? When the answer to these questions was yes, those students were given further consideration for representative sampling of qualitative phase II.

Sampling considered where students fit on a scale of global climate change content understanding; attaining representatives of low, average, and high score. Efforts were also made to equally represent gender across the sub-sample. Unfortunately, the three student attitude categories differed greatly in their numbers and student willingness to elaborate and share ideas through work or by interview was not consistent. Therefore, the sub-sample of fifty and subsequent eight student cases were not equally representative of different levels of content understanding or gender.

Analysis was inductive, looking for patterns and themes in student thinking displayed within a variety of student artifacts. These included; concept maps, journal entries, mid-unit survey responses, prompted essays, inquiry projects, and open-ended assessment question responses.

Qualitative analysis of student artifacts offered a richer understanding of how students' conceptions of global climate change are organized than test score data could. Focus was on understanding these conceptions in light of scientific conceptions; identifying misconceptions. Analysis also paid attention to the conceptual change in student thinking about global climate change over the course of their instruction. Supplementary artifacts were also examined to reveal student conceptions and identify changes in student attitude about global climate change. For an example of supplementary artifacts that were used see Appendix D. In-depth analysis of these artifacts required an inductive approach, searching for patterns of student understanding within, applying an approach described by Corbin & Strauss (2008).

Each student artifact was examined using an open-coding approach to identify categories, themes, and patterns of student conceptions of global climate change topics; recorded as memos. The artifacts were reviewed again, looking for lower level codes and generating another round of memos. The memos themselves were analyzed for axial codes, illustrating relationships between one or more open codes. From this analysis, a diagram was constructed to highlight common patterns and themes in students' thinking about global climate change topics (Corbin & Strauss, 2008). In comparing these analysis diagrams from pre-assessment to post-assessment, patterns of conceptual change should be revealed, along with new ideas worthy of further research (Creswell, 2007). A similar coding approach was taken on artifacts; focusing this time on student attitudes and beliefs about global climate change.

Analysis focus and process. Attitude trends by attitude category were analyzed for all students using the pre-post attitude survey responses completed in conjunction with the content knowledge assessment. Frequency responses before and after were noted in follow-up memos, identifying some initial trends. The next step assessed student attitude language by inductive qualitative analysis, requiring a smaller representative sample.

Qualitative analysis of each participant's attitude was beyond the scope of this research. However, a representative sample of data (phase I) was necessary to gain a sense of the attitudes students were expressing (Creswell & Clark, 2011). Skeptic students numbered only twelve, so everything obtained by this group was analyzed for trends in attitude language. For open-skeptic students (numbering 24) and open students (numbering 54), attitude data were organized for close to twenty for each, choosing students based on their degree of data available. These students completed and turned in more of the assigned work and expressed their ideas with more lengthy in-depth responses, offering more language to expression for coding. The small group of skeptic students did not allow for the same approach and at times lacked the richness of language found in the open-skeptic and open student samples.

For students in the representative sample, each available artifact was reviewed. Notes on each student were taken, including quotes expressing language of attitudes, beliefs, and emotion. Open codes were developed from these notes along with reflective memos. General trends by student attitude category were described.

Phase III: Student Cases

Following analysis and coding of attitude language from the representative sample, further analysis began on the purposeful sample (Creswell & Clark 2011). This effort focused on attitude language and student conceptions, revealing unique insights from each participant. Cross-profile analysis followed, revealing conceptual and attitude themes shared by many within the purposeful sample.

Purposeful sampling was done in order to get a deeper sense of the relationship between students' attitudes and conceptual understanding. It was also done to better understand variety of student conceptions and attitudes expressed over the course of a global climate change unit.

The process of developing a purposeful sample focused on three criteria. First, efforts were made to get representatives from each of the attitude categories. Second, a survey was given to g generate a list of students willing to grant a post-unit interview. Those students choosing "yes" or "maybe" were further considered. This limited the pool of students greatly, as many students shied away from granting an interview. Finally, of those open to an interview and with consideration of representation of each attitude category, students were chosen by richness of overall data for actually setting up interviews. Richness of data was determined by open-ended assessment responses and degree of elaboration in journal entries and other unit assignments. Three months following the global climate change unit, eight interviews were recorded and subsequently transcribed.

A sample of student data was given to two university colleagues for evaluation, independently developing codes and themes for conceptions and attitude language to generate a degree of inter-coder agreement (Creswell & Clark, 2011; Miles & Huberman, 1994). Follow-up discussion over areas of agreement and disagreement took place to determine if certain areas were in need of further analysis. Also, three student participants volunteered to member-check; reviewing findings and conclusions identifying their own areas of agreement and disagreement (Creswell & Clark, 2011).

Interviews provided insight to both conceptual understanding and student attitudes and beliefs. First, the interview provided another open-ended format for students to describe their understanding of how the greenhouse effect, global warming and climate change are related. Second, students were also asked to elaborate on the kinds of evidence scientists use to support global warming and climate change, and whether or not scientists were in agreement or not. Finally, they were asked to elaborate on any changes they noticed in their viewpoint over the course of the unit and what kind of value they found in learning about climate change in the classroom.

Limitations

As with any research study, the issue of validity must be considered as part of the design, implementation, and write-up. For this study, there were a number of threats to its internal and external validity. Below is an outline of efforts to minimize these limitations.

Internal validity. Is the designed study structured in such a way as to measure adequately or solve the problem being researched? This question is at the heart of internal validity. A key factor in answering that question is to consider the measurement instruments themselves. For this particular study it was important to pilot the pre-post assessment instruments. This was done by a section of high school General Science students beforehand, to identify problematic terminology and formatting. The attitude and content knowledge measures were modifications of peer-reviewed published research (Leiserowitz et al., 2011), so this could strengthen validity. However, one weakness in modification comes in the inability of the Google.doc form to incorporate visual models or randomize the answer selection choices. This study's assessment also required many fewer redundant questions than that used by Leiserowitz et al., likely reducing its validity some without that built-in check for survey consistency.

One challenge presented by this study is that it lacked a control group. It allowed testing for significance in student knowledge growth, but did not allow for comparison with other teaching approaches. All it could determine was if an inquiry approach to teaching has a significant impact on student learning of global climate change content. A sample size of ninety should offer enough statistical power to suggest significant growth in student understanding. Lack of a control group is also why it was necessary to look qualitatively at student learning by using concept maps and supplementary artifacts. These offer a richer understanding of how student ideas change over time as they experience global climate change concepts through inquiry teaching practices.

Of course the position of the researcher in relation the participants of the study was also an important variable impacting internal validity. At times it was difficult to differentiate between the role as teacher and researcher. Efforts were made to ensure that data analysis time did not overlap with teaching contract hours, helping to separate these two roles temporally. Often the rigors of daily teaching interfered with timely reflection organization and analysis of student data.

With qualitative data, researcher bias becomes a larger threat as it requires more interpretation. How accurately do the codes, categories and themes derived from one researcher's interpretation of the data reflect its true character? Several steps were taken to minimize researcher bias in analyses of qualitative data. Triangulation of data was used to reduce threats to internal validity (Cohen, Manion, & Morrison, 2005; Miles & Huberman, 1994), looking at quantitative data, qualitative analysis of student artifacts, and qualitative analysis of interview transcripts.

For this study, independent analysis of data was needed to determine some degree of agreement on the codes and themes. This involved independent coding analysis from two university colleagues of a small sample of student data. Three students volunteered to member-check the researcher's interpretations and whether they truly reflected their attitudes and understanding.

One other challenge with doing educational research is maintaining a natural setting. If the setting is too contrived or controlled, it may not reflect normal student teacher interactions. For this study, having the researcher as the teacher may have reduced this aspect. Having inquiry teaching as a part of their prior curricular work and prior experiences with concept mapping helped students perceive both as normal.

External Validity. Could these results be replicated or would the finding generalize to other settings? This question is at the heart of external validity. For this study, there was an intervention or teaching approach that was tested for significance. To make this valid in a larger sense, inquiry teaching was clearly defined and exemplified earlier in this chapter. Thick, rich description of the students and their contextual setting were also important to let readers determine its generalizability to their own context (Miles & Huberman, 1994). The write-up includes embedded data samples from student participants that exemplify ideas expressed by the researcher. Other data examples come from student explanatory quotes, sample concept maps, displays of quantitative data in table or graph form, and sample codes representing key concepts. Thick rich description of analysis procedures and numerous data displays in chapters IV and V offer the greatest means toward minimizing threats to external validity in this study.

Chapter IV: Whole Group Analysis & Results

Chapter Overview

This was a sequential phase mixed methods study (Greene, 2007). It involved quantitative analysis of students' pre-post content knowledge and attitude assessments. An inductive qualitative approach to data was also taken to enrich the quantitative. Conceptually there were two analysis approaches, however the time-frames for each overlapped and information from one approach at times informed work on the other. This chapter emphasizes a broad look at all of the study participants with the follow-up student cases being presented in chapter V. Quantitative analysis was used on all participant data to determine changes in content knowledge and attitudes regarding global climate change, using statistical tests and frequency tables. R statistical software was used to assist in this phase. Qualitative analysis of the whole class open-ended assessment items resulted in several codes and themes reflecting students' conceptual understanding and attitudes.

To better follow the analysis procedures and results it is helpful to be reminded again of the initial research questions for this study:

1. To what extent and in what ways do students' conceptions change in association with an 8-week inquiry-based unit on climate change?
2. In what ways do student attitudes change in association with an 8-week inquiry-based unit on climate change?
3. How does growth in content knowledge and conceptual understanding correspond with attitudes about climate change?

What follows in this chapter are details on the analytic processes and whole class findings. Chapter V will discuss the individual student cases drawn from this larger data set. The chapter begins with quantitative analysis, with descriptive statistics of the study's population, which showed normality. Second, a paired t-test was used to determine if the teaching unit resulted in statistically significant gains in content knowledge by students of the study. Third, frequency tables from student attitude survey responses were developed and then used to develop three student attitude categories for comparative analysis. These three student attitude categories are: skeptics (SK), open-skeptics (OSK), and opens (OP). Fourth, student pre and post content assessment scores were analyzed by student attitude groups (SK, OSK, and OP); as raw averages, using a one-way ANOVA, and as necessary using Tukey's HSD statistical test. Fifth, qualitative analysis was then used to identify trends in students' conceptual understanding and attitudes. Finally, the chapter summarizes how the whole-class results helped answer the study's research questions.

Phase I: Quantitative Analysis

Descriptive Statistics. Initially quantitative analysis was used to determine if the student participants were representative of a normal population, based on the score distribution on the content knowledge pre-assessment measure. This was done by running a Normal Q-Q Plot on student pre-assessment scores. Data points scattered in close proximity to a normal population regression line support that the sample student population is representative of a normal population. The graphic representation of this can be seen in Figure 4.1.

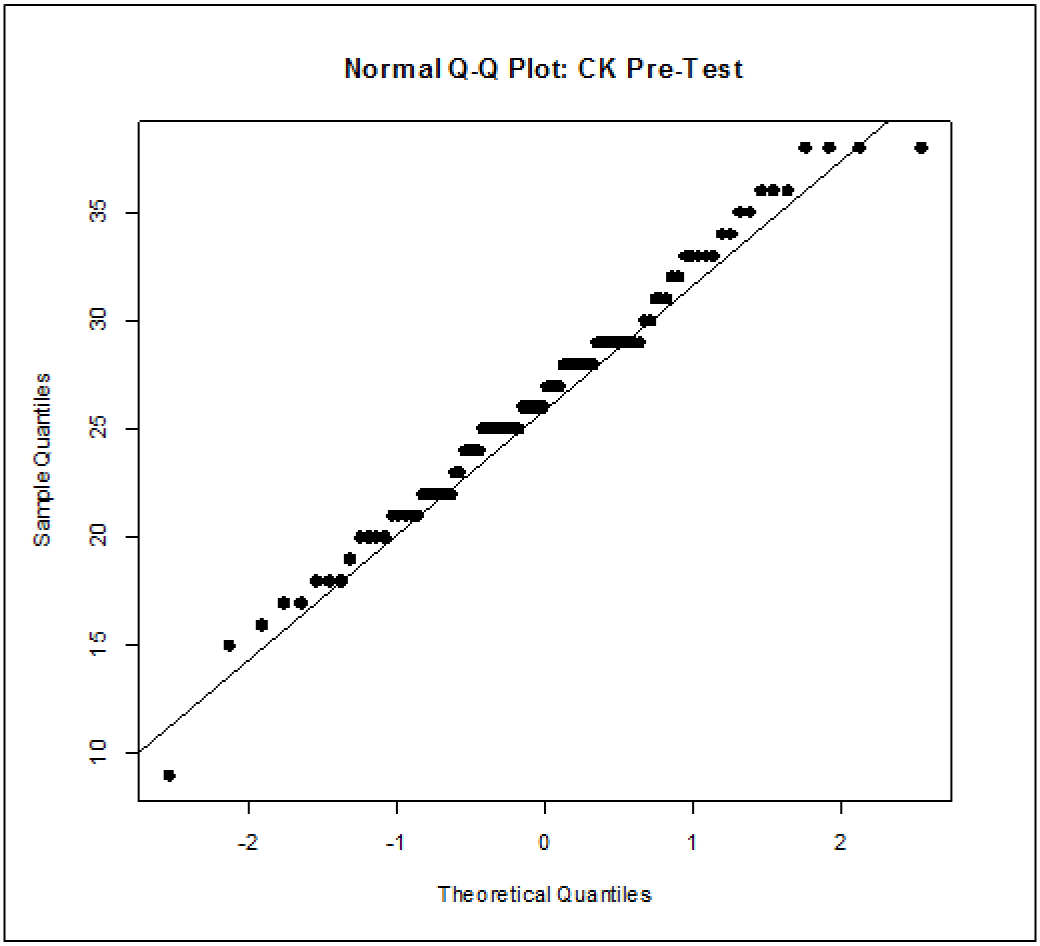


Figure 4.1. Normal Q-Q Plot showing student score distribution relative to a normal distribution (represented by the line).

Statistical Testing. Student pre and post-assessment scores were analyzed using a paired t-test to determine if student growth in content knowledge was statistically significant. Results show a p-value of $< 2.2\ e^{-16}$ indicating the student gains are statistically significant over the course of the global climate change unit (see Figure 4.2). The average exam score increased by fifteen percent. A more complete look at this statistical output can be found in Appendix E.

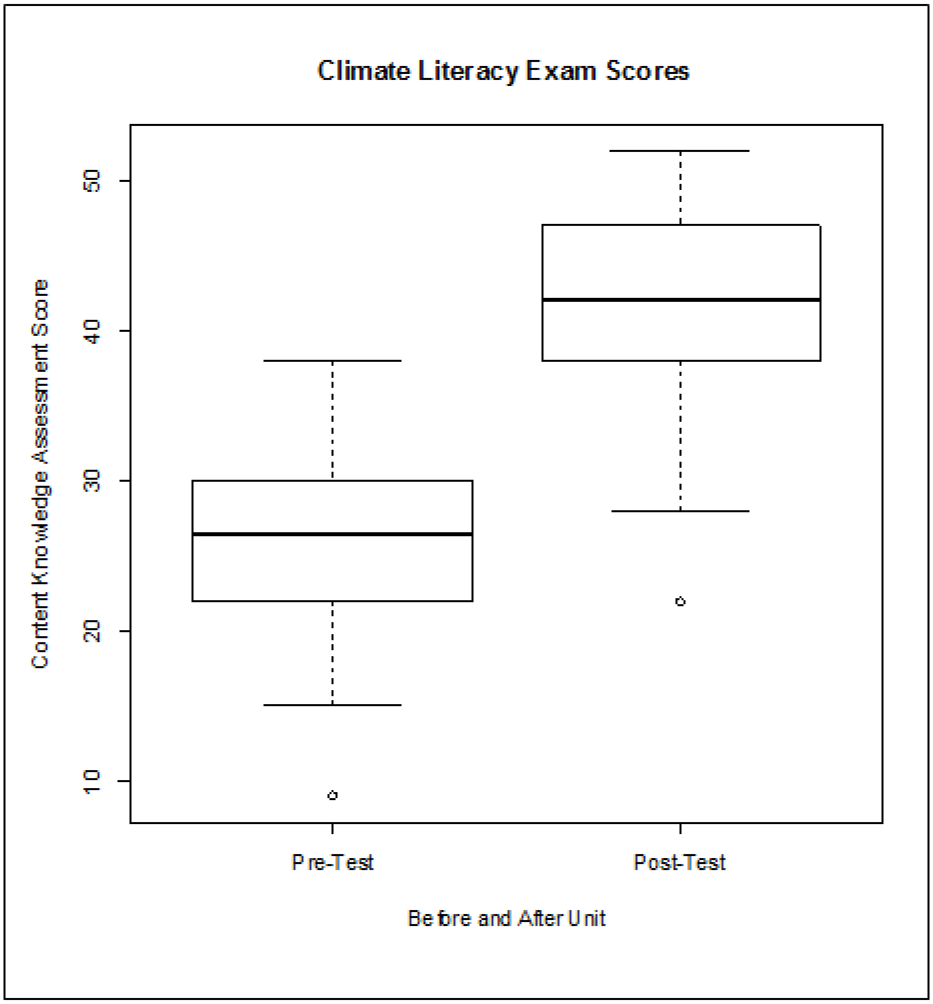


Figure 4.2. Box plot comparison of student pre-assessment scores to post-assessment scores.

Attitude Survey Trends. To get a more specific look at student attitudes and belief, it is important to understand the questions asked of students and answer selection choices available. These attitude assessment items and range of answer choices are outlined on Table 4.1. The attitude assessment items were survey questions embedded in the pre and post unit content knowledge assessment. It was assumed that students' answer selections were reflective of their beliefs. Specific shifts in student attitudes and beliefs by pre and post unit student percentage are shared in Table 4.2.

Table 4.1

Pre and Post Attitude Assessment Items and Answer Selection Choices

Attitude Assessment Question	Range of Answer Choices
Do you think global warming is happening?	Yes; No; Don't Know
If you think global warming is happening, how sure are you about it?	Extremely sure; Very sure; Somewhat sure; Not sure at all; I didn't pick yes for the last question
Assuming global warming is happening, do you think it is.....	Caused mostly by human activities; Caused by both human activities and natural changes; Caused mostly by natural changes in the environment; None of the above because global warming isn't happening; Don't know; Other
Which comes closer to your own view?	Most scientists think global warming is happening; Most scientists think global warming is not happening; There is a lot of disagreement among scientists about whether or not global warming is happening; Don't know enough to say
How worried are you about global warming?	Very worried; Somewhat worried; Not very worried; Not at all worried
Personally, how well informed do you feel about how Earth's climate system works?	Very well informed; Fairly well informed; Not very well informed; Not at all informed
Personally, how well informed do you feel about the different causes of global warming?	Very well informed; Fairly well informed; Not very well informed; Not at all informed
Personally, how well informed do you feel about the different consequences of global warming?	Very well informed; Fairly well informed; Not very well informed; Not at all informed
Personally, how well informed do you feel about the ways in which we can reduce global warming?	Very well informed; Fairly well informed; Not very well informed; Not at all informed

Table 4.2

Pre and Post Unit Percentages of Student Beliefs from Attitude Survey Questions

Attitude Assessment Question	Chosen Beliefs	Percentage-Pre	Percentage-Post
Do you think global warming is happening?	**Global warming is happening**	62.2%	86.7%
If you think global warming is happening, how sure are you about it?	**Very sure or extremely sure global warming is happening**	40.0%	57.7%
Assuming global warming is happening, do you think it is.....	**Global warming is caused mostly by human activity**	32.2%	32.2%
Which comes closer to your own view?	**Most scientists think global warming is happening**	23.3%	57.8%
Which comes closer to your own view?	**There is a lot of disagreement among scientists about global warming**	60.0%	35.6%
How worried are you about global warming?	**Feeling at least somewhat worried about global warming**	32.2%	63.3%
Personally, how well informed do you feel about how Earth's climate system works?	**Feeling uninformed about Earth's climate system**	47.8%	3.3%
Personally, how well informed do you feel about the different causes of global warming?	**Feeling uninformed about causes of global warming**	45.6%	1.1%
Personally, how well informed do you feel about the different consequences of global warming?	**Feeling uninformed about consequences of global warming**	37.8%	3.3%
Personally, how well informed do you feel about the ways in which we can reduce global warming?	**Feeling uninformed about ways to reduce global warming**	30.0%	4.4%

Table 4.2 shows a nearly twenty-five percent increase in students that believed global warming was occurring by unit's end. Of those believing in global warming, there was a 17.7% increase in how sure they felt about that belief, feeling very or extremely sure about it. Concluding the unit, over eighty-six percent of students professed to believe that global warming is happening. Over a quarter of students in the study changed their mind about whether or not global warming is happening. Therefore, learning about global climate change may have potential to shift related attitudes toward global climate change.

Interestingly, one belief did not change on average over the course of the teaching unit, despite explicit teaching to the contrary. 32.2% of students acknowledged that humans are the main cause of global warming pre and post-unit. There were only a few students who shifted to embrace this belief, but they were canceled out by others back-tracking on this belief. This resulted in the same post-unit percentage.

During the unit, students were explicitly taught that over ninety-seven pecent of climate scientists agree that global warming and climate change are occurring mainly as a result of human activity. Despite this teaching, only 57.8% of students acknowledged such a belief following the unit (see Table 4.2). The tendency was for students to see the issue as very contentious, more often believing that there is a lot of disagreement among scientists about whether or not global warming is happening.

Prior to the unit, students did not express a great deal of worry about the topic of global warming, with less than a third expressing that they felt somewhat worried about it. As would be expected, more students expressed feelings of being at least somewhat worried upon the unit's completion. Following instruction, 63.3% of students acknowledged such feelings, over a thirty percent increase from the unit's onset.

Students were asked how well informed they felt they were about global climate change. Before the teaching unit, many students expressed feelings of being not well informed about the topic. Specifically, they rated how well informed they felt on several global climate change topics; Earth's climate systems, causes of global warming, consequences of global warming, and ways to reduce global warming. Upon completion of the unit on global climate change, nearly all students felt well informed about the four topics. Less than five percent of students reported feelings of not being well informed across the various global climate change topics.

Categorization Process. Following pre and post assessment, students were categorized based on their attitude survey responses to the question "do you believe global warming is happening". Fifty-three students answered "yes" before and after the instructional unit. These students were called "Open" (OPs) based on their stance toward global warming. Twenty-three were labeled "Open Skeptics" (OSKs), having started the unit feeling uncertain whether or not global warming was happening and later concluding they believed it was. Eleven of the participants were classified as "Skeptics" (SKs), maintaining that they did not believe global warming was happening despite instruction that said otherwise. A rare anomalous category unexpectedly emerged, where three students began the unit saying they believed that global warming was occurring but reversed their opinion after instruction, saying that they did not believe global warming was happening. The qualitative analysis of students' open-end assessment items, other course artifacts, and interview transcript was used to re-categorize these anomalous results into the final three groups (see Table 4.3).

Table 4.3

Final Attitude Categorization of Students

Attitude Category	**Pre-Unit**: Do you think global warming is happening?	**Post-Unit**: Do you think global warming is happening?
OP; n = 54	**Yes**	**Yes**
OSK; n = 24	**No** or Don't Know	**Yes**
SK; n =12	**No** or Don't Know	**No**

Student Attitude-group Comparison of Content Knowledge. Student mean pre-post assessment scores by attitude category are represented in Table 4.4. These data suggest that there may have been a difference between the skeptics and the other two groups in terms of changes in content knowledge. On average skeptics started lower in their content knowledge and finished slightly below both the open and open-skeptic students. The average growth by category indicates that open students grew slightly less than the other two groups in their content knowledge. Open students started out knowing on average more than the other two groups but failed to grow as much in their understanding, about two points below the average growth of the other two groups. Skeptics started out lower in pre-assessment measures but on average grew more than their open classmates.

Table 4.4

Average Content Knowledge Assessment Scores by Student Category

Category	Average Pre-Assessment Score	Average Post-Assessment Score	Average Change in Score
Open (OP)	27.31	41.98	14.67
Open Skeptic (OSK)	26.33	42.79	16.46
Skeptic (SK)	23.50	39.83	16.33
Whole Class	26.54	41.91	15.37

In order to further determine whether or not these three groups were statistically different, one way ANOVA tests were run. The first test compared mean pre-assessment scores by student attitude category (OP, OSK, SK). The next one compared means of post-assessment scores by student attitude category. Average change in content knowledge scores and mid-unit quiz scores were also analyzed using one way ANOVA. Table 4.5 shows the resulting p-values. A more complete table of this statistical output can be found in Appendix F.

Table 4.5

Resulting p-values from ANOVA Comparing Assessment Mean Scores by Student Attitude Category

Assessment Score of Comparison	Attitude Categories of Comparison	p-value
Content Knowledge Pre-Assessment	SK, OSK, OP	0.118
Content Knowledge Post-Assessment	SK, OSK, OP	0.402
Change in Content Knowledge Score	SK, OSK, OP	0.336
Mid-Unit Quiz Score	SK, OSK, OP	0.356

For each of the above measures, there appeared to be no statistically significant difference between the skeptic, open-skeptic, or open students. None of the generated p-values were less than the 0.05 cut-off for statistical significance at a 95% level of confidence. The strongest mean difference appeared to be from student pre-assessment scores.

A two-group pair-wise test using Tukey's HSD was plotted to offer a visual comparison of pre-assessment scores by attitude category (Figure 4.3). It is recognized that each two-group comparison results in a 95% confidence interval crossing zero, confirming the ANOVA results that none of the student categories vary significantly in their pre-assessment content knowledge scores. Though not statistically significant, the trend indicated potential for a difference between open students' and skeptic students' pre-unit climate literacy based on the confidence interval ranging nearly below zero. A greater student sample size would be required to test this further.

Statistically speaking, there did not appear to be a significant difference between the overall content knowledge of the three groups of students as it pertains to climate literacy. In other words, it did not seem to matter what degree of skepticism students in this study had about global warming, the potential for growth in their content knowledge was statistically the same. Student attitude did not seem to be a barrier impeding these students from learning about climate change.

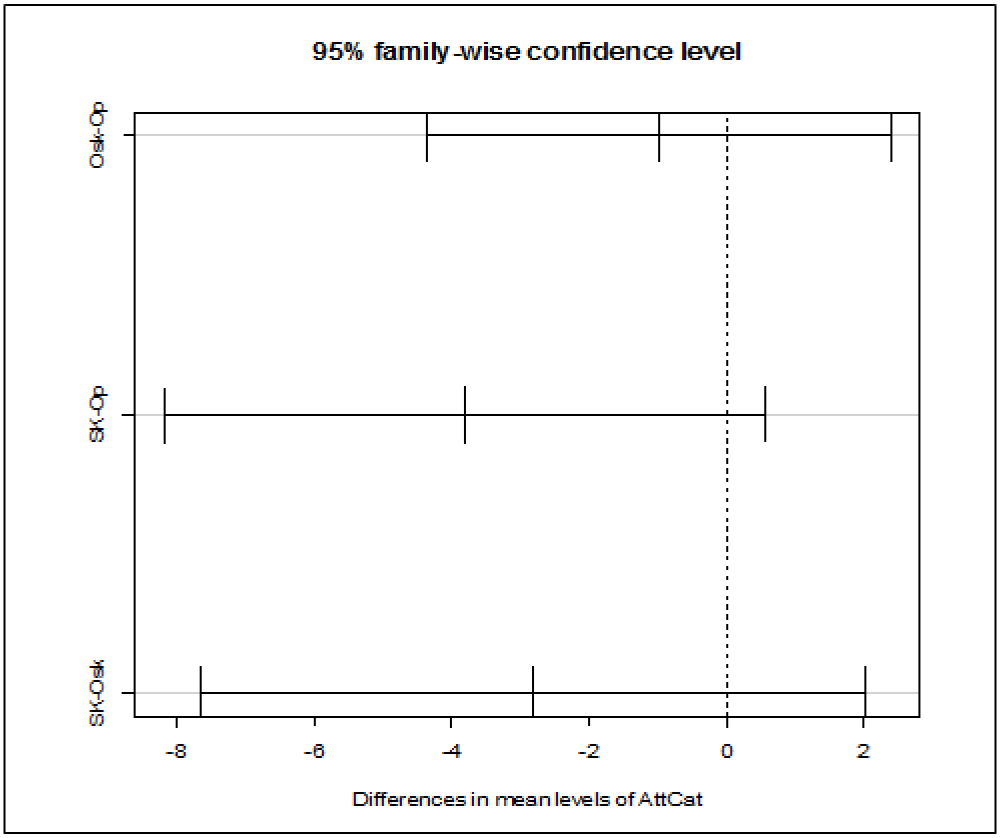


Figure 4.3. Two-group pair-wise test plots from Tukey's HSD, comparing content knowledge pre-assessment scores.

Refined Analysis. Overall, content literacy for the three groups appears to be statistically the same. To determine whether or not students in the different groups might vary by the specific climate change concepts they had difficulty with, the content knowledge assessment instrument was analyzed for conceptually different kinds of questions. This effort was used to determine if students got similar types of questions wrong or if there were differences in the kinds of concepts students from different attitude categories struggled with. The conceptual categories for assessment items are represented on Table 4.6.

Table 4.6

Assessment Item Categories, Frequency, and Examples

Assessment Item Category	Number of Items	Item Examples
Climate Systems	9	"The 'greenhouse effect' refers to:"
Weather vs. Climate	5	"Climate often changes from year to year" T or F
Earth's History	10	"In the past, rising levels of carbon dioxide in the atmosphere have caused global temperatures to increase."
Evidence	9	"Over the past 100 years, has the speed of glacier melting increased, decreased or stayed the same?"
Predictions	5	"If organisms find themselves outside of their normal climate ranges of temperature, precipitation, humidity or sunlight for extended periods of time, which of the following will occur?"
Causes	6	"Which gas is produced by the burning of fossil fuels?"

A spreadsheet was compiled, categorizing students by attitude category and noting their responses to assessment items organized by conceptual category. Some assessment items were not categorized due to their open-ended nature, reserving response analysis for the qualitative phases of this study. Of the items categorized, several were questions that students could get partially correct. To simplify analysis, frequency tables were created of students' wrong answers per category rather than contemplate the degree of "correctness" of some answers. Thus, unlike the pre-post assessment scores where positive results gave a trend of increasing scores, here it was hoped that the number of wrong answers by category decreased following instruction.

In order to determine if students of differing attitudes varied in the conceptual category of questions they got wrong, one-way ANOVA was used on each assessment category, comparing student attitude groups by the mean of wrong answer scores. The resulting p-values by assessment conceptual category are outlined in Table 4.7. A more comprehensive look at this statistical output can be seen in Appendix G.

Table 4.7

Resulting p-Values from ANOVA Comparing Mean of Wrong Answers for Assessment Item Categories by Student Attitude Category (OP, OSK, & SK)

Assessment Item Category	**p-value**
Climate Systems Pre	0.373
Climate Systems Post	0.630
Weather vs. Climate Pre	0.370
Weather vs. Climate Post	0.581
Earth's History Pre	0.009*
Earth's History Post	0.962
Evidence Pre	0.035*
Evidence Post	0.005*
Predictions Pre	0.125
Predictions Post	0.201
Causes Pre	0.506
Causes Post	0.631

Results outlined in Table 4.7 indicated that for most climate literacy concepts, students on average struggled with correct answers to a similar degree. There are two conceptual categories where p-values indicated a statistically significant difference between students of different attitudes: evidence of climate change and items dealing with Earth's climate history. It seems that skeptic student have more difficulty dealing with evidence-based questions, before and after the teaching unit. They also have a less robust understanding of Earth's historical climate prior to instruction, but end up with understanding similar to open-skeptic and open students concluding the unit. Tukey's HSD was used to parse out the statistically significant differences by student attitude category (see Figures 4.4 through 4.6).

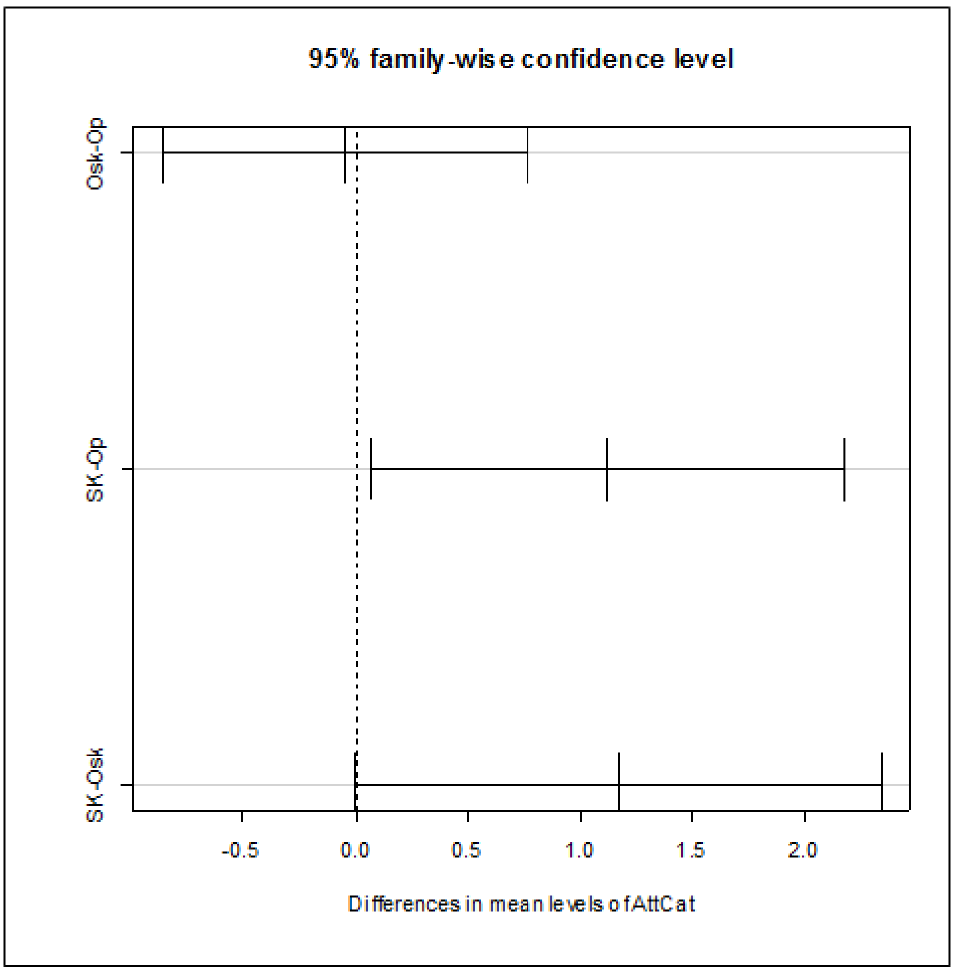


Figure 4.4. Two-group pair-wise test plots from Tukey's HSD, comparing pre-assessment number wrong Evidence scores.

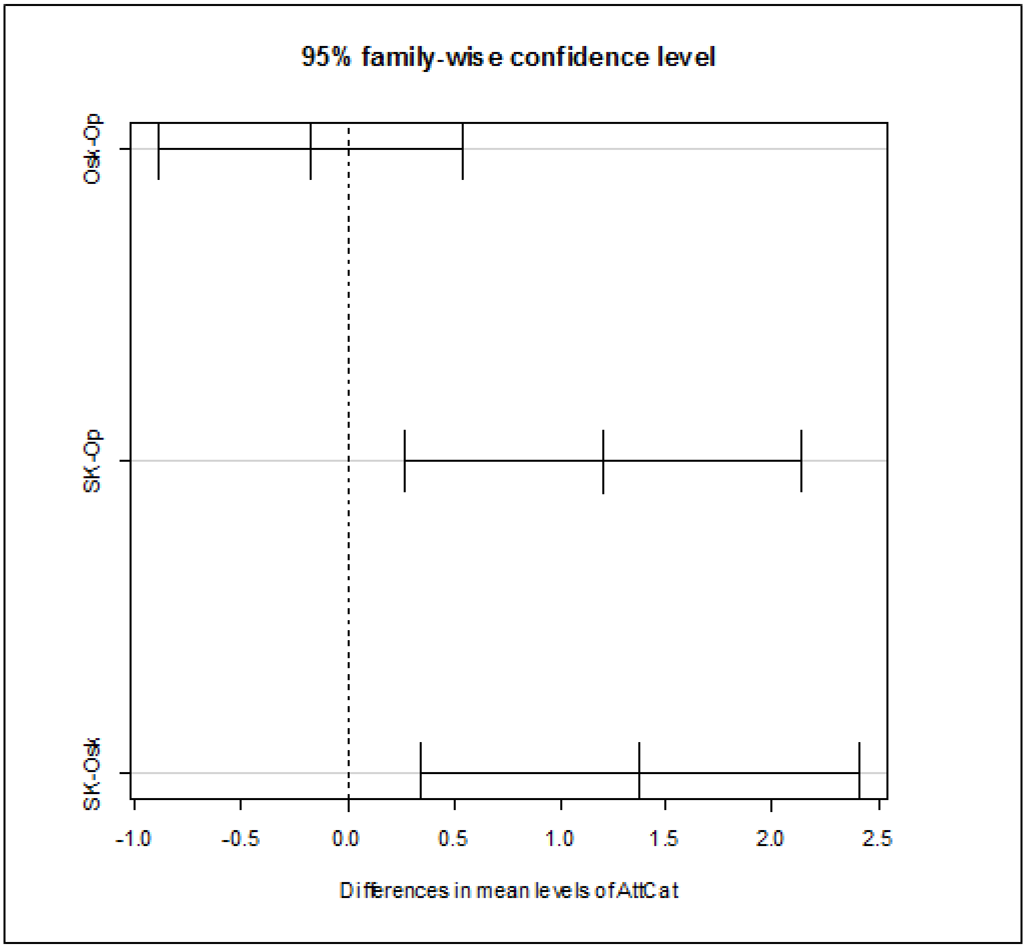


Figure 4.5. Two-group pair-wise test plots from Tukey's HSD, comparing post-assessment number wrong Evidence scores.

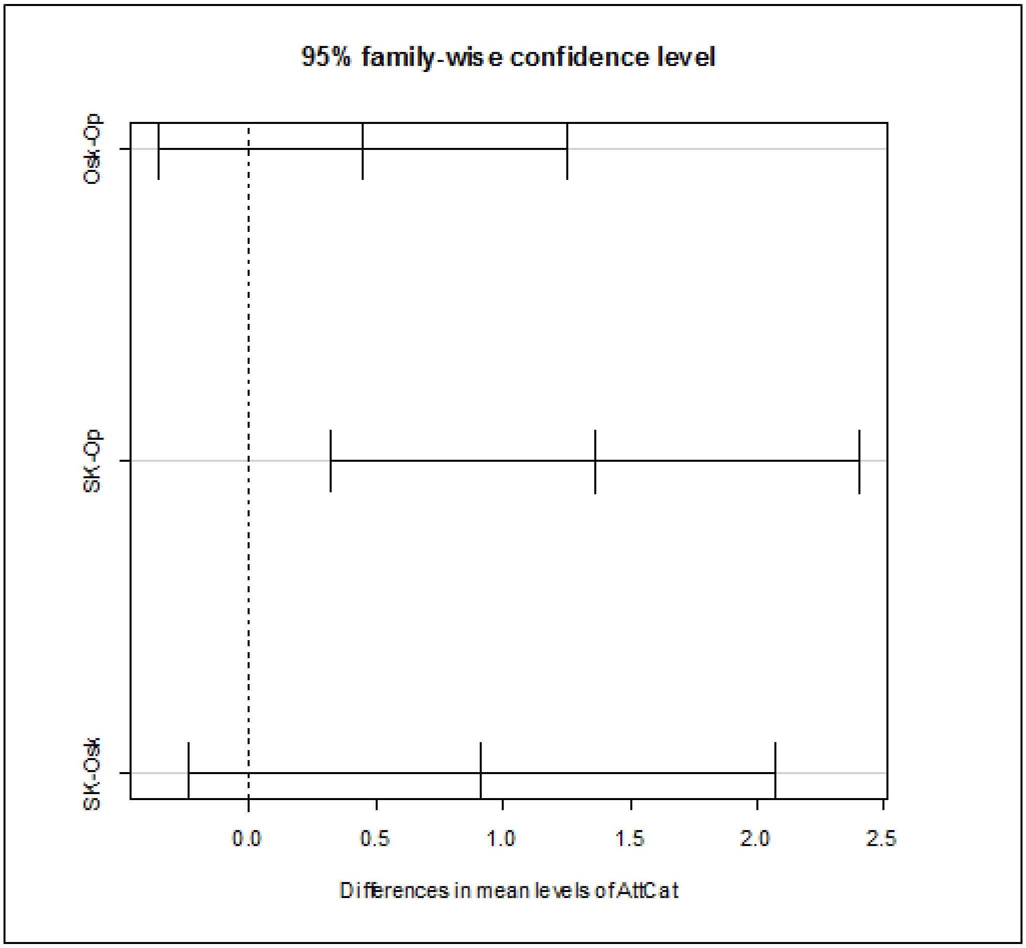


Figure 4.6. Two-group pair-wise test plots from Tukey's HSD, comparing pre-assessment number wrong Earth History scores.

Phase II: Qualitative Analysis

This effort explored both students' conceptual understanding and attitudes and beliefs about global climate change. The focus of conceptual understanding was to identify growth trends. Analysis of attitudes and beliefs began first with the attitude survey data, before the coding process of student artifacts.

Trends in Conceptual Growth. Although misconceptions about global climate change concepts persisted, students tended to use more specific examples and evidence to explain their ideas on open-ended questions. For example, Maria explained the greenhouse effect this way initially, "when we drive our vehicles, the carbon dioxide that is emitted enters our atmosphere, it is depleting our ozone layer (a guess), allowing the sun to heat earth's surface even more". After instruction Maria said, "Heat-trapping gases enter our atmosphere, and as the sun's heat is warming the earth, the gases trap in the heat, allowing only small amounts to escape, causing an increase in temperature in certain areas. Clouds and ice reflect the heat, but the increases in temperatures are melting the ice, so less heat is being reflected, making it warmer". Though still incomplete in her understanding of the greenhouse effect, her conceptions have evolved toward a more detailed and scientifically accurate view.

Preliminary qualitative analysis comparing the conceptions of students by attitude category focused on a developed continuum of conceptual understanding. Codes were developed ranging from "no conception" to a "scientific conception", based on alignment to *Climate Literacy* principles outlined by the U.S. Global Change Research Program. See Table 4.8 for code descriptions and reflective examples using student data.

Table 4.8

Coded Continuum of Conceptual Understanding

Code	Symbol	Description	Example using GHE
No Conception	N	No conception was offered by the student.	Allen: "IDK"
Complete Misconception	CM	Conception nearly all incorrect or incorporated unrelated concepts.	Maria: "when we drive our vehicles, the CO_2 that is emitted enters our atmosphere, it is depleting our ozone layer (a guess), allowing the sun to heat the earth even more"
Partial Conception	P	Conception too short or incomplete to illustrate full understanding, but correct at some general level.	Joseph: "the greenhouse effect heats the earth by trapping the suns heat in the atmosphere"
Partial-Advanced Conception	P-Ad	Conception reveals more detailed complete understanding, but falls short of aligning with a scientifically complete conception.	Shelby: "the sun gives of energy in the form of light which comes into the atmosphere in short wavelengths and turns into the energy form of heat. The heat is then absorbed by heat-trapping gases such as CO_2 and H_2O vapor. The heat waves have trouble escaping the atmosphere though because they are longer wavelengths."
Scientific Conception	S	Conception described in full detail aligning with *Climate Literacy* principles.	Kris: "Sunlight comes to Earth in a shorter wavelength, so it easily passes through the atmosphere. Once it makes contact with the surface, it absorbs the sunlight, and radiates heat in a longer energy wavelength. This wavelength makes it more difficult to escape the atmosphere and some of it gets trapped by gases such as CO_2 and H_2O vapor, increasing the average temperature of Earth."

Student open-ended responses of two climate change concepts were analyzed using this coded continuum. The first looked at students' explanation for how the greenhouse effect works on Earth. The next had students describe the difference between global warming and climate change, explaining the relationship between them. Each student's pre and post unit responses were coded, and then codes were tallied by student attitude category on frequency tables. See Table 4.9.

Table 4.9

Frequency Table of Students' Conception Codes by Student Attitude Category

Student Attitude Category	**Concept: GHE**					**Concept: GW vs. CC**			
SK n = 12	**Code**	Pre Total	Pre %	Post Total	Post %	Pre Total	Pre %	Post Total	*Post %*
	N	4	33.3	0	0	5	41.7	1	8.3
	CM	4	33.3	2	16.7	2	16.7	0	0
	P	3	25	8	66.7	3	25	7	58.3
	P-Ad	1	8.3	1	8.3	2	16.7	4	33.3
	S	0	0	1	8.3	0	0	0	0
OSK n = 24	**Code**	Pre Total	Pre %	Post Total	Post %	Pre Total	Pre %	Post Total	Post %
	N	6	25	1	4.2	2	8.3	0	0
	CM	8	33.3	5	20.8	3	12.5	1	4.2
	P	8	33.3	13	54.2	15	62.5	15	62.5
	P-Ad	2	8.3	5	20.8	4	16.7	8	33.3
	S	0	0	0	0	0	0	0	0
OP n = 54	**Code**	Pre Total	Pre %	Post Total	Post %	Pre Total	Pre %	Post Total	Post %
	N	22	40.7	2	3.7	16	29.6	6	11.1
	CM	20	37	19	35.2	7	13	12	22.2
	P	12	22.2	20	37	31	57.4	25	46.3
	P-Ad	0	0	10	18.5	0	0	7	13
	S	0	0	3	5.6	0	0	4	7.4

Overall, student conceptual understanding shifted for all three groups toward a more scientifically accurate conception over the course of the global climate change unit.

However, very few moved beyond a “partial conception” of either concept. Out of one hundred eighty given responses for the two concepts, only eight aligned with a scientifically accurate conception by unit’s end.

Considering the differences in sample size, it is difficult to say anything substantive when comparing frequency shifts in conceptual understanding by student attitude category. One interesting trend is apparent when considering students with less than a partial conception (N, CM) compared with those with a partial conception or greater. Skeptic students had a 50% increase in those who developed partial conceptions or better on both concepts analyzed. This is higher than both open and open-skeptic student gains. This trend supports the earlier quantitative analysis showing that skeptic students made the greatest average gains of the three attitude categories on the content knowledge assessment.

It is also interesting to notice that open students began and ended the unit below the other two groups in percentage of students having partial conceptions or greater, looking at the greenhouse effect. They also began lower than the open-skeptic students and maintained a much lower post-unit percentage of students with partial conceptions or greater for the global warming vs. climate change conception. This lack of growth relative to the other two groups toward higher levels of conceptual understanding is supported by quantitative test scores.

Conceptually speaking, all three groups grew in their understanding about the greenhouse effect, global warming, and climate change. Skeptic students show a higher percentage of students growing into at least a partial conception. Open students show the least gains compared to skeptic students in their conceptual understanding, especially when looking at the concept of global warming vs. climate change. Other than these two trends, there seems to be little in the way of differences between these groups' growth in conceptual understanding.

Survey Trends in Student Attitudes and Beliefs. When looking at beliefs regarding a human cause to global warming before and after instruction, the same whole class trend was maintained looking across student attitude categories, outlined on Table 4.10. On average students did not shift in their belief that humans are responsible for global warming. Instead, students mostly chose survey response options attributing some degree of global warming to natural causes.

Table 4.10

Pre and Post Unit Percentages of Students by Attitude Category Expressing Belief of: Human Cause to Global Warming, Scientific Consensus, Scientific Disagreement, and Personal Worry

Chosen Beliefs	Attitude Category	Percentage-Pre	Percentage-Post
Global warming is caused mostly by human activity	OP	40.7%	40.7%
	OSK	20.8%	20.8%
	SK	16.7%	16.7%
Most scientists think global warming is happening	OP	35.2%	66.7%
	OSK	4.2%	50.0%
	SK	8.3%	33.3%
There is a lot of disagreement among scientists about global warming	OP	51.9%	31.5%
	OSK	83.3%	41.7%
	SK	50.0%	41.7%
Feeling at least somewhat worried about global warming	OP	46.3%	83.3%
	OSK	16.7%	45.8%
	SK	0.0%	8.3%

A much higher percentage of open students believed in a scientific consensus among scientists about global warming than either skeptic or open-skeptic students. Over thirty-five percent of open students began the unit with this belief, while 8.3% of skeptics and 4.2% of open-skeptics initially held this belief. Belief that the issue of global warming is contentious among the scientific community also varied across student attitudes categories to start the unit. Over eighty percent of open-skeptic students began the unit thinking there was a lot of disagreement scientists about whether or not global warming is happening, nearly thirty percent higher than the other two groups. By unit's end the three groups had shifted to within ten percent of one another in this belief.

Another attitude trend that varied by student category was that of worry. Very few skeptic students expressed any degree of worry about global warming. Over eighty percent of open students expressed feeling somewhat worried during their post assessment. While not as worried as open students, the percentage of open-skeptic students expressing the same attitude rose by over twenty-five percent. One attitude that did not vary by student category was the degree to which they felt informed on global climate change topics, especially by post assessment results.

Many students did not express worry about global warming. Still, it is worth noting that over eighty-six percent of students believe that learning about climate change in school has value, according to mid-unit survey results. These beliefs are outlined by student attitude category in Table 4.11.

Table 4.11

Percentage of Students Believing Teaching of Global Climate Change has Value by Attitude Category

Student Attitude Category	Mid-Unit students believing that learning about climate change in school has value
OP	98.2%
OSK	79.2%
SK	50.0%
Whole Class	86.7%

Coding Student Attitudes. An inductive open coding approach was taken for gaining a deeper sense of student attitudes about global climate change. To tap in to student feelings and emotions about climate change, open-ended response formats were used. A number of student artifacts were compiled for analysis including; journal entries, open-ended survey questions, and predictive essays. Open-ended survey items were initially read, looking for attitude language used by students to reflect feelings and emotions about global climate change. This preliminary look helped to develop attitude language codes, used to generally describe the spectrum of student feelings about global climate change. The resulting codes are outlined in Table 4.12, including definitions and student quotes exemplifying each code. These codes were later used for more in-depth analysis of data from eight purposefully selected students (phase III) discussed at length in chapter V.

Table 4.12

Attitude Language Codes, Definitions, Data Examples, and Frequency

Attitude Code	Definition	Student Data Examples	Code Frequency
Matter of Fact (MoF)	Student expression of understanding reveals no particular feeling or emotion	"global warming is basically what causes climate change" "CO2 goes into the atmosphere and traps heat in and warms the earth"	80
Knowledge is Power (KIP)	Belief that knowing more about the topic as value, by empowering people either to change or better cope	"If we are to slow down or even stop global warming we have to be more aware of what we're doing to hurt the environment" "I want to be a farmer and with that I need to know what the climate is going to be doing"	48
Do Your Part (DYP)	Belief that society/individuals should take responsible actions to mitigate the effects of GCC	"use the information….and do something about the climate change" "if you can get a lot of people to do little things all those little things add up and become a much larger thing"	44
Extremism (Ext)	Belief in exaggerated status of environment and predicted consequences of GCC	"if we keep this up and the earth keeps getting hotter then we all might die" "MN's winters could become nothing more than an extended fall"	20
Lack of Power (LoP)	Feeling that individual & societal efforts of mitigation won't be enough to exact meaningful change	"there is nothing we can really do about how the climate changes" "even if I did know I couldn't really do anything about it…..I'm only one person"	18
Doubt the Science (DtS)	Feeling of skepticism about the scientific evidence of GCC & future predictions	"Humans aren't causing the global warm-up. We are coming out of an Ice Age" "I don't completely understand how we know humans are 100% responsible for raising the level of CO_2"	16
Frustration (Fru)	Expressed feeling of anger or frustration about GCC; the learning of it or the societal debate on the issue	"What I'm struggling with is if people know that global warming is happening, why doesn't the U.S. create cars….that have 70+ MPG like Europe does?" "I dislike it when people try to push their beliefs on me, and that's what I feel this unit is trying to do….I thought biology was dissecting stuff and learning about animals. Not hugging trees."	6

Strong Opposition (STOP)	Feeling that the issue of GCC and learning of it has no relevance	"It doesn't matter if I know about it or not. I really couldn't care less about the earth's climate"	5
		"no because I think global warming was made up"	
Other People's Problem (OPP)	Feeling that the issue of GCC is not pressing and that not everyone needs to be concerned; deflecting responsibility to others	"Living in a rural area like we live in that doesn't produce much CO2 from fossil fuels, I wouldn't think I need to be informed"	3
		"I can let someone else worry about it….I don't think it will really affect me too much"	

Nearly all attitude language codes crossed student attitude category boundaries. However their relative abundance by group differed. Skeptics showed a higher percentage of negative language attitude codes and a greater range of codes than open students. Open students had fewer codes expressed, but tended to have a higher percentage of positive expressions. These are outlined in Table 4.13.

Table 4.13

Number of Different Attitude Language Codes and Frequency of Positive to Negative by Student Attitude Category

Student Category	Number of Different Attitude Codes	Frequency of Positive Codes	Frequency of Negative Codes
OP	6	31%	69%
OSK	8	73%	27%
SK	8	78%	22%

In most of the student artifacts, a "matter of fact" attitude was expressed when describing their understanding of global climate change concepts. More often, no particular feelings or emotions were shared as they revealed their understanding of unit topics. For example, Lauren demonstrated this through her statement, “global warming is basically what causes climate change”, articulating the relationship between global warming and climate change, absent of attitudinal language.

Students also commonly expressed an attitude of “knowledge is power” and “do your part”, believing that by knowing more about this issue they are more empowered to make changes needed to reduce the effects of global warming and climate change. Dave attested to that in his journal excerpt: “If we are to slow down or even stop global warming we have to be more aware of what we’re doing to hurt the environment. And then we can do what we can to help prevent more change.” It was also echoed in Simon’s journal quote stating, “the most helpful thing that we did during this unit was learning how we could stops climate change”. For Doug knowing about it has power in helping him cope. He stated, “I want to be a farmer and with that I need to know what the climate is going to be doing”.

Many students believed that the effects of global warming and predicted consequences are more severe than they actually are. When describing the situation, these students expressed an attitude of “extremism”. Following his thoughts on learning how to stop climate change, Simon warned that, “if we do not change our ways either lots of living things will die or everything will eventually because of too hot of temperatures for life”. Without steps to mitigate the problem Jake believed that, “MN's winters could become nothing more than an extended fall”.

Other challenges became evident after hearing students express that they feel hopeless to fix the problems created by global warming. Some students used language reflecting a “lack of power” in the face of global climate change. Still others were plagued with doubt, about how bad the situation is and whether or not humans are really responsible. Their language reflects that they “doubt the science”. Feeling of powerlessness was evident in Lynn’s words, as she said “there is nothing we can really do about how the climate changes”. Amelia echoed that too with the belief that “even if I did know I couldn’t really do anything about it……..I’m only one person”. Doubt of the scientific evidence and feelings of uncertainty emerged in the words several students. Grant stated in his journal, “I don’t completely understand how we know that humans are 100% responsible for raising the level of CO_2 levels”. Despite what was taught in class, more doubt was verbalized by Amelia saying that, “Humans aren't causing the global warm-up. We are coming out of an Ice Age”.

More attitude challenges became clear from a vocal minority of students that expressed “strong opposition” to the teaching of climate change. This was evidenced by John’s response regarding the value of learning about climate change. He said, “no because I think global warming was made up”. These students often expressed “frustration” with having to learn about global climate change. Finch did so by saying, “I dislike it when people try to push their beliefs on me, and that's what I feel this unit is trying to do….I thought biology was dissecting stuff and learning about animals. Not hugging trees”.

Summary

To conclude, over the course of a teaching unit on global climate change, nearly all attitudes or beliefs shifted to some degree. These shifts tended to move closer to beliefs held by the scientific community. Students believed they knew more about global climate change after the unit, which was supported by student post content knowledge assessment scores. Some attitudes appeared resistant to change. Students had difficulty believing in a scientific consensus about global warming. More often they adhered to a belief that there is much disagreement among scientists about global warming. Another persistent belief was the acceptance that humans are mainly responsible for global warming.

Though not statistically significant, it did appear to matter what attitude category students were placed in while assessing content knowledge about global climate change. Each student attitude group showed statistically significant gains in content knowledge based on pre-post assessment measures. The mean difference between groups' scores was not statistically significant. When considering the types of content questions being asked, it is noteworthy to consider the notion of evidence. Skeptic students may be different than the other students in their understanding of evidence as it supports global warming and climate change. This was the only category of content knowledge questions where skeptic students showed a statistically significant difference over other students, both before and after the unit on global climate change. Skeptics may also have a different conceptual understanding about Earth's history.

For a deeper look at student conceptions and attitudes, a purposeful sample of eight students was formed. These students all volunteered to grant a post-unit interview. The interview questions helped gather more data on student thinking and post-unit attitudes. Continued qualitative analysis of these eight profiles is detailed in chapter V.

Chapter V: Purposeful Sample and Cross-case Analysis

Through the course of a teaching unit on global climate change, nearly all student conceptions and attitudes or beliefs shifted to some degree, as described in the previous chapter. These shifts tended to move closer to those held by the scientific community. Students believed they knew more about global climate change after the unit, which was supported by student post content knowledge assessment scores. However, some attitudes appeared resistant to change. Students had difficulty believing in a scientific consensus about global warming and often adhered to a belief that there is much disagreement among scientists about global warming. Another persistent belief was the acceptance that humans are mainly responsible for global warming.

Though not statistically significant, the student attitude category did appear to influence content knowledge about global climate change. While each student attitude group showed statistically significant gains in content knowledge based on pre-post assessment measures, the mean difference between groups' scores was not statistically significant. When considering the types of content questions being asked, it is noteworthy to consider the notion of evidence. Skeptic students may be different than the others in their understanding of evidence as it supports global warming and climate change and understanding of Earth's history. These were the only content areas where skeptic students showed a statistically significant difference over other students.

For a finer look at student conceptions and attitudes, a purposeful sample of eight students was selected (see chapter III for details). These students all volunteered to grant a follow-up interview. The interview questions helped gather more data on student thinking and post-unit attitudes. Continued qualitative analysis of these eight cases is detailed in this chapter. To guide this process it is helpful to be reminded again of the initial research questions for this study:

1. To what extent and in what ways do students' conceptions change in association with an 8-week inquiry-based unit on climate change?
2. In what ways do student attitudes change in association with an 8-week inquiry-based unit on climate change?
3. How does growth in content knowledge and conceptual understanding correspond with attitudes about climate change?

First, this chapter describes the analytic process leading to the formation of a purposeful sampling of eight students. Second, the students profiled are introduced with a description of unique insight gleaned from each. Third, cross-profile analysis is described, resulting in ten subsequent themes. Fourth, each theme is defined and contextualized within student data. Finally, a summary of qualitative findings are outlined to conclude this chapter.

Purposeful Sampling. Purposeful sampling was done in order to get a deeper sense of the relationship between students' attitudes and conceptual understanding. It was also done to better understand variety of student conceptions and attitudes expressed over the course of a global climate change unit.

The process of developing a purposeful sample focused on three criteria. First, efforts were made to get representatives from each of the attitude categories. Second, a survey was given to generate a list of students willing to grant a post-unit interview.

Those students choosing “yes” or “maybe” were further considered. This limited the pool of students greatly, as many students shied away from granting an interview. Finally, of those open to an interview and with consideration of representation of each attitude category, students were chosen by richness of overall data for actually setting up interviews. Richness of data was determined by open-ended assessment responses and degree of elaboration in journal entries and other unit assignments.

Three months following the global climate change unit, eight interviews were recorded and subsequently transcribed. Each of the eight interviewees was able to offer some unique insight toward this research. Some offered a stronger perspective on attitudes. Others reflected different ways of conceptualizing global climate change concepts. See Table 5.1 for a list of student pseudonyms, their attitude category and a summary of their insights. A summary was developed for each interviewee describing their unique contributions. Following the individual summarization, data on these eight were reviewed for cross-cutting themes.

Table 5.1

Student Interviewees, Pre-Post Content Knowledge Scores and Unique Insights

Student	Attitude Category	Pre-CK Score	Post-CK Score	Strongest Insight
Eli	OSK	15	43	Political and economic issues linked to attitudes, especially in light of solutions
Darren	OSK	33	52	Reasoned shift in his GCC perspective due to evidence
Tyler	OP	31	46	Openness to the issue rooted in continued belief that CC is a natural process
Maria	OP	28	43	Change in conception of the GHE over time
Shawn	OP	27	44	The role of parental and peer pressure on student's ability to declare their own opinion
Dawson	SK	18	46	Strong attitude against GW & CC with little conceptual understanding
Amelia	SK	28	40	Becoming disenchanted and less willing to elaborate on conceptual understanding
Jake	SK	35	51	Self-declared skeptic revealing strong conceptual understanding of GCC

Student Cases

Eli. Eli was a very social individual who could talk easily with anyone. In class he worked and stayed on task for the most part, but opportunity to socialize could be a distraction for him. He always maintained a high level of respect despite times of needed redirection by the teacher. Academically, Eli had to work hard for the grades he earned. Part of that effort included being an active participant in class discussion and asking questions when he did not understand something. Unfortunately, he would often state he understood something and subsequent assessments suggested otherwise.

The strongest insight stemming from qualitative analysis of Eli came from his attitude language in discussing global warming and climate change. His first concept map indicated that he believed this to be a political topic, connecting climate change to Al Gore. Eli softened a bit in his position by acknowledging that global warming is happening by unit's end and omitting further mention of political figures like Al Gore. Instead, he spent time articulating ideas about the economic challenges of fighting climate change and impact of his upbringing on shaping his ideas.

Conceptually, Eli began the unit below average based on his pre-assessment score, but made gains to average understanding relative to his peers by unit's end. Initially he believed that the greenhouse effect was melting the ozone layer and causing climate change. On post-assessment items and interview transcripts Eli mentioned no connection of climate change concepts to changes in the ozone layer. We cannot be certain that this omission meant he really believed there was no connection between this climate change and the ozone layer, but it's possible he had gained a clearer understanding that these are different environmental issues. While he did grow in his understanding, he still maintained some major misconceptions. One instance was revealed as he claimed in a mid-unit quiz that, "climate is the landscape like hills, lakes, rivers", well after class discussions defined the differences between weather and climate.

In his predictive essay Eli attempted to explain the kinds of changes that could be expected if warming of the earth were not slowed down. His efforts were shadowed by his own doubt as he discussed sea level rise. He stated that, "if the entire south pole were to melt, the sea level would rise over 200 feet. But the average temperature in the Antarctic is a -37 degrees Celsius". He countered his own argument. It seemed as though Eli did not believe it could ever happen and that sea level rise was not a big concern. This belief may be rooted in misunderstanding about heat energy transfers from ocean currents and positive feedback loops resulting from lost albedo. Eli was only focused on the statistic of average air temperature. This confusion was supported on his post-assessment, where he failed to recognize the heat distribution patterns of the atmosphere and oceans.

Darren. Darren was a diligent, hardworking student who strived for and attained good grades. He could be counted on for getting work in reliably and with quality. He was not obsessed with attaining every point possible, but knew that his efforts and abilities would result in grade success. Darren was a good athlete with a number of friends as teammates. Within his circle of friends, he seemed to play a leadership role with others looking up to him. He was an independent thinker, yet did seem to care somewhat what his peers thought too.

He credited the barrage of evidence presented during the unit for helping him change his position on the issue. The change started, "by looking at all the models and the different notes and everything that we took….we did all the worksheets that we had to answer questions on, just kinda made me change my mind, all the, the little things that showed populations and how there's obvious evidence that the earth is warming just by all these graphs that we're taking and things like that. So……it definitely changed a little bit." The worksheets he referred to were discussion questions that students worked on in groups in conjunction with reading excerpts from Tim Flannery's "*We are the Weather Makers*". In it there were graphs to interpret and many evidenced examples of how changing climate impacts communities of organisms around the globe. That part of the unit made an impression on Darren, enough to shift his position.

Conceptually, Darren began and ended the unit well above average relative to his peers. One interesting area of growth was evidenced by comparing his pre and post concept maps. At first he linked human pollution to the greenhouse effect and global warming which caused climate change, yet did not specify what that pollution was. By unit's end, Darren was more specific in his mapping; connecting the ideas that humans create greenhouse gases, which lead to the greenhouse effect that creates global warming leading to climate change. He remembered the way the greenhouse effect was discussed in class, based on his post-assessment response on how it works.

> "The greenhouse effect is how the earth stays habitable. In the atmosphere there are a lot of greenhouse gases that are able to trap in heat. As the sun shines, the light- short wave lengths are able to flow through these gases very easily. The light energy is then transferred into heat energy- long wave lengths. These long wave lengths aren't able to escape as easily so they stay on earth. More light comes in than heat goes out so therefore the earth warms up and stays heated."

By changes in his concept map and well-articulated explanation of the GHE, one might conclude that Darren understood this concept rather well. However his post-unit interview hinted at some possible underlying confusion. Darren was asked whether or not you can have the greenhouse effect without global warming. He said, “uh yes you can because the greenhouse effect is actually good because you need it to uh protect us from the sun…..” He was committed to the idea that the greenhouse effect is a necessary thing for sustaining life on earth; however it was not clear in this instance if he fully understood what the greenhouse effect was. It sounded like a conceptual inter-connection with the role of the ozone layer.

Tyler. A very enthusiastic and gregarious nature described Tyler. He was unafraid to speak his mind even when other students disagreed. The strength of his opinions came from backing them up with sound reasoning and evidence. Tyler was great at looking at new information and paraphrasing main points in his own words, shown often in contributions to classroom discussion. He was very social, yet that did not hinder his efforts to complete all of his work and maintain good grades.

From the unit’s onset Tyler recognized a human influence on global warming, believing that it was occurring. He stated, “As we spew more greenhouse gases into the atmosphere, temperatures are going to rise”. He was aware that a switch away from fossil fuels toward renewable sources of energy would have the greatest impact on reducing the effects of global warming. With Tyler’s personality, openness to global warming, and recognition of human cause might lead one to assume that he would be a good candidate to catalyze change among his peers. Closer scrutiny of his ideas identified a potential roadblock toward meaningful change.

Tyler understood enough about Earth's long history to recognize that climate change was the norm. As such, he could not let go of the idea that climate change is natural and that what we are experiencing now could be as well. In his comparison of global warming and climate change Tyler stated, "climate change has happened on Earth naturally for 4 billion years". He recognized mid-unit that scientists believe that climate change is occurring and is mostly caused by human activity; referencing supportive evidence like the Seuss affect, atmospheric warming from the bottom up, and correlation between CO_2 levels and human rates of fossil fuel use. Yet, post-unit data did not support a personal conviction of this reality.

He maintained that, "climate change is a natural process that the Earth is accustomed to over long periods of time. Such instances were explained through the Milankovich Cycle." Though he recognized that the past ten thousand years of warming, "does not follow the Milankovich Cycle and henceforth is considered an unnatural global warming instance", he emphasized that, "this isn't the warmest our Earth has been, because it has gone through global warming in the past naturally on its own". During Tyler's post-unit interview he suggested that, "many scientists say- agree that the Earth is getting warmer, there is a climate change and it- the Earth has been warmer than it has been for a while, I know…….the argument now is whether this is natural or if this is human causing purely".

Maria. Hard work and high achievement went hand in hand for Maria in biology. She was always on task, contributed to discussion when called upon, and those contributions nearly always were accurate. Maria was somewhat quiet by nature. Yet, she did advocate for herself in unobtrusive ways to achieve clearer understanding. She was not overly verbose in responses, but rather tried to be concise in her expression of thought. She continued to grow as an independent thinker while avoiding the spotlight.

Maria's first concept map revealed some obvious misconceptions. For her, humans were part of the cause of global warming, yet clarity on that role was missing. She linked human use of gas and oil to the problem of the greenhouse effect, but she also stated that, "if everyone would stop littering and pick up garbage it would help the problem (global warming)". She also chose to add the ozone layer to her concept map saying that this was, "where the greenhouse effect is taking place". Maria also included the ozone layer in her open-ended assessment questions about the greenhouse effect where she stated that, "when we drive our vehicles, the carbon dioxide that is emitted enters our atmosphere, it is depleting our ozone layer (a guess), allowing the sun to heat the earth's surface even more". There was confusion as to how the atmosphere and more specifically how the ozone layer actually functions. By unit's end, Maria had an improved grasp of the greenhouse effect and fairly accurate conceptions displayed regarding its connection to global warming and climate change. Her inclusion of the ozone layer in post-unit assessment disappeared, while she still seems confused as to how greenhouse gases work. She said that, "all the gasses and stuff that we emit into the air is bouncing off all the heat back to earth".

Amidst her misconceptions, Maria did not seem to waiver from a human responsibility and need for commitment to make mitigating changes in response to climate change. She attested to that in her concept map initially stating that, “if everyone would stop…..it would help the problem”. Mid-unit she said that, “(I) would like to know more about what we can do in our everyday lives”. In her post-unit journal response she referred to the greenhouse effect, global warming, and climate change as, “the horrible things that will really be affecting us if we don’t change our unhealthy habits”. She said, “…we need to make a solution. The solution I think we should switch to solar power, wind energy, and hydroelectric power”. She said that by learning about climate change “it helps me make a smarter decision on how I’m gonna make like a change in it and like how I’m gonna try I guess help it you know”.

Maria believed in the scientific consensus and did not need a perfectly accurate scientific understanding of climate change concepts to believe in it and a need to make changes. For her the issue became personal when she discussed predicted changes to precipitation in Minnesota. “This can have a big impact on my family, because we run a dairy farm, and we grow and buy crops to feed the cattle. It would heavily affect our crops because of the droughts and flooding.” The critical thing she understood was that this environmental issue was going to affect her and her family.

Shawn. Shawn was an interesting student. He would willingly contribute to classroom discussion without worrying if his responses were wrong. He had his own way of seeing things and appeared not to care if his perspective blended in with his peers, giving the impression that he was a free thinker. He worked at school, but did not seem compelled to work for grades alone. Shawn appeared to work hard enough to please himself, not concerning himself with pleasing the teacher. Ironically, Shawn's data revealed that he was more worried than he revealed about what others think.

Shawn showed openness to the issue of global warming initially with a declared belief as being somewhat sure that it was occurring. Pre-assessment showed him as average in his recognition of correct conceptions, expressing little doubt that this was a contentious issue for him. Like most of his peers Shawn had limited conceptual understanding at first, having made some correct general connections between climate change concepts and expressed misconceptions. By unit's end Shawn scored above average from his peers in conceptual understanding, but he had a strange shift in attitude leading to closer scrutiny.

His expressed belief that global warming was occurring shifted from yes to start the unit, to a "don't know" when the unit concluded. For the first time during the unit, Shawn expressed denial about global warming and a bit of animosity. While somewhat accurate in his post-unit description of the greenhouse effect, Shawn seemed reluctant to offer a genuine comparison of global warming to climate change. He stated, "Global warming: is a theory made up by scientists that greenhouse gases are affecting climate change and is going to heat the world and cause mass destruction in the world. Climate change: is the atmosphere changing weather patterns as time goes on". This deviation from his overall pattern of attitude expression was partially explained during his post-unit interview.

When asked about how his position on global warming may have changed over the course of the unit Shawn expressed that, "well um actually did change a little bit, um my parents don't believe it. But when I saw the facts and uh just go with whatever the scientists are saying and like all the proven facts about it and like base it on my own conclusion….yeah". He said that the value for him in learning about climate change in school was that, "it gives you your own perspective on it instead of actually listening to your parents". From his interview responses, Shawn seemed to be returning to a belief open to global warming. To conclude his interview, he was probed on his conflicting post-unit responses.

Parental viewpoint seemed to have influenced Shawn to some degree. However, peers may have played a stronger role for him. When asked about his break in position during the post-assessment. He said, "I was iffy during that time, I mean I…" Based on his previous replies, during the interview he was asked if he was "getting pressure from home". He responded that, "Uh peers most of the time….peer pressure, that's what yeah most people get their opinion on, families and peers I mean". He acknowledged knowing that someone would be asking him about it later. The influence of peers added an interesting dimension to the exploration of student attitudes and beliefs on global warming and climate change.

Dawson. Dawson was very outspoken, never hesitating to add his opinion to classroom discussion. These opinions however were not backed up by reasoning or supported by evidence. Dawson usually worked hard in class and followed through on assignments. His work efforts resulted in slightly better than average grades, but his understanding of concepts hindered a high GPA in science. He made it clear early in the school year that he was not very interested in biology, evidenced by responses to a survey used by the teacher to get to know students.

Pre-post assessment measures showed that Dawson started out the unit several points below average. However, he finished with an above average score. He revealed very limited conceptual understanding about the climate change early on, but did draw some general conceptual propositions about how global warming and climate change are connected. His initial concept map said that energy was, “used by humans for technology to make machines that cause global warming which leads to climate change”. His conceptual growth was not noticed immediately due to the strong nature of his attitude expressions.

Dawson seemed more interested in expressing a continued attitude of denial, rather than articulating his conceptions about global warming and climate change. On the pre-assessment measure, he often avoided answer choices that could reveal conceptual understanding in favor of replies that denied global warming was occurring. For the open-ended question asking him to discuss the relationship between global warming and climate change Dawson replied, “Global warming isn’t real so therefore cannot be compared”.

By the unit’s end Dawson lost the tendency to declare his denial so fully. His post-assessment measure showed him offering answer choices that revealed his recognition of correct conception, rather than those that deny global warming. He also decided to answer the open-ended responses in a way that revealed conceptual understanding, rather than deny or avoid giving a response like he did on the pre-assessment. Point values associated with the post-assessment may have influenced this change of attitude expressed.

Amelia. Amelia was bright but not motivated to achieve in science class. She had poor follow-through with classroom work assignments and projects, which sometimes hindered her grades on summative assessments. She did ask questions during lecture discussion, at times challenging what was being taught. She had the ability to articulate her thinking on paper, but it was questionable whether or not she would choose to offer those ideas. Her lack of work follow-through and offering of ideas made her a poor candidate for qualitative data analysis. However, she had an anomalous trend in attitude in need of exploration and she volunteered to share her ideas during a post-unit interview.

Amelia began and finished the unit above average from her peers on pre and post assessment measures. From the start, she was very well informed about global warming and could articulate a strong conceptual understanding. She initially expressed a belief that global warming was a result of human activity and she was somewhat worried. Somewhere along the way, Amelia seemed to become disenchanted with learning about and discussing global warming and climate change.

During the mid-unit survey she concluded that learning about climate change had no value, "because there is nothing we can do about climate change". She deemed it as a, "natural cycle" and that, "humans aren't causing the global warm-up, we are coming out of an ice age". Her willingness to articulate her conceptions on open-ended questions was withdrawn as the unit progressed. She did reiterate the idea of climate change being a natural phenomenon several times. It seemed as though Amelia may not have fully processed the connection between global warming (attributed to humans) and climate change (viewed as natural) at first.

During her post-assessment, Amelia repeatedly chose answer selections denying global warming. She claimed to not believe in global warming and when asked about its cause she selected, “none of the above because global warming isn’t happening”. She also expressed a belief that most scientists think global warming is not happening. Amelia shifted from being somewhat worried about global warming to “not at all worried” to conclude the unit.

Amelia’s interview fell short of clearly explaining why she began denying global warming. Most confusing was her response to the question about changes in her views on global warming. She said, “umm, I don’t think my position changed, it opened up to more of a like understanding as to.. the a-why people think global warming is happening but I don’t think my views changed on the fact”.

During the interview it was pointed out that her position seemed to have changed, using her own words to point this out. In that moment, she struggled to reply coherently. Amelia replied, “well I don’t think I, because when I, when we first entered the unit I didn’t really understand the concept of global warming”. Strangely, her pre-assessment and subsequent assessments suggest she does have a solid general understanding of what global warming is and what causes it. She continued the interview to say, “I don’t think that we’ve really, my personal opinion is that we haven’t been around long enough make that big of a difference based on how hold the earth is”. Amelia did not believe her position had changed, and there is no clear explanation for her pre and post assessment discrepancies.

Jake. Jake was a bright student who knew he was, and could often come across as a know-it-all. He thought about things in great detail. His classroom behavior and demeanor fluctuated depending on whether or not he had a receptive audience. At times he seemed to verbally grandstand, to show how smart he was to others. Other times he displayed an antagonistic “outsmart-the-teacher” persona. In a one on one setting, he talked collegially in a “people-pleasing” manner, coming across as united with his teacher in mind and spirit. Jake also vocalized his displeasure in writing when he disagreed with classroom decisions, evidenced by his journal response stating that global climate change was not a topic well placed in the biology curriculum.

Jake’s skepticism decreased over the course of the unit. Pre-unit, he claimed not to believe in global warming and would not choose a cause because, “global warming is not happening”. As the unit concluded Jake claimed he didn’t know if global warming was occurring, and that its main cause was likely both human and natural processes. When considering the scientific viewpoint, he went from believing there was a lot of disagreement among scientists about whether global warming was occurring to selecting the answer option, “don’t know enough to say”. What became clear while analyzing Jake’s work and ideas were three things; he had very strong conceptual understanding about global warming and climate change relative to his peers, his expressed frustration was not against the topic in principle, and he had a hard time believing that climate change is more than a natural cycle.

Jake had the second highest starting score on the pre-assessment and the second highest post-assessment score in the study group. On an open-ended pre-assessment item he described the relationship between humans and global warming as he stated that, "global warming is created mostly by humans and overly large amounts of certain gases that cause the greenhouse effect". This contradicts other responses on his pre-assessment attitude survey. Although Jake grew conceptually in his understanding more than most in his peer group, he did not waiver from his views on climate change. For him, "climate change is the earth warming or cooling naturally due to either seasons or ice age cycles". This belief seemed to make it difficult for Jake to extinguish his skepticism.

Cross-Case Analysis

While seeking the unique ideas contributed by each member of the purposeful sample, it became evident that there were some emergent cross-cutting themes that transcended the attitude categories students were placed in. Each student's set of artifacts was analyzed again, reviewing the codes expressed by each, looking for themes all these students had in common both conceptually and by attitude. Table 5.2 outlines ten cross-cutting themes by students, revealing five related to student conceptions and five related to student attitudes or beliefs. Each of these themes is discussed in detail in the following section. Figure 5.1 distinguishes themes by type and relative frequency.

Table 5.2

Emergent Themes Shared by Students Across Attitude Categories.

	Theme	Jake	Dawson	Amelia	Darren	Eli	Shawn	Maria	Tyler
Conceptual	False Links	X		X	X	X	X	X	X
	Energy Elusion	X	X		X	X	X	X	X
	Natural Cycle	X	X	X	X	X	X	X	X
	Discord	X	X	X	X	X	X	X	X
	Pruning	X	X	X	X	X	X	X	X
Attitudinal	Conflicted	X	X	X	X	X	X		X
	Social Pressures		X			X	X		
	Money Matters	X	X		X	X	X	X	
	Overstated	X	X	X	X	X	X	X	X
	Action	X	X		X	X	X	X	X

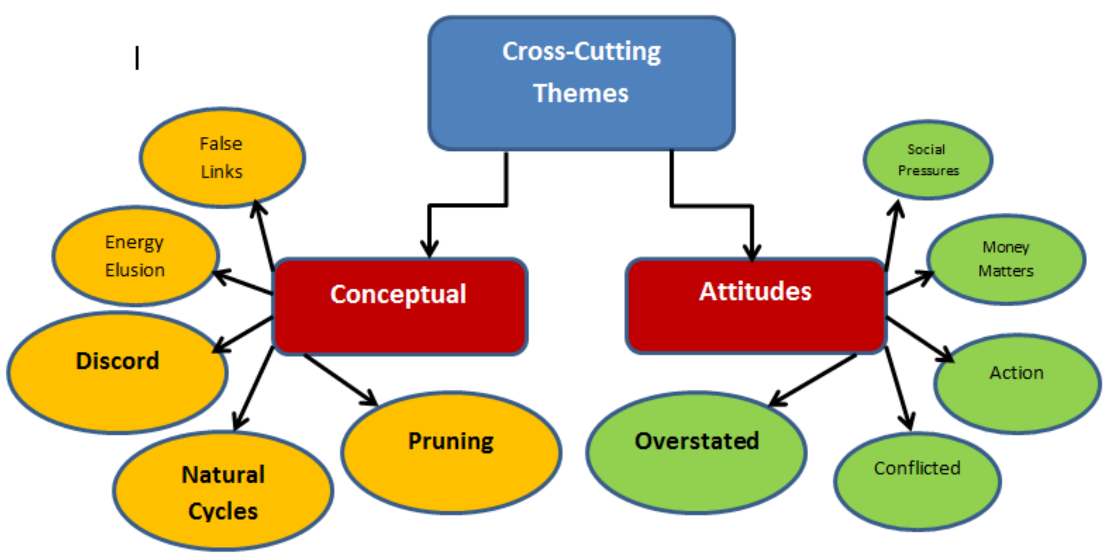


Figure 5.1. Relative theme frequencies across purposeful sample.

Conceptual Themes. Of the five conceptual themes that emerged from student data, one of these is a general theme that could apply to other learning situations. The other four are topic specific to the global climate change teaching unit. The general theme is called pruning. The four climate change-specific conceptual themes are: False Links, Energy Elusion, Natural Cycles, and Discord.

Pruning. Pruning describes the conceptual regression noticed in each of the student's interview transcripts. The conceptual trend during the unit had been of growth and refinement of ideas, developing greater detail and nuanced understanding. Following the post-unit assessment there was approximately a three month gap before the post-unit interviews. Each student regressed in their conceptual understanding, as though the details they previously articulated had been pruned away leaving a more vague general conceptual understanding.

Pruning is best illustrated by comparing student descriptions of the greenhouse effect. During the post-assessment, students responded to an open ended question asking them to explain how the greenhouse effect works. During a post-unit interview, students were asked to explain how the greenhouse effect and global warming were related to one another. Table 5.3 illustrates comparative descriptions students used in responding to the questions. Looking at each student's responses you can see a decline in detailed language used to articulate understanding, moving from post-assessment responses to interview responses over three months later.

Table 5.3

Theme of Pruning Evidenced in Student Explanations about the Greenhouse Effect

Student	Post-Unit Assessment	Interview Response 3 Months Later
Eli	"the greenhouse effect starts with the sun and transfers heat to the Earth through short wave lengths……heat wavelengths then leave the Earth as long wavelengths"	"the greenhouse effect is basically just there is the earth, uh the earth receives sunlight and the earth would then warm and create with photosynthesis it would make like plants and stuff like that"
Darren	"how the earth stays habitable....there are a lot of greenhouse gases that are able to trap in heat….light-short wavelengths are able to flow through these gases very easily….then transferred into heat energy into heat energy- long wavelengths…..aren't able to escape as easily….earth...stays heated"	"whenever the greenhouse effect occurs this potentially leads to global warming because it just adds more emissions in the atmosphere and then the heat gets trapped in….from pollutants we create, like from cars and things like that….they just get trapped in like a blanket"
Tyler	"gases such as carbon dioxide, methane, and water vapor work by trapping the sun's short wavelength energy shone on the Earth and transferring it to heat…heat is slowly given off in long wavelengths gradually over a long period of time….creating the greenhouse effect"	"the greenhouse effect is basically uh the gases that are in our atmosphere that uh, help trap heat….water vapor, carbon dioxide….they trap the sun's rays and let 'em out slowly"
Maria	"heat trapping gases enter our atmosphere and as the sun's heat is warming the earth, the gases trap in the heat, allowing only small amounts to escape, causing an increase in temperature in certain areas"	"isn't the greenhouse effect where um, all the heat that comes from the sun comes in and bounces off but only so much of it gets back out 'cause it comes back down 'cause of clouds and such"
Shawn	"first the sun directs sunlight into the atmosphere to heat our planet to be habitable, but if there's too many greenhouse gases in the atmosphere more the more the heat won't be releases, leading to an increase in temperature"	"the greenhouse gases I guess are like CO2 and like other mixtures and they go up into the atmosphere and they cause global warming which is pretty much like a blanket on the atmosphere making earth a lot warmer"

Dawson	"sun sends to earth energy in the form of light. This energy is then transformed into short wavelengths. Once it reaches earth it then turns into heat, and if so, the energy wants to leave it is in long wavelengths because the atmosphere has a lot of carbon dioxide molecules"	"the greenhouse effect can kind of cause global warming because it keeps the gases in the at-atmosphere creating um the earth to warm up….um carbon dioxide"
Amelia	"the sun's rays come through the earth's atmosphere and are either absorbed by the earth or are reflected by albedo. When the sun's rays come into….they are short light wavelengths……when they try to leave as heat waves…they are much longer, making it harder for them to escape"	"the greenhouse effect is like when the sun's rays come in through our atmosphere and…they….and some heat gets trapped but some goes out of the atmosphere, the long and short rays"
Jake	"Heat comes into earth's atmosphere from the sun as light. It has a higher wavelength so most of it makes it into the atmosphere. Some is bounced back out into space. Typically these light waves make it down to the surface of the earth and are absorbed....these wavelengths....turn into heat which has a lower wavelength....only some of the heat can get back into space....process is what makes our earth warm enough to sustain life"	"the greenhouse effect is various gases in the atmosphere that trap in the sun's heat in ways that it is not supposed to….typically the sun's rays would leave the atmosphere, but what we're seeing with the greenhouse effect is they're actually staying in our atmosphere"

Natural cycles. Natural Cycles is another theme that cut across all eight student profiles. This theme describes the way students conceptualize climate change. For them, climate change is a natural phenomenon that can be understood in two different ways. One way is to recall Earth's past ice ages and how glaciers advanced from the North Pole and receded several times, well before humans existed. The other is to describe changing climate in seasonal terms; spring transitioning into summer, summer changing over to fall, and so on. With two valid conceptions of what climate change could mean, it is no wonder students find it difficult to conceptualize climate change in connection to human impacts.

Even more knowledgeable students like Jake struggled to see climate change as more than part of a natural cycle. On his post-assessment Jake described climate change as, "something that happens naturally over time….the earth is constantly moving back and forth between being hot and cold". Eli described the disagreement among scientists during his interview. He contended that, "some people would have a valid argument that is could just be (a) natural process….the dinosaurs of course went away…..had to do with climate change…like it's true there were ice ages". In his post-unit journal entry Tyler described climate change saying it, "is a natural occurrence on our big blue orb that had brought us from the dinosaurs to the big freeze- twice- and back to more stable conditions that we have come to know today". In her post-assessment Amelia professed that, "climate change is how the climate changes from year to year". She initially described climate change during pre-assessment as, "…natural. The earth's climate has been changing for millions of years". Students' preconceived ideas about climate change as a natural cycle seem to hinder their embracing of human-caused climate change even when they may accept a human cause to global warming.

Discord. The theme of Discord was shared by all eight student cases, and expressed at some level throughout the unit. Discord refers to the conception that there is ongoing disagreement about global warming and climate change. Often this disagreement was about whether or not global warming and climate change are actually occurring. For others, the disagreement was whether or not the change that is occurring is natural or human caused. Discord typically was placed in the context of the scientific community, but some students expanded the idea to include the larger society.

Different degrees of Discord were expressed by students. Maria reshaped her initial conception that there is a lot of disagreement among scientists about whether or not global warming and climate change is occurring. She understood and expressed the scientific consensus viewpoint, yet still recognized that the larger society was conflicted. In her open ended response she hinted at this while stating that, “if global warming is true (some think that it is false), if we continue on our current path, we can assume that the earth will continue to get warmer”.

Even as they came to believe global warming is occurring, both Eli and Darren still contended that there was disagreement among scientists about whether or not global warming is happening. This was evidenced on their pre and post assessment responses, as well as in their interview transcript. Eli saw the disagreement being about climate change being natural or human caused. When asked about a consensus he said, “I don’t think so….it could just be a natural process….then of course other scientists would blame uh humans of course”. Darren on the other hand suggested that scientists do not even agree on whether or not climate change is happening. When questioned about a consensus he replied, “uh scientists, many of ‘em do not come up with an agreement because it’s pretty split, some say it is happening, some think that it’s not”.

Even when a scientific consensus is understood, Discord was still recognized. Jake shifted his thinking to recognize the scientific consensus that climate change is occurring and mainly caused by human activities. However, during his interview, he did not quite let go of the idea that the issue is controversial. Jake said, “There are some scientists that believe, some very loud scientists that like to say that it’s not true and they point out all the other things, however there is a, there is a consensus that says global warming is happening”. With a media that sensationalizes controversy, it is no wonder students continue to conceptualize climate change as such.

Energy Elusion. Energy Elusion is a theme stemming from a lack of common clarity shared by students surrounding the concept of energy. Energy was one of the most difficult things for students to conceptualize correctly. A clear understanding of what energy is, its various forms, its transfer, and laws governing it seem to elude most students. Nearly every student expressed some sort of misconception when describing or discussing energy. Considering the key role energy plays in Earth’s complex climate systems, it makes sense that students might struggle to understand climate change if they cannot accurately conceptualize energy.

A variety of misconceptions were revealed by Eli, Darren, and Maria. For example, Eli described the relationship between the greenhouse effect and global warming during his interview. He said that, “pollutants trap warm gases inside the earth’s atmosphere and then cause the earth to eventually get warmer”. Darren described the greenhouse effect as a necessary thing but for the wrong reason stating that, “the greenhouse effect is actually good because you need it to uh protect us from the sun”. Maria wrestled with the concept of energy transfer from light to heat, trying to explain in terms of wavelengths. Her mid-unit quiz response revealed the elusive nature of an accurate conception of energy. She wrote, “The energy that enters earth’s atmosphere is in the form of heat from the sun, it enters in great amounts (long wavelengths?) and less leaves because of greenhouse gases (leaves in short wavelengths?)".

False Links. Students regularly discussed global warming and climate change while incorrectly linking these concepts to unrelated environmental issues. One of the most common False Links involved students seeing the ozone layer as related to global warming. Other falsely linked environmental issues included; littering, water pollution, acid rain, and toxic waste. In some cases students shared very strong conceptual links, while other times only a weak connection was described.

Maria articulated a strong understanding of the human role in current global warming and climate change, but incorrectly linked this to the ozone layer. On her initial concept map she chose to add the concept of the "ozone layer" linking it to the greenhouse effect by writing, "where the greenhouse effect is taking place". One of Maria's open-ended responses to start the unit suggested that, "the carbon dioxide that is emitted enters our atmosphere, it is depleting our ozone layer". Another concept she added to her map was littering describing that, "if everyone would stop littering and pick up garbage, it would help the problem (of global warming)".

Like Maria, Tyler also added the concept of the "ozone layer" to his pre-unit concept map, suggesting that humans puncture it. During his pre-assessment Tyler stated that, "as we spew more greenhouse gases into the atmosphere, the temperatures are going to rise. Also, as these gases continue to increases, our ozone layer will weaken and the sun's rays will get stronger, increasing heat on Earth even more".

Eli's pre-assessment responses suggested that the greenhouse effect referred to Earth's ozone layer, and that reduction of toxic waste was the number one way for us to reduce global warming. He even mapped out a connection between the greenhouse effect and climate change which suggested that it was due to the, "ozone layer melting". During his interview he also linked climate change to acid rain saying that, "there was the uh acid rain also from the CO_2 emissions being trapped".

For many students like Maria, Tyler, and Eli, environmental issues are conceptually connected incorrectly, especially before instruction. As students grew in their understanding, they seemed to reduce False Links to climate change concepts. For example, Maria, Tyler, and Eli all eliminated expressions of the ozone layer when discussing climate change post-unit.

Attitude Themes. There were five attitude related themes found within the student profiles, spanning the sample across student attitude categories (see Table 5.2). One general theme that encompassed all eight profiles was "Overstated". Two were shared by seven of eight students: "Action" and "Conflicted". Six students expressed a theme called "Money Matters". Social Pressures was the final theme represented by only three of the profiled students, one from each attitude category.

Overstated. While expressing beliefs about the future and predicted consequences of global warming and climate change, students tended to exaggerate consequences beyond what scientists actually predict. From this tendency the Overstated theme emerged as students predicted a variety of consequences from climate change. Ideas ranged from impacts on society, to animals, and even whole ecosystems.

The Overstated theme was most often expressed in students' predictive essay assignment. Dawson, self-proclaimed denier of global warming, said, "if humans keep producing CO_2 then most of these wonders (animals) will soon leave or go extinct". Jake predicted that, "our famous Minnesota winters could become nothing more than an extended fall where animals die without food, and businesses plunder". Darren worried that his love for fishing would be affected predicting that changes in MN's evaporation may result in lakes and ponds drying up leaving, "no water holes for me to hit up". He also predicted more forest fires and, "if a fire started, and there would be no water to put it out, it would just continue on and take out the whole forest".

Conflicted. The Conflicted theme was demonstrated as students expressed ideas that were not consistent or congruent with one another while expressing attitudes and beliefs about global warming and climate change. This theme was often demonstrated as students showed a questioning of their own denial climate change. Others illustrated this by doubting their own acceptance of global warming and climate change. In either case, self-doubt of personal beliefs emerged. This comparative theme is illustrated in the student ideas outlined in Table 5.4 below. It illustrates conflicting beliefs expressed by three case study students from two points in time.

Table 5.4

Evidence of Conflicted Theme from Student Artifacts

Student	Idea Expression 1	Idea Expression 2
Amelia	"Global warming is the production of humans. It's un-natural, we emit so much gas into the atmosphere that the gases can't get out before more gases are coming in. Global warming is the rising heat resulting in climate change for a lot of regions"	"Humans aren't causing the global warm up. We are coming out of an ice age"
Shawn	"Global warming is when the atmosphere gets polluted and the pollutants get hit by the sun's rays and makes everything warmer"	"Global warming: Is a theory made up by scientists that greenhouse gases are affecting climate change and is going to cause mass destruction in the world"
Dawson	"Global warming isn't real so therefore cannot be compared (to CC)" and "neither of these effects are happening"	"what I'm struggling with is if people know global warming is happening why doesn't the US create cars that have 70+ MPG like Europe does…the only thing stopping us is money" and "why aren't changes being made faster"

Action. Nearly all students expressed beliefs that something needs to be done, even if they denied that global warming and climate change exist. There was a sense of shared responsibility toward the natural world and one another, including future generations. From these expressions the theme of Action emerged. In some cases this theme aligned with Conflicted.

Dawson suggested that for a solution to be achieved people should, “burn less fossil fuels”. He doesn’t want to lose snowy MN winters and thinks we should, “see if what you do regularly can be changed to decrease CO_2 emissions”. Ironically, he fails to see his own regular winter hobby of snowmobiling as being a contributor of carbon dioxide emissions.

Other calls to action were suggested. Jake believed that, “if we can prove that global warming has an entirely human cause…..it will help us make informed decisions about how to minimize greenhouse gas use”. During his interview he discussed the value in learning about CC stating that, “if more people know about it’s, obviously more people are going to be aware and try to prevent it and I guess it creates a better world for everyone”.

For Maria learning about climate change also had value. She stated that, “it helps me make a smarter decision on how I’m gonna make like a change in it and how I’m gonna try I guess like help it you know”. During her mid-unit survey she declared a desire to, “learn more about what we can do in our everyday lives to reduce…CO_2 entering the atmosphere”. From skeptic to believer there seemed to be an underlying attitude of stewardship in students, calling them to action to improve the state of the world in which they live.

Money Matters. Money Matters was a theme stemming from the belief that the economic ramifications must be considered when thinking about and responding to global warming and climate change. For some, the economic losses predicted from social inaction should motivate people to demand change. Counter to that, an argument was made for considering the economic losses resulting from drastic changes to energy policy. From either side of the issue, a case could be made appealing to human fiscal concerns.

Economic impacts of climate change were expressed on a personal, state, and global level. Maria personalized the issue when describing her family's farm. She said, "we run a dairy farm, and we grow and buy crops to feed the cattle. It would heavily affect our crops because of the droughts and flooding. Other farmers….could lose their crops, and overall their living". Jake also mentioned the state's farm economy stating that, "Minnesota ranks among the top states in corn, soybean, sugar beet, and wheat production. Extra heat causes these plants to die in droughts, and our nation feels the effects of these losses".

Eli also mentioned economic losses to MN based on a changing climate. However, he seemed more concerned with the economic impacts of making drastic changes to mitigate the effects of climate change. During his post unit interview he stated that, "I don't think we should pay with it with like tax dollars just because we're in such like a major economic crisis". He was concerned that many people would lose their jobs when he said, "you it's a touchy subject because people get offended because you know, people, that's their job…you know in North Dakota there's a lot of people depending on this oil thing, this oil boom, um and you know you can't tell them that they, you know gotta stop". So, economic factors did get student consideration, whether it related to consequences of human inaction on climate change or the mitigation strategies to be employed.

Social Pressures. The final, least prominent, attitude theme was Social Pressures. This came from students expressing beliefs about the topic without prompting, or during post-unit interviews where they were asked to elaborate on their beliefs or explain them.

Early in the unit, political pressures were expressed, but disappeared in student data by the unit's conclusion. Parental influence was described or revealed by a three students. Peer pressure was used to explain inconsistent belief expressions by another student. One can assume that all three of these social pressures were at work on some level for these students, even if they were not aware enough to express it.

Both Jake and Eli chose to add political figures to their pre-unit concept maps, suggesting political pressures underlying the topic of global climate change. However, as politicized as the topic of climate change is very few students talked about it in political terms. These two concept maps were unusual compared to their peers, and both students dropped the political references during the post-assessment map.

Eli revealed the idea of parental influence on students during his post-unit interview. It happened as he was talking about the value of learning about climate change. Eli wrote, "I was always sorta brought up on the side that global warming is just kind of a hoax". When the unit concluded and Eli acknowledged a belief that global warming was happening, he argued that it may be a natural cycle rather than caused by humans. His continued resistance to the science of global warming may be a result of his upbringing. He suggested this during his interview stating, "I was always just sorta brought up on the side that global warming is just kind of a hoax".

Shawn also shed light on the idea of parental pressure, but expanded on that to include peers as well. During his interview he acknowledged that his position changed on global warming. He said, "actually did change a little bit, um my parents don't believe it. But then I saw the facts and uh I just go with whatever the scientists are saying”. While describing the value of learning about climate change in class he said, “it gives you your own perspective on it instead of actually listening to your parents”. Shawn seemed to appreciate learning about a perspective other than what he had heard at home.

To conclude Shawn’s interview, he was questioned about his changed belief about global warming that emerged from his open-ended post-assessment. His response revealed an ambivalence that occurred while completing the assessment. He stated, “I was iffy during that time, I mean I”. It was suggested that he was getting pressure from home but in rebuttal he said, “uh peers most of the time…..peer pressure, that’s what yeah most people get their opinion on, families and peers I mean”. Shawn struggled to develop a viewpoint beyond what his parents offered only to buckle under the pressure of his friends.

Summary

Limitations. Deeper qualitative analyses of eight purposefully selected students, including follow-up interview transcripts, suggest possible limitations to whole-group analysis student artifacts alone in chapter IV. A case could be argued that some students were mislabeled. For example, Jake was categorized as a skeptic yet his interview transcript suggested he might be more of an open-skeptic. When asked about global warming during his interview he stated that, “there is a consensus among the scientific community….I believe in global warming….I’m wondering if there are any other things….if there’s something else that’s happening naturally because of this, not because of us that’s also contributing to global warming”. Eli also may be mislabeled. His interview transcript stated that, “as much as uh you know I don’t agree with it (global warming), and a lot of people don’t agree, that everybody should be informed about this stuff. Student artifacts and survey data may not be enough to accurately categorize students by attitude.

The usefulness of interview data for better understanding student attitude inconsistencies was evidenced by Shawn, but could not explain those expressed by Amelia. Shawn explained his inconsistent assessment responses in the context of peer pressure. However, Amelia did not articulate an explanation for her inconsistencies of attitude expression through her interview. Interviews revealed depth of student understanding and personal beliefs that artifacts alone could not, yet they too were limited by students’ ability or willingness to articulate a comprehensive response.

Insights. The data revealed insight from each student profiled. These were primarily conceptual, attitude-based, or some combination of both. Each offered a unique clarity toward better understanding of how students understand global climate change and the attitudes associated with that understanding.

Both Jake and Dawson were skeptics, doubtful to some degree about global warming and climate change. Jake revealed that a student can have very strong conceptual understanding of a topic and still remain skeptical about it being real. Dawson’s lower than average pre-assessment score and subsequent growth in content understanding suggested that skepticism does not pose a barrier for learning.

For some students, beliefs are difficult to let go of despite multitudes of evidence to dispute them. Eli revealed that some student attitudes have economic and political roots, unlikely to change. Shawn illustrated the influence peers and parents have on the attitudes and beliefs students express. Darren on the other hand suggested that students can change their beliefs in light of evidence. Amelia's interview made it clear that understanding student attitudes and beliefs is limited by students' willingness or ability to express them.

For some students, being open to an idea and believing in it may be enough to promote change. While others' openness may be constrained by the ability to let go of prior beliefs. Maria revealed that even without accurate conceptual understanding of climate change concepts, she could still believe in it and the need for action to mitigate it. She declared a desire to, "learn more about what we can do in our everyday lives to reduce…CO_2 entering the atmosphere". Tyler also believed that humans were causing global warming illustrated by his statement that, "as we spew more greenhouse gases into the atmosphere, the temperatures are going to rise". However, he could not reconcile that belief with his consistent belief that climate change was a natural process. As such, Tyler did not express strong beliefs about a need for societal response to climate change but simply described that learning about climate change in biology was, "a good life lesson".

Themes. Cross-profile analysis of data revealed several themes shared by nearly all students. Some of these were conceptual themes, while others were attitude-based. One theme related generally to students' expression of concepts, while the rest were more specific to concept or attitude.

All eight students conceptualized climate change as natural, either by reference to past Ice Ages or as climate changes seasonally. Each one also contended that the science was not settled on climate change, and that disagreement continued among scientists. While growing significantly in their content knowledge, all students displayed Pruning during their interview. Each interview revealed a post-unit a decline in understanding of global climate change concepts.

Though not evidenced by all eight, most students did express the conceptual themes of Energy Elusion and False Links. Most students struggled to articulate a clear conception of energy throughout the unit. Nearly all students tended to incorrectly associate global climate change with unrelated environmental issues. However, these misconceptions were often extinguished by the unit's conclusion.

Three attitude-based themes were common to nearly all profiled students. All eight evidenced the Overstated theme, often exaggerating the evidence used to support global warming and climate change or the predicted outcomes expected if humans fail to reduce greenhouse gas emissions. Most students expressed the theme of Conflicted, where some expressions of their attitudes or beliefs were inconsistent with others. Finally, most students contended that something needed to be done in response to global warming and climate change. However, there was not agreement on what that something ought to be.

Chapter VI: Discussion

This study was guided by the following three research questions:

1. To what extent and in what ways do students' conceptions change in association with an 8-week inquiry-based unit on climate change?
2. In what ways do student attitudes change in association with an 8-week inquiry-based unit on climate change?
3. How does growth in content knowledge and conceptual understanding correspond with attitudes about climate change?

In this chapter, each of the research questions is answered and summarized using the findings of each of the three phases of analysis for this study: 1. Quantitative analysis of student surveys and assessments, 2. Qualitative analysis of student surveys, assessments and classroom artifacts, and 3. the eight student cases. Second, a number of study limitations are discussed. Finally, implications for teachers, researchers, and future research are presented.

Results Summary

Question 1. Students' content knowledge increased significantly over the course of the eight-week inquiry-based global climate change unit, based on pre-post assessment scores. Statistically significant growth on other teens' content knowledge using an inquiry-based teaching approach was also evidenced by Kanter & Konstantopoulos (2010), exploring the concept of energy as it relates to food. Traditional textbook-based approaches can also lead to significant knowledge gains according to Heddy & Sinatra (2013) while studying student conceptions of evolution. This study's quantitative evidence supporting growth in conceptual understanding was also supported by the qualitative analysis of classroom artifacts and surveys.

Qualitative analysis revealed that conceptual understanding shifted toward a more scientifically accurate conception over the course of the global climate change unit. However, very few students moved beyond a "partial conception" of the greenhouse effect, global warming, or climate change. Misconceptions about these global climate change concepts persisted; including the belief that energy from the sun hits the earth as heat which bounces off the earth to then do the same off clouds preventing its escape, or that pollutants trap warm gases which causes earth to get warmer. However, students tended to use more specific examples and evidence to explain their ideas on open-ended questions. For example, some students talked about differences in wavelengths entering the atmosphere and leaving as part of the greenhouse effect, but didn't always get the correct directionality of the exchange or thought of wavelengths as material. Though still incomplete in understanding, student conceptions evolved in the direction of a more detailed and scientifically accurate view. Rye & Rubba (1998) also describe student conceptual growth in understanding the greenhouse effect, but acknowledge continued ozone related misconceptions post-instruction.

Cross-cutting themes from the student cases also reflected past research findings, related to the concept of energy and the false connections students made between global climate change and other environmental issues. Students also overstated the evidence for and predicted consequences of climate change. This fits evidence stating that twenty percent of American teens over-estimated scientific predictions of sea level rise (Leiserowitz et al., 2011).

Though not evidenced by all eight, seven students struggled to articulate a clear conception of energy throughout the unit. Misunderstanding this very basic concept may be a barrier to understanding the more complex idea of climate. It is not unusual for students to have misconceptions about energy. Some common energy misconceptions are: that it is only associated with animate objects, that it is a causal agent stored in objects, that energy is fuel, that it is a tangible object, or that energy is lost rather than conserved (Driver et al., 1994). The struggle of students in this study with such a basic scientific concept supports similar findings by Koulaidis & Christidou (1999).

Seven students incorrectly associated global climate change with unrelated environmental issues. Some of these false links include; the ozone layer, littering, water pollution, and toxic waste. These false links to global climate change flood the literature. The most common of these was a connection to the ozone layer (Andersson & Wallin, 2000; Gowda et al., 1999; Hestness et al., 2011; Leiserowitz et al., 2011; Liu et al., 2015). While not absent in all student data post-unit, the ozone misconception was not apparent in these eight students' data by the unit's conclusion. Learning about global climate change seemed to reduce the frequency of some expressed misconceptions.

All profiled students exaggerated the situation when describing the current state of evidence supporting climate change and the predicted consequences of societal inaction toward mitigating the problem. One example described Minnesota's winter as being nothing more than an extended fall. Another showed concern that warmer temperatures would dry up all the fishing holes and forest fires would not be stopped because there would be no water left to fight them. This overstating trend seems to be similar to findings by Gowda et al. (1997), where students regularly inflated estimates of temperature.

All eight cases described climate change as a natural cycle across several data contexts. They described it in open-ended pre and post-assessment items, post-unit journal responses and post-unit interviews. They described climate change in context of Earth's Ice Ages or as seasons changes annually. Conceptualizing climate change in a way that deems it natural may be easier for students to embrace. This description of climate change was not clearly evidenced in the literature.

As earlier data suggested, all eight students demonstrated growth in their conceptual understanding about global climate change through post-unit open-ended assessment items and post-unit interviews. However, one trend emerged during interview transcript analysis. While growing significantly in their content knowledge, all students revealed a post-unit decline in their understanding of global climate change concepts three months following the unit. While still ahead of where they were pre-instruction, students' conceptual understanding was less robust and detailed three months following instruction. This suggests that students' conceptual change may have been a temporary phenomenon. Arzi, Ben-Zvi, & Ganiel (1986) quantified this phenomenon studying teen students' (ages 13-16) chemistry knowledge over a three year period. They discovered that even though students failed to retain much of what they learned previously, it had a significant impact on efforts to relearn related concepts in the future.

This is not surprising considering the much earlier work done by David Ausubel (1962) in educational psychology describing how learned material is forgotten.

Question 2. Students' attitudes about global climate change changed over the course of the teaching unit. Initially, 62.2% of participating students believed global warming was happening. This was higher than those teens studied by Leiserowitz et al. (2011), where 54% of teens believed global warming was happening. In fact teens in this study believing that global warming is occurring more closely resembles the percentage of adults believing the same (Leiserowitz et al., 2011). By unit's end, over 86% of students professed to believe that global warming was happening. Nearly a quarter of students changed their mind about whether or not global warming was happening. Therefore, learning about global climate change may have potential to shift attitudes or beliefs about it. Interestingly, one belief did not change on average over the course of the teaching unit, despite explicit teaching to the contrary. Only 32.2% of students acknowledged that humans are the main cause of global warming pre and post-unit. Despite instruction, students seemed to maintain the belief that global warming is attributable to natural causes. This falls well below teens studied previously, where 57% believed humans were the main cause of global warming (Leiserowitz et al., 2011).

The media often portrays the science of global climate change as being very tentative, yet within the scientific community there is a nearly unanimous consensus (Oreskes, 2004), including many online sources. This may explain some of the findings of this study, considering that the number one source students say they would turn to well above any other was the internet (Leiserowitz et al, 2011). Prior to the climate change unit, just over twenty-three percent of students believed there was a scientific consensus. Students (60%) tended to see the issue as very contentious, more often believing that there is a lot of disagreement among scientists about whether or not global warming is happening. This is much higher than findings of Leiserowitz et al. (2011), where they determined that 31% of American teens believed there is a lot of disagreement among scientists about global warming. Only after instruction did data reflect a similar attitude about scientific disagreement (35%).

Despite instruction, only 57.8% of students acknowledged belief in a scientific consensus following the unit. This is substantial growth from the initial twenty-three percent. Teens in this study started well below Leiserowitz et al. (2011) teens, but grew beyond their 35% belief in a scientific consensus by unit's end.

Prior to the unit, students did not express a great deal of worry about the topic of global warming, with less than a third expressing that they felt somewhat worried about it. This is a little lower than other American teens studied where 43% expressed feelings of being at least somewhat worried about global warming (Leiserowitz et al., 2011). As might be expected, the amount of worry increased over the unit teaching about the impacts of global warming. Following instruction, 63.3% of students acknowledged such feelings, over a thirty percent increase from the unit's onset. Despite learning about many solution options to help reduce global warming and climate change, mid-unit and post-unit data reflected a potential attitude barrier. Students often expressed feelings of lacking power to enact meaningful change on such a global issue. This echoed findings from previous interview data that students don't believe they have power to make significant change toward mitigating climate change (Pruneau et al., 2003).

Though not a measured change in this study, mid-unit survey results indicated that nearly eighty-seven percent of students believed that learning about global climate change in school was valuable. That value may be reflected in findings where students overwhelmingly state that they would like to know more about global warming (Leiserowitz et al., 2011), or that global climate change is an important issue to the majority of Americans and one that many feel should be taught (Fortner, 2001; Leiserowitz et al., 2011).

Similar attitude trends were reflected in phase III analysis of eight profiled students. However, data three months after the teaching unit suggested that changes in students' attitudes evidenced on post-assessment may have been temporary. Some shifted beliefs in global warming and its causes were recanted three months later. Most research studies on student attitude changes due to some sort of intervention do not consider long term changes following the intervention, calling into question the longevity of any measurable attitude shifts (Fortus, 2014).

Attitude change trends by student category revealed some differences. A much higher percentage of open students initially believed in a scientific consensus among scientists about global warming than either skeptic or open-skeptic students. Over thirty-five percent of open students began the unit with this belief, while 8.3% of skeptics and 4.2% of open-skeptics initially held this belief.

Belief that the issue of global warming was contentious among the scientific community was another that showed variation across student attitudes categories to start the unit. Over eighty percent of open-skeptic students began the unit thinking there was a lot of disagreement among scientists about whether or not global warming is happening, nearly thirty percent higher than the other two groups. By unit's end the three groups had shifted to within ten percent of one another in this belief.

A higher percentage of open students (40%) attributed global warming to human activity. Open-skeptics and skeptics reported this belief much less often, attributing global warming to human activity only 21% and 17% of the time respectively. As mentioned earlier, this belief on average did not shift over the course of the study.

Nearly all attitude language codes were reflected in data across all three student attitude categories. However their relative abundance differed by group. Skeptics showed a higher percentage of negative language attitude codes and a greater range of codes than open students. Open students had fewer codes expressed, but tended to have a higher percentage of positive expressions.

Question 3. A clear corresponding relationship between students' conceptual understanding and attitudes of global climate change was not found. Students in different attitude categories did not show a statistically significant difference in average global climate change content knowledge scores from pre-post assessment. Student attitude does not seem to be a barrier to these students learning about climate change. This reflected previous research describing the relationship between attitudes and learning as mixed and difficult to determine (Mattern & Schau, 2002; Nieswandt, 2006).

Though not statistically significant, student mean pre-post assessment score data suggested that there may some difference between skeptic students and the other two groups in terms of changes in content knowledge. On average skeptics started lower in their content knowledge and finished slightly below both the open and open-skeptic students. The average growth by category indicated that open students grew slightly less than the other two groups in their content knowledge. Open students began the unit knowing more on average than the other two groups but failed to grow as much in their understanding, with average gains about two points below the others. Skeptics started out lower in pre-assessment measures but on average grew more than their open classmates. A similar trend was found in data from in-service teachers trained in the topic of global climate change (Liu, et al., in press).

There may also be a difference in the kinds of global climate change concepts students struggle with based on their degree of skepticism. Analysis of content knowledge concepts assessed revealed statistically significant differences between students of different attitudes on two concepts: evidence of climate change and Earth's climate history. It seemed that skeptic student had more difficulty dealing with evidence-based questions, before and after the teaching unit. They also had a less robust understanding of Earth's historical climate prior to instruction, but end up with understanding similar to open-skeptic and open students concluding the unit.

Conceptually speaking, all three groups grew in their understanding about the greenhouse effect, global warming, and climate change. Skeptic students showed a higher percentage of students growing into at least a partial conception. Open students showed the least gains compared to skeptic students in their conceptual understanding, especially when looking at the concept of global warming vs. climate change. This trend supports the earlier pre-post assessment scores trend comparing students by attitude category.

Data revealed that students can have very strong conceptual understanding of global climate change and still remain skeptical about its reality. From some lower than average pre-assessment scores and subsequent growth in content understanding, it is suggested that skepticism does not pose a barrier for learning global climate change concepts. Students can have continued misconceptions about climate change concepts yet still believe change in needed to reduce its impact. Still, other students can have strong conceptual understanding and remain skeptical and unworried about climate change. Similar findings were evidenced by Liu et al. (in press) studying attitude and knowledge changes among in-service teachers over the course a professional development program for teaching global climate change in the classroom. These results cast some doubt on the knowledge-deficit model and the potential for conceptual growth and attitude change to lead to meaningful behavioral change (Kraus, 1995; Primack, 1998;Thompson & Mintzes, 2002). It likely requires more than learning about global climate change in the classroom to expect shifts in attitudes and beliefs to enact actionable responses by students.

Limitations

One clear limitation of this study came from the main assessment instrument. The intent was that modeling the study on the survey used by Leiserowitz et al. (2011) would increase instrument validity. However, formatting and time constraints did not allow a full-scale use of their instrument in this study. As such, the redundancy built in to the survey to check for answer consistency was not included in this study's assessment instrument. The survey was not designed to quantify attitude responses. This made quantitative comparison of students' content knowledge and attitudes about global climate change much less robust. It would have been a stronger study with greater comparative ability had is used a different attitude measure instrument and more clearly operationalized the definition of attitude (Fortus, 2014; Mattern & Schau, 2002).

The full extent of students' content knowledge and attitude change from this study's teaching unit were possibly skewed by non-participating students. There were ninety student participants in the study, but more than that took the biology course. Some biology students chose not to participate in the study, leaving a void in data which would have more accurately captured the nature of changes in students over the course of the global climate change unit. Having direct access to all student artifacts, including those not participating in the study, it was evident that a larger pool of skeptics could have been formed. This could have revealed a more accurate perspective of this group's attitudes and conceptual understanding.

The teacher as researcher was another likely study limitation. First, obligations to full time teaching hindered efforts to be responsive to the data as it was being gathered. There was not time immediately after data collection to engage in deep thoughtful analysis amidst the demands of day to day teaching responsibilities. As such, data was analyzed well after collection when it was too late to be responsive and gather more.

Second, students have motivations to share ideas in a way that they believe the teacher wants them shared. They may be worried about what the teacher thinks of their ideas and therefore less authentic in sharing attitudes and beliefs than if the researcher were independent of the teacher.

The teacher-as-researcher also calls into question the authenticity of student responses on pre-post assessment measures. During pre-assessment, students were asked to complete the items to show before and after growth but no point values attributed to course grade were associated with this. This might account for students' lack of completion or sharing of ideas on open-ended assessment items. The post-assessment (content portion) measure was associated with a graded score for class.

The same issue with scoring was evident in student concept maps, only in reverse. Students were asked to complete a concept map before the global climate change unit, but assumed they would get assignment points toward their grade. Later, they found out that points were not tied to the concept maps, which may have reduced student motivation to thoughtfully complete the post-unit concept map. Besides the points factor, timing of the post-unit concept mapping likely reduced its significance for students. This was done a day prior to the much anticipated Holiday break. In fact, one student submitted the identical concept map he had produced during pre-assessment. This was not noticed immediately, again due to the poor responsiveness to generated student data.

Students did not follow through on work completion to the same degree. This resulted in holes in the artifacts collection. This was especially apparent when analyzing data from skeptic students. They had less work completion and submission, making it difficult to capture the essence of this groups' conceptual understanding or compare evenly across attitude groups.

Finally, lack of interviewing experience was a limitation. Review of transcripts made it clear that leading of the interviewee occurred at times. Lack of experience also kept the researcher from being more responsive to student answers. Worry about the recording device functionality, interview questioning and flow, and overall comfort leading the interview kept the researcher from seizing moments to have interviewees expand upon ideas or ask more clarifying questions.

Implications

Global climate change is a scientific topic but also a social issue. What society should do in response to the scientific evidence is heavily debated in the media, making this socio-scientific topic controversial. Teachers often avoid or shy away from teaching students about topics deemed controversial. Belief that global warming is controversial was evident throughout this study. The key message for teachers is the importance that learning about climate change has for students. Over eighty-six percent of students in this study expressed the belief that learning about global climate change in school held value for them. Teens want to learn about this topic (Leiserowitz et al., 2011). Therefore, teachers should feel empowered to educate students about global climate change. Students also tend to believe in shared responsibility to make the world better, requiring knowledge about the solution options available to deal with climate change.

Sometimes student attitude language revealed less about their feelings about the topic, and more about the inquiry approach and delivery of instruction during the unit.

Most students did not voice these attitudes, but those that did generally supported the inquiry approach. This could be further explored to encourage an inquiry teaching approach, especially considering that student content knowledge gains in this study were statistically significant.

This study revealed an underlying confusion students tended to have about the concept of energy. To fully understand the complexities of climate change, one must understand clearly the concept of energy. Perhaps the main barrier preventing students from gaining strong scientifically grounded conceptions of climate change is their underlying confusion of the concept of energy. Further research into this idea should be considered. This might present avenues for curriculum developers and teachers to better scaffold lessons, so students develop fundamental conceptions before tying several together in order to understand something as complex as climate change.

This study was done in a biology classroom. Some student feedback and implementation of the unit by the teacher called into question the placement of a climate change unit within the biology classroom. There were times when the unit did not seem to fit in biology, as its content expanded way beyond the ecology unit taught in previous years. As such, more research should explore ways to better integrate science classrooms and break down the by-discipline approach to curriculum. Better mapping of curriculum around the Next Generation Science Standards would be a great place to start. Science has distinct disciplines. Yet, science is also strongly cross-disciplinary in nature as described by the NGSS. More work needs to be done to break down the figurative walls between science disciplines; allowing for more collaboration by science teachers. This could better ensure that the topic of global climate change finds its due place in the high school curriculum.

References

Abd-El-Khalick, F. (2004). Inquiry in science education: international perspectives. *Science Education*, 88, 397-419.

Adams, S. (2001). Views of the uncertainties of climate change: a comparison of high school students and specialists. *Canadian Journal of Environmental Education*, 6, 58-76.

American Association for the Advancement of Science. (2009). *Benchmarks for science literacy*. New York: Oxford University Press. Retrieved from http://www.project2061.org/publications/bsl/online/index.php

American Association for the Advancement of Science. (1989). *Science for all Americans*. New York: Oxford University Press.

Anderson, R.D. (2002). Reforming science teaching: what research says about inquiry. *Journal of Science Teacher Education*, 13(1), 1-12.

Andersson, B., and A. Wallin. 2000. Students' understanding of the greenhouse effect, the societal consequences of reducing CO2 emissions and the problem of ozone layer depletion. *Journal of Research in Science Teaching* 37(10) 1096–111.

Arzi, H., Ben-Zvi, R., & Ganiel, U. (1986). Forgetting versus savings: the many facets of long-term retention. *Science Education*, 70(20), 171-188.

Asay, L.D., Orgill, M.K. (2010). Analysis of essential features of inquiry found in articles published in science teacher, 1998-2007. *Journal of Science Teacher Education*, 21, 57-79.

Ausubel, D. (1962). A subsumption theory of meaningful verbal learning and retention. *Journal of General Pyschology*, 66, 213-224.

Bloom, B., Englehart, M., Furst, E., Hill, W., & Krathwohl, D. (1956). Taxonomy of educational objectives: the classification of educational goals. *Handbook I: Cognitive Domain*. New York, Toronto: Longmans, Green.

Boyes, E., & Stanisstreet, M. (1992). Students' perceptions of global warming. *International Journal of Environmental Studies*, 42, 287-300.

Boyes, E., Chuckran, D., & Stanisstreet, M. (1993). How do high school students perceive global climatic change: what are its manifestations? what are its origins? what corrective action can be taken? *Journal of Science Education and Technology*, 2(4), 541-557.

Clark, D. (2010). Bloom's taxonomy of learning domains: the three types of learning. *Big Dog & Little Dog's Performance Juxtaposition*. Edmonds, WA:Author. Retrieved from http://www.nwlink.com/~donclark/hrd/bloom.html

Clark, D., & Linn, M. C. (2003). Designing for knowledge integration: the impact of instructional time. *The Journal of the Learning Sciences*, 12(4), 451-493.

Cohen, L., Manion, L., Morrison, K. (2000). *Research methods in education*, (5th ed.). New York, NY: Taylor & Francis Group.

Conway, E. (2012). *What's in a name? Global warming vs. climate change*. NASA. Retrieved from http://www.nasa.gov/topics/earth/features/climate_by_any_other_ name.html

Corbin, J., Strauss, A. (2008). *Basics of qualitative research*, (third edition). Thousand Oaks, CA: Sage Publications, Inc.

Creswell, J., Clark, V. (2011). *Designing and conducting mixed methods research* (2nd ed.). Thousand Oaks, CA: Sage Publications, Inc.

Creswell, J. (2007). *Qualitative inquiry and research design: choosing among five traditions*, (2nd ed.). Thousand Oaks, CA: Sage Publications, Inc.

Darling-Hammond, L. (2010). *The flat world and education: How America's commitment to equity will determine our future*. NY, NY: Teachers College Press.

Driver, R., Asoko, H., Leach, J., Mortimer, E., Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher*, 23(7), 5-12.

Dupigny-Giroux, L. (2010). Exploring the challenges of climate science literacy: lessons from students, teachers, and lifelong learners. *Geography Compass*, 4(9), 1203-1217.

Duschl, R. (2003). Inquiry in science education: international perspectives. *Science Education*, 88, 411-414.

Flannery, T. (2006). *We are the weather makers: how we are changing the climate and what it means for life on earth*. Toronto, Ontario, Canada: Harper Collins Publishers.

Flannery, T. (2005). *The weather makers: How man is changing the climate and what it means for life on earth*. New York: Atlantic Monthly Press.

Fortner, R. W. (2001). Climate change in school: where does it fit and how ready are we? *Canadian Journal of Environmental Education*, 6, 18-31.

Fortner, R. W., Lee, J., Corney, J. R., Romanello, S., Bonnell, J., Luthy, B., Figuerido, C., Ntsiko, N. (2000). Public understanding of climate change: certainty and willingness to act. *Environmental Education Research*, 6(2), 127-141.

Fortus, D. (2014). Attending to affect. *Journal of Research in Science Teaching*, 51(7), 821-835.

Gautier, C., Deutsch, K., Rebich, S. (2006). Misconceptions about the greenhouse effect. *Journal of Geoscience Education*, 54(3), 386-395.

Gowda, M., Fox, J. C., Magelky, R. D. (1997). Students' understanding of climate change: insights for scientists and educators. *Bulletin of the American Meteorological Society*, 78(10), 2232-2240.

Greene, J. (2007). *Mixed methods in social inquiry*. San Francisco, CA: Jossey-Bass.

Hansen, J., Holm, L., Frewer, L., Robinson, P., & Sandoe, P. (2003). Beyond the knowledge deficit: recent research into lay and expert attitudes to food risks. *Appetite*, 41, 111-121.

Harrington, J. (2008). Misconceptions: Barriers to improved climate literacy. *Physical Geography*, 29(6), 575-584.

Heddy, B., & Sinatra, G. (2013). Transforming misconceptions: using transformative experience to promote positive affect and conceptual change in students learning about biological evolution. *Science Education*, 97(5), 723-744.

Hestness, E., McGinnis, J.R., Riedinger, K., & Marbach-Ad, G. (2011). A study of teacher candidates' experiences investigating global climate change within elementary science methods course. *Journal of Science Teacher Education*, 22(4), 351-369.

Hewson, P. (1992). Conceptual change in science teaching and teacher education. Paper presented at a meeting on "Research and Curriculum Development in Science Teaching," under the auspices of the National Center for Educational Research, Documentation, and Assessment, Ministry for Education and Science, Madrid, Spain.

Hines, J., Hungerford, H., & Tomera, A. (1986). Analysis and synthesis of research on responsible environmental behavior: a meta-analysis. *The Journal of Environmental Education*, 18(2), 1-8.

Hodson, D. (1990). A critical look at practical work in school science. *SSR*, 70(256), 33-40.

Hodson, D. (1988). Toward a philosophically more valid science curriculum. *Science Education*, 72(1), 19-40.

Hoffman, M., Barstow, D. (2007). *Revolutionizing Earth system science education for the 21st century: Report and recommendations from a 50-state analysis of Earth science education standards*. TERC, Cambridge MA.

Hwang, Y., Kim, S., & Jeng, J. (2000). Examining the causal relationships among selected antecedents of responsible environmental behavior. *Journal of Environmental Education*, 31(4), 19-24.

Intergovernmental Panel on Climate Change (2014). *Climate change 2014: synthesis report*. https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf

Jervey, B. (2012). What would it take to rein in greenhouse gas emissions and solve climate change? *Momentum*, 4(1), 14-17.

Kanter, D., & Konstantopoulos, S. (2010). The impact of a project-based science curriculum on minority student achievement, attitudes, and careers: the effects of teacher content and pedagogical content knowledge and inquiry-based practices. *Science Education*, 94, 855-887.

Khourey-Bowers, C. (2011). Active learning strategies: the top 10. *The Science Teacher*, April/May, 38-42.

Koballa, T. (2007). Affective domain and key issues. Presented at Carlton College, Northfield MN, http://serc.carleton.edu/NAGTWorkshops/affective/workshop07/program.html

Koulaidis, V., Christidou, V. (1999). Models of students' thinking concerning the greenhouse effect and teaching implications. *Science Education*, 83, 559-576.

Kraus, S. (1995). Attitudes and prediction of behavior: a meta-analysis of the empirical literature. *Personality and Social Psychology Bulletin*, 21, 58-75.

Laugksch, R. C. (2000), Scientific literacy: A conceptual overview. *Science Education*, 84(1): 71–94.

Lawrenz, F., Wood, N., Kirchhoff, A., Keol Kim, N., & Eisenkraft, A. (2009). Variables affecting physics achievement. *Journal of Research in Science Teaching*, 46(9), 961-976.

Leiserowitz, A., Smith, N., & Marlon, J. (2011). American teens' knowledge of climate change. Yale University. New Haven, CT: Yale Project on Climate Change Communication. http://environment.yale.edu/uploads/american-teens-knowledge-of-climate-change.pdf.

Liu, S., Roehrig, G., Bhattacharya, D., Varma, K. (in press). In-service teachers' attitudes, knowledge, and classroom teaching of global climate change. *Science Educator*, 4(1), 1-11.

Mattern, N., & Schau, C. (2002). Gender differences in science attitude-achievement relationships over time among white middle-school students. *Journal of Research in Science Teaching*, 39(4), 324-340.

McCaffrey, M., Buhr, S. (2008). Clarifying climate confusion: Addressing systemic holes, cognitive gaps, and misconceptions through climate literacy. *Physical Geography*, 29(6), 512-528.

Meadows, G., Wiesenmayer, R.L. (1999). Identifying and addressing students' alternative conceptions of the causes of global warming: the need for cognitive conflict. *Journal of Science Education and Technology*,8(3), 235-239.

Miles, M.B., Huberman, A.M. (1994). *Qualitative data analysis*, (second edition). Thousand Oaks, CA: Sage Publications, Inc.

National Aeronautics and Space Administration. (2012). *Global climate change; vital signs of the planet*. Retrieved from http://climate.nasa.gov/

Monroe, M. C. (1993). Changing environmental behaviors. *Clearing*, 77, 28-30.

Nations Center for Education Statistics (NCES). (2012). *Trends in International Mathematics and Science Studies* (TIMSS). Retrieved from http://nces.ed.gov/timss

National Commission on Exellence in Education (NCEE). (1983). *A nation at risk: The imperative for educational reform*. Washington, DC.

National Oceanic and Atmospheric Administration. (2012). *Global warming; frequently asked questions*. Retrieved from http://www.ncdc.noaa.gov/oa/climate/globalwarming.html

National Research Council. (2012). *A framework for k-12 science education: Practices, cross cutting concepts, and core ideas*. Washington, D.C., The National Academies Press.

National Research Council. (2010). *Advancing the science of climate change*. Washington, DC: National Academies Press.

National Research Council. (2006). *America's Lab Report: Investigations in High School Science*. Washington, DC: The National Academies Press.

National Research Council. (1996). *National science education standards*. Washington, DC: The National Academies Press. Retrieved from http://www.nap.edu/openbook.php?record_id=4962&page=R1

Niepold, F., Herring, D., McConville, D. (2008). The role of narrative and geospatial visualization in fostering climate literate citizens. *Physical Geography*, 29(6), 529-544.

Nieswandt, M. (2007). Student affect and conceptual understanding in learning chemistry. *Journal of Research in Science Teaching*, 44(7), 908-937.

Organization for Economic Cooperation and Development (OECD). (2007). *Programme for International Student Assessment 2006: Science competencies for tomorrow's world*. Paris: Author. Retrieved August 14, 2012, from: http://nces.ed.gov/surveys/pisa/index.asp

Oreskes, N. (2004, December 3). Beyond the ivory tower: The scientific consensus on climate change. *Science*, *306*(5702), 1686. Retrieved from http://www.sciencemag.org

Papadimiriou, V. (2004). Prospective primary teachers' understanding of climate change, greenhouse effect, and ozone layer depletion. *Journal of Science Education and Technology, 13(2),* 299-307.

Perrier, F., & Nsengiyumva, J.-B. (2003). Active science as a contribution to the trauma recovery process: preliminary indications with orphans for 1994 genocide in Rwanda. *International Journal of Science Education*, 25(9), 1111-1128.

Piaget, J. (1970). *Genetic epistemology*. (E. Duckworth, Trans.). New York: Columbia University Press.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accomodation of a scientific conception: toward a theory of conceptual change. Science Education, 66(2), 211-227.

Primack, R. (1998). *Essentials of Conservation Biology*, 2nd edition (Sunderland, MA: Sinauer Associates).

Pruneau, D., Gravel, H., Bourque, W., Langis, J. (2003). Experimentation with a socio constructivist process for climate change education. *Environmental Education Research*, 9(4), 429-446.

Rebich, S., & Gautier, C. (2005). Concept mapping to reveal prior knowledge and conceptual change in a mock summit course on global climate change. *Journal of Geoscience Education*, 53(4), 355-365.

Rye, J. R., & Rubba, P. A. (1998). An exploration of the concept map as an interview tool to facilitate the externalization of students' understandings about global atmospheric change. *Journal of Research in Science Teaching*, 35(5), 521-546.

Rye, J. R., Rubba, P. A., Wiesenmayer R. L. (1997). An investigation of middle school students' alternative conceptions of global warming. *International Journal of Science Education*, 19(5), 527-551.

Sadler, T. D., & Zeidler, D. L. (2009). Scientific literacy, pisa, and socioscientific discourse: assessment for progressive aims of science education. *Journal of Research in Science Teaching*, 46(8).

Schwartz, R. S., Lederman, N. G., & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: an explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, 88, 610-645.

Schwartz, M. S., Sadler, G. S., & Tai, R. H. (2008). Depth versus breadth: how content coverage in high school science courses relates to later success in college science coursework. *Science Education, 1-29*.

Shepardson, D.P., Niyogi, D., Choi, S., Charusombat, U. (2009). Seventh grade students' conceptions of global warming and climate change. *Environmental Education Research*, 15(5), 549-570.

Simpson, R., Koballa, T., Oliver, J., & Crawley, F. (1994). Research on the affective dimension of science teaching. In D. L. Gabel (ed.), *Handbook of Research on Science Teaching and Learning* (New York: Macmillan), 211-234.

Socolow, R., Hotinski, R., Greenblatt, J., Pacala, S. (2004). Solving the climate problem: Technologies available to curb CO_2 emissions. *Environment*, 46(10), 8-19.

Thompson, T., & Mintzes, J. (2002). Cognitive structures and the affective domain: on knowing and feeling in biology. *International Journal of Science Education*, 24(6), 645-660.

Tobin, K., Tippins, D., & Gallard, A. J. (1994). Research in instructional strategies for teaching science. In D. Gabel (Ed.), *Handbook of research on science teaching and learning*. New York: Macmillan. pp. 43-93.

Trowbridge, L. W., Bybee, R.W., Carlson-Powell, J. (2004). Teaching secondary school science: strategies for developing scientific literacy (eighth edition). Upper Saddle River, NJ: Merrill Prentice Hall.

Union of Concerned Scientists. (2012). *Global warming*. Retrieved from http://www.ucsusa.org/global_warming/

United States Global Change Research Program (2009). *Climate literacy: The essential principles of climate sciences*. Washington, DC.

Will Steger Foundation. (2012). *Climate change basics overview*. Retrieved from http://www.willstegerfoundation.org/climate-change-basics.

Windschitl, M. (2001). Inquiry projects in science teacher education: what can investigative experiences reveal about teacher thinking and eventual classroom practice?. *Science Education*, 87, 112-143.

Zimbardo, P., & Boyd, J. (1999). Putting time in perspective: a valid, reliable individual differences metric. *Journal of Personality and Social Psychology*, 77(6), 1271-1288.

Appendix A

Global Climate Change Unit Outline

Key:

WM = Reading from *We are the Weather Makers* by Tim Flannery

MNCC= Lesson from *Minnesota's Changing Climate* Curriculum (WSF)

GW101 = Lesson from *Global Warming 101* Curriculum (WSF)

Day	Lesson	Main Objectives
Pre-unit (2days)	MNCC Online Classroom Activity "Climate Close-up: Temperature"	Intro to MN biomes and defining abiotic factors
1	C-mapping Assessment	Elicit Prior Knowledge
2	GCC Content & Attitude Assessment	Elicit Prior Knowledge
3-4	WM Rdg 1: Intro to Climate Change, Everything is Connected, & The Great Aerial Ocean (Intro, Chp 1, Chp 2); Slides/Notes Discussion	Distinguish between weather & climate
4-6	MNCC Lesson 3: What defines MN's Climate?	Graphing Data & Identify trends in longitudinal data from MN
6	MNCC Online Classroom Activity "From Ice Age to Today"	Reinforcement of previous lesson
7	Earth's Long History Lecture/Discussion	Understand the types of proxy data scientists use to understand Earth's climate of distant past
8-9	Pond Water Study Part I.	Morphology Reinforced, Organism ID, & Feeding Relationships; Identification of Abiotic Factors
10	Computer Work Time & Introduction to Pond Water Study Part II	Predicting Changes for MN Wetlands (pond water communities) if trends toward warmer & drier
10-11	WM Rdg 2: Time's Gateways & Born in the Deep Freeze (Chp 5 & Chp 6); Follow-up Lecture/Discussion & 10 min. John Abraham video clip	Identify examples of climate changes impacts on ecosystems and organisms (Earth's past)
12	GW101 Lesson 1: Our Unique Atmosphere	Define greenhouse gases & their role in relation to the greenhouse effect
13-14	Lecture/Discussion, Computer Work Time (PWS Pt II, Journaling)	Reinforce previous lessons
15	WM Rdg 3: Greenhouse Gases & Ice Ages and Sunspots (Chp 3 & Chp 4)	Reinforce GW101 Lesson 1: Our Unique Atmosphere
16-17	GW101 Lesson 2: Emissions of Heat Trapping Gases; Started HBO video	Explain the impact of increasing GHG's & identify sources

	"Too Hot Not to Handle" (15 min.)	
Ex. Credit	WM Rdg: Fossil Fuel Formation	Distinguish between three types of fossil fuels & describe their role in the carbon cycle
17	Unit Quiz; EPA's Online Carbon Calculator	Determining household emissions based on home utilities information
18	Phenology Observations & Personal Work Time	Part of an ongoing phenology project started earlier in the year.
19	Finished HBO video "Too Hot Not to Handle"	Focus: Evidence of today's changing climate; predictions for the future; & solutions
20	Introduction to Climate Change Inquiry Project	Expand upon GW 101 Lesson 2 or the Pond Water Study with short scientific study
21	Lecture/Discussion; continuing look at climate determiners & evidence for changing climate today; Inquiry Project Planning Time	Groundwork for Upcoming WM Reading
22	WM Rdg 4: Magic Gates & Peril at the Poles (Chp 9 & Chp 10)	Evidence of changing climate today
23	Lecture/Discussion; follow-up to yesterday's reading; Inquiry Project Work time	Evidence of changing climate today
24	GW101 Lesson 3: Communities of Living Things	Explain using examples how changing weather patterns disrupt communities of organisms and predict what may happen to them
25-26	WM Rdg 5: The Great Stumpy Reef or The Golden Toad (Chp 11 or Chp 12)	Ecological impacts of today's changing climate
26-27	WM Rdg 6: Rainfall, Extreme Weather, & Sea Level Rise (Chp 13,14, & 15)	More evidence of today's changing climate; where specific regional changes have impacted humans
28	Planet Earth Series video "Ice Worlds"	Reinforcing feeding relationships & adaptations concept; consider climate change impacts on this community
29-30	Lecture/Discussion; WM Rdg 7: Model Worlds & Danger Ahead (Chp 16 & 17)	Criteria for computer climate models & predictions for the future
31-33	MNCC Lesson 5: What Does the Data Show?; IMPACTS Predictive Essay Assignment Given	Analyze and interpret various kinds of corroborative data in support of climate change
34	Revisit "Ice Worlds"; Essay & Inquiry Project Work Time	Varied by individual
35	Solutions Notes Handout w/accompanying questions assigned	Identifying solutions possible for dealing with climate change
36	Unit Review Questions	Assessment preparation
37	Post-Instruction GCC Content	Summative assessment

	Knowledge Assessment	
38	Post-Instruction GCC Concept Mapping Assessment	Summative assessment

*One and one half days were lost during this instructional unit due to snow storms.

Appendix B

BOX 3-1

PRACTICES FOR K-12 SCIENCE CLASSROOMS

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Appendix C

Unit 2 Exam: Climate Literacy

For each item, choose the answer that best fits your understanding.

Your username (**mcclellandj@maplelake.k12.mn.us**) will be recorded when you submit this form. Not **mcclellandj**? Sign out

* Required

Question 1: The "greenhouse effect" refers to: *

- ○ How plants grow
- ○ Gases in the atmosphere that trap heat
- ○ Pollution that causes acid rain
- ○ The Earth's protective ozone layer
- ○ Don't know

Question 2: Which of the following have an affect on the average global temperature of the Earth? *

Choose all that apply.

- ☐ greenhouse gases in the atmosphere
- ☐ changes in the Earth's orbit around the sun
- ☐ volcanic eruptions
- ☐ sunspots
- ☐ earthquakes
- ☐ clouds
- ☐ the amount of dust in the atmosphere
- ☐ phases of the moon
- ☐ whether the Earth's surface is light or dark colored

Question 3: Which of the following gases in the atmosphere are good at trapping heat from the Earth's surface? *

Choose all that apply

- Oxygen
- Carbon dioxide
- Hydrogen
- Methane
- Water vapor

Question 4: Are each of the following statements true, false, or you do not know? *
Weather often changes from year to year.

- True
- False
- Don't know

Q4a: Are each of the following statements true, false, or you do not know? *
Climate means the average weather conditions in a region.

- True
- False
- Don't know

Q4b: Are each of the following statements true, false, or you do not know? *
Climate often changes from year to year.

- True
- False
- Don't know

Q4c: Are each of the following statements true, false, or you do not know? *
Weather means the average climate conditions in a region.

- True
- False
- Don't know

Q4d: Are each of the following statements true, false, or you do not know? *
Ocean currents carry heat from the equator toward the north and south poles.

- True
- False
- Don't know

Q4e: Are each of the following statements true, false, or you do not know? *
The atmosphere carries heat from the north and south poles toward the equator.

- True
- False
- Don't know

Q4f: Are each of the following statements true, false, or you do not know? *
Climate and weather mean pretty much the same thing.

- True
- False
- Don't know

Question 5: Are each of the following statements true, false, or you do not know? *
In the past, the Earth's climate always shifted gradually between warm and cold periods.

- True
- False
- Don't know

Q5a: Are each of the following statements true, false, or you do not know? *
The Earth's climate is warmer now than it has ever been before.

- True
- False
- Don't know

Q5b: Are each of the following statements true, false, or you do not know? *
In the past, rising levels of carbon dioxide in the atmosphere have caused global temperatures to increase.

- True
- False

- Don't know

Q5c: Are each of the following statements true, false, or you do not know? *
Climate changes have played an important role in the advance or collapse of some past human civilizations.

- True
- False
- Don't know

Q5d: Are each of the following statements true, false, or you do not know? *
In the past, rising global temperatures have caused carbon dioxide levels in the atmosphere to increase.

- True
- False
- Don't know

Q5e: Are each of the following statements true, false, or you do not know? *
Compared to the climate of the past million years, the last 10,000 have been unusually warm and stable..

- True
- False
- Don't know

Q5f: Are each of the following statements true, false, or you do not know? *
The Earth's climate has been pretty much the same for millions of years.

- True
- False
- Don't know

Q5g: Are each of the following statements true, false, or you do not know? *
Earth's climate is colder now than it has ever been before.

- True
- False
- Don't know

Question 6: Which of the following are "fossil fuels"? *
Choose all that apply.

- ☐ Wood
- ☐ Oil
- ☐ Solar Energy
- ☐ Natural Gas
- ☐ Coal
- ☐ Hydrogen

Question 7a: From the model descriptions about how the climate system works, which best describes the current scientific model? *

- ○ Earth's climate is slow to change. Global warming will gradually lead to dangerous effects.
- ○ Earth's climate is delicately balanced. Small amounts of global warming will have abrupt and catastrophic effects.
- ○ Earth's climate is very stable. Global warming will have little to no effects.
- ○ Earth's climate is stable within certain limits. If global warming is small, climate will return to stable balance. If it is large, there will be dangerous effects.
- ○ Earth's climate is random and unpredictable. We don't not know what will happen.

Question 7b: The energy from fossil fuels originally came from *

- ○ Fossilized remains of dinosaurs
- ○ Photosynthesis by plants over millions of years
- ○ Magma from within the Earth
- ○ Uranium in the Earth
- ○ Don't Know

Question 8: What gas is produced by the burning of fossil fuels? *

- ○ Oxygen

- Hydrogen
- Helium
- Carbon Dioxide
- Don't Know

Question 9: To the best of your knowledge, roughly how much carbon dioxide was in the atmosphere in the year 1850? *

- 150 parts per million
- 290 parts per million
- 350 parts per million
- 390 parts per million
- 450 parts per million
- Don't Know

Question 10: Roughly how much carbon dioxide is in the atmosphere today? *

- 150 parts per million
- 290 parts per million
- 350 parts per million
- 390 parts per million
- 450 parts per million
- Don't Know

Question 11: If we were to stop burning fossil fuels today, global warming would stop almost immediately. *

- True
- False
- Don't know

Question 12: On average, how long does carbon dioxide stay in the atmosphere once it has been emitted? *

- 1-10 days
- 1-10 years
- 100 - 1,000 years
- Don't know

Question 13: Which of the following countries emits the most carbon dioxide per person? *

- United States
- China
- India
- Germany
- Japan
- Don't know

Question 14: Which of the following countries emits the largest total amount of carbon dioxide? *

- United States
- China
- India
- Germany
- Japan
- Don't know

Question 15: Of the following, which one do you think contributes the most to global warming? *

- Cars and trucks
- Cows

- Nuclear power plants
- Burning fossil fuels for heat and electricity
- The sun
- Toxic wastes
- Deforestation
- Other:

Question 16: The decade from 2000 to 2009 was warmer than any other decade since 1850. *

- True
- False
- Don't know

Question 17: Global warming will cause some places to get wetter, while others will get drier. *

- True
- False
- Don't know

Question 18: Scientists' computer models are too unreliable to predict the climate of the future. *

- True
- False
- Don't know

Question 19: Global warming will increase crop yields in some places, and decrease it in others. *

- True
- False
- Don't know

Question 20: Earth's climate has changed naturally in the past, therefore humans are not the cause of global warming. *

- True
- False
- Don't know

Question 21: Any recent global warming is caused by the sun. *

- True
- False
- Don't know

Question 22: The record snowstorms in the Eastern United States (2010) prove that global warming is not happening.. *

- True
- False
- Don't know

Question 23: Which of the following statements is correct? *

- All the glaciers on Earth are melting away
- Most of the glaciers on Earth are melting away
- Some of the glaciers on Earth are melting away
- None of the glaciers on Earth are melting away
- Don't know

Question 24: Over the past 100 years, has the speed of glacier melting increased, decreased, or stayed the same? *

- Increased
- Stayed the Same
- Decreased

Question 25: How much do scientists estimate global sea levels rose from 1900 to 2000? *

- 10-12 feet
- 3-4 feet
- 6-9 inches
- Zero
- Don't know

Question 26: If no additional actions are taken to reduce global warming, how much do you think global sea level will rise by 2100? *

- 10-12 feet
- 3-4 feet
- 6-9 inches
- Zero
- Don't know

Question 27: Which of the following causes coral bleaching? *

- Chemical spills in the ocean
- Acid rain
- Warmer ocean temperatures
- Overfishing
- Don't know

Question 28: Which of the following causes ocean acidification? *

- Chemical spills in the ocean
- Acid rain
- Absorption of carbon dioxide by the ocean
- Warmer ocean temperatures

- Don't know

Question 29: Of the following actions, which one do you think would reduce global warming the most? *

- Planting trees
- Driving less
- Reducing toxic waste (nuclear, chemical)
- Switching from fossil fuels to renewable energy (wind, solar, geothermal)
- Reducing tropical rainforest deforestation
- Switching from fossil fuels to nuclear power
- Switching from gasoline to electric cars
- Other:

Question 30: Which of the following is an example of a positive feedback system relating to global warming? *

Choose all that apply.

- As snow and ice melts, there is more surface area of Earth to absorb light energy, increasing temperatures even more
- A warmer Earth will lead to increased growing seasons and higher food production for humans and animals
- As permafrost melts in the arctic, more decomposition occurs and releases carbon dioxide, which warms temperatures even more
- A warmer Earth will lead to more water evaporation and increased cloud cover, which should cool Earth down

Question 31: Explain how the greenhouse effect works on Earth. Include the sun and the atmosphere in your explanation. *

Discuss energy forms, wavelengths, or rate of transfer in you explanation (4 pts.)

Question 32: Explain the difference between global warming and climate change, while also describing their relationship. *

3 pts.

Question 33: Which of the choices below are components of Earth's system influencing climate? *

Choose all that apply.

- ☐ Ocean currents such as the Gulf Stream
- ☐ Trade winds and other atmospheric circulation
- ☐ Concentrations of greenhouse gases
- ☐ Clouds and water vapor
- ☐ Degree of polar ice and snow
- ☐ Aerosols

Question 34: If organisms find themselves outside their normal climate ranges of temperature, precipitation, humidity, or sunlight for extended periods of time, which of the following will occur? *

- ○ Adapt
- ○ Migrate
- ○ Go Extinct
- ○ All of the above

Question 35: Describe two types of proxy data (indirect evidence used for inference) for interpreting Earth's past climate. Then, describe the developing scientific approach toward predicting future climate. *

What is the evidence type and what specifically can it tell us about Earth's past climate. (4 pts.)

Do you think global warming is happening? *

- Yes
- No
- Don't Know

If you think global warming is happening, how sure are you about it? *

- Extremely sure
- Very sure
- Somewhat sure
- Not sure at all
- I didn't pick yes for the last question

Assuming global warming is happening, do you think it is..... *

- Caused mostly by human activities
- Caused by both human activities and natural changes
- Caused mostly by natural changes in the environment
- None of the above because global warming isn't happening
- Don't Know
- Other:

Which comes closer to your own view? *

- Most scientists think global warming is happening
- Most scientists think global warming is not happening
- There is a lot of disagreement among scientists about whether or not global warming is happening
- Don't know enough to say

How worried are you about global warming? *

- Very worried
- Somewhat worried
- Not very worried
- Not at all worried

Personally, how well informed do you feel about how Earth's climate system works? *

- Very well informed
- Fairly well informed
- Not very well informed
- Not at all informed

Personally, how well informed do you feel about the different causes of global warming? *

- Very well informed
- Fairly well informed
- Not very well informed
- Not at all informed

Personally, how well informed do you feel about the different consequences of global warming? *

- Very well informed
- Fairly well informed

- Not very well informed
- Not at all informed

Personally, how well informed do you feel about the ways in which we can reduce global warming? *

- Very well informed
- Fairly well informed
- Not very well informed
- Not at all informed

Send me a copy of my responses.

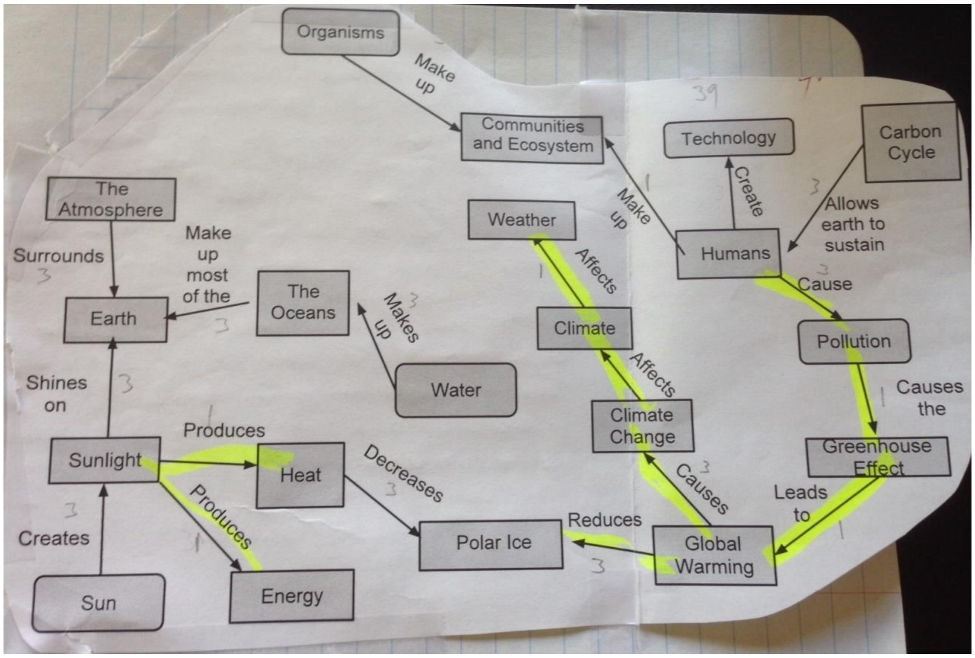
Submit

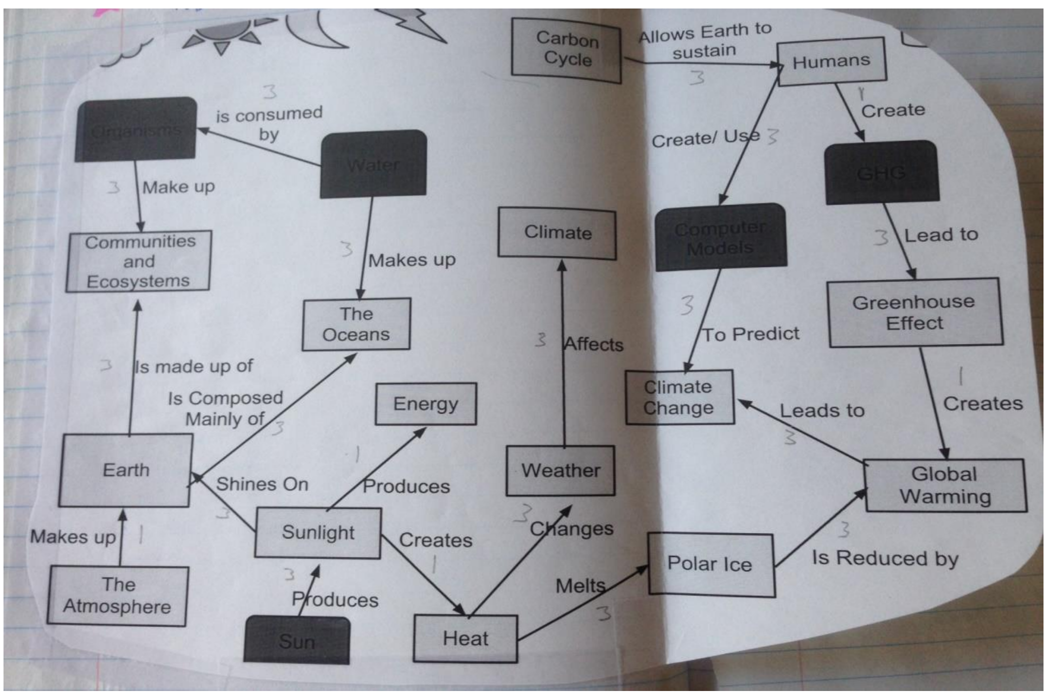
Never submit passwords through Google Forms.

Appendix D

Supplementary Artifacts Examples

Concept Maps; Pre & Post





Predictive Essay

Global warming has been affecting our state in many different ways. As time goes by, changes are occurring more and more. There are a few things that are happening now or they could potentially happen that will affect me more than others. Three changes that come to mind that I believe would affect me the most would be: shorter and milder winters, increasing temperatures, and increasing evaporation.

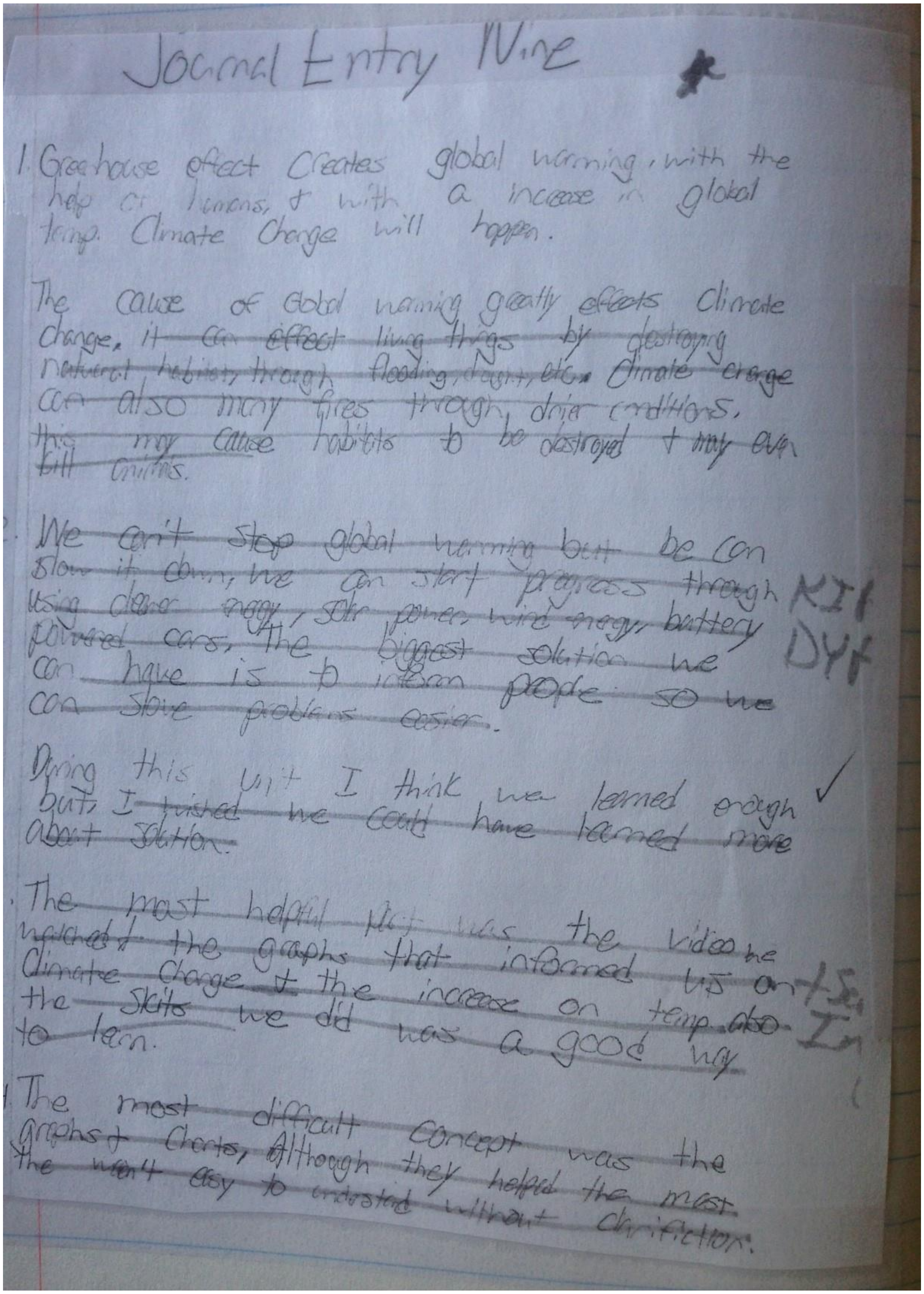
The first change that could affect me the most is shorter and milder winters. I absolutely love ice fishing. I spend over half my days in the winter out on the ice. I don't just fish for the sport of it either, I also like catching fish for food to fill up the freezer. If the winters get milder and shorter, then I would not be able to go ice fishing or I won't be able to go as much as I would like to. According to Minnesota Public Radio, as the El Nino takes hold, odds are is that it will result in a mild winter this year. I also hate bugs, so if the winters are milder, than the bugs may not die off and i will have to deal with them more.

A second change that will affect me is an increase in temperature. This change will affect me in many different ways. According to Minnesota Climatology Working Group, since the early 1980s, the temperature has risen slightly over 1°F in the south to a little over 2°F in much of the north; the trend has been upward. Much of the warming in the record seems to have occurred in the last 2 or 3 decades. If the temperatures increase, it could cause many problems in the agricultural aspects. If crops don't grow like they usually do, it could cause prices at the grocery store to sky rocket. This could hurt many people economically. Rise in temperatures could also hurt the tourism which would affect our economy because of lost revenue. Increases in temps also may cause me to not want to do certain things. If it is too hot out, I will just want to stay inside and not do anything. Since I like to deer hunt, the rise in temperatures will affect that. When the air starts to get cold, the rut starts. When the rut is going, the deer move around which gives the hunters a better chance to kill them. If the temperatures rise, the rut may not happen until later in the year which may cause the deer hunters to not even get a chance to get these deer. Increasing temperatures can also cause more evaporation.

The 3rd change that I feel will affect me the most is an increase in evaporation. If more evaporation occurs, then the land may dry out. If the land dries out, then certain crops may not grow because they need water and a moist soil to grow. This would highly affect our agricultural based economy. Environmental Entrepreneurs says that an increase in evaporation can create potentially large reductions in corn and wheat yields and the need for potentially massive investments in irrigation systems, which are currently rare in the state. Also, if more evaporation occurs, then the lakes and ponds could potentially dry out. Since I am an avid fisherman this would greatly affect me. It would be very hard for me to go fishing if there was no water holes for me to hit up. An increase in evaporation could also cause more forest fires. If a fire started, and there would be no water to put it out, it would just continue on and take out the whole forest. This would greatly affect my hunting schemes and the schemes of many others as well.

With global warming becoming a more talked about topic, there should be many things that should be considered. Even if a change seems insignificant, it can have a very big reaction. Even the smallest changes can have a worldwide impact. I believe that three possible changes that would affect me the most would be: shorter and milder winters, an increase in temperature, and lastly, and increase in evaporation. If these changes keep occurring, they will change my life drastically.

Post-Unit Journal Entry



Journal Entry Nine

1. Greenhouse effect creates global warming, with the help of humans, + with a increase in global temp. Climate Change will happen.

The cause of Global warming greatly effects Climate change, it can effect living things by destroying natural habitats, through flooding, drought, etc. Climate change can also many fires through drier conditions, this may cause habitats to be destroyed + may even kill animals.

2. We can't stop global warming but we can slow it down, we can start progress through using cleaner energy, solar power, wind energy, battery powered cars, The biggest solution we can have is to inform people so we can solve problems easier.

During this unit I think we learned enough but, I wished we could have learned more about solution.

The most helpful part was the video we watched + the graphs that informed us on Climate change + the increase on temp. also the skits we did was a good way to learn.

The most difficult concept was the graphs + charts, Although they helped the most they weren't easy to understand without clarification.

KIF DYK

Partial Interview Transcript

Alright uh let's see, over the course of the unit uh did your position, or thinking on global warming change in any way? And if so could you elaborate on any of those changes or what mighta contributed to those changes, things that stuck out?

Um I believe that my position changed a little bit. I think I'm more aware and I've looked at some more actual facts and saying, uh I-I didn't really believe in global warming at first, but I think it changed slightly. Um I still don't think we should change our whole agenda and daily lives over it, but I think we should still be more aware of it and more people should be taught in this sense, where we should look at a different alternative for fuel, or we should look at um maybe the exhaust pipes and how much they're really looking forward or you know we should have- we should put more time and science into it. I don't think we should pay with it with like tax dollars just because we're in such like a major economic crisis not right now well maybe not a s much as we were five years ago but I still think that we, that there's more funding out there that of course car places have, like Chevrolet has like this new flex fuel thing and uh there's like a biodiesel that's made from corn which I think we should still look into, um but then we also of course need to look for um an alternative in like wind – wind and solar power. I think that helps a lot, but- and we should probably just... you know I , it's difficult to like say that we can just change our whole entire thing. It's of course gonna take a lota time. (yep) Um the whole entire you know energy source but I think that with global warming we should still look at more like investigate more stuff on it, like..

So keep getting more research?

Yeah

Or trying to build more evidence?

Yeah, because as much as there is a lot of evidence, you're asking for a lot of people to change their daily lives, like there is millions of j- well maybe not millions, but thousands of jobs relying on oil (yep) you know like the oil industry, if you're going to change something that big you're gonna need a lot of evidence to mount against that because it's a very, it's a very big industry and a lot of people's..

Right, right, so to change those livelihoods that depend on that you need to have some other avenue for them to support their families?

Yes

And we need to be very sure of what we're doing?

Yeah exactly, you know, you hit it right on the head. Um you know it's a touchy subject because people can get offended because you know, people, that's their job. (absolutely) you know in north Dakota there's a lot of people depending on this oil thing, this oil boom, um and you know you can't tell them that they, you know gotta stop. (you don't have the right to go make a living, right) exactly, you know as much as it's like a defacto, you know it's gonna take time for people to change their opinion. Umm you know because they may not agree with the evidence and people probably just they just don't want to agree with it 'cause of their jobs really depend on it and I think that as much as there's evidence that we were shown in the unit, I still think that it could just be natural, in a sense that it's very hard to look at data collected before the 1900s and say, 'yes it was cooler back then,' or 'yes we had more snow back then.' Um

Cause it's indirect, instead of direct evidence?

Appendix E

Paired T-Test Output Comparing Pre and Post Content Assessment Scores		
t	df	p-value
-26.5915	89	<2.2e-16
Tested at a 95% Confidence Interval		

Appendix F

ANOVA Output Values Comparing Student Assessment Score Means by Attitude Category				
Assessment Item	F statistic	df num	df den	p-value
Content Knowledge Pre-Assessment	2.1908	2	87	0.118
Content Knowledge Post-Assessment	0.9221	2	87	0.4016
Change in Pre-Post Content Knowledge Assessment Score	1.1052	2	87	0.3358
Mid-Unit Quiz	1.0467	2	85	0.3556

Appendix G

ANOVA Output Values Comparing Mean of Wrong Answers on Specific Categories of Content Knowledge Assessment Items by Student Attitude Category				
Assessment Item Category	F statistic	df num	df den	p-value
Pre-Assessment Evidence Questions	3.4722	2	87	*0.03542
Post-Assessment Evidence Questions	5.6183	2	87	*0.005072
Pre-Assessment Predictions Questions	2.133	2	87	0.1246
Post-Assessment Predictions Questions	1.6347	2	87	0.201
Pre-Assessment Causes Questions	0.6874	2	87	0.5056
Post-Assessment Causes Questions	0.4633	2	87	0.6307
Pre-Assessment Weather vs. Climate Questions	1.0058	2	87	0.37
Post-Assessment Weather vs. Climate Questions	0.5464	2	87	0.581
Pre-Assessment Earth's History Questions	5.0185	2	87	*0.008656
Post-Assessment Earth's History Questions	0.039	2	87	0.9618
Pre-Assessment Climate Systems Questions	0.9971	2	87	0.3731
Post-Asessment Climate Systems Questions	0.4648	2	87	0.6298