2011

Middle School Students' Conceptual Change in Global Climate Change: Using Argumentation to Foster Knowledge Construction

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MIDDLE SCHOOL STUDENTS’ CONCEPTUAL CHANGE IN GLOBAL CLIMATE CHANGE: USING ARGUMENTATION TO FOSTER KNOWLEDGE CONSTRUCTION

By

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A Dissertation submitted to the School of Teacher Education in partial fulfillment of the requirements for the degree of Doctor of Philosophy

Degree Awarded:
Summer Semester, 2011
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Dedicated to: my wife Shari
ACKNOWLEDGEMENTS

This has been a long journey in which I have relied upon the assistance of others to an exorbitant degree. I would like to express my extreme gratitude to my major professor, Sherry Southerland, for her assertive nurturing of my scholarly talents in ways too numerous to mention. Likewise, my other committee members have provided immeasurable help. Vic Sampson introduced me to argumentation, and was supportive of my project at all times. Paul Ruscher helped shape my thinking about climate change through numerous content discussions. Jeff Milligan's classes in philosophy shaped my overall thinking about education. In addition, the comments provided by each of my committee members have provided insights which have shaped not only this document but also my total understanding of what it means to be a scholar.

The person that provided the most assistance to me was my wife Shari Buckingham. She showed an amazing degree of patience and tolerance while I was physically and/or mentally preoccupied during the course of my doctoral studies, and was somehow still supportive of me.

I must also thank my parents, Lynn and Kirsten Golden, for the value systems which I inherited or learned, including the respect for academia, and for keeping me grounded. A belated "thank you" must also be extended to my grandfather, Olaf Hov, for the pride he showed in my academic prowess, which secretly powered me through moments of doubt.

I cannot possibly express enough thanks to other colleagues and friends at FSU and the local science education community. Judy King was an incredible mentor for me as a science teacher. Willie Brown generously provided his middle school classroom for my pilot study needs. Ms. "Octane", obviously, provided her classroom and her students for the dissertation research project. She was selfless in providing this and other extended help which I needed. My peers at FSU provided immeasurable support of both technical and emotional dimensions. Jonathon Grooms and Patrick Enderle helped me in timescales more convenient for me than for them. Three colleagues provided particular help in regards to test-piloting my climate change unit in conference settings: Bob Lutz, Beth Kostka, and Martin Balinsky. Additionally, one member of the FSU community is probably as responsible as any for the overall direction of my academic journey: George Dawson, who first recruited me as a science teacher. Thanks also to Meg Blanchard, the first mentor/colleague to make me think that I might not only be able to teach science, but that I might actually be very good at it!
Also, I want to thank my colleagues at OSTA for their friendship, professionalism, and support. First and foremost in this regard is Ellen Granger, who has been most understanding as I have juggled my professional and academic goals.

Lastly, I want to thank the children involved in this research, who amazed me with their eagerness to help me: –Beyonce”, –Bono”, –Đanko”, –Nigella”, and –Shania”. Without them none of this was possible.
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ABSTRACT

This research examined middle school student conceptions about global climate change (GCC) and the change these conceptions undergo during an argument driven instructional unit. The theoretical framework invoked for this study is the framework theory of conceptual change (Vosniadou, 2007a). This theory posits that students do not simply correct incorrect ideas with correct ones, but instead weigh incoming ideas against already existing explanatory frameworks, which have likely served the learner well to this point. The research questions were as follows:

1. What are the patterns of students‘ conceptual change in GCC?
   a. What conceptions are invoked in student learning in this arena?
   b. What conceptions are most influential?
   c. What are the extra-rational factors influencing conceptual change in GCC?

This research took place in an urban public school in a medium sized city in the southeastern United States. A sixth grade science teacher at Central Middle school, Ms. Octane, taught a course titled –Research Methods I”, which was an elective science course that students took as part of a science magnet program.

A unit was designed for 6th grade instruction that incorporated an Argument-Driven Inquiry (ADI) approach, centered on the subject matter of Global Climate change and Global Warming. Students were immersed in three separate lessons within the unit, each of which featured an emphasis upon creating scientific explanations based upon evidence. Additionally, each of the lessons placed a premium on students working towards the development of such explanations as a part of a group, with an emphasis on peer review of the robustness of the explanations proposed.

The students were involved in approximately a two week unit emphasizing global climate change. This unit was based on an argumentation model that provided data to students and asked them to develop explanations that accounted for the data. The students then underwent a peer-review process to determine if their explanations could be modified to better account for the data as pointed out by peers.
As the students experienced the three lessons comprising the unit, data were taken of various modes, including pre-unit, mid-unit, post-unit, and delayed-post unit interviews, observer notes from the classroom, and artifacts created by the students as individuals and as members of a group. At the end of the unit, a written post-assessment was administered, and post-interviews were conducted with the selected students.

These varied data sources were analyzed in order to develop themes corresponding to their frameworks of climate change. Negative cases were sought in order to test developing themes. Themes that emerged from the data were triangulated across the various data sources in order to ensure quality and rigor. These themes were then used to construct understandings of various students’ frameworks of the content.

Several findings emerged from this research. The first finding is that each student underwent some conceptual change regarding GCC, although of varying natures. The students’ synthetic frameworks of GCC were more complex than their initial, or naïve frameworks. Some characteristics of the naïve frameworks included that the students tended to conflate climate change with a broader, generic category of environmental things. Examples of this conflation include the idea that climate change entails general pollution, litter, and needless killing of dolphins while fishing for tuna. This research suggests that students might benefit from explicit attention to this concept in terms of an ontological category, with the ideal synthetic view realizing that GCC is itself an example of an emergent process. Another characteristic of their naïve frameworks includes some surprisingly accurate notions of GCC, including a general sense that temperatures and sea levels are rising. At the same time, none of the students were able to adequately invoke data to support their understandings of GCC. Instead, when data were invoked, students tended to include anecdotal information.

Students’ synthetic frameworks showed great improvements in these and other aspects. Each student without exception made great strides in reference to data invoked to explain his or her position. The data analyzed show evidence of epistemic scaffolding in that the students’ poor ability to invoke evidence was improved through the experience in the argumentation unit.

This research also suggests that each student’s learning was greatly impacted by his or her own affective tendencies and understandings. Darko provided an example of this called belief identification (Cederblom, 1989), in that he stated that his anti-global warming beliefs are
the same as those of his family. Other affective factors of note included self-efficacy and fascination with animals.

While each student's understanding of GCC grew substantially, an explanation of their growth was offered with reference to four major categories: Ontological, Epistemological, Analytical, and Affective. In order to understand any one student's conceptual change, a thorough accounting of each of these factors needs to be examined. This research described the interaction of these factors for these students.
CHAPTER ONE

INTRODUCTION

―Be worried. Be VERY worried‖, read the cover of *Time* magazine in April of 2006 (April 3). There were many crises of note during that time, but the editors of *Time* were not warning about international terrorism or anything of that nature. Instead, they were admonishing readers to be worried about global warming. Nor was *Time* the only media outlet to take such a stand. In recent years, especially since the record heat waves of 1988 (at least in the United States), the concepts of Global Warming (GW) and Global Climate Change (GCC) have received much press attention (Begley, 2007; Kluger, 2006).

Although these two terms, Global Warming (GW) and Global Climate Change (GCC) are used somewhat interchangeably in the press, I will here differentiate how this research views those two terms. I concede that the first, Global Warming, refers to the current worldwide warming trend within the overall trend that is climate change in general. While some areas of the Earth may not warm, or may even cool slightly in the near future, the overall global trend seen in current data is one of warming. Recent studies point to this overall warming trend as equaling approximately .8 degrees Celsius over the course of the 20th century (IPCC, 2007) or about 2 degrees Celsius over the last 30 years (Hansen, Sato, Rudy, Lo, Lee, & Medina-Elizade, 2006). Although there may not be a ―correct‖ term to choose between global warming (GW) and global climate change (GCC), this research focuses particularly on students‘ understandings of the mechanisms of global warming, which are themselves a subset of the overall trend of climate change. Therefore, both terms will continue to be used in this research. However, these terms are not used interchangeably. Global warming (GW) will refer specifically to warming mechanisms or trends within GCC, while Global Climate Change itself will refer to the broader background trend of changing climate, including both periods of warming and cooling.

The theoretical framework of GCC is drawn from many branches of science and has far-reaching implications for society on both national and international levels, including the environment, health, agriculture, population demographics, finance, and international relations cite needed. Given the need for action called for by a consensus of the scientific community and
the vast national and international resources that will be required to deal with this problem, it is clear that any viable long-term solution to the problems posed by GCC will be contingent upon a population of citizens with a robust understanding of the science involved and the challenges posed by the phenomenon (AAAS, 2007). To produce this informed citizenry, it is necessary to understand factors influencing student learning in this area, as this understanding is necessary to inform the development of more effective curricular approaches and materials.

The emphasis on the need for a carefully crafted, empirically based set of pedagogical approaches is particularly keen given the conflicting messages about GCC that abound in the American media. There are many media ‘reports’ challenging the ‘truth’ of GCC (Brown, 2010; Dawidoff, 2009; Michaels, 2008). Some of these reports come from scientists or scientific organizations, while others originate in popular editorial columns in widely circulated newspapers or newsmagazines. For example, the eminent physicist Freeman Dyson said “All the fuss about global warming is grossly exaggerated” (Dawidoff, 2009, p. 2). Others, such as the columnist George Will, don’t question GCC, but question the possibility that humans contribute this change (Will, 2009). In contrast, other media reports position GCC as a matter of international urgency (IPCC, 2007; Kluger, 2006). The state of confusion in the popular media is indicative of the need for a set of clearly designed, theoretically informed guidelines to inform the teaching and learning GCC. The research presented here begins to address this need by producing a rich, detailed account of student learning of GCC.

As GCC is such a complicated field, relying upon a myriad of data sources and understandings, this research requires a framework that uses a model of learning that sufficiently captures various aspects of and influences on student learning. In my research I used the framework theory approach to conceptual change as its theoretical framework (Vosniadou, 2007b). The framework theory, instead of positing conceptual change as a strictly rational replacement of misconceptions with more correct understandings, invokes a model of domain-specific conceptual change. This view considers the conceptions that need changing are “the naïve, intuitive, domain-specific theories constructed on the basis of everyday experience under the influence of lay culture” (Vosniadou, 2007b, p. 10). I argue that it is critical for this research to invoke a framework that highlights extra rational aspects of learning because the subject matter, GCC, is a topic about which many students are likely to form opinions about for both rational and extra-rational reasons. I hope to foster this conceptual change regarding GCC by
using a pedagogical approach that places students in classroom situations in which they are challenged to not only interpret standard scientific data, but also to discuss those meanings with their peers. I hope to capture not only the finished product of such socio-cultural interactions, but also to understand the actual interactions themselves. The approach that I have chosen is argumentation-based approach called Argument-Driven Inquiry (Sampson & Gleim, 2009; Sampson & Grooms, 2009), as several authors have suggested that argumentation-based pedagogy may be useful in producing conceptual change (Dole & Sinatra, 1994; Nussbaum & Sinatra, 2003)

**Statement of Problem and Research Questions**

Many have called for science education researchers to develop relevant approaches in terms of preparing students for their roles as participating citizens in a democracy (Fraser & Tobin, 1998; Hodson, 2008; Sadler, 2004). To inform an effective pedagogical approach to GCC, we must first generate a fruitful description of student conceptual change in this arena. Effective pedagogy should be structured upon an understanding of how climate change is understood and learned by students. This is the background against which the present research is situated.

My research questions include an emphasis on describing students’ conceptual change in this arena as well as describing an effective pedagogical approach to foster this change. Thus, my questions are:

1. What are the patterns of students’ conceptual change in GCC?
   a. What conceptions are invoked in student learning in this arena?
   b. What conceptions are most influential?
   c. What are the extra rational factors influencing conceptual change?

I will return to the research questions in chapter three, in which methods of research will be addressed. For now, attention must be turned to the subject of reviewing the relevant literatures. There are five sets of literature this research draws upon and will contribute to. The first set of literature is the history of the science behind global warming. Once that is unearthed, the extent to which there is or is not scientific consensus in those fields will be examined. The second set of literature is the set of educational policy and research. An examination of these fields is critical in that we need to understand policy recommendations regarding GCC. The third set of
literature to be examined involves climate change education. That field will be scrutinized for any relevant studies broaching upon global warming and global climate change-related issues. The fourth set of literature involves conceptual change. This will constitute the major theoretical framework for this study, so that will be dealt with in depth. Lastly, the field of argumentation will be examined, as it constituted a major portion of the methodology surrounding the actual classroom experiences being researched.
CHAPTER TWO

REVIEW OF THE LITERATURE

In this chapter, I present salient aspects from the relevant literatures surrounding global warming science, global warming in educational policy and research, climate change education, conceptual change, and argumentation.

Global Warming/Global Climate Change

The idea that the Earth’s climate has not always been the same started to develop in the early 19th century as scientists attempted to explain anomalous data such as strange assortments of boulders in Alpine valleys, and the origins of rock scouring in such places. Scientists such as Louis Agassiz and Karl Schimper developed theories suggesting that not only had there once been a period of time in which ice sheets had descended on most of Europe, but in fact that there had been several different such periods (Weart, 2003). Thereafter, many scientists devoted time and energy into seeking the causes for these historical descents into ice ages. Serbian scientist Milutin Milankovitch developed a theoretical explanation which is still thought to account, at least partially, for the historical periods of ice ages. His idea became known as Milankovitch cycles, which account for the changing conditions of Earth’s orbit. Three factors were found to change on periods of several thousands of years: the Earth’s tilt changes from about 22 degrees to about 24.5 degrees; the Earth’s axial precession, or rotational motion, changes on a period of about 26,000 years; and Earth’s orbit around the sun itself changes over time to periods of greater ellipsis. These three factors combine, according to Milankovitch Theory, to account for the climatic changes due to ice ages (Weart, 2003). Milankovitch cycles now constitute a significant portion of the modern understanding of global climate change.

As will be described, the theory of global climate change was derived from a more confined theory of global warming that has been a part of scientific discourse for well over a century. In the early to mid 1800’s, scientists like Fourier and Tyndall researched the incoming and outgoing
energy of the earth (energy budget) and noticed that the earth’s atmosphere was warmer than expected (Weart, 2003). In other words, the earth does not seem to radiate away enough heat to maintain its temperature, according to energy budget calculations. These scholars argued that the atmosphere retains some of the heat absorbed from the sun, because of the role of atmospheric gases. For instance, CO\textsubscript{2} allows in heat energy when it enters the atmosphere at particularly wavelengths. However, as that same heat energy is re-radiated, CO\textsubscript{2} blocks its loss to the atmosphere. This idea of allowing energy into the atmosphere, while blocking much of it from escaping, would later become known as the greenhouse effect (Weart, 2003).

Building upon the works of these scientists, Svante Arrhenius set out to perform some laborious calculations regarding atmospheric temperature and levels of CO\textsubscript{2}. In 1896, Arrhenius concluded that doubling the then-present levels of atmospheric CO\textsubscript{2} would amount to an increase in temperature of 5-6 degrees Celsius. Although he also concluded that human activities such as factory production contributed mightily to the gas levels, he argued from these calculations that it was not a matter for concern because he felt that warming the Earth may be somewhat beneficial (Weart, 2003).

The next significant contribution to the global warming discussion came in Britain in 1938, when Guy Callendar made the case, based on an examination of temperature and CO\textsubscript{2} data from the nineteenth century, that global warming was indeed happening, and that industrial CO\textsubscript{2} emissions were the culprit (Callendar, 1938). The oceanographer Roger Revelle complicated matters in 1957, when he published a paper claiming that the world’s oceans would not readily absorb the CO\textsubscript{2} emissions from industry. This implied a greater likeliness that industrial emissions would cause global warming (Weart, 2003).

Another critical advance in the science of global warming came in 1960, when Charles Keeling set out to definitively measure CO\textsubscript{2} amounts in various locations around the world, notably Hawaii and Antarctica. He found the baseline level of atmospheric carbon dioxide to be 315 parts per million. Keeling re-measured the CO\textsubscript{2} amounts every year at observatory atop the Hawaiian volcano Mauna Loa, resulting in the famous “Keeling curve” (Figure 1, below). This graph illustrates that, on average, the CO\textsubscript{2} concentration in the Earth’s atmosphere has risen by about 2 parts per million per year since 1960 (Weart, 2003).
These annual CO₂ measurements provided, for the first time, direct evidence that the chemistry of the atmosphere was in fact changing over time, in a way that could indicate climate change. Also, the Keeling Curve provided evidence that the atmospheric chemistry was changing in a way that signaled a likely increase in heat due to the greenhouse effect, and also that such an increase may be due to anthropogenic contributions, in the form of increased CO₂ output from industrialization. Keeling’s data provided the necessary warrants to take seriously the largely theoretical work that preceded him (Weart, 2003). This connection of data and theory provided much of the motivation for the first ever International Conference on the Causes of Climate change in Boulder, Colorado, in 1965. Also in that year, the President’s Science Advisory Committee formed a panel that addressed climate change, along with a host of other environmental issues (IPCC 2007; Weart, 2003).

Over the course of the next twenty years, the accumulation of data from various sources, especially from deep ice cores, gave more evidence of past climatic changes (IPCC 2007; Weart, 2003). One thing of major concern for many in the scientific community was the implication that the Earth, in the deep past, has been susceptible to large changes in climate on relatively
small time scales (100 years or less), indicating a great sensitivity of the climate to small variances in the levels of greenhouse gases (Broecker & Kunzig, 2008). One example may be an ancient “burp” of greenhouse gases from the sea floor which may have caused the warming of 5-8 degrees Celsius marking the end of the Eocene (Broecker & Kunzig, 2008).

During the summer of 1988, the United States experienced an intense heat wave that saw 69 cities experience monthly mean high temperature records in June alone (Heim, 1988). During this record heat wave, global warming received an unprecedented amount of press attention, when the U.S. congress held hearings on the weather events. NASA scientist James Hansen warned that the extreme weather events that were being experienced were a result of global warming due to an enhanced greenhouse effect (IPCC, 2007; Weart, 2003). In fact, he went further, claiming that the Earth is warmer in 1988 than at any time in the history of instrumental measurements (Bowen, p. 22).

An additional momentous event in 1988 involved the creation of the Intergovernmental Panel on Climate Change (IPCC), which was tasked with providing objective information about climate change, its causes, and its effects, to policy makers of all member nations (IPCC, 2007). The international body, made up of both scientists and government representatives, was charged with producing reports every 5-7 years on the current status of research on Global Climate Change. Reports were issued in 1990, 1995, 2001, and 2007, the last of which was called the IPCC‘s Fourth Assessment Report. Amongst the findings of this latest report were that:

- "Warming of the climate system is unequivocal…” (p. 50)
- "Most of the global average warming over the past 50 years is very likely due to anthropogenic GHG increases…” (p. 50)

The assertive wording of the 4th IPCC report is more striking when the composition of that panel is examined. It included a diverse group of thousands of scientists and policy makers from around the globe (IPCC, 2007). Such a large and diverse body of individuals would be unlikely to resort to alarmist hyperbole. Thus, when the IPCC used language indicating that the data currently overwhelmingly support the anthropogenic global warming hypotheses (IPCC, p. 72), it should not be construed as coming from an inherently alarmist organization. It is important to note that the views expressed by the IPCC are indeed consistent with the relevant scientific literature. For example, Naomi Oreskes, professor of History and Science Studies, analyzed 928 papers published in scientific journals between 1993 and 2003. She found that
none of the 928 papers disagreed with what was deemed the position of scientific consensus, that
the Earth is warming, on average, and that humans are very likely contributing to the warming
effect (Oreskes, 1994). Indeed, scientific publications which support the view that
anthropogenic climate change is ongoing are legion: Barnett, Pierce, & Schnur (2001) found that
a climate model structured around anthropogenic causes of GCC accurately accounted for the
observed heating in the past 45 years, and that there was less than a 5% chance that the
observations would have been made without human actions. Karl and Trenberth (2003)
describes that

Modern climate change is dominated by human influences, which are now
large enough to exceed the bounds of natural variability. The main source of
global climate change is human-induced changes in atmospheric composition. (p. 1719)

Hansen et al. (2006) found that global surface temperature has increased by 0.2 degrees
Celsius per decade in the past 30 years, in accordance with predictions made from previous
climate modeling based on anthropogenic sources. Rosenzweig, Karoly, Vicarelli, Neofotis,
Qigana, Cassassa, et al. (2008) later found that changes in physical and biological systems are
occurring on all continents and in almost all oceans”, and that the –increases at continental scales
cannot be explained by natural climate variations alone (p. 353)”.

The modern scientific community has an overwhelming acceptance of the assertion that
climate change via global warming is currently happening, on the average, at a known rate
(Hansen, et. al, 2006; IPCC, 2007). This rate is also thought to be commensurate with the
anthropogenic sources of carbon dioxide and other greenhouse gases being place into the
atmosphere, which accelerates the greenhouse effect that naturally occurs. In further support of
the scientific consensus emerging, the list of scientific organizations which have issued
statements supporting the notion that the evidence for human modification of the climate is
compelling: Intergovernmental Panel on Climate Change (IPCC), the American Meteorological
Society, the American Geophysical Union, the American Association for the Advancement of
Science, and the National Academy of Sciences (Oreskes, 2004).

The purpose of this section has been to underscore the salience of global warming and
global climate change, in both media and scientific circles, and also to support the notion that the
science behind global warming, including anthropogenic warming, represents a well-supported
scientific consensus. Next I address the status of global warming within the scope of educational policy and research.

**Educational Policy Concerning Global Warming or Global Climate Change**

Given the extreme importance of GW in the broader societal context, it is also necessary to examine the extent to which this science has been addressed as educational policy. Because the United States has no single, unified, curricular mandates regarding science content, a natural and fruitful place to examine is the landscape of reform documents and national and state science frameworks and initiatives. While these initiatives do not necessarily dictate curricula, examining them can give a sense of what is prioritized by their framers, who influence educational policy.

**Reform Literature, National and State Science Frameworks and Initiatives**

The science education reform literature, which would provide a nice starting point upon which to build state and national science frameworks, have had little to contribute on the subject of GCC. Project 2061 (AAAS, 1990, 1993) (a long-term project developed by the American Association for the Advancement of Science) in its early documents mentions climate change but not global warming. (AAAS, 1990, 1993). Given the vast scientific literature which supports the salience of anthropogenic causes of global warming (Barnett, et al., 2001; Hansen, et al, 2006; IPCC, 2007; Karl & Trenbarth, 2003; Rosenweig, et al, 2008) it is reasonable to examine educational literature for this aspect of consensus climate change science. The literature below is accordingly examined with the anthropogenic aspects of climate change being considered as crucial to a robust consideration of that branch of science. The only reference to climate change in those documents that actually makes a link to human activity states only this: —The landforms, climate, and resources of the earth’s surface affect where and how people live and how human history has unfolded. At the same time, human activities have changed the earth’s land surface, oceans, and atmosphere” (AAAS, 1993, p. 77).
In contrast, the National Science Education Standards (1996) were developed as a framework from which to develop a “scientifically literate populace”, outlining what students need to know, understand, and be able to do to be scientifically literate at different grade levels” (National Research Council, 1996, p. 2). The NSES, published in 1996, making them contemporary to the early AAAS (1990, 1993) documents, do not treat GCC in any detail. In the NSES only one mention is made of climate change and that is a simple statement is made alluding to how certain bodies of scientific knowledge, such as evolution or global warming, may constitute incompleteness, and that new data may well lead to changes in current ideas or resolve current conflicts” (NRC, 1996, p. 201).

The relative silence on GCC in the early reform documents was due to change, however and more than a decade later, the AAAS (2007) developed “Communicating and Learning About Global Climate Change: An Abbreviated Guide for Teaching Climate Change”, as an extension of Project 2061. The purpose of this document is to provide a guide that “maps out what students should be learning in kindergarten through 12th grade and describes what a science literate adult should know and be able to do” (AAAS, 2007, p. 3). In particular, the guide gives specific recommendations, such as standards that address GCC under the strand “Weather and Climate” for 3-5 graders (AAAS, 2007, p. 19). One of these recommendations is that students understand that “when warmer objects are put with cooler ones, heat is transferred from the warmer ones to the cooler ones” (p. 19). The year following this, the grade 6-8 portion indicates that the students should understand that “thermal energy is transferred through a material by the collisions of atoms within a material” (p. 19). Finally, at the 9-12 level, this is built into a more direct connection to climate, with an emphasis on “Transfer of thermal energy between the atmosphere and land…” (p. 19). AAAS’s Benchmarks for Science Literacy provide some specific recommendations for GCC. Included are notions of climates having been changed in the past by volcanic eruptions or impacts from space (8th grade benchmark), and the notion that burning fossil fuels “…in the last century has increased the amount of greenhouse gases in the atmosphere, which has contributed to Earth’s warming” (AAAS, 2008, p. 21). Thus there is a growing recognition among national leaders in science education that GCC can and should be a focus of science instruction. However, even such a modern resources as Communicating and Learning about Climate Change (AAAS, 2007) can be deemed as far from robust in that, as
shown above, it simply provides curricular links to GCC between various grade levels, and has little to suggest in the way of actual lessons or unit plans.

Given that the reform agents mentioned above have started to focus on issues of GCC as recommended for science frameworks, it is necessary to examine the frameworks of individual states. This is necessary to examine because in the United States no national body sets curricular requirements. Instead, the states perform this task. I conducted a study analyzing individual state science frameworks for the emphasis given to GW, GCC, and to anthropogenic sources (Golden, 2009). Frameworks scored a 4 if they had a benchmark itself devoted to issues of global warming and/or climate change AND a standard dealing specifically with anthropogenic causes. A score of 3 was given if the framework mentioned both GCC and possible anthropogenic causation. A score of 2 indicated that the framework merely mentioned GCC or GW, along with a vague reference to human effects. A 1 was given only if the framework had no mention either of global warming, climate change, or human contributions to such. In this analysis, I found that few states scored very poorly in their coverage of GCC or GW. Eighteen of the 50 states earned the lowest grade possible, indicating that they did not mention climate change or global warming. Only four states earned the highest grade (4), indicating that they recommended a robust treatment of global climate change, with an emphasis at least on the possibility of human-induced changes (Golden, 2009). In the state in which this study was conducted, Florida, the science framework went through a very recent modification (State of FL, 2009). Part of that modification involved the creation of an entire strand devoted to the Nature of Science (NOS). However, even this recent version of a state science framework scored only a 2 out of a possible 4 points. Florida’s standards did mention both climate change and global warming, but failed to give explicit attention to a likely anthropogenic cause (Golden, 2009). Given that the states, for the most part, developed their frameworks after the reform documents came into being, and well after this science started to become very public, it is noteworthy that this topic is given such little relevance by most state documents. Also, it is reasonable to infer that if state and national science frameworks do not emphasize GCC material, then it is likely not widely emphasized within the school systems whose curricula are tied, to varying extents, to those frameworks.

The above section would support the argument that GCC-related curricula are likely not in widespread in U.S. schools. However, there has been some research conducted on the
learning of GCC within K-12 systems. I now turn to examine what has been learned in these areas.

**Research on learning about GCC**

In researching literature relevant to GCC education in secondary settings, a trend emerged. Researchers either tended to focus on the content/conceptual aspects pertaining to GCC, including the greenhouse effect, or they focused instead on the Nature of Science, with conceptual aspects of GCC being of ancillary interest. Following is a brief discussion of the scant literature relevant to learning about GCC within secondary school environments.

**GCC & Greenhouse Effect**

Several authors have reported research findings concerning the greenhouse effect. Boyes and Stannisstreet (1993) investigated Australian 11-16 year old’s understandings of the greenhouse effect through a combination of survey and interview data. They found that the notion that the greenhouse effect might change weather patterns was widespread, while the mechanism of global warming was poorly understood. Koulaides and Christidou (1999) conducted research using semi-structured interviews of 11-12 year old Greek students. These students were asked to describe their understandings of the greenhouse effect. Koulaides and Christidou found several patterns that were problematic for students’ understanding of the greenhouse effect, including a conflation of the greenhouse effect with the ozone hole, difficulty in making distinctions between varying forms of radiation, and difficulty in understanding the distinction between sunlight and terrestrial radiation. These findings were buttressed by Andersson and Wallin (2000), who researched Swedish 9th and 12th grade students. As part of a large national test, these students were asked in a written prompt, to explain the greenhouse effect. They found that the notion of trapping the outgoing radiation is difficult to understand, even at those grades, and that those students still had trouble in differentiating between the greenhouse effect and the ozone layer/hole. One item missing from this research on students’ understanding of the greenhouse effect is a focus on anthropogenic causes.
Schuster, Filippelli, and Thomas (2008) researched students’ climate change understandings as part of an effort to understand student mentorship models between high school and middle school students in the Midwestern United States. In a series of interviews and concept-map exercises, they found that middle school students’ initial understandings of climate change were significantly “limited in scope”, even while the students previously reported familiarity with the concept of GCC. In particular, the students seemed familiar with terms such as deforestation and fossil fuels, but not terms like “ice core” and “paleoclimate”. Therefore, students had some understanding of key terminology, but little understanding of key sources of data for GCC.

Shepardson, Niyogi, Choi, and Charusombat (2009) conducted research on 51 secondary students (grades 7, 8, 10, 11, and 12) in the Midwestern United States about their conceptions of global warming. An assessment instrument was given to these students, which featured 5 open response questions. These questions included asking students to draw and explain the greenhouse effect, and to interpret a commonly used scientific graph. Similar to previous research, they found that students were confused about the greenhouse effect, particularly in regard to aspects of radiation. It is interesting that they did not find the conflation of the greenhouse effect and ozone hole found in previous research. Shepardson et al. also found that when students explained the CO$_2$ and temperature graph, they did not necessarily see it as evidence for global warming, with some even claiming that the temperature increases caused the CO$_2$ increases shown in the graph.

Note that the extent of research on learning about issues of GCC in the secondary educational settings is indeed sparse. This paucity delineates the need for this present research.

**GCC and the NOS**

Some research involving issues of GCC education are found in literature primarily dealing with Nature of science (NOS) issues. As GCC is fraught with issues of weight of evidence and judgment of knowledge claims, and because it is still considered by the lay public to be controversial, its learning is intimately linked to NOS as will be described.

The nature of science (NOS) refers to “…a set of underlying principles describing what makes science –science” (Southerland, Johnston, & Sowell, 2006). This includes the
characteristics of scientific knowledge, the epistemology of science, its presuppositions, methodological assumptions, goals, and boundaries, as well as the conventions underlying the knowledge produced through science (Lederman, 1999). Although there is little unanimity as to NOS amongst philosophers, scholars of the science education community agree in its applications for use in K-12 education. Critical elements of the NOS include that scientific knowledge is tentative, yet durable; empirically based; subjective; the product partially of human creativity and imagination; socially and culturally embedded; uses observation and inference (Abd El-Khalick & Akerson, 2004); and that the NOS itself is bounded in nature (Southerland et al., 2006). It is argued that an emphasis on teaching the nature of science goes hand in hand with an understanding of the practices of science (Hodson, 2008). Because the understanding of GCC science is so contingent upon understanding how to evaluate varying evidence claims and sources, and considered controversial in some circles, then the links between students‘ conceptions of GSS and the NOS are evident.

Sadler, Chambers, and Zeidler (2004) were among the first to examine the issues of GCC education in regard to the NOS. Responses from 84 high school students were given conflicting accounts by ‘experts’ to read, one supporting the hypothesis that global warming is a real problem, with the other article stating the opposite. Focusing particularly on the NOS tenets of empiricism, tentativeness, and social embeddedness, they found that students had trouble separating data from opinions, and that students had difficulties in grasping the empirical nature of science. Although students were most convinced when presented with things consistent with their prior beliefs messages with a sense of personal relevance were also very persuasive to them. That is, if the students felt that they could personally relate to discussed consequences, then they may evaluate decisions differently. Note that the researchers who focus on the relationship between NOS and GCC tended to use global warming as a substrate within which to embed the nature of science. That is, the issue of GCC was not the central issue, it was simply a means to an NOS end.

At least one study found that when using GCC as a context within which to address the nature of science, that the results were inconclusive in terms of successful learning of the NOS tenets (Khishfe & Lederman, 2007). Other researchers focused on the integration of NOS and GCC have found that placing NOS within the context of global warming was indeed useful for enhancing understandings in more than one area. Matkins and Bell (2007) found that, at least in
an elementary methods course, contextualizing NOS within GCC led to improved conceptions of both NOS and GCC over the course of the term. This gain in both sets of understanding was achieved through a carefully planned set of activities over the course of the term, including eliciting prior knowledge about GCC in a class discussion, NOS activities such as the mystery tube, in which students are asked to examine a tube with four holes in it, through which strings protrude, which the students can manipulate by pulling on one end and seeing the effects, if any, on its opposite number, and interactions with a faculty member from the department of Environmental Science.

Clearly, GCC is a very complicated scientific concept that has scarcely been incorporated into educational strategies in the United States. Given that an understanding of GCC requires a familiarity with a myriad of pieces of evidence across different fields, an understanding of scientific models, and an understanding of the extent to which consensus exists amongst a shared scientific community, it is understandable that it has not been dealt with extensively in classrooms. It certainly does not lend itself to a quick or easy lesson that a teacher can readily "cover" in order to satisfy his or her needs for state and/or federal mandates like No Child Left Behind (NCLB), which can be perceived as pressure to "cover" more material in superficial ways (Southerland et al., 2007).

From this literature review related to GCC and education, several conclusions can be drawn. First, the science of global climate change has become increasingly robust to the point of overwhelming consensus amongst climate scientists. Second, that the research literature looking at the extent to which GCC/GW has been addressed in the U.S. educational system is marginal, although a few findings emerge. Some literature exists showing the difficulty of learning the greenhouse effect, partly due to confusion with the ozone layer/hole (Andersson & Wallin, 2000). Also, the literature that does exist governing GCC largely concerns other things, and treats the climate science as a means to an end, for example, focusing on students’ understanding of NOS. Additionally, the research concerning GCC education generally does not treat in a meaningful way the anthropogenic contributions to climate change. The only exception found is the work of Shepardson et al. (2009). A fourth finding that emerges from the literature review is that the national and state science frameworks do not address GCC in anywhere near the seriousness that seems warranted, given the recent scientific consensus and worldwide media attention. The extent of the coverage of GCC has been minimal in nearly all such frameworks.
and the attention paid to any connection with human activity is negligible in the vast majority of these documents.

**Conceptual Change Theory**

Given the sometimes controversial nature of GCC and GW in the general public, in order to adequately comprehend the various factors that contribute to students‘ understandings of such complicated subject matter, I needed a theoretical framework that can adequately account for students‘ expressed verbal and written understandings, socio-cultural interactions with peers and teacher, his or her belief systems, and other rational and extra rational factors that may impact a student‘s learning of a difficult concept. Therefore, I have chosen a model of conceptual change that allows me to understand these various facets of learning that is the framework theory (Vosniadou, 2007a, 2007b). The framework theory posits conceptual change as a complex process involving not only personal psychological factors, but also socio-cultural, affective, and other extra rational factors. However, prior to examining what this particular model portends for the present research, it is necessary first to examine some of the history of conceptual change theory, in order to understand the origins of the framework theory.

Conceptual Change Theory (CCT) was borne out of a famous work of philosophy of science. Thomas Kuhn (1962), in his groundbreaking –Structure of Scientific Revolutions‖, reacted against the linear representations of science as depicted by many philosophers of science, and instead advocated that scientific ideas go through occasional periods of crisis, during which anomalies accumulate, and may eventually result in a –paradigm shift‖.

Kuhn‘s ideas influenced many scholars of education, who were looking for frameworks to describe how scientific concepts are learned (Driver & Easley 1978; Viennot, 1979). Some (Posner, Strike, Hewson, & Gertzog, 1982) drew directly from Kuhn in the sense that the sense in which their model of conceptual change posits that the fashion in which scientific theories undergo change provides an analogy for how students —change their alternative frameworks and replace them with the scientific concepts instructed at school‖ (Vosniadou, 2007b, p. 9). For Posner et al., such conceptual change required four preconditions:

1. A dissatisfaction must already be present in existing conceptions;
2. A new conception must be readily intelligible;
3. The new conception must appear to be plausible;
4. The new conception should suggest the possibility of a fruitful research program.

The first requirement for conceptual change listed above simply refers to the idea that the student must be cognizant that her present understanding may not fit with new and/or anomalous data, while desiring/needing to resolve this dissatisfaction. In order for the new conception to be intelligible, the individual must be able to understand the concept in a way that allows him/her to explore within the concept. To meet the criterion of plausibility, the individual needs to see the concept as a tool with which some of the dissatisfying problems can be solved, and: a ‘fruitful research program’ means that the concept can be extended towards new, previously unanticipated areas.

This view of conceptual change infers that the student is analogous to a scientist, in that the process of learning is thought to be akin to the scientific process of theory change. Given this framing, within this theory the process of conceptual change is thought to be largely if not purely rational, and that given the proper cognitive prodding or conflict, the conceptual change is likely to be fairly rapid. This rapidity was questioned by some who claimed that conceptual change is mitigated by the various extra rational factors such as motivation, self-efficacy, prior knowledge, etc (Pintrich, Marx, & Boyle, 1993). Given the reliance of the original conceptual change model on a largely rational, empirically driven learning process some authors effectively labeled the model as “cold” conceptual change (Pintrich et al., 1993). In refuting the view of purely rational factors as the sole agents of conceptual change, Pintrich et al. took the contrarian position that the process of conceptual change is influenced by personal, motivational, social, and historical processes, thereby advocating a “hot” model of individual conceptual change” (p. 170). Advocates of “hot conceptual change” pointed out the need for the inclusion of affective and motivational factors (Pintrich et al., 1993; Sinatra & Dole, 1998; Vosniadou, 1999).

**Affective Aspects of Conceptual Change.**

Given these critiques, conceptual change theory underwent significant revisions to incorporate various extra rational factors, including the addition of affective factors. The team of Strike and Posner (1992) themselves improved upon their model in the revisionist theory of conceptual change, stating that “motives and goals [for the change] and the institutional and social sources of them need to be considered” (p. 148). Although there is no unanimous
consensus as to what these affective factors are, one important view is that affective traits are predispositions towards emotional responses that tend to remain stable throughout a lifetime (Rosenberg, 1998). These affective factors include emotions, attitudes, motivation, and beliefs (Sinatra & Mason, 2008; Strike & Posner, 1992). Any of these affective factors can have a significant impact upon learning, whether it is facilitative or inhibitory. One example of this is anxiety. Although anxiety is often perceived as a negative emotion, and therefore inhibitory, it can lead to improved learning if it is perceived as an opportunity for growth (Sinatra & Mason, 2008).

Self-efficacy beliefs can be an important affective factor. Self-efficacy refers to individuals’ judgments on how well they will be able to perform in given situations” (Bandura, 1986, p. 3). Although higher self-efficacy may seem to be desirable, Pintrich (1999) cautions that its impact may be positive or negative. For example, a student's high self-efficacy may indicate that she is confident in her abilities to learn by changing her ideas, or instead the high self-efficacy may indicate a confidence in her existing ideas, such that changing her mind may be unlikely (Pintrich, 1999).

Another example of an affective consideration is dissatisfaction. Some models posit that in order for conceptual change to occur, the learner must encounter a sense of dissatisfaction with his or her current conception (Dole & Sinatra, 1998; Gregoire, 2003; Strike & Posner, 1992). For such models, the affective component is a required component of the conceptual change itself. For example, the concept of dissatisfaction with a current framework is critical prior to engaging in any lasting conceptual change. Beliefs are another affective consideration that may impact conceptual change. For example, religious beliefs may be important factors in determining conceptual change. For many students, religious beliefs may predispose them to either accept or not accept a particular scientific explanation for a phenomenon such as evolution through natural selection, particularly if that scientific view is perceived to be at odds with his or her religious belief system. However, the learner’s religious beliefs in total may not be the determining factor in such a case (Demastes, Good & Peebles, 1996).

Epistemological beliefs have also been found to be important in conceptual change (Nussbaum & Sinatra, 2003). Epistemological beliefs refer to beliefs about how knowledge is acquired, in other words, beliefs about how learning happens. Such beliefs are critical to this research in that one learner may simply not value or privilege the same sources of knowledge as
others, including the teacher, influencing the learning that can occur. Epistemological beliefs can be very important in a science classroom in many ways, including the understanding of how scientific knowledge is generated and accepted. If a learner does not privilege such things as scientific consensus through science research and journals, possibly because she values the opinions of esteemed friends or relatives, then he or she may have a radically different learning trajectory from the desires of the instructor. This is important to account for from the framework of conceptual change theory, in that the instructor is presumed to be interested in helping this student understand not only the norms associated with scientific knowledge creation, but also to help the student understand his or her own epistemological values.

In these discussions it is important to focus on the outcome of conceptual change. The most obvious outcome of conceptual change is an increased understanding of the concept, and an understanding is a well received and uncontroversial goal of science teaching (Smith & Seigel, 2004). However, it is commonly accepted that focusing on a student’s belief in a concept is not an appropriate goal. In that science learning should be based on a rational evaluation of empirical evidence, belief (in which one takes on faith a knowledge claim), seems to be antithetical to rigorous science teaching. Instead, a teacher may use the goal of acceptance as appropriate. Smith and Seigel (2004) describe acceptance in science as understanding that the theory in question affords the best current scientific account of the relevant phenomena based on the available empirical evidence. While most science teachers focus on acceptance, often, particularly in matters of personal welfare and environmental education, a teacher might also hope students come to accept the knowledge claims presented, understanding that such acceptance is an important step in guiding action.

Regardless of the learner’s personal stance, my goal of my research is to describe students’ understandings of GCC, along with a description of how he or she comes to that particular understanding.

The relationship between acceptance and conceptual change is itself contested among many theorists (Bishop & Anderson, 1990; Demastes-Southerland, Settlage, & Good, 1995), particularly in relation to controversial subjects such as evolution. Some argue that understanding does not necessarily guarantee acceptance (Demastes et al., 1995). Indeed, these same authors have found that understanding of scientific ideas such as evolution need not necessarily be accompanied by acceptance (Demastes, 1994, 1995). This research not only examines students’ acceptance or nonacceptance of ideas, but the reasons given for such
acceptance/nonacceptance and relate this to the understandings students generate. The context of argumentation assisted me in uncovering these connections.

**Context of Conceptual Change**

Although the addition of affective and motivational factors have significantly broadened the considerations one might make when examining conceptual change, others focus on the location or context of that change. Caravita & Halden (1994) and Hatano (1994) argue that other contextualized factors, such as situational and sociological contexts, play an important role in explaining conceptual change.

Another historical tension seen in conceptual change has been termed the “cognitive-situative divide” (Vosniadou, 2007a, 2007b). Some perspectives of conceptual change have belonged in the cognitive camp, by virtue of their emphases on personal, psychological processes. Greeno, Collins, and Resnich (1996) describe the cognitive perspective as one that treats knowing as having structures of information and processes that recognize and construct patterns of symbols in order to understand concepts and exhibit general abilities, such as reasoning, solving problems, and using and understanding language. The cognitive perspective invokes a model of knowledge as something that exists in the minds of the individual, which can be acquired, developed, and changed (Vosniadou, 2007a). Although the Strike and Posner (1992) model is an example of a conceptual change model emphasizing the cognitive aspects of learning, it is by no means the first model to understand conceptual change. In fact, its intellectual forebears can be traced back as far as the work of Jean Piaget, whose work on learning posited individual, internal aspects of learning. He described assimilation, in which new information gets readily absorbed into an existing knowledge structure, and accommodation, in which new information causes some structural changes in the individual’s understanding (Piaget, 1985).

In contrast, the situative perspective, exemplified by the situated learning of Lave & Wenger (1991), treats knowledge not as discrete units within an individual, but as a process that “takes place among individuals, the tools and artifacts that they use, and the communities and practices in which they participate” (Greeno et al., p. 20). The situative perspective considers knowledge as embodying the metaphors of participating, knowing and doing, all as part of particular sociocultural activities (Lave & Wenger, 1991; Rogoff, 1990). Examples of such activities in the situative learning scenario include apprenticeships in thinking (Rogoff, 1990), or
legitimate peripheral participation (Lave & Wenger, 1990). Again, the situated perspective has long philosophical roots, this time in the social psychology of theorists such as Lev Vygotsky, for whom knowledge building was an inherently social process (Vygotsky, 1978).

Recent work in conceptual change theory has attempted to address perceived weakness on each side of the cognitive/situative schism. One such model is the Cognitive Reconstruction of Knowledge Model (CRKM) by Dole and Sinatra (1998). This model begins with the learner's existing conception regarding an event or topic. The existing conception is to be assessed in terms of its strength, coherence, and commitment (Dole & Sinatra, 1998). Another important aspect of the learner in the CRKM model is their motivation to process the new information.

Unlike the classical model of conceptual change, motivation, as invoked by the CRKM, is more than just dissatisfaction (Dole & Sinatra, 1998). Other potential motivating aspects of the learner include the personal relevance, which includes an already existing interest in the topic, emotional involvement in the topic, or high or low self-efficacy in relation to the topic; the social context, including peer interest in the topic; and the need for cognition, which attempts to account for those learners who are intrinsically motivated to pursue intellectual activity for its own sake (Dole & Sinatra, 1998). In addition to the above aspects of the learner his or herself, aspects of the message need to be accounted for as well in the CRKM. Important aspects of the message include its comprehensibility, coherence, plausibility, and rhetorically compelling nature (Dole & Sinatra, 1998). In other words, a message is unlikely to yield conceptual change if the learner cannot understand it, if the person does not find it credible, or if the learner does not value the sources or justifications for the message (Dole & Sinatra, 1998). Once the above aspects of the learner and message are in place, conceptual change is not guaranteed in the CRKM. Instead, the last requirement is engagement (Dole & Sinatra, 1998). A classroom featuring a high level of metacognitive engagement is necessary, but not sufficient for strong conceptual change. The situation with the most promise for strong conceptual change would involve intentional learners, or students with metacognitive awareness and control over their own learning (Berieter, 1990), in an environment featuring high engagement.

Another recent model of conceptual change which attempts to broach the cognitive-situative divide is the framework theory approach of Vosniadou (2003, 2007a). In this domain-specific view of conceptual change, the items that need to be changed are not the students' misconceptions, but instead the naïve, intuitive, domain-specific theories constructed early in
childhood, on the basis of everyday experience under the influence of lay culture” (Vosniadou, 2007b, p. 4). These naïve theories refer to “relatively coherent body of domain-specific knowledge that can give rise to prediction and explanation”, but not “an explicit, well-formed and socially shared scientific theory” (Vosniadou, 2007b, p. 11). These theories are considered to enable learners, even very young ones, to make predictions concerning unfamiliar entities. These naïve theories are thought to help the learner “function more efficiently in everyday life” (Vosniadou, 2007b, p. 11) and to develop throughout their experiences in lay culture, either by enriching or restructuring existing knowledge structures (Vosniadou & Brewer, 1987; Vosniadou, 2007b). In the framework theory, conceptual change is posited to occur either by bottoms-up or top-down means. Bottoms-up means can include Piagetian processes such as assimilation or accommodation (Piaget, 1985) or Vygotskyian internalization (1978). Top-down processes include the deliberate use of models, thought experiments, and analogy (Vosniadou, 2007b). The key differences between bottom-up and top-down mechanisms refers simply to whether the change is initiated by phenomena perceived by the learner, or is initiated in more of a gestalt context, a whole-picture idea, often initiated by others, such as a teacher.

An example of bottom-up conceptual change cited by Vosniadou concerns plant growth. A young learner's experience with plants, after noticing that plants become larger as they grow, and indeed eventually die, leads them to consider plants as living things instead of inanimate objects. This represents a conceptual change sometimes known as branch jumping (Thagard, 1990) or an ontological shift (Chi, 1997). Vosniadou argues that this sort of additive, bottom-up conceptual change is not productive in terms of instruction-induced conceptual change, as learning science requires that children learn a counter-intuitive theory quite different from their naïve theories (Vosniadou, 2007b). In addition, the extent of time required for such models of conceptual change may simply make the practice untenable as an instructional strategy. An important outgrowth of the interaction of naïve theories with learning science in the classroom is the development of synthetic models. These models are developed as children assimilate new scientific information into an “existing but incompatible knowledge base, implicitly and without metacognitive awareness” (Vosniadou, 2007b, p. 12). An example of such a synthetic model involves the day and night cycles experienced by young learners. Often, night is interpreted as happening when the sun goes down and the moon comes up, etc. This implies a naïve model of
physics in which the Earth is a stable, stationary object with the sun and moon above the top of it. This is a view radically different from currently accepted scientific models.

In addition, students are known to sometimes misinterpret scientific models in ways that add to the fit of their naïve models in a way similar to Piagetian assimilation. For example, as long as the students think that the Earth is a flat, stable body, they cannot understand that it moves in any way related to the cycle of day and night (Vosniadou, 2007b). It is not until they understand the spherical nature of the Earth that they can begin to change their initial model of the Earth and its place in space.

The framework approach also posits that each student’s initial framework is largely informed by their ontological and epistemological understandings (Vosniadou 2007a). For example, in her research in elementary students’ conceptions of the Earth, she found that these children had ontological understandings that consisted of solidity, stability, and up/down axes (Vosniadou, 2007a). These children’s epistemologies consisted of understanding that things were indeed as they seemed to be (Vosniadou, 2007a, 2007b). Therefore, I deemed it necessary to capture these aspects of the students’ understandings of GCC.

The framework theory of conceptual change is an improvement on the classical model (Posner et al. 1982) in many ways. First, it focuses on misconceptions not as discrete, incorrect conceptions, but on a complex, intricate knowledge system. Second, it distinguishes between naïve explanations and those resulting from the learners’ attempts to synthesize new information. Third, the framework theory invokes a constructivist theoretical position, enabling it to explain the building of new understanding on the existing knowledge structures. Also, it positions conceptual change not as the replacement of incorrect ideas or theories with the correct ones, but the “opening up of conceptual space through increased metacognitive awareness, creating the possibility of entertaining different perspectives and different points of view” (Vosniadou, 2007b, p. 15).

**Domain specificity of conceptual change**

Conceptual change is necessarily domain-specific (Vosniadou, 2007a, 2007b), in that changes in one area may or may not effect conceptual changes in other content areas. For this reason, and because this research seeks to understand conceptual change within a particular science content area, I will examine some examples of content-specific conceptual change research here. Domain-specific conceptual change research exists on a number of scientific
topics, especially physics/astronomy and psychology. For example, children's conceptions of the Earth has been shown to change considerably between ages 4-6 and 10-12 (Vosniadou & Brewer, 1992). Younger children consider the Earth a flat, geocentric object, whereas 10-12 yr. olds tend to think of the Earth as a heliocentric object located in space. In between these two different notions of Earth, a large conceptual change has taken place. In the field of biology, Demastes, Good, and Peebles (1996), found four patterns of conceptual change in high school students' understandings of evolution. These included cascades of changes, in which one change initiated a series of changes, wholesale changes, in which one way of thinking was completely replaced by another, incremental changes, in which smaller changes were recognized in their thinking, and dual constructions, in which students held onto seemingly incommensurate ideas at the same time. Interestingly, classical conceptual change theory could only account for two of these patterns (cascades and wholesale).

In conclusion, the framework theory of conceptual change is an appropriate framework for me to understand the learning encountered in this research. This is because, unlike other models, it helped me to understand the entirety of the frameworks held by the learners in a way that helped the synthesis of their understandings with the desired understandings. The framework theory will also help me to capture the extra rational components of the learning, which may range from prior beliefs (religious or secular), self-efficacy, epistemological views about which sources constitute privileged information, and interpersonal, social issues such as peer relationships. This framework theory of conceptual change is particularly appropriate when considering that it is combined with an argumentation model that is well-suited to generate these data.

Methods Employed in Conceptual Change Research

In this section, I will attempt to describe some of the general methods used in the conceptual change research pieces cited above. The methods used by the above authors in researching conceptual change tend to focus on written explanations and open-ended interview questions (Dole & Sinatra, 1992; Vosniadou & Brewer, 1992; Vosniadou, 2007a, 2007b). That is, conceptual change research privileges qualitative data that is open-ended. These data are necessary in order to understand the conceptual understandings of students. For example, Vosniadou and Brewer (1992), trying to learn about the mental models held by young students
about the earth, asked the students a series of questions such as —what is the shape of the Earth?” These interviews allowed the researchers to follow up and ask for clarification concerning their understandings. Important findings included the idea that students can simultaneously hold contrasting models of “Earth”, one being a spherical object in space, and the other a flat model, referred to as “the ground”.

In order to describe students’ conceptual change as they learned about biological evolution, Demastes and her colleagues (1995, 1996) conducted their research in a setting purposefully selected because of the instructional approach employed the teacher in teaching evolution. Indeed, given the emphasis the topic received in this classroom and the student centered nature of classroom instruction, the setting was selected as a “best case scenario” to foster and thus allowed for a thick description of students’ conceptual change for evolution. The qualitative data sources were varied, including journal entries, artifacts produced by the students, and multiple structured interviews conducted amongst a purposefully selected subsample of students. Using these varied data sources allowed them to confidently assert four different patterns of conceptual change encountered amongst the students.

Common threads found in the methods used by conceptual change researchers include many of the hallmarks of good qualitative research: careful purposeful selection of participants and setting, triangulation of methods and data sources, and especially a heavy emphasis on analysis of interview data. Through these methods, I can be more confident that I have documented conceptual change, as opposed to some other form of learning, such as merely miming key vocabulary, etc.

The implications of conceptual change research for the structure of this research

This research seeks to invoke a model of conceptual change that does not stop at the cold rationality of the cognitivist position, nor at the situative extreme, in which knowledge itself has little meaning for an individual. Instead, for the purposes of this research, I view conceptual change within the framework theory of conceptual change (Vosniadou, 2007b). That is, in this research I view conceptual change as: “hot”, that is, affected by many extra rational factors, including motivation; something that builds on prior knowledge and conceptions, as opposed to simply casting such as incorrect or even “misconceptions”, and which also acknowledges that all
conceptual change is inherently specific to a certain domain of content knowledge. Additionally, I consider the concepts to be changed as not just discrete parcels of knowledge, but instead parts of a framework that the learners have used with some success in their experiences, but which need help to synthesize with accepted scientific explanations. The framework theory approach also compels me to consider that “teaching for conceptual change cannot be achieved through cognitive means alone but requires extensive socio-cultural support” (Vosniadou, 2007a, p 12). This sociocultural support required for conceptual change is something that can be provided by the method of argumentation. Indeed, the particular pedagogical model of argumentation invoked, Argument-Driven Inquiry (ADI), seems ideally suited to provide exactly such support. Together, the framework theory of conceptual change and the pedagogical method of ADI helped me to understand a best-case scenario for learning about GCC.

**Argumentation**

In lay terms arguments often are thought of as terms indicating a rhetorical position, with the goal being persuasion rather than explanation (Sampson & Clark, 2008b). However, scholars of argumentation use the term “argument” in a much different sense. Instead of the traditional, oppositional form of argument, they place the emphasis on dialogical, knowledge-building, collaborative forms (Mortimer & Scott, 2003, Sampson & Clark, 2008b). For these scholars, the “argument” itself becomes an opportunity to openly dialogue with peers in a manner which prioritizes the co-construction of evidence-based explanations (Windschitl, Thompson, & Braaten, 2008). This recent emphasis on argumentation has been justified within a move from positivistic grounds, where science has traditionally been situated, to a more constructivist representation. This is thought by many scholars to reflect the actual work of practicing scientists in the pursuit of scientific inquiry. That is, they consider different modes of investigation, interpret results amongst alternative theories, and argue in the public domains of conferences, journals, and other media (Driver, Newton, & Osborne 2000). Because of this, some argue that to help students engage with scientific claims, science education “must give access to these forms of argument through promoting appropriate classroom activities and their associated discursive practices” (Driver et al., p. 288). Thus, much of the motivation for argumentation can be seen as an attempt to better teach science by having students experience much of those discursive practices that actually result in the production of scientific understanding. A very important aspect of this involves the expectation that in opposition to
memorization of scientific information, students should instead generate their own arguments that unite evidence and theory (Driver et al., 2000; Sampson & Clark, 2008,). In order to do this, however, the epistemological criteria in science need to be explicitly examined.

Although there is not total agreement as to how to define argumentation, nor to differentiate it from ‘argument’, a useful understanding of the two terms has been given by recent scholars (Sampson & Clark, 2008). The term ‘argument’ describes the ‘artifacts students create to articulate and justify claims or explanations’, while ‘argumentation’ refers to the process of generating those artifacts (Sampson & Clark, 2008, p. 448).

**Some historical examples of Argumentation Patterns**

Toulmin’s Argument Pattern (TAP) (1958) presented an initial model showing the basic elements of argumentation. He invoked four components: data, claim, warrant, and backing. Data include facts involved in the argument that are appealed to for the claim’s support. Claims are the conclusions whose merit is being explored. Warrants are the reasons that justify connecting data and the given claim. Backing includes the basic assumptions that provide justification for a given warrant. Therefore, the structure of the TAP can be thought of as grammatically as: because (data)…since (warrant)…on account of (backing)…therefore (conclusion) (Driver et al., 2000). This constitutes one framework for examining patterns of argumentation.

![Toulmin's argument pattern](image)

**Figure 2: Toulmin's argument pattern (Toulmin, 1958)**

An example of the TAP can be seen in the following argument between two students:
S1: the space shuttle has escaped Earth’s gravity. [CLAIM]
S2: How so?
S1: It floats in space—it doesn’t have to run its engine (DATA)
S2: What does that mean?
S1: The space shuttle has to blast its rocket engine in order to escape Earth’s gravity. It then turns off its engine, and floats in space. So it is no longer in gravity. [WARRANT]

Note that the argument above begins with a claim, simply that the space shuttle has escaped Earth’s gravity. Student 1 then offers evidence to support the claim, in the form of data, in this case, the space shuttle doesn’t need its engine to float in space. The student then links the claim specifically to the data invoked by using a warrant, or stating that the shuttle needed its rocket motor only to escape the Earth’s gravity. Any such statement that explicitly links data to the claim is considered a warrant. Note that while this is a viable argument according to the TAP, it is fraught with naïve conceptions of gravity.

Although Toulmin’s argument pattern has proved influential in examining the nature of argumentation, other models have since added other components or changed their focus somewhat. One particular example is the issue of domain specificity. Toulmin’s argument pattern was domain-general, that is, it can be applied regardless of the content. Although some scholars have come up with revised versions of domain-general argument models (Schwartz, Neuman, Gil, & Ilya, 2003) others have invoked domain-specific argumentation analysis frameworks (Lawson 2003; Sandoval 2005; Sandoval & Millwood, 2005; Zohar & Nemet, 2002).

In terms of an argumentation framework, this research compels me to choose one that will allow me to readily assess arguments as constructed by 6th grade students with little experience in constructing explanations from evidence. This is particularly necessary given the relatively unsophisticated frameworks that they may be likely to have entering into a unit on GCC. Also, given the complexity of GCC, it is best to adopt a relatively simple model that can allow me to assess their arguments relatively quickly. A simple model has the added advantage of being more readily understood by the age range in question (12-13 year old students). This has a pedagogical advantage, in terms of less class time being spent on learning the argumentation pattern, and more time focused on developing content-based arguments. Therefore, I have chosen to use a modified Toulmin Argument Pattern for this research, following Sampson (2007). However, some modification was necessary in order to make a Toulmin-inspired approach more consistent with science education reform (NRC, 1996) and also to help translate scientific argumentation to the 6th grade level. The Toulmin Argument Pattern
breaks down a scientific argument into two components: the conclusion, and reasons (See Figure 2). The conclusion is thought of as an explanation, conjecture, answer to a research question, or another claim, while “reasons” include observations and measurements (data) that have been interpreted by the researchers or accepted theories, laws, and models in science. Note that a complete scientific argument is thought to unite the reasons with the conclusions, stating clearly how the reasons support the conclusions, etc.

In this framework, the goodness of the argument is gauged by three sets of criteria: Empirical, Theoretical, and Cognitive criteria. Empirical criteria cover such things as evidence and data quality. Theoretical criteria address the adequacy and usefulness of the conclusion, as well as its consistency with other theories, models, or laws. Cognitive criteria include explanations of how the reasons support the conclusion and why the reasons were included. This model concedes overall that scientific practice is influenced by discipline-based norms that may vary greatly within specific sub-disciplines of science. Therefore, this model is implicitly very domain-specific.

Argumentation has been shown to be a particularly fruitful construct for science educators. There is evidence that focusing on argumentation increases the motivation of students to communicate their thinking in relation to conceptual and epistemic goals (Millar & Osborne, 1998). Several authors have concluded that engaging in argumentation also enhances understandings of the nature of science (NOS), possibly due to the increased opportunities to participate in aspects of the nature of science (Driver, Newton, & Osborne, 2000). Others have shown that argumentation enhances the understanding of content knowledge in different domains of science Sandoval & Reiser, 2004). Another way in which argumentation has been shown to be helpful is in encouraging learners to develop different ways of thinking (Kuhn, 1993; Sandoval & Millwood, 2005). Finally, argumentation has been shown to improve the investigative skill and understanding of what of students by framing the goal of inquiry as an effort to understand natural phenomenon and then articulating and convincing others of that understanding which encourages students to investigate more systematically (Sandoval & Reiser, 1998).

*How argumentation enables learning*

Although there is ample evidence that argumentation does catalyze learning in the ways mentioned above, there is little agreement as to how it does so. One potential model for the
learning fostered by argumentation is that of sociocognitive conflict (Sampson & Clark, 2008b). That is, the process of argumentation produces interactions with peers that produce discrepancies between her views and new information, which then produces cognitive conflict. This is an understandable outcome of argumentation, in that the process involves the favoring of conflict and the examination of one's ideas concerning that conflict/issue.

Another model invokes the internalization of group products and processes as a mechanism for argumentation (Sampson & Clark, 2008b). That is, by engaging in argumentation as a group, and coming to certain conclusions as a group, then the individual may benefit from the collective social problem-solving that takes place, and therefore internalize that solution and/or process (Webb & Palinscar, 1996). This process works in a manner consistent with the ideas of Lev Vygotsky (1978), who describes that learning is very much a social process, as opposed to the then-prevalent notion of learning as an individual’s acquisition of new understanding without the need for social interaction.

A third model for how argumentation allows for learning is that it enables learning by virtue of imitation/modeling alone. That is, students may well learn skills, behaviors, understandings, etc., simply by observing his or her peers and choosing an explanation given by them. That is, if a learner believes her own understanding to be lacking, she may use the argument as a tool from which to choose a better explanation or answer (Leitao, 2000). In this way, the perceived benefits of argumentation may be overstated, in that the student is simply imitating a view she perceives to be better. However, even such students, whose actions may be very passive indeed, may well benefit from the multiple opportunities given through argumentation to listen to the various explanations rendered by others (Leitao, 2000).

Although each of the above models may account for some of argumentation’s success, some lessons are apparent for science education. The particular model chosen has an impact on how the argumentation should be structured. For example, if imitation is a significant factor, then it is incumbent upon the teacher to design the argumentation unit/lesson in such a way that the student is in fact listening to the explanations of others. That necessitates that the learner has an opportunity to hear his/her peers as they attempt to explain their thinking. This is doubly important in that recent research hints that a smart student meme, for example, may influence such decisions (Yoon, 2008). In other words, it may be easy (and smart, in some regards) for a
learner when uncertain, to simply agree with a person she perceives to be smarter, regardless of the actual answer given.

It should be noted that each of the above models for how argumentation enables learning provides a viable avenue to bridge conceptual change and argumentation (see Figure 3). The sociocognitive conflict model of argumentation itself provides a powerful link from argumentation directly to the framework theory of conceptual change, by positing that interactions with peers provides an opportunity for the learner to notice discrepancies between his or her views and new information which must be synthesized. The second model reinforces this link, along a situative pathway, by positing that the group interaction processes of argumentation become internalized within the learner. The third model indicates that the process of imitation and/or role modeling alone may result in significant learning gains, although this would not be the most desired result. As the framework theory invoked for this research (Vosniadou, 2007b) attempts to bridge situative and cognitive aspects of conceptual change, I argue that it is an appropriate tool with which to understand argumentation.

Figure 3: How argumentation might enable conceptual change (adapted from Sampson & Clark, 2007)

**Specific classroom strategies employing argumentation**

Argumentation is still uncommon in modern science classrooms, which are still epitomized by the triadic dialogue of question-answer-evaluation (Duschl, Schweingruber, &
Shouse, 2007; Lemke, 1990) is to produce an event for students, who then have to develop explanations for it. They then share explanations with peers, and evaluate their ideas based on the available data. Several authors have shown this to be an effective model of argumentation (Linn & Eylon, 2006; White & Gunstone, 1992).

Another argumentation strategy involves the students’ production of the necessary artifacts to investigate and explain a phenomenon. Note that this often requires that the students decide on the investigation to be conducted and the methods necessary for gathering the requisite data. The artifacts created can take on a myriad of forms from posters to written reports to websites created, etc. They would typically then be asked to share their artifacts and evaluate those of others. This format could potentially work equally well if the artifacts were developed individually or in small groups. However, building in ways for students to work collaboratively on argumentation projects has been shown to improve both the final product and the quality of their constructed explanations (Driver et al., 2000). That is, those students who worked collaboratively on argumentation projects often constructed a better argument and also displayed a better understanding of the scientific concepts being investigated.

An additional approach is to have students, in small groups, amongst two or more competing explanations for a given phenomenon. Given various statements providing evidence for one or another theory, the students are tasked with developing their arguments fit the evidence available to them (Osborne, et al., 2004).

It should be noted that the classroom use of argumentation is not limited to the practices outlined above. Fruitful argumentation lessons could conceivably result from a combination of some of the above ideas. Additionally, argumentation need not be limited to real-time, physical interaction, but could also be effectively employed in written format, even via the web. Some benefits may result from such actions, as some researchers found that electronic discussions were more productive “in supporting gender equitable discussions in science” (Hsi & Hoadley, 1997, p. 24).

This perspective also differentiates between terms such as explanation, argument, and argumentation. Explanations are statements that explicate or describe natural phenomenon, arguments provide and justify an explanation, and argumentation is the process of generating explanations, constructing arguments, and critiquing the processes, contexts, and products of inquiry (i.e., explanations or arguments). When conceptualized in this manner, argumentation
–can be seen to take place as an *individual* activity, through thinking and writing, or as a *social* activity taking place within a group” (Driver et al., 2000, p. 291 emphasis in original).

**Summary of Literature Review**

In this literature review, I have attempted to establish that GW represents established, consensus science; that GW, within the context of GCC, is an important scientific framework for students to understand; and that the minimal frameworks extant that address learning of GCC suggests that knowledge construction should begin as early as middle school. This, combined with the relative paucity of studies concerning the conceptual change regarding GCC topics at the middle school level, invites research into the conceptual change of GCC ideas at the middle school level.

In order for researchers and professional development leaders to craft instruction productive in helping students to understand GCC, a description of learning is needed in this area. It was the hope of this research to provide a rich description of conceptual change concerning GCC at the sixth grade level, paying careful attention to the various rational and extra rational factors that influence this conceptual change.

In order to pursue a best case scenario for this conceptual change, I elected to employ argumentation as a pedagogical and methodological strategy. Given that GCC, and GW in particular, are viewed by a large percentage of the public as controversial, the epistemological analysis afforded by argumentation was an extremely promising avenue on which to elicit conceptual change.

Now I turn my attention to an examination of methods needed for this research, or in particular, the details of how the research was conducted.
CHAPTER THREE

METHODS

Before I elaborate on the methods of the research, I feel it necessary to establish the philosophical foundations upon which my research design was based. I used the perspective of post-positivism. Post-positivism is considered an "orientation", not a unified school of thought (Phillips, 2000, p. 25). But post-positivists share the understanding that all human knowledge is "conjectural". That is, "we have grounds, or warrants, for asserting the beliefs, or conjectures, that we hold as scientists, often very good grounds, but these grounds are not indubitable. Our warrants for accepting these things can be withdrawn in the light of further investigation (Phillips, 2000, p. 26)." As the post-positivist Karl Popper stated, "there are all kinds of sources to our knowledge, but none has authority" (Popper, 1965, pp. 24-25).

Using a post-positivist mindset has some implications for the researcher. One is that, for the post-positivist researcher, reality is created by the individuals involved in research, as opposed to being a fixed entity of its own (Crossan, 2003). At no point in the research did I or could I claim to know the Truth of the situation, as post-positivism is itself inherently nonfoundationalist in this regard. That is, I can claim to provide evidence that supports my conjectures, but I cannot go beyond. Instead, an implication of post-positivism is that the researcher should provide as much evidence as possible, by a variety of methods and data sources. This aspect helped me in my approach to the theoretical framework, conceptual change theory, discussed below.

Given that this work was grounded in a post-positivistic approach emphasizing the collection of a variety of evidence through multiple sources, I now turn to the research methods to be used in this study. One of the primary concerns of this proposed research is to contribute to the literature on GCC education. In particular, I was interested in learning about how secondary students come to understand GCC, particularly aspects of anthropogenic contributions to global warming. As students come to the classroom with some forms of prior knowledge (Dole & Sinatra, 1998; Vosniadou, 2007a, 2007b) already in place, it is necessary to understand not only what the students' conceptions are, but how they change over the course of time.
Research Design

As the methods chosen for the research design are contingent upon the research questions themselves, I re-examine those questions here. As given earlier, the research questions are:

1. What are the patterns of students’ conceptual change in GCC?
   a. What conceptions are invoked in student learning in this arena?
   b. What conceptions are most influential?
   c. What are the extra rational factors influencing conceptual change?

Research Setting

I chose to research secondary students because of the complex nature of GCC/GW. Given the multiple aspects of the science involved, and literature indicating the difficulties that elementary level students have with complex topics related to climate change (Boyes & Stanisstreet, 1993) I think it is unreasonable to look for understandings of human-causes of climate change at the elementary level. As argued above, a consideration of GCC that addresses the evidence for anthropogenic global warming represents consensus climate science (IPCC 2007; Rosenweig et al., 2008). Therefore, I selected a public middle school that suited these purposes. I sought a school that had a diverse student population so that I might have an opportunity to understand the conceptual change undergone across a broad spectrum of ability levels and outlooks. The school in question was a diverse middle school (43% African American) in a mid-size city in the Southeastern United States. The school, Central Middle School, offered a magnet program for students with interest and aptitude in the sciences. While zoning regulations dictate most of the student population, entrance requirements did exist for those hoping to join the magnet program. Requirements included a minimum grade point average of 3.0, FCAT scores in the 75th percentile, and a student essay on the topic of “my favorite science class memory”. Once selected, magnet students were required to maintain standards of both grades and conduct.

Participants

I selected a teacher in the magnet program for involvement in this research, for several reasons. Her pseudonym is Ms. –Octane”. She taught 6th grade science. There were several
reasons for choosing her for this research. First, she had some experience in teaching using argumentation already, as is personally known by this researcher. Having that experience, Ms. Octane was already motivated to pursue more attempts at using argumentation in the classroom. While I still needed to work with her in order to implement the unit, doing so with a teacher unfamiliar with the goals of argumentation would have added extra layers of issues to resolve. Ms. Octane was not only familiar with argumentation, but in fact, she was familiar with a version of the argumentation model being used in this study, Argument-Driven Inquiry. Being so experienced made her a very willing and eager participant in this research. Also, Ms. Octane was a veteran teacher, well-established at her school, and had a strong local profile, both by reputation and by immersion in leadership opportunities. The class that I chose for research was the class titled “Research I”. This class encompassed subject matter that Ms. Octane considered under the domain of “current science”. That subject matter fit easily into the global warming content that was at the heart of this research. Additionally, part of the curriculum for this course includes an emphasis on data analysis, particularly in regards to understanding data displayed in graphs. Given that this research features much data analysis with reference to time and temperature graphs, this course was particularly well suited for this research. Also, because this course was considered an elective, therefore it was not particularly bound by constraints imposed by standardized tests such as the FCAT. Therefore, this course provided an appropriate set of students, within a context that allowed me to examine the extent of what is possible, as opposed to what is typical in a 6th grade classroom. The combination of the above factors, from the abilities and experience of Ms. Octane, to the demographics of the school, to the curriculum of the class itself, make this an extremely compelling location for the present study, particularly because it represented a unique opportunity to research a best case scenario.

I studied only one teacher and one class full of students for several reasons. First, the theoretical framework, conceptual change, demands that the researcher collect copious interview data from a select group of students. Background literature on conceptual change, at least in the guise of “hot” conceptual change, makes it obvious that the extra rational factors of the experience are an important part of the learning landscape. Therefore, it is necessary to immerse myself in this setting for an extended period of time, in order to document these varied contextual factors that bear upon the students’ experience. In so doing, I concede my role as a participant observer. Some authors claim that participant observation is an essential starting
point to gain access to the participants' understandings through extensive observations in the research setting (Goodson & Mangan, 1991). Indeed, it is considered by some to enhance the credibility of research involving case studies (Yin, 2003). In addition, acquiring the sheer volume of descriptive data required necessitates an investigation of smaller scope, but greater depth. The amount of and type of data required for argumentation are of a nature that is impractical to consider for more than one class of students and one teacher. For example, up to 6 video cassettes per class period were taken, along with 6 digital voice recordings per class, in addition to observation notes, and artifacts of argumentation, including white boards. Either way, this constituted a great commitment of time to ensure that the process happens and is documented appropriately. Given these requirements, one researcher cannot possibly do such research on more than one teacher/school at a time.

Five students from amongst the class in question were purposefully selected for multiple interviews. They were selected based on a variety of factors, including demographics, ability levels, and willingness to participate. The questions posed to the students are given in appendix C, and also described below, along with other data to be collected.

**Instruction**

The Model of Argumentation used in this study invoked a Toulmin-inspired model of what constitutes an argument similar to frameworks adopted by a number of other researchers in science education (e.g., Kuhn & Reiser, 2005; Lizotte, McNeill & Krajcik, 2007; Osborne, Erduran, & Simon, 2004). The foundation of this framework (see Figure 4) focuses on the scientific claim being made and the reasons provided to support that claim. Although this simplifies the Toulmin model that is most prevalent when addressing argument structure, the more detailed elements (data, warrants, qualifiers) become incorporated through the various types of evaluative criteria emphasized in our model. The evaluative criteria provided for quality considerations are distinguished into three categories: empirical, theoretical, and cognitive. Among these categories, attention is given to the structure, content, and justification of an argument within science specific, normative qualification (provided at the bottom of the figure).
In sum, one of the outcomes of the unit in question is for students to be able to construct arguments satisfying the criteria above. The lessons constituting the GCC unit are themselves largely based on an instructional strategy known as Argument-Driven Inquiry (ADI) (Sampson & Gleim, 2009; Sampson & Grooms, 2009). The purpose of the ADI unit I employed included (Sampson & Gleim, 2009):

- Frame the goal of classroom activity as an effort to develop, understand, or evaluate a scientific explanation for natural phenomena or a solution to a problem.
- Engage students in meaningful inquiry using methods of their own design and to help students learn how to design better investigations.
- Encourage individuals to learn how to generate an argument that articulates and justifies an explanation for a research question as part of the inquiry process.
- Provide opportunities for students to learn how to propose, support, evaluate, and revise ideas through discussion and writing in a more productive manner.
- Create a classroom community that values evidence and critical thinking.
- Encourage students to take control of their own learning by helping them learn how to define goals and monitor their progress in achieving them based on scientific criteria.

Figure 4: The argument framework used in this study
In order to accomplish the above tasks, this particular ADI unit involved:

- The identification of a task to examine historical climate data and develop the best explanation that fits the data.
- A laboratory-based experience in which students were able to test the greenhouse effect & create their own graphs from historical data.
- The production of a tentative argument, on a white board, that articulated and justified an explanation on a medium that could be seen by others (Sampson & Gleim, 2009).
- An argumentation session, in which groups communicated their group-derived arguments, then critiqued these explanations.
- A written investigation report by individual students that explained the goals of the investigation, the methods used, and provided a well-reasoned argument.
- A double-blind peer review of these reports to ensure quality and to generate valuable feedback for the individual authors.
- The subsequent revision of the report based on the results of the peer review.
- An explicit and reflective discussion about the inquiry.

The argumentation literature indicates that it can be an effective way of addressing many aspects of science, including NOS, specific area content, and scientific inquiry in general. Additionally, it seems a uniquely suited manner for making explicit the developing conceptions of students. Therefore, argumentation seems to lend great promise for the present research.

The research design employed a unit on climate change. The unit took approximately two weeks, from early to late March of 2010. Ms. Octane taught the unit, with the researcher engaging in participant observations. The unit consisted of three argumentation-based, multiday lessons. The first lesson focused on the general concept of global warming and the greenhouse effect. The second lesson focused particularly on historical patterns of climate change. The third focused on anthropogenic contributions to global warming. The sequence of the lessons helped not only in data generation, but also in quality control. That is, the first lesson helped to ensure that students are familiar with the lesson formats and habituated to the research presence, including video cameras and digital voice recorders. I have designed a GCC unit, which has a substantial argumentation-driven component. A variety of methods were used within the argumentation context, including giving data to students for purposes of explanation building,
and having them generate their own data to answer/explain a given problem. The unit in question can be found in Appendix B.

**Data Collection**

Previous sections described the literary basis and foundations for the methods being used in this study, in terms of argumentation and conceptual change. In this section, I answer the question – Exactly what data was collected, how, and when?” See table 1 for a description of the data to be collected and the timing of the collection.

The table below shows the timing of the data collection:
Table 1: Timing of data collection

<table>
<thead>
<tr>
<th>Data Item</th>
<th>Collected When:</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation Notes</td>
<td>Throughout the unit</td>
<td>Describe instruction, describe the students, describe their learning</td>
</tr>
<tr>
<td>Interviews w/Selected Students</td>
<td>Prior to First Day of Unit, mid-unit, and after Last Day of Unit</td>
<td>Provide data to provide fine-grain documentation for conceptual change</td>
</tr>
<tr>
<td>Pre and Post Assessments</td>
<td>First Day and Last Day of Unit</td>
<td>Provide more gross data for conceptual change; to gauge begin/end argumentation skills</td>
</tr>
<tr>
<td>Digital Photos of Argumentation displayed via poster boards</td>
<td>During each of 3 argument-based lessons</td>
<td>Provide record for how arguments developed over time; Documentation of students‘ conceptions</td>
</tr>
<tr>
<td>Audio &amp; Video tapes of each group argument constructions</td>
<td>During each of 3 argument-based lessons</td>
<td>To provide transcripts to understand how each argument developed and how individuals contributed</td>
</tr>
<tr>
<td>Written explanatory narrative</td>
<td>At/near last day of unit</td>
<td>To understand how the individual constructed the explanation after series of exchanges within and between groups</td>
</tr>
<tr>
<td>Other artifacts</td>
<td>As available</td>
<td></td>
</tr>
</tbody>
</table>
Observation Notes

For the first part of the research, I was an observer in the classroom. Data collected during this phase consisted of my own observation notes. There are several purposes of this phase. These purposes included coming to understand the classroom, getting to know the students and to make my presence familiar to them, and the initial identification of students to invite into the interview phase of the research. (See appendix H for a format for these field notes.) While in the classroom conducting research, I focused on what groups are having what sorts of conversations. I attempted to make a note of any interesting or instructive quotes heard, along with the time during the lesson it was said, by whom.

Student Interviews

I asked the teacher to identify 2-3 students who appear to be from one of three groups: high-performing, low-performing, and others in between. Also, I intended to select students that represented a diverse group in terms of race and gender. This was simply to ensure that I collected a wide diversity of thoughts. Interviews with these purposefully selected group of students provided for the data necessary to describe the many factors influencing conceptual change as well as to document that pathways of these changes. Students were interviewed before the unit, and again at the end using the interview protocol found in Appendix C.

Part of the strength of open-ended interviews is that they allow the interviewer to capture unforeseen aspects that become salient only during the interview itself (Bogdan & Biklen, 2003; Miles & Huberman, 1999). Therefore, I entered into each of the interviews with the full intention of following up on any aspects that emerge during the interview process.

Pre-Post Assessment

At the outset of instruction, a pre-assessment was administered. These pre-assessments themselves constituted a rich source of data, from which to examine conceptual change. These were analyzed in accordance with both an argumentation based framework (shown in argumentation section) and also for evidence of students’ preconceptions. (See Appendix D for the assessments.)

Poster boards from Argumentation Sessions, Recordings of Sessions

Data collected during instruction of the three lessons comprising the unit will include digital photographs of arguments displayed on poster boards, audiotapes (via digital voice
recorders) of each group discussion, and videotapes of each group discussion as well. The whiteboards themselves followed the format shown in the table below:

In developing their arguments using poster boards, the students followed this format:

Table 2: Argument structure for poster boards (adapted from Sampson & Gleim, 2009)

<table>
<thead>
<tr>
<th>Names of group members</th>
<th>Goal of investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(What were you trying to do?)</td>
</tr>
<tr>
<td>Your explanation</td>
<td>Your evidence and Reasoning</td>
</tr>
<tr>
<td>(How do you explain the phenomenon under investigation?)</td>
<td>(how can you be sure of your explanation?)</td>
</tr>
</tbody>
</table>

Because the students’ comments on whiteboard arguments themselves fluctuated across time, I intended to capture digital photographs of each group’s argument construction at key stages.

Video/Audio recordings

Another aspect of data captured, mentioned above, are video-tapes of student interactions during argumentation. In order to ensure appropriate quality in this regard, I widely separated student groups so that there was as little noise overlap as possible. I also had a video camera set up at each particular station, with its own microphone to capture only that group’s interaction. As a failsafe method, each group also had a digital voice recorder at each table, so that I had two sources from which produce the transcripts. The two different sources of audio recordings helped to ensure quality and also better enabled me to capture what as being said by what individual.

On the final day of the unit, the teacher debriefed students regarding the students’ individual written explanations for what best explains the entire sets of data given to them. These narratives, collected for homework assignment, were photocopied and constituted a data source for analysis. The final day of the unit also featured a class discussion, which was recorded to provide transcripts for analysis. Each of the data sources were analyzed in reference to the quality construction of an argument in addition to the conceptual change framework chosen for this study.
The time for collection spanned much of the spring semester of the 2009-2010 school year. In order to generate the necessary contextual understandings, I visited the school to observe more than one month prior to the beginning of the unit in question, so that I could understand the needs of the students and teacher, the interaction patterns between them, and the constraints, etc., imposed by the school itself. I felt strongly that I should enter my target unit with an already-established relationship with the school, teacher, and students.

**Data Analysis**

The collection of data and analysis go hand-in-hand in qualitative research. Therefore, there is no clearly demarcated time boundary in which collection has ended and analysis has begun. Instead, the analysis begins with the first data collection. All data were analyzed in accordance with Strauss and Corbin’s three-stages of data analysis (Strauss & Corbin, 1990). The first stage comprises open coding, in which the researcher analyzes each data piece and assigns codes to them (Strauss & Corbin, 1990). During this stage, it is desirable to generate as many codes as possible (Bogdan & Biklen, 2003). To assist me in this process of storage and coding, I used software known as NVIVO, which helped me in that I was better able to store and query my database as it built. The second stage of analysis is known as axial coding. Axial coding consists of a search for patterns in the data. In the case of this research, this entailed searching for patterns in the thought patterns shown in the interview and transcript data that enabled me to understand the frameworks held by the students. The final stage of analysis is known as selective coding (Strauss & Corbin, 1990). At this stage, the patterns and themes that emerged in the axial coding stage were tested again and again against the data, in order to either support, reject, or modify the emergent themes as necessary.

Data were analyzed carefully for negative cases at each stage, using the constant comparison methods of Strauss & Corbin (1990). In particular, the interviews were recorded on digital voice recorders, and analyzed according to the framework theory of conceptual change. This enabled the researcher to better understand some of the students’ prior understandings of the subject matter. Using the framework theory, the transcript data were analyzed to understand what naive frameworks the students held entering the unit in question, and to understand how such students might go about synthesizing their pre-existing understandings with any new
concepts encountered in the class. The arguments that were constructed in the small group settings were analyzed according to the framework theory of Vosniadou (2007a, 2007b). These data were juxtaposed with the interview transcript data to better understand the group interactions’ effects upon the frameworks held by the individual learners themselves.

Quality of Research

I used several methods in an attempt to ensure quality in my research. One method involved member checking, or asking participants if my views of their understandings are warranted, etc. I also used a triangulation of methods, data, and theoretical frameworks. For example, interview data were tested against artifact construction, observation notes, etc. When conflicts are encountered between one data source and another, I sought additional data sources, including additional member checks, in order to understand the phenomenon. Another aspect of quality control was used by conducting searches for negative cases. As tentative understandings were developed, it is recommended by some authors (Bogdan & Biklen, 2003; Miles & Huberman, 1999; ) that a purposeful search for negative cases be conducted. This was helpful in that it requires the researcher to constantly test any developing themes that emerge, and allows for the researcher to discard and/or modify those with an excess of negative cases. Additionally, the different frameworks of conceptual change and argumentation may themselves constitute a way of using different theoretical lenses through which to examine the data. This dichotomy may be particularly useful to examine how the artifacts (generated through argumentation) contrast with the interview data (consistent with conceptual change).

Another check on the quality of research was performed via peer debriefing, consisting of open and critical discourse conducted with my peer graduate students and especially with members of my doctoral committee.
Table 3: Timeline in which the research was conducted

<table>
<thead>
<tr>
<th>Time Line of Research Date</th>
<th>Action/Item</th>
<th>Purpose</th>
<th>Date end</th>
</tr>
</thead>
<tbody>
<tr>
<td>02-22-10</td>
<td>Began observations in Ms. Octane class</td>
<td>Establish relationships; identify students for purposeful selection interviews</td>
<td>End of semester</td>
</tr>
<tr>
<td>02-26-10</td>
<td>Conducted pre-interviews</td>
<td>Understand students‘ prior conceptions/frameworks</td>
<td></td>
</tr>
<tr>
<td>03-01/day one of unit</td>
<td>Conducted pre-assessment</td>
<td>Understand students‘ prior knowledge/ability to deliver scientific argument</td>
<td>Same day</td>
</tr>
<tr>
<td>03-01</td>
<td>Began research unit</td>
<td></td>
<td>~2 weeks after unit began</td>
</tr>
<tr>
<td>03-15</td>
<td>Post-assessment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03-16</td>
<td>Post-interviews</td>
<td>Understand students‘ modified conceptions</td>
<td>03-18</td>
</tr>
<tr>
<td>04-20</td>
<td>Delayed post interviews</td>
<td>Understand lasting conceptual change</td>
<td>04-22</td>
</tr>
<tr>
<td>03-01</td>
<td>Analyze Data/Write Dissertation</td>
<td></td>
<td>06-10-11</td>
</tr>
<tr>
<td>06-10-11</td>
<td>Defend Dissertation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER FOUR

CLASSROOM CULTURE

All research takes place in a particular, contextualized setting, and given the role context plays in shaping teaching and learning (Saka, 2007), it is essential to describe this setting. Indeed, it is important to describe the setting to the extent that the reader should be able to "visualize that setting" (Patton, 2003, p. 281). This chapter begins with a thick description of the school setting including both physical and cultural characteristics. The school itself will be described first, followed by the classroom/course, ending with a description of the participants in the course.

The School

Central middle school (CMS) was an urban middle school situated in the middle of a mid-sized Southern university town. It was situated in a neighborhood that featured a mixture of working-class and middle class families, situated near one of the main thoroughfares of the city. One of the central features of the school was a large courtyard situated between two of the main classroom buildings. Originally built in 1954, prior to local integration, the school was comprised of several buildings reminiscent of the era, with a combination of angular brick structures with large windows. Substantial security fencing in various areas of the school lent a sinister atmosphere to the school’s aura, which were in direct contrast to the activities found within the school’s walls.

The students at CMS were largely drawn from the working class/middle class neighborhoods within its assigned busing district. More than 40% of the student population was consequently African-American, with 42% of the student body on free or reduced lunch (FLDOE, 2010). However, Central Middle School was also the host of the local science magnet program. As a "School of Choice", or magnet school, Central had a pool of applicants from which to select their incoming students into this program. Entrance requirements included a minimum grade point average of 3.0, FCAT scores in the 75th percentile (FCAT is Florida’s standardized measures for No Child Left Behind Legislation), and an essay written on the subject
of “my favorite memory in science class”. Once selected into the program, students were required to maintain minimum standards in both grade performance and conduct. Because of the existence of this magnet program, the make-up of the student body was more varied than the demographics of its school zone would otherwise suggest. Consequently, CMS had a student body which ranged from working class to middle class students; also provide ethnicity and percentage of English language learners. The middle class students who attend CMS were disproportionally represented in the science magnet program, which served as the focus of the present research.

In their first year in the magnet program, students typically enrolled in two science courses. The first of the two courses was “Life Science” and each 6th grade student at the school took this course. The second science course, only open to magnet students, was titled “Critical Thinking and Research, although the instructor referred to it as “Research 1” (Octane int, p. 2). I will continue to refer to this course by Ms. Octane’s title of “Research 1”.

The Course and Classroom

According to CMS’s magnet brochure, “Research 1” was a course that “provides extended times for developing biological field technique and laboratory experience” (School brochure). In the words of Ms. Octane herself, it was a class in “data analysis” (Oct int, p. 2). In her view, the class was a place for students to “do lots of labs” and “do lots of graphing” (Oct int 1, p. 2). In fact, there were two classrooms available for the use of the Research 1 class. The first was Ms. Octane’s primary classroom, which was a fairly typical middle school classroom, adorned with various motivational posters along the walls, along with specimens of various organisms, both alive and dead. A large fish tank lined one entire wall, across from the front door, whose gurgling sounds were prominent only during the rare moments of silence in the classroom. A door in the far wall led outwards into a small courtyard, which was itself closed in by security fencing. The classroom contained several lengthy tables where students sat facing frontwards towards the teaching area. Immediately at the front of the classroom was a very large whiteboard, in front of which was a stand with a projector. The side of the classroom nearest the front door had another large whiteboard, which was marked with miscellaneous tracking issues for each of her 5 classes, including assignments due and points earned/detracted for
misbehaviors. Near this board, there were several baskets and folders used for turning and collecting homework.

The second classroom available for the Research 1 class was a laboratory classroom, adjacent to the first room. Immediately in front of the entrance are several large worktables in the center of the room, with sinks lining the perimeter of the room. With no decorative, motivational, or informational posters adorning the walls, this laboratory classroom was very Spartan in its appearance. Its set-up was appropriate for dissection labs, which were prominently featured in Ms. Octane’s curriculum. In fact, about half of my initial observations occurred when Ms. Octane was having students dissect organisms, from worms to frogs.

The Research 1 class, in Ms. Octane’s opinion, was a class about ―data analysis‖. Despite this statement, much of my observation time was spent noting students engaged in either dissections of organisms or being immersed in the discussion of such, as opposed to data analysis issues. The curriculum was loosely tied to Life Sciences, and, in accordance with Ms. Octane’s personal strengths and outlook, focused more on anatomy and physiology of organisms than on other aspects of life science. For Ms. Octane, focusing the class upon dissections and anatomy was consistent with the idea of the course being about research methods. However, at many points in the class, the students were required to create line graphs and analyze the results or such graphs. While the course was officially titled ―Research Methods‖, there seemed to be little evidence of an official curriculum. Given that the subject matter of the course was loosely affiliated with Life Sciences, the focus on dissection was an appropriate focus of research, despite the fact that other methods of research within Life Sciences were not explicitly explored. However, at one point in the class, the students were busily engaged with an ADI project involving the collection of and examination of local pond water, with the guiding emphasis being on what microorganisms were present in the water. This particular classroom activity was facilitated by the presence of Ms. Octane’s intern.

The Teacher

Ms. Octane was a highly energetic teacher in her late thirties to early forties at the time of the research. She was Caucasian, from a middle-class background. Ms. Octane had a B.S. degree in Life Sciences, in addition to having worked as an epidemiological specialist for a state department. She had taught at CMS for five years prior to the study, having switched teaching
assignments many times, from regular science classes to the magnet program classes. During the year of the research, Ms. Octane had just been reassigned to the “Research I” course, having previously taught “Research II”, at the 7th grade level. Having switched careers from working for an environmental state agency, Ms. Octane brought a great deal of subject expertise and passion for teaching to her classroom. Given that she taught in the magnet program, a coveted position in the school, she enjoyed high status amongst her peers.

Her typical style was to engage her students in discussion, then free them up to perform dissections or other labs with loose sets of instructions. She then made herself readily available to assist any student with problems, whether during or after class. While answering questions about the subject matter, she answered in a very excited tone, conveying an enthusiasm that was apparently contagious, as students responded with similar degrees of enthusiasm (examples would be nice). Upon reflection, Ms. Octane considered herself as very motherly to her students, in fact too much so, saying “I am too much of a mom” to me when explaining her teaching style (Oct int, p. 3). For example, Ms. Octane often reminded students of upcoming due dates multiple times in the same class period, and also offered encouraging remarks such “You CAN do it!”

Ms. Octane was also highly open to learning new things, whether content or pedagogy-related. For example, I first met her during the previous school year when she was accommodating a research project in assessing an argumentation-based lesson about evolution. She welcomed the opportunity, despite being unversed in the pedagogy of argumentation at that time. When I started observing her for the present research project, she was in fact overseeing a student intern, who herself was using the same argumentation strategy for a lesson. When I first approached Ms. Octane about participating in this present research, she responded with enthusiasm, despite admitting that climate change was not in her primary content field.

Ms. Octane also showed a great interest in being involved in leadership functions in the local science teaching community. For example, she was and had been highly involved in the activities of the regional science fair board. In fact, during the year of research she was the president of that organization, in effect being the head of the local tri-county science fair competition. She also served as the official county coordinator for sex education, a touchy topic in this southern town. Ms. Octane often demonstrated pride in being heavily involved in these aspects of local community efforts in science education.
The Class

The particular class that was the focus of this research was period seven, at the end of the day. This class was chosen because it was the largest in terms of students, and also presented the most diversity in students’ backgrounds and ethnicity of any of Octane’s sections. Ms. Octane described the class, in an exasperated tone, as ―fun bunch!‖ (Oct int, p. 1). She then proceeded to describe that what she really meant by this was that they were very challenging, in comparison to her other classes. By "challenging" she meant in the sense of being her most "off-task" period and one of her least high-performing classes. Indeed, while the 7th period” group was composed of magnet students, they were not deemed by the instructor to be of extraordinary talent in comparison to others in the school.

Period 7 had twenty-nine students in the class. Twenty-one of the students were of Caucasian backgrounds, 3 of whom were apparently of Hispanic origins, with the other 8 being African-American. In early observations, the class seemed to interact with each other, and with the teacher, in a back-and-forth manner, seemingly having as much fun as possible. Often, this "fun" was in the form of such behaviors as chatting with friends about social events, or quick bursts of laughing at one another’s answers. This was evidenced often when the class was in a group discussion mode. For example, as Ms. Octane would ask a question to the class, calling for a show of hands to answer the question, many hands would typically be raised. Along with the raising of hands, some of those who were impatient to be called upon would start shouting or murmuring their answers. Most of Ms. Octane’s questions were of the type which could be answered simply with a quick content answer (example). Such questions were often asked by the teacher, regardless of the classroom format, whether whole class discussion or in small group-dissection mode. Ms. Octane’s voice would often be heard on the class microphone system asking her students to label the parts of the worms they were dissecting, for example.

The Interview Participants

During January of 2010, the requisite permission slips were sent home with each of the students so as to enable them to participate in the research. Twenty of the students turned in the forms. Of those, Ms. Octane and I selected five participants to invite into the full research, for interview purposes. The strategy was to select a variety of performance levels, gender, and
ethnic backgrounds. In addition, students were selected based on the perceived likelihood of their being willing to talk enough to provide the needed data. The five students chosen were provided pseudonyms that retained their gender and ethnic identities. These pseudonyms are used throughout the rest of this document. Below is a brief description of each.

**Beyonce** was an African-American female who was chosen because she was in the low-to-middle range of perceived academic performance, as identified by her instructor, Ms. Octane. Beyonce exuded a quiet confidence about her that belied her inability to clearly articulate ideas using the grammar or discursive styles of most of her peers. For example, she sometimes inverted the “k” and “s” sounds, when saying “ask.” Sometimes she showed confidence as evidenced by her reaction to my interview question, asking her if there was anything else about climate change that I did not ask her that she wished to tell me. She answered “You pretty much asked all the basics (Bey int 1, p. 4).” She often raised her hand to answer questions in class, often expressing disappointment with an audible sigh or shrug of the shoulders, as if not understanding how, once again, she was not called upon.

**Bono** was a Caucasian male whose participation was sought due to Ms. Octane’s perception that he was a very high-performing student. He was a generally quiet young man who did not engage in the friendly chatter with most of his classmates. When classroom dialogue occurred, he raised his hand and patiently waited to be called upon before speaking. In interviews, he volunteered that he came from a family that valued science. As a result, his favorite pastimes included watching television shows such as “Mythbusters” and other informative shows that came on the “Science” and “History” channels. During class downtime, Bono often sat quietly to himself, occasionally interacting with other quiet children around him.

**Darko** was a very shy Caucasian male who was invited into the research on the basis of his relatively low performance level, as perceived by Ms. Octane. Despite this, Darko exuded an extremely polite manner, in which “no, sir” and “yes, ma’am” were used in all social discourse with adults. While he was not one of the top students in the class, Darko seemed to diligently work on all of his assignments. When he was confused, he asked for clarification. Darko was not one of the more popular students in the class, as evidenced by his relative solitude during moments of “downtime” in the last few minutes of class prior to the bell, etc. During such times, Darko typically remained in his seat, sometimes putting his head down, even while his peers gathered in small groups for informal discussions. While not one of the more popular students in
class, Darko often spoke in ways that indicated some degree of quiet confidence. For example, during interviews, he often paused in order to gather the most articulate version he can possibly render for what he wanted to say.

**Nigella** was invited into the research as a young lady in the mid to high performance level, as identified by her instructor. She was of Hispanic descent. Nigella was extraordinarily organized for someone of her age. For example, when I asked her for an interview time, she patiently pulled out her planner, and said “no” to three different dates, all a week or more in advance, citing other specific things that were to be done that day. Despite her organizational skills and her brightness, she was somewhat reserved in the classroom. For example, she kept mostly to herself during classroom activities of all kinds quietly working on her own. Although she would usually not volunteer to talk in class, she occasionally would raise her hand to volunteer an answer if the conversation stopped or if other students were apparently not catching on.

**Shania** is a Caucasian young lady from a middle class family who showed an extreme degree of confidence. For example, she often mentioned how bright she was, in terms of success in classes. In fact, she was fond of pointing out that she was bored in many classes, and she often reminded me that she was identified as gifted early in her school career. She was invited into the research upon Ms. Octane’s suggestion that she was a high-performing student. While extremely confident in herself, she was prone to be less than enthused about the ability levels of her peers. In fact, when she was not successful in getting her peers to agree with her point of view, she tended to sulk brazenly, often even to extreme levels. For example, at one point in the research, Shania, as the result of a group disagreement, folder her arms angrily and walked to a corner of the classroom, facing that corner for several minutes. Shania did recognize that she was not easy to get along with, often citing her intolerance of “stupidity”.
Table 4-1: Students in the Research

<table>
<thead>
<tr>
<th>Name (pseudonym)</th>
<th>Performance level as identified prior to research</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beyonce</td>
<td>Mid</td>
<td>African American female; working class background &amp; affect.</td>
</tr>
<tr>
<td>Darko</td>
<td>Low</td>
<td>Caucasian male; hard working, but limited in performance level; shy, though confident when he took time to gauge his thinking.</td>
</tr>
<tr>
<td>Bono</td>
<td>High</td>
<td>Caucasian male of middle class background and high performance level. Was not socially popular.</td>
</tr>
<tr>
<td>Nigella</td>
<td>Mid</td>
<td>Hispanic female; mid performance level and extremely organized; confidence minimal, even deferential to others.</td>
</tr>
<tr>
<td>Shania</td>
<td>High</td>
<td>Caucasian female of high performance level and very high self-confidence; difficult to get along with; admits to being “control freak” (Sha int 1, p. 6).</td>
</tr>
</tbody>
</table>

The researcher’s role in the study and setting

In order to facilitate my research in period 7’s class, I consulted with Ms. Octane as to the best strategy to scaffold her teaching of a unit that was not of her design and not explicitly tied to her curriculum. The solution negotiated was for me to teach the unit during periods one and two each day. After that point, Ms. Octane (and her intern) would either teach or co-teach the day’s lesson during the next two periods, with Ms. Octane teaching the lesson and unit during the final class of the day, period 7. This was the pattern during the course of the entire unit. Therefore,
my role was more complicated than that of simply being a researcher. That is, I was a teacher for some students (in sections not being researched), a mentor and lead teacher for two sections, and merely the researcher only for the target class, period seven. This immersion in the entire school setting allowed me to feel an important part of the school community for the duration of my research at CMS. Equally importantly, this strategy allowed for Ms. Octane to become more comfortable with the teaching approach that was to be used. In effect, part of the motivation for choosing this strategy was to carefully scaffold the instructional methods to be employed.

Summary

This research took place in an urban middle school with a largely working-class population of students, but the research was conducted in a class in the magnet science program, which included mostly middle-class students. The teacher, Ms. Octane, was a veteran teacher with 5 years of experience at Central Middle School. The magnet program students took two science classes in the 6th grade year, Life Sciences, and Research and Critical Thinking 1, which is loosely based in Life Sciences. As Ms. Octane enacted her curriculum, it was largely comprised of anatomy and physiology, as emphasized in numerous dissection labs. However, she considered the class a course in data analysis, with heavy emphasis on interpretation of graphs and histograms. Her period 7 class, a magnet science group, was chosen for this study given the diversity of students it contained. Upon consultation with Ms. Octane, I chose five students to invite into the project selected purposefully. I sought to include students who, for practical reasons, would be willing to talk and provide abundant data. Second, I sought to capture as diverse an array of students as possible and I wanted to represent a variety of backgrounds and performance levels. The students chosen were given pseudonyms which retained their gender and ethnic identity. The pseudonyms given were Beyonce, Darko, Bono, Nigella, and Shania.

In addition to being the researcher, one role that I had in the setting was to scaffold the research-unit instruction. This was necessary because Ms. Octane had some experience in teaching through argumentation, but not a great deal. In addition, her expertise was more closely aligned with Biology and Anatomy/Physiology than with fields like climate change. And lastly,
I wanted to be sure the unit was conducted in a manner consistent with the purposes for which I designed the unit. That is, I wanted to make sure that the unit emphasized the students' sense-making of the available data by teaching the first classes of the day, assisting with the next two sections, and then researching the final section of the day, period 7.
CHAPTER FIVE

DESCRIPTION OF CONCEPTUAL CHANGE IN CLIMATE CHANGE

In this chapter, I describe and discuss the patterns in conceptual change found in the five interview participants regarding their understandings of global climate change. I begin by revisiting Vosniadou's framework theory of conceptual change (2003), in order to connect it directly to the climate change content at hand. I will then proceed to examine each student's conceptual change in reference to Vosniadou's framework. For each of the interview participants, I begin with their initial conceptions of climate change science. I then proceed to examine their particular synthetic theory of climate change that resulted from the interaction of their initial/naïve theory with the science unit. I then turn to an examination of other, extra rational factors that influenced each student, in order to account for their particular conceptual change. There were nine data sources used to understand the students' conceptions. These sources were as follows, followed by the notation which will be used throughout this document to refer to each:

1. Interview transcripts-pre (pre int), mid/concept map interview (C-M int), post (post int), and delay post interviews (delpost int);
2. Written arguments in the pre test and post test (pre T/post T);
3. Written arguments written by students at unit’s end (writ);
4. Written arguments depicted on the group’s poster boards (ADI 1/ADI 2);
5. Observation notes (including student talk) taken during the climate change unit (Day 1 not).

Each of the above data sources was examined to provide evidence of the students' GCC conceptions.
Vosniadou’s Framework Theory of Conceptual Change

Vosniadou’s framework theory of conceptual change focuses on the idea that students do not enter any science lesson as blank slates, but instead have relatively intact “theories” which work for them (Vosniadou, 2003). These stories may not pass muster as robust scientific theories, but the theories do work for their needs. That is, these constructs are theories in the sense that they allow students to organize their knowledge and serve some rudimentary needs for prediction, yet they are naïve theories in that they are not scientifically accurate. When a student encounters more scientifically accurate versions of the science in question, then this can force the students to synthesize new understandings, forming a synthetic theory, in this case, of global climate change. Below, in Figure 5, is a diagram showing a sample description of naïve GCC science understanding, compiled from several students’ ideas, as compared against a more scientifically accurate representation of global climate change views.

<table>
<thead>
<tr>
<th>Naïve GCC Understandings</th>
<th>Scientific Model of GCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Temperature increasing;</td>
<td>• Temp. increasing, on avg., across Earth;</td>
</tr>
<tr>
<td>• Ice melting;</td>
<td>• Polar ice and glacial melt as evidence/consequence of warming;</td>
</tr>
<tr>
<td>• Pollution happening;</td>
<td>• Sea level rise as result of warming;</td>
</tr>
<tr>
<td>• Climate changing;</td>
<td>• GW as a subset of GCC;</td>
</tr>
<tr>
<td>• Sea levels rising;</td>
<td>• Ozone not related to GCC;</td>
</tr>
<tr>
<td>• Animals dying;</td>
<td>• Sea levels rising due to thermal expansion, glacial melt;</td>
</tr>
<tr>
<td>• Ozone hole as factor in climate change;</td>
<td>• GW as result of enhanced greenhouse effect;</td>
</tr>
<tr>
<td>• GW as either (exclusively) man-made or natural;</td>
<td>• GW as having natural and anthropogenic causes;</td>
</tr>
<tr>
<td>• GW as something to believe in or not.</td>
<td>• GW as (partly) result of industry emissions</td>
</tr>
</tbody>
</table>
In order to make sense of the students' views on climate change, it was necessary to create a template to serve as an organizing structure for the science at hand. The creation of this template (Figure 6) was informed by analysis of the data. Five major dimensions are captured in this template, including the characteristics of GCC, the characteristics of global warming, characteristics of their general environmental theory, evidence for the above categories, and mechanisms being the last. The examination of evidence for each student's views within each dimension of this may reveal that certain of the five categories may be combined with others or relatively nonexistent in their own right:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Characteristics of GCC</td>
</tr>
<tr>
<td>2.</td>
<td>Characteristics of GW</td>
</tr>
<tr>
<td>3.</td>
<td>Characteristics of the environment</td>
</tr>
<tr>
<td>4.</td>
<td>Evidence for GCC/GW</td>
</tr>
<tr>
<td>5.</td>
<td>Causal mechanisms of GCC/GW</td>
</tr>
</tbody>
</table>

After describing each student’s conceptual framework for GCC understanding, and changes in that understanding, I then describe how their synthetic theories emerged. Critical to this understanding is examination of several non GCC-specific factors upon this learning. Theoretical considerations as well as deep analysis of the data revealed four categories that most impacted the learning of these students. I now explain the origins of each of these factors. As described earlier, the framework theory (Vosniadou, 2007a) invokes the need to understand the ontological and epistemological aspects of learners as aspects that serve as presuppositions to the remainder of the theory invoked by the learner. My analysis supported the need to understand these foundational aspects of the learners’ understandings. The coding and other analyses performed also underscored the need to investigate two other broad categories that tied directly to GCC understandings. These were analytical ability and extra rational considerations.
I first must clarify what I mean by an “ontological” category. Merriam-Webster’s (2011) defines ontology as either “a branch of metaphysics concerned with the nature and relations of being” or “A particular theory about the nature of being or the kinds of things that have existence.” In this work, I use ontology to refer to first definition, akin to the nature of being. The second definition would imply that the students involved in the research had a high level of metacognitive awareness of their own theories about existence. I do not claim to have documented such a level of awareness in the 6th graders in this research. However, they were well capable of understanding simplified versions of ontology, such as whether or not something existed in its own category, or whether or not that thing was a process as opposed to a collection of things. In fact, recognizing such a shift in a student’s ontological stance is recognized as one indicator of conceptual change (Chi, 1992; Vosniadou, 2007a).

Likewise, I also use the term “epistemology” not as an indicator of the students’ metacognitive awareness of how knowledge is attained, but as a guide to understand the epistemic weight given by these students to arguments, evidence, etc. For example, some students may be more prone to relativist versus absolutist types of epistemological stances (Kuhn, 1993). Therefore, it is not necessary to derive a complete theory from the student participants as to how they think knowledge is attained. Instead, evidence was examined from which I inferred what weight was given to which types of evidence and/or arguments. Again, this is a usage consistent with conceptual change theory, and particularly with the framework theory of Vosniadou (2007a, 2007b).

I remind the reader that the four categories described above were invoked out of necessity by theoretical considerations or by data analysis, in order to understand the shift in GCC content understandings. Without considering the ontological, epistemological, analytical, and affective aspects of the learners’ conceptual awareness and understanding of the learning growth would have been impossible to adequately understand.

A conceptual diagram to illustrate the interaction of these factors is given below in Figure 7.
After examining the interaction between the above non-GCC science factors along with the students’ science understandings, I then connect each explanation to relevant literatures on learning theory. I then conclude chapter five with a summary of some of the major findings concerning these students’ conceptual changes.

**BEYONCE: Scientist as Qualified Truth-Teller**

*Beyonce initially viewed science as something which one had to be qualified in to be able to give “True” information about it. She did grow significantly in many regards but retained this notion of authority in science.*

**Beyonce’s understandings of GCC Science**

Beyonce’s initial understandings of climate change science were characterized by discrete facts, often accurate facts, either unconnected to each other or at least poorly so. For
example, prior to instruction, she identified that glaciers were melting (pre-T) and that sea levels were rising (Pre-int). It is important to note at the outset that Beyonce did think that climate was changing. She answered “yes” to question one on the pre-test (Do you think the Earth’s climate is changing?) and she elaborated as to why, indicating that the weather isn’t like it used to be” (Bey pre, p. 1). Also, Beyonce’s initial conceptions of climate science tended to were largely absent of mechanisms. In general, her description of climate change science focused on “general characteristics” and “evidence for”. Expanding on Figure 5 above, Beyonce’s particular template for climate change conceptions is given below in Figure 8.

The examination of evidence for each student’s GCC framework may reveal that certain of the five categories may be combined with others:

<table>
<thead>
<tr>
<th>GCC Science Framework Category</th>
<th>Naïve</th>
<th>Post Instruction/Synthetic GCC Framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics of GCC</td>
<td>Climate is changing (Pre-T); Weather isn’t like it used to be” (Pre-T, p. 1); Climate has no pattern-it’s hard to predict (pre-T); Natural disasters happening more (Pre-T)</td>
<td>Climate is changing for the bad (Post-T); Climate change doesn’t have to be global warming, it could be cooling. (Post int, p. 3); Carbon Dioxide is a part of climate change (C-M, p. 2).</td>
</tr>
<tr>
<td>Characteristics of GW</td>
<td>Global warming is a type of Climate change (pre-int, p. 2)</td>
<td>Gradual warming will melt all ice masses &amp; cause water to rise (Post-T); GW traps heat &amp; that changes the climate (C-M int, p.1);</td>
</tr>
<tr>
<td>Characteristics of Environment</td>
<td>Pollution happens (Pre-Int); GHE has to do with plants (pre-Int, p. 3); Natural disasters happening</td>
<td></td>
</tr>
</tbody>
</table>
Evidence for above

| Evidence for above | Figures 1, 2, and 3 all show effect of temperature rising (Post-T);
Glaciers have shrunk (Post-T);
Scientists collect data from temperatures they record every day…the do comparisons like that” (Post-int, p. 1).” |

Mechanisms of above

<table>
<thead>
<tr>
<th>Mechanisms of above</th>
<th>Rise of pollution, CO₂, and Nitrogen in the air (Pre-Int)</th>
</tr>
</thead>
</table>
|                     | –Main cause is GHG’s, mainly CO₂. Graph 4 is my main witness b/c it shows CO₂ is affecting the time temperature…I’m not sure which, but I think the carbon affects the temperature” (C-M int, p. 2);
GHG’s heats up the atmosphere…so…either the temp. is making CO₂ levels rise or CO₂ levels is making temperature rise” (Post-Int, p. 4); |

Figure 8: Beyonce's GCC science framework before & after instruction

A look at Beyonce’s naive GCC framework, as summarized in the table above, reveals several patterns. First, Beyonce’s initial framework featured many inaccurate scientific ideas. Included in these ideas are notions that increasing natural disasters are a part of climate change, that climate has no pattern, that Doppler radar is a useful way of detecting climate change,
general pollution is a function of climate change, and that the greenhouse effect is a function of plants. Note that several of these constructs fit better into a general environmental category rather than a climate change category. It appears that Beyonce, at least initially, has lumped generic environmental issues like pollution and natural disasters into her mental category of "climate change". This is most obvious in her pre-test, in which her answer included "Natural disasters are happening more of late" in response to question 4, which asked: "If the climate of the earth is changing, what do you think is the major cause of climate change on the Earth? Please explain, citing as much data as possible. (Be sure to indicate whether or not the climate change is cooling or warming)."

Additionally, Beyonce had not, at the outset, particularly differentiated global warming from climate change, indicating only that one (GW) is a subset of the other (GCC). For example, Beyonce volunteered that "The climate change now is global warming (p. 2)." Second, it is apparent that Beyonce actually did understand many things about climate change prior to engaging in this unit. She already understood some facts such as glaciers are melting, climate is changing, and that global warming is a subset of climate change. Third, what Beyonce initially understood about climate change, whether scientifically accurate or not, fit into the categories of "characteristics of", and "evidence for", with very little initially understood in the way of mechanisms of climate change. Her answer to the pre-test question 7, asking her to explain, using data, what she thinks is the major cause of climate change, if it is in fact changing. In response to this question, Beyonce wrote "I think the major cause of climate change is the rise of pollution, CO₂, and Nitrogen in the air (Pre-T, p. 1)". In that answer, Beyonce appeared to be invoking a set of graphs available on the pre-test, showing the relationships of various gases in the atmosphere. However, none of those graphs focused specifically on "pollution", or even mentioned that word. Therefore, I argue, the idea of pollution as the cause was Beyonce’s naive idea, which she then merged with the data in front of her.

At the unit’s end, however, Beyonce’s demonstrated understanding of GCC science had grown considerably. At that point, her understandings were marked by a significant emphasis upon the causes and mechanisms of climate change. Figure 8 above shows Beyonce’s final synthetic theory of climate change.
A comparison of Beyonce’s GCC pre and post GCC understandings quickly reveals some further patterns. First, Beyonce’s explications of climate change no longer include generic environmental things not related to climate change. At no point in her voluminous data collected post-instruction does she mention “pollution”, nor does she again invoke the idea of natural disasters, as she did in her pre-test, as being a component of climate change. Second, she discussed not only characteristics of climate change and global warming, but gave attention to specific pieces of evidence and mechanisms. For example, she cited particular graphs to buttress her claims (“See? Look at the graph—co2 goes up!”), as opposed to only including general notions of ice melting. Also, her synthetic framework of GCC science included multiple references to causal mechanisms of warming. She indicated that the main cause of GCC is “greenhouse gases, mainly carbon dioxide” (C-M, p.2); that GHG’s “heats up the atmosphere…” (Post-int, p. 3); and that “in conclusion, yes, I do think the earth is warming I conclude the most likely reason for recent climate change has been CO2 and Greenhouse gases (Bey writ, p. 2).”

In conclusion, Beyonce’s GCC science framework has improved significantly from the naïve to her synthetic framework. Her naive framework consisted of a hodgepodge of unconnected data, much of which was inaccurate, and much of which belonged in a general environmental category as opposed to a climate change specific category. Most of her early understandings were things that fit into “characteristics” categories, although she did have a limited early sense of evidence for climate change. Her understanding of mechanisms of climate change was extremely limited. However, her after instruction framework showed a marked improvement across all categories, particularly the “mechanisms of” aspect of her framework. In addition to multiple references to (generally accurate) renditions of the greenhouse effect mechanism (“The greenhouse gases heats up the atmosphere, and the atmosphere is the like a blanket of gases around the earth”), Beyonce also showed a nuanced grasp of the evidence for GCC, as delved into in her written argument, in which she cited the trends in the glacial melt photos in addition to the rising temperature data (data point). Her post data showed her accurately citing particular graphs for evidence of the warming [paleoclimate graph showing temperature and CO2 data]. However, her synthetic framework after instruction remained limited, in that her understanding focused only on the connection between GHG’s and the
greenhouse effect, as opposed to adding the connection that human industries may have enhanced the already-existing greenhouse effect.

The above section sought to describe Beyonce’s conceptual change, to the extent that it did happen, in regard to her GCC science understandings. Now, I turn to the issue of explaining that conceptual change. Many authors have described how conceptual change is a complex process consisting of rational and extra-rational factors, including self-efficacy, learning dispositions, belief identifications, and more (Sinatra, 2005; Southerland, Sinatra, & Mathews, 2001; Vosniadou, 2003, 2007b). I now turn again to examine the impact of some of these other factors, including the extra-rational, which impacted the construction of Beyonce’s synthetic GCC science framework.

The three sets of factors investigated here include epistemological understandings, analytical abilities, and extra-rational factors.

**Beyonce’s Epistemological Understandings**

Prior to the unit on GCC, Beyonce showed an epistemological understanding that was naïve in some respects and more complicated in other ways. She responded to one question about science: “…different cultures have types of faiths, or studies, or science.” This implied a relativist epistemology (Kuhn, 1998), in that science was not the same everywhere, for all cultures. However, her epistemological understanding was complicated somewhat when clarifying how scientists go about what they do: “→ think all scientists should go a certain way about science, or use the scientific method” (Bey pre int, p. 1). This is interesting in that her reference to THE scientific method was seemingly at odds with her prior statement about multiple cultural versions of science. Beyonce went on to say that she viewed important sources of scientific information to include TV news, teachers, books, and magazines. She clarified what made such sources trustworthy as being:

…it’s written, has a copyright date…and like if you ask me, it’s legitimate if it’s a scientist, and it’s proven they’re a scientist. Or a person who has scientific knowledge (Bey pre int, p. 4).

What the above reveals about Beyonce is that she considers scientists to be figures of authority whose pronouncements should be accepted by others because of scientists’ unique qualifications. Hence, anything they say, whether in written form or not, constitutes a trustworthy source of
information. This notion of Beyonce’s, positioning scientists as authoritative transmitters of parcels of Truth is a notion described by scholars as “scientistic” (Duschl, 1988, Southerland, 2000). Beyonce showed some signs of conceptual change and some signs of stasis regarding her epistemological understanding in her post interview, in which she mentioned that scientists learn about the world — by researching and running tests. And using the scientific method” (Bey post int, p. 4). Evidence of growth came later in the interview, when she answered the question of the validity of scientists’ explanations for climate change. In response, she said:

…If you ask me, they compare data, they run tests, they do stuff over and over again until they come to a conclusion. And I’m sure they post information, the temperature’s rising, they you know, have to run the tests over and over again, and continue to look at the data (Bey, post int, p.2).

While the previous passage showed some nuance in her epistemological understanding in that she understood that scientists must continue to look at the data, while also focusing on the need for scientists to use THE scientific method, she later clarified that

You have to be careful what you use as a source”, because of some people out there with the internet. You have to be careful because anybody can make a webpage. For instance, I could make a webpage in middle school, and I’m not that qualified. Anyone can give you information. You have to be qualified to give TRUE information (Bey, post int, p. 4).

The above passage indicates that Beyonce still held onto a thread of absolutist thinking (Kuhn, 1998) after the instructional unit, in that TRUE information was privileged. However, she nuanced that TRUE information by noting that certain qualifications were necessary in order to be able to give that Truth.

Her “post” instruction epistemological understandings showed growth in that she cautioned about the need for scientists to continually evaluate data:

They have to be qualified for what they do. If you ask me, they compare data, they run tests, they do stuff over and over again until they come to a conclusion. And I’m sure the post information, the temperature’s rising, they you know have to run the tests over and over again, and continue to look at data (Bey post int, p.2).
However, her clarification showed a combination of lack of self-efficacy and deference to authority, in that she, Beyonce, was not qualified, but some (scientists) are qualified to give ‘TRUE information” (Bey, post int, p. 2). While her cautionary tone about the need for constant evaluation denotes some growth, her tone of deference to authority seems relatively unchanged from pre to post, as does her epistemological understanding and valuing of Truth. Beyonce’s insistence upon qualifications required to give True information imply that her epistemology is based upon a foundationalist premise that certain knowledge is attainable, at least for some. She seems to be invoking a foundationalist notion of Truth relying upon empirical claims (Southerland, et al., 2001), but she then places a layer between herself and those competent enough to reveal such information. Therefore, Beyonce’s epistemic ideas, although showing a trend towards the empirical, maintained an authoritative stance after instruction.

One other epistemological aspect emerged from an analysis of Beyonce’s overall data. She was initially greatly impacted by her own anecdotal experience. The data in question overlap with some of the subject matter understandings examined below. Beyonce showed how important anecdotal information was early in her pre interview. In responding to a question as to her understanding of climates around the world, she said:

Everybody’s climate changes. It gets cold, it gets hot, they have different stages. Like for example, in the morning here it’s cold, then it warms up during the day and it gets cool during the evening (Bey Pre int, p. 2).

In her post interview, Beyonce’s anecdotal reference is much more complex when she reflects back on what was learned:

I learned that sooner or later global warming is gonna be a big problem. I learned that over…well you don’t really notice it when you’re walking around on a regular basis, but when you sit down and look at the data you see the temperatures actually rising, but you don’t really notice it” (Bey Post int, p. 5).

She seemed to be reflecting back and evaluating her own use of anecdote by prioritizing the graphic data over her own personal, anecdotal experience. This speaks to her growth in epistemological understanding, in that she has learned to either understand or value the kinds of evidence presented in the unit she had just participated in. In other words, she has adopted the epistemic values of science, in that she prioritized the scientific norms of giving credence to non-anecdotal data. It is likely that the social interactions facilitated in the unit served to scaffold the
students’ learning of new epistemic values, i.e., that data in graphic form are valued in the scientific community more so than are anecdotal data. In addition, arguments and explanations generated by students were more likely to withstand scrutiny if they referenced such data as opposed to personal experience alone. Thus, the design of the unit in question was one that explicitly taught the epistemic norms of science. The above data suggest that Beyonce did indeed incorporate those norms into her own thinking.

In conclusion, Beyonce’s naive epistemological understandings showed emphases upon deference to authority, Truth, and references to anecdotal information. After the unit, her epistemological views changed to value other data sources, in addition to simply valuing the personal anecdote. However, Beyonce’s deference to authority remained intact. Beyonce’s epistemic positioning of the Scientist as qualified Truth-teller remained intact post-instruction, even though she developed a more nuanced position as to what the “qualifications” were. Her post-instruction views of those qualifications had moved to a position of valuing data sources consistent with the epistemic values of science, i.e., data collected and depicted in graphic form, etc., as opposed to simply anecdotal Information. I now turn to examine the changes in Beyonce’s analytical abilities, as evidenced in this research.

*Beyonce’s Analytical understanding*

Beyonce’s initial understandings of the graphic data employed in the unit reveal that she, at first, had a limited ability to analyze data contained in line graphs. Instead, she tended to simply describe the graphs based on the labels given. In her pre-interview, she describes graph one, showing the time/temperature of the Earth over 100 years, as “showing...the temperature how the temperature is earth’s changing over a period of time. Up all the way to today” (Bey pre-int, p. 4). Referring to graph two, which referred to time and temperature as measured from Antarctic data over 300,000 years, Beyonce said that “It’s seeing how much water is falling off the ice caps and that could relate to the temperatures down there, how the temperatures in Antarctica are rising” (Bey, pre-int p. 4). One thing absent from her depiction of the graphic data was the relation of any patterns or trends present in them. In her pre-test, Beyonce did do some minimal interpretation of the graphs. She said the data support her answer (that the Earth’s climate is changing) because “you can see how glaciers change over a period of time their melting” (Bey, pre-T, p. 2). The most interpretation she did prior to the unit was in her pre-test,
in which she said that “The major cause of climate change is the rise of pollution, CO2, and Nitrogen in the air. This is causing the earth to warm and this is causing global warming” (Bey, pre-T, p. 4). In this answer, she was interpreting the causes of climate change from the graphs, and ascribing it largely to pollution (not explicitly described in any graph).

Beyonce’s graphic interpretation underwent some changes after the unit, but the mid-unit interview captured her still struggling with this idea. She said that “Carbon dioxide is affecting the time and temperature on the time/temperature graph for the last 300 thousand years. I’m not really sure which affects which, but I think the carbon affects the temperature….the time/temperature and carbon dioxide graph and the time/temperature graph are related because they’re both about time and temperature” (Bey, C-M int, p. 1). This passage indicated a superficial reading of the graphs in question, with little evidence of the interpretation of patterns from them.

In contrast, in the post data, Beyonce gave clear evidence of having developed a more robust idea of graphic data interpretation. When asked to discuss the graphic data, she started “with the one with the glaciers on it….you could see that there’s less ice on the one that’s more current…the picture that was taken later back in time has more ice on it…like you see on this one, where ice was a little pond’s starting to develop in this picture, (meaning)..that it’s melting!” (Bey, post int, p. 3). When asked to discuss the line graphs, Beyonce admits that she was:

…still not understanding it, but either the temperature is making CO2 levels rise, or CO2 levels is making temperatures rise. But I think the CO2 concentration rises because as the CO2 line goes up, you see the temperature line follows (Bey, post T, p. 2).

Not only was this substantially more detailed than the explanations given in her pre instruction data, but after the unit she extrapolated what would happen next:

Cause you see the CO2 is leading it. See look at the graph-CO2 goes up, and temperature kind of goes off to the side. I think if the graph was to continue, the temperature would shoot back up after the CO2” (Bey post int, p. 3).

Beyonce then dismisses the graph referring to sunspot data:

If you ask me the sunspots don’t have anything to do with the temperature, because they’re going in the totally different direction from the temperature. Both of them never plateau or they never reach the equilibrium where they’re in a straight line, where the

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data is the same over a period of time. And as the temperature rises, the sunspots kinda decrease (Bey post T, p. 2).

In these passages, Beyoncé showed a great degree of conceptual change with respect to her ability to understand the graphic data underpinning this subject matter. She started out with a simple reading of what the graph entailed, and developed to the point where she was interpreting patterns from the graphic data, inferring causality from the data, and even extrapolating future patterns from the current patterns. In fact, Beyoncé even made a metacognitive connection to the graphic data as well. Reflecting back on what she learned in the unit, she said:

I learned that sooner or later global warming is gonna be a big problem. …you don’t really notice it when you’re walking around on a regular basis, but when you sit down and look at the data you see the temperature’s actually rising, but you don’t really notice it (Bey, post int, p. 5).

Here, she showed that she had overcome her prior commitment to anecdotal experience, in favor of non-anecdotal data. In this regard, Beyoncé went through a dramatic conceptual change. To summarize, Beyoncé’s analytical skills in reference to the GCC unit improved greatly. In particular, her early analysis pertaining to the scientific graphs was focused on summarizing (often incorrectly) what the graph was about, as opposed to relating patterns in the data. In contrast, her later graphic analysis inferred patterns, causality, and even extrapolated into future events at least on at least one occasion. It may be more accurate to say that Beyoncé appropriately recognized the lack of causality in the sunspot graph, due to the non-correlation of the two lines in question. This recognition indicates a quantum leap in her understanding. I argue that her improvement in this analysis was central to her improvement in her epistemological shift from anecdotal to empirical.

**Beyoncé’s affective factors**

There were several affective issues affecting Beyoncé’s learning throughout this unit. First, she stated at the beginning that science was “not her favorite subject”. Instead, she preferred math. She clarified this position both pre and post research. Her preference for math tied directly into her science specific learning in one particular way, in that her math teacher had used climate change data to teach her students about addition and subtraction (Bey pre int, p. 3). Like my math teacher she uses how the sea level rises, for addition and subtraction.
The exchange above indicates the possibility that Beyonce's experiences in mathematics directly impacted her prior understanding of climate change, it that it was the context in which she first learned about consequences such as sea level rise. And this occurred within the context of her favorite class (Science was described as her third favorite). This may account for some of Beyonce's naive GCC framework, in that she was aware of sea level rise, but not in any particularly contextualized way.

Another extra rational component that emerged in Beyonce's data was her concern about the outcomes of climate change. In her pre interview, we had this exchange (p. 2):

Beyonce: what I get from the …ice caps…melt and it’s causing a rise of water and sooner or later its flow.
BG: The ice caps melt, causing sea levels to rise? And what’s that gonna do?
Beyonce: That’s gonna cause it to float. And that could affect animal life.

Later on in the same interview, Beyonce again expressed concern, but with a different target in mind (p. 4):

BG: Do you think it's important to understand the scientific evidence for things like climate change?
Beyonce: Yes. Because sooner or later, it's gonna affect the earth, and it's gonna take ahold of us, so we need to know what's going on.

In this case, Beyonce's concern was expressed over how climate change will affect the Earth in general, and humans in particular.

Later still, Beyonce showed continued evidence of concern about the outcomes of climate change (Bey post int, p. 2.):

BG: Do you think it's important to understand evidence for things like climate change?
Beyonce: Yes, because sooner or later, we're gonna have to study it because it'll effect…how we live.
BG: How WE live, here in (Southern city), for example?
Beyonce: It’ll affect everybody around the globe, it you ask me…If the sea levels keep rising, soon it will flood all the land. And all the…humans will die out, kinda like the dinosaurs did.

What is particularly interesting about the above passage is that not only was Beyonce explicit in describing how climate change would affect humans, but her concern was tied to a potential
extinction of humanity. She invoked her understanding of the dinosaur extinction as evidence that an apocalyptic situation may be at hand concerning climate change. Interestingly, she invoked a situation that had not been explicitly tied to climate change at all, at least in the course of this particular class.

In conclusion, some affective factors that emerged from the analysis of Beyonce’s data included her concern for animals, referenced numerous times pre and post instruction, and her low-to-moderate science self-efficacy (‘I’m not that qualified. You have to be qualified to give TRUE information (Bey post int, p. 2).

Above, I described the conceptual change in regard to Beyonce’s GCC science frameworks. Then I highlighted the factors in shaping her learning. Now I turn to explain the influence of the content-specific factors in her conceptual growth. As noted already, Beyonce underwent some significant improvements in her understandings of GCC science, moving from a loose description of accurate and inaccurate facts, to a cogent description of climate change including appropriate evidence and mechanisms. The epistemological, analytical, and affective factors all played an extremely important role in her growth. The examination of multitudes of factors such as these in understanding conceptual change has been described by some scholars as understanding the ‘conceptual ecology’ of the learner (Southerland Johnston, & Sowell, 2006). As such, the conceptual ecology is thought to include cognitive aspects and affective, dispositional, and social and cultural influences” (Southerland et al., p. 875). This study focuses on the ontological, epistemological, analytical, and affective aspects of the learners‘ conceptual ecologies.

A summary of the aspects of these factors particular to Beyonce’s conceptual change is given in Figure 9:
The changes in Beyonce’s epistemological understandings were a necessary component in comprehending the learning that she experienced. For her to evolve towards a model in which she often described mechanisms of global warming, and to cite appropriate, specific evidence, Beyonce had to move beyond her personal epistemological world view that emphasized anecdotal information and information from trusted authority figures. Her early attempts to invoke her personal experience in weather patterns, etc., indicate that she was confused as to the scale of the phenomenon involved. By scale, I mean specifically to underscore that her initial framework was insufficient to grasp the complex science of GCC both on the temporal and the spatial scales. That is, when asked about climate change, her frame of reference invoked her
anecdotal experience with weather. While other authors have pointed out the difficulties in learning issues of scale on spatial levels (Tretter, Jones, & Minogue, 2006), and the concept of deep time (Dodick & Orion, 2006), I emphasize here that many of these problems may stem from an ability to appropriately process the scale of events on both axes. For example, the concept of climate change invokes a long historical scale, spanning periods of time ranging from years to hundreds of thousands of years or more. At the same time, GCC invokes a large spatial scale as well, invoking climate across large areas from regions of a country to entire nations, continents, and even the world. From the reference point of a middle school student such as Beyonce, whose frame of reference is about 8 years temporally, and regional to her home area spatially, she was not well-prepared to understand a science that encompasses such broad vistas.

One notion that may help to explain the vast improvement made by Beyonce in her GCC understanding is that many factors converged for her. For example, her epistemological understanding dovetailed with her advances with analyzing the graphic data. Her post explanations of GCC are rife with references to the graphic data. In her case, improving in her analysis skills in reference to graphs showing varying ranges of time scaffolded her understanding of the concept of scale to a degree to where her epistemological understanding was improved. One aspect of the unit likely played a part here, in that the argumentation format used placed a premium on understanding graphic data. Therefore, this skill was privileged by the unit, possibly creating a social pressure to emphasize the epistemic valuing of graphic data. By doing so, Beyonce was learning about the culture of science in that she was practicing the norms of scientists. In this regard, she accomplished what some scholars have called for more focus in science education, that is, to participate productively in scientific practices and discourse (Duschl et. al, 2007). Engle and Conant (2002) describe productive participation as occurring when there is contact between what students are doing and the issues and practices of a discipline’s discourse” (p. 402). By adopting the appropriate epistemic values of science, I argue that Beyonce was indeed productively participating in the practice of science.

In terms of her affective relationship to the material, Beyonce’s favorite class was identified by her as mathematics. It is a likely factor in her growth, in that graphing analysis required probably invoked her mathematics skills and values. Another affective factor that is difficult to appropriately analyze is Beyonce’s expressed concern for animals. Many times this concern became apparent, including in the post data in which
Beyonce expresses a concern about a possible human extinction. Perhaps it is surprising that there are two affective notions which appeared for the first time in Beyonce’s post data. The first is the extension of her concern for animals to concern for humanity’s continued existence (“And all the ...humans will die out, kinda like the dinosaurs did” (Bey post int, p. 4). The second is an affective component of climate change itself. In her post test, she specifically indicated that climate change was bad (Bey post T, p.1). Although she showed awareness of many effects of climate change prior to the research, she had not demonstrated a value judgment prior to the unit’s end, other than regarding concern for animal life. Beyonce expressed concern for humanity in both her post-test and her post interview, and indicated that climate change itself was something that was negative, requiring the attention of humanity to solve in her post-test.

Finally, one aspect of Beyonce’s conceptual growth includes an ontological dimension. Prior to the instructional unit, Beyonce did not have a separate cognitive category for climate change that was distinct from other environmental issues. Some scholars have pointed out that students may sometimes need to undergo such a cognitive restructuring (Ausubel, 1978). In his subsumption theory, Ausubel posits that much learning consists of such reorganizing of knowledge. In a description of different types of organizational scaffolds, called advanced organizers, Ausubel invokes two different types: expository and comparative organizers. Expository organizers are “used when the new learning material is completely unfamiliar” (Ausubel, 1978, p. 252), while comparative organizers are used when the material is relatively familiar. In Beyonce’s case, she had no advanced organizers by which to help her make sense of her new learning about GCC. However, the data make clear that she did indeed undergo a shift in an organizational category that would imply that an appropriate advanced organizer would have been an extremely helpful aid. In particular, the idea that Beyonce had no particular category into which to store her new knowledge about GCC as opposed to environmental things points to the usefulness of an added ontological category, in addition to her mental model of the general environment. The data above make it clear that Beyonce’s understanding of GCC was initially limited, and would have remained limited, if she did not invoke some sort of ontological category for climate change that could help her separate her GCC understandings from her other environmental constructs. That leaves the question of what sort of ontological category should be created as an appropriate organizing construct. One helpful notion would be a move from a
view of GCC as an entity towards an understanding of GCC as a process (Chi, 2008). Chi (1997, 2008) identifies two different types of processes, direct and emergent. Direct processes feature those that seem to have a single causal agent which will respond in a predictable, corresponding way (Chi, 2008). In contrast, “emergent processes” are those whose causal agents are multiple, wherein no single causal determinant is thought to be at play. Additionally, local patterns may be seen which are ignorant of the greater global patterns, whose changes may be proportional to the causal agents, instead of incremental. That is, feedback mechanisms may result in increases/decreases in the system to the extent that small changes in causal agents may result in relatively large systemic outcomes. This emergent process is a useful description of the phenomenon of global climate change itself, wherein the net results of global warming and/or climate change may be multiply causal, with no one factor clearly being THE determinant. In addition, small changes, for example, in CO₂/other GHG’s, on the order of 50 parts per million, in the atmosphere, may produce changes in temperature and/or rainfall patterns, etc., which are difficult to project (IPCC, 2007). I argue that the data above indicated that Beyonce’s lack of appropriate ontological category both limited her initial understanding and restricted her growth, in that she never fully constructed an ‘emergent process’ category of GCC.

**Summary of Beyonce’s growth**

Beyonce did undergo some significant conceptual change during the course of the GCC unit. Given that her initial epistemological stance of Scientist-as-qualified-Truth-Teller positioned her in the absolutist to relativist realm of epistemology (Kuhn,1998; Phillips & Burbules, 2000), her growth was remarkable. Her understanding of the GCC science grew, particularly in regard to her invoking of CO₂ as a major warming agent as a GHG, and her acknowledgement of graphic data as demonstrating climate change, several factors were key in explaining this growth. Beyonce’s epistemic thinking evolved over the course of the unit to a point where her focus on anecdotal data was largely replaced with a systematic emphasis on the data given in the graphs. Also helping to explain her growth was the fact that her analysis of the graphic data greatly expanded, from a point where she simply read the graph labels, to a place where she inferred patterns from graphs, extrapolated into the future from those patterns, and even interpreted causality from the graphs.
Beyonce was initially hampered by an ontological barrier, in that she did not have a cognitive category for climate change that was significantly distanced from her category of the environment. And her growth overall was moderated by affective factors unique to her, in that her low-to-moderate self-efficacy limited her ability to expand beyond the Scientist-as-Truth-Teller position, except in nuancing what the qualifications were. Also, Beyonce demonstrated early on an affection for and concern for animals. It is likely that her sense of empathy, shown pre-instruction, evolved into an extended sense of empathy which included the welfare of human beings as a result of climate change.

The above gains in Beyonce’s conceptual understandings can be best explained by regard to the design of the GCC unit; in particular, the unit’s reliance upon collaborative argumentation, which placed students in the position of having to render explanations which best fit the available data. This strategy was successful in the important aspect of helping to scaffold Beyonce’s acquisition of scientific epistemic norms of valuing data that support reasoning. This connection between argumentation and its positioning as a tool with which to facilitate conceptual change has been made by scholars (Linn & Hsi, 2000; Miyake, 2008). Some pathways posited include that collaborative argumentation models help by “making scientific reasoning visible” (Linn & Hsi, 2000) and/or by treating students as “epistemic agents” who are responsible for changing their own knowledge and sustaining the intellectual community they belong to” (Miyake, 2008, p. 473). In addition, this collaborative model seemed to facilitate Beyonce’s ability to make use of graphic data, in that she grew from label-reading to interpreting causality from graphs. Without careful, collaborative deliberation with her peers, it does not seem likely that her views would have grown in these ways or to these extents.

**BONO: Scientist as Proof-Deliverers**

_Bono initially conceived of science as something requiring strict proof in order to believe in or accept its tenets. Therefore, he initially was very skeptical about the idea of global warming. Additionally, he viewed global warming as a concept requiring belief in 100% human causality. Because that had not “been proven” in his mind, he was initially reluctant to accept global warming._
**Bono’s understandings of GCC Science.**

Bono’s naive GCC science framework could best be described as naïve in general, although he clearly did understand some components of climate change, although again in a poorly connected way. For example, he was initially skeptical of the idea of global warming partially because he perceived that global warming was the idea that only humans are causing the Earth to warm. His idea was that if any significant portion of this might occur naturally, then the idea is not global warming. As such, he considered global warming to be "just a theory” that is "not proven yet” (Bon C-M int, p. 1). For example, Bono explained "I have doubts that humans are the only ones causing it. It may be natural (Bon, pre int, p. 3).” A little later in the unit, Bono was still struggling with this idea, as indicated in his concept map interview: —Proof they have is not solid proof that humans are the only ones causing it” (Bon, C-M int, p. 2). It is clear that although he concedes that climate change is occurring (Bon pre-T), he considered the idea of anthropogenic global warming objectionable due to his perception of the unaccepted nature of that science, and also because of his perception that a belief in global warming required a total commitment to anthropogenic causes of the warming. Despite his skepticism as to the causes of warming, he indicates on his pre-test that he thinks that such warming is indeed happening. However, on that pre-test, he attributed the causes to sunspots.

Bono’s grasp of the evidence of climate change before instruction was rudimentary, although he quickly made references to pieces of evidence that he saw, such as photos of glaciers. In his pre-test, glacier photos are the only pieces of evidence to which he referred. Before instruction, the only mention of a mechanism regarding climate change which Bono initially referred to involved a metaphor of a bodily infection. When he attempted to explain the presence of greenhouse gases in the atmosphere, he explained:

—Foreign matter gets introduced in the atmosphere. It’s kinda like the body. Where if you ever get a blood transfusion and the blood wasn’t right type, the blood cells fight it off” (Bon, pre int, p. 3).

In fact, when asked directly about the greenhouse effect, Bono’s response referred to ozone, SUV’s and the need to drive hybrid cars. In other words, like Beyonce, Bono seems to have activated a general environmental framework in response to GCC. However, Bono’s extent of overlap between his GCC and his environmental frameworks were not as complete as Beyonce’s, in that his initial environmental references were more limited to ozone-related factors.
<table>
<thead>
<tr>
<th>GCC Science Framework Category</th>
<th>Pre-instruction/naive GCC Framework</th>
<th>Post Instruction/Synthetic GCC Framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics of GCC</td>
<td>Is occurring (Pre-int, pre T);</td>
<td>The Earth may be raining more, hailing, cooling, etc.” (Bon post int, p. 2);</td>
</tr>
<tr>
<td></td>
<td>Is happening via warming (Pre-T, p. 1);</td>
<td>– I think climate change is definitely real” (Bon, post int, p. 1);</td>
</tr>
<tr>
<td></td>
<td>Is either natural OR anthropogenic (C-M int, p. 1);</td>
<td>– They’ve recorded temperature, fossil fuel emissions &amp; GHG emissions for years. Each one is rising” (Bon, post int, p. 1).</td>
</tr>
<tr>
<td></td>
<td>proof they have is not solid proof that humans are the only ones causing it”(Bon pre int, p. 2);</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Highly skeptical of GW due to view that he must commit to total causality by humans.</td>
<td></td>
</tr>
<tr>
<td>Characteristics of GW</td>
<td>GW is happening (Pre-T p.1);</td>
<td>GW as just the heating specific subset of GCC (Bon post int, p. 2);</td>
</tr>
<tr>
<td></td>
<td>Hasn’t been proven yet, so it’s still kind of a theory” (Bon C-M, p. 1);</td>
<td>Skepticism has vanished (all docs);</td>
</tr>
<tr>
<td></td>
<td>It has some validity, but not completely. They need to gather more evidence” (Bon Pre-int, p.2).</td>
<td>Understands that GW has both natural and anthropogenic components (post-T, post int).</td>
</tr>
<tr>
<td></td>
<td>I have doubts that humans are completely causing it…It may be just natural” (Bon pre, p. 3).</td>
<td></td>
</tr>
<tr>
<td>Characteristics of Environment</td>
<td>GHE not good for ozone (Pre-int, p. 3);</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>SUV’s connection to ozone- we should drive hybrids (Bon</td>
<td></td>
</tr>
<tr>
<td>Evidence for above</td>
<td>Glacier photos (pre-T, pre-int); Proof they have is not proof that humans are the only ones causing it” (Bon pre int, p.2);</td>
<td>“I hear a lot on the news, and I’ve seen a lot of scientific evidence in graphs. I mean the news, they can say anything—that doesn’t really prove it, but the graphs do” (Bon post int, p. 2); They all show that our emissions from GHG’s and CO2 &amp; stuff have increased a lot, which humans are definitely contributing to” (Bon, post int, p. 3); Ice caps are melting. That signifies that it’s heating up (Bon delpost, p. 1); It makes sense. And we’ve tested it with a couple of labs” (Bon post int, p. 4).</td>
</tr>
<tr>
<td>Mechanisms of above</td>
<td>Infection metaphor: Foreign matter gets introduced in atmosphere, it’s kinda like the body. Where if you ever get a blood transfusion &amp; the blood wasn’t right type, the blood cells fight it off” (Bon, pre int, p. 3); Sunspots as cause of GW (Pre-T)</td>
<td>Conflates classroom model with actual scientific evidence for GW (delaypost int, post int); Does not fully grasp idea of human-enhanced GHE (post int, delaypost int);</td>
</tr>
</tbody>
</table>
After instruction, Bono’s synthetic framework for GCC science showed signs of tremendous improvement, although even then it was still fraught with some major inaccuracies. A summary of these synthetic notions is given above in Figure 10. For example, Bono adequately described the differences between climate change and global warming. In particular, he described accurately that global warming just referred to the heating subset of climate change in general, and that climate change might include such phenomena as hailing, cooling, increased rainfall, etc. (Bon post int, p. 2). One area of improvement was that Bono’s synthetic framework of GCC included the notion that climate change, and warming, have both natural and anthropogenic parts, potentially. Perhaps as a direct result of this, Bono’s skepticism towards global warming had vanished.

Bono demonstrated a solid understanding of the evidence for climate change. He cited the scientific data shown in graphs in the following passages:

I hear a lot on the news, and I’ve seen a lot of scientific evidence in graphs. I mean the news, they can say anything—that doesn’t really prove it, but the graphs do” (Bon post int, p. 2);

They all show that our emissions from GHG’s and CO$_2$ and stuff have increased a lot, which humans are definitely contributing to (Bon, post int, p. 3);

→Ice caps are melting. That signifies that it’s(i.e., the world is) heating up” (Bon delpost, p. 1);

Concerning mechanisms, Bono again made some conceptual progress. In this case, he evolved from invoking a bodily infection metaphor to appropriately connecting the role of CO$_2$ as a greenhouse gas of trapping heat in the atmosphere. However, Bono seemed to struggle with the idea that the greenhouse effect is natural, and that humans are thought to simply add to it with their emissions. Instead, he thought the greenhouse effect was itself to blame for the general phenomenon of global warming. For example, in his post interview, Bono said:

Since the other graphs all have rising things, it probably shows that the greenhouse effect …could be real-definitely. (p. 3)
What the above response indicates is that Bono failed to grasp the idea that the greenhouse effect was itself a background issue to that of warming, i.e., the greenhouse effect happens already, with increased GHG’s thought to simply multiply the already-occurring greenhouse effect.

Also, Bono seemed to conflate the model lesson that he experienced with the actual evidence for the greenhouse effect. This unit merely modeled the trapping of heat in the atmosphere with Saran wrap, while the greenhouse gases in the atmosphere simply capture re-radiated energy in the actual atmosphere. In reference to the greenhouse effect, Bono said: “It makes sense. And we’ve tested it with a couple of labs” (Bon post int, p. 4). This is inaccurate in that the lab that Bono did in the class was simply a lesson meant to model the workings of the greenhouse effect. There is no physical barrier in the atmosphere that serves as a container to prevent the escape of rising air, as the Saran wrap did in the lesson. Later, in his delayed post interview, Bono referred back to the lab where they “experimented the effects of heat on the atmosphere”: The atmosphere “heats up when there’s greenhouse gases, which were represented by the Saran wrap. When there’s not as much greenhouse gases, the heat escapes so it kinda fades into space” (Bon del post, p. 1). Again, these data point clearly to Bono’s inability to differentiate the physical model from the scientific model. Further evidence of Bono’s inability to master that aspect is in the form of Bono’s final writing assignment. In it, he claimed that “My argument is that the surface temperature is rising because of greenhouse gasses sealing off any heat from escaping earth’s atmosphere” (Bon writ, p. 1). In these exchanges, Bono clearly mistakes the model as the evidence for the effect being modeled. What may have inadvertently facilitated this misunderstanding is that the model used led some students to invoke the “heat rises” misconception, in that they pictured that greenhouse gases directly trap heat in the form of rising air within the atmosphere, just as the Saran wrap trapped the hot air in. Rather, in the greenhouse effect model, it is not the heated air that is trapped in, but the re-radiated energy, which interacts with the individual molecules of the greenhouse gases, as opposed to a large plastic barrier doing the capturing.

Bono’s epistemological understandings

Bono’s epistemological understanding was the most sophisticated of the five students at the beginning, yet continued its development over the course of the research. In his pre interview, Bono referred to science as being about “learning things through experiments.” When
elaborating on the evidence for dinosaurs, Bono responded with "you can use carbon dating to trace it back to how old it was" (Bon pre int, p. 1). When the interview turned to specific climate change subject matter, Bono indicated that he was "unsure I completely believe everything…because solid proof they have is not solid proof that humans are the only ones causing it" (p. 2). When asked what sort of proof scientists had, Bono responded with "the ice caps are melting….they can measure the actual temperature and compare it to past temperatures to see if it's rising….(with) thermometers (Bon, pre int, p. 2). Another glimpse into Bono's epistemology came in the following exchange (Bon pre int, p. 2):

BG: When scientists discuss climate change, how valid of a scientific explanation do you think it is?
Bono: I think it has some validity to it, but not completely. They need to gather more evidence before they can make claims.

The data above were indicative of Bono's naive epistemological understandings. He tended to invoke physical evidence to the extent of proof being needed to completely make an idea valid. It is clear that proof, to Bono, came in the form of physical evidence out there to be discovered; that knowledge was not created or inferred from physical evidence. However, Bono also was the only student in the research to (initially) cite the importance of scientific graphs as a source of scientific information. His understandings of climate change as something supported by evidence, yet "without solid proof yet, being just a theory", provided a glimpse into Bono's epistemic mindset. For Bono, the importance of scientific graphs was a means of providing proof for scientific ideas, which he saw as the role of scientists to furnish.

Bono's epistemological understanding showed significant growth during the unit, as evidenced by the data collected. As of the concept map interview, his idea of theories needing proof showed that it was in need of modification, during his concept map interview (p. 1):

Bono: "Theories like global warming are tested by ADI's…"
BG: What do you mean by that?
Bono: Well global warming hasn't been completely proven yet, so it's still kind of a theory.

While he still clung to the idea of theories as being unproven entities, he also acknowledged here that theories were undergoing testing, although he misconstrued the ADI's as instruments with which to test such theories. Bono's concept of a scientific theory, at this point, was at odds with
the view of scientific theories as developed by scholars of NOS (AAAS, 1993; Abd El-Khalick & Lederman, 2000; Southerland, et al., 2006). The aspect of a scientific theory that Bono seemed not to capture is that—if it is not enough for scientific theories to fit only the observations that are already known. Theories should also fit additional observations that were not used in formulating the theories in the first place” (AAAS, 1993, p. 6). Instead, Bono’s use of “theory” seems to call to mind a hierarchical model of theory as an unreliable entity, which might eventually be “proven”.

After the unit, Bono showed an interesting development, in reference to the evidence for climate change. He indicated that scientists have (Bon post int, p. 1):

Bono:…recorded temperatures over the years and fossil fuel emissions and greenhouse emissions, stuff like that. And they’ve studied them, and figured out that each one is rising.

BG: Do you think that in general their explanation for climate change is a valid one, that makes sense?

Bono: It makes sense. And we’ve tested it with a couple of labs….we did the greenhouse gas lab where we had 2 bottles, and we covered one with Saran wrap to represent greenhouse gases, and the other one was empty, the one with Saran wrap was heated up much more.

In this exchange, Bono made an appeal to scientific evidence to support his claim. What complicated his explanation is that the scientific evidence he invokes here was actually a lab designed to model the greenhouse effect. As discussed previously Bono appeared to conflate the idea of a model with the actual scientific experimentation. In this regard, he has conflated the physical model for the ideas meant to be represented by the model, a problem consistently reported in the literature on student learning of scientific models (Cartier, Rudolph, & Stewart, 2001; Grosslight, Unger, Jay & Smith 1991).

After the GCC unit, Bono again discussed the value of graphs, saying that the most important source of scientific information for him was “scientific evidence in graphs” (Bon post int, p. 2). He continued “Before what I had learned was what people had told me about it. But now I have scientific evidence to support claims” (Bon post int, p. 4). His shift is also visible in the following exchange:

BG: Okay-how do we know it’s (climate change) happening?
Bono: By looking at photos of ice caps and taking temperatures and CO2 records.
BG: And what do we learn from those things?
Bono: Well with the ice caps, we learn that they’re melting. That signifies that it’s heating up, which is causing them to melt. And with the CO2 and heat, we look at them and we know that the earth is heating up, and because they look pretty similar and related, we can infer that CO2 and heat are related…
BG: Sorry can you go back for a second to “we can infer“?
Bono: We can infer that heat and CO2 levels could be related since they look very similar and uh we know we’ve done studies-CO2 is a greenhouse gas and it could be causing more heat. (Bon del post int., p. 3).

Such statements make it clear that Bono’s epistemological understanding had grown from its pre-research emphasis on just physical evidence and proof. After the unit he couched his language more carefully by eschewing proof for terms like “scientific evidence to support claims“. However, his conflation of the modeling lab in the unit with the scientific evidence at hand remained somewhat problematic in that he failed to adequately understand the nature of modeling, instead viewing the model as the evidence for the model. The persistence of this conflation of the physical model with the ideational model supports the idea of the robustness of this problem in students’ learning of scientific modeling (Cartier, et al., 2001; Grosslight et al., 1991).

Overall, Bono’s original epistemic position of scientist-as-deliverer-of-proof became greatly nuanced by the end of the unit. Such nuancing as claiming “scientific evidence is necessary to support claims” shows somewhat of a shift in his epistemic position over time. However, his stance may have constrained his ability to overcome the propensity misperceiving the physical model as the scientific model for the greenhouse effect. Bono’s need for proof may have predisposed him to see the model-based lab as providing the “proof” needed for the greenhouse effect. Hence, his language made sense when he said “we’ve tested it with a couple of labs (Bon post int, p. 1). The fact that Bono did interpret this as the needed proof likely prevented him from taking the next step and understanding that the greenhouse effect is not the cause of warming, but is instead a background phenomenon, whose enhancement by anthropogenic (and other) causes is the major concern for climate scientists.
**Bono’s analytical understanding**

Prior to the GCC unit, Bono showed that he was fairly adept at reading graphs, although he generally was still reading instead of interpreting. In his pre interview, Bono described graph 1 (showing changes in recorded temperature for the last 130 years) in the following fashion (Bon pre int, p. 4):

Bono: I think it means that this is a long time ago. Before we started having ideas about climate change. Up here about 1970 it starts peaking. And early it kinda stays the same down there…temperature change.

BG: What’s the pattern in graph 2 (showing paleoclimate date featuring temperature and CO2 levels for the last 300,000 years)?

Bono: Oh it’s temperature, okay, well…it’s pattern kinda goes up and down, and it goes with the carbon dioxide concentration most of the time, so they probably do seem related.

In the above exchange, Bono showed signs of inferring patterns from graphs, especially in noting the connection between carbon dioxide and temperature. However, in his pre-test, he made an interesting inference in regard to the sunspot graph. In answering question 7 of the pre-test, asking what he thinks is the major cause of climate change, Bono answers (p. 3):

The main cause of the climate change in my opinion is that it is warming because of solar activity on graph 5 or it may be caused greenhouse gases or possibly natural occurrences like the ice age.

In the next question, which asked how the evidence above supports his answer, Bono continued:

The evidence to support my hypothesis is that Graph 5’s data shows that the solar radiance is usually similar to earth’s surface temperature.

There are two salient aspects to Bono’s graphic understanding evidenced here. First, he initially struggled to infer patterns and causality from the various graphs. For him, the different graphs all support a few different hypotheses, which he stated may be the cause. Second, the graph he seized upon for his main evidence was convincing to him because the solar radiance is —usually similar” to the earth's temperature. Even though Bono was identified as a high-performing science student, he failed to understand that a causal question would demand more evidence than just a similarity in the graph. The graph in question showed the temperature and solar radiance completely at odds with each other for the last portion of the graph, effectively undermining any notion of one variable being the sole outcome of the other. But to Bono, the usual similarity of
the two correlates was more convincing than any other data shown to him at this point, prior to
the unit. Some scholars point out that in order for middle school students to successfully make
sense of graphic data, that several features of the learning environment need to be in place
including that the inscriptions used need to be embedded within the students‘ science inquiry and
that appropriate scaffolds need to be in place (Wu & Krajcik, 2006). Because Bono had not yet
experienced such appropriate scaffolds, he was not yet able to effectively understand the causal
nature of the graph,

Data collected after the unit showed massive signs of growth concerning Bono‘s ability
to understand the graphic data pertinent to GCC science. First, in response to Graph 2, showing
temperature and CO$_2$ levels over a 300,000 year period (Bon post int, p. 4):

It makes it look like the CO$_2$ and temperature are related. Cause they spike up together
and really kind of fall. And recently the CO$_2$ spiked up a whole lot today and hopefully
the temperature won‘t follow up. But based on the previous data it probably will.

In summarizing all the graphs, Bono continued:

They all show that our emissions from greenhouse gases and carbon dioxide and stuff
like that have increased a lot, which humans are definitely contributing to, and the surface
temperature, it shows that that‘s rising. Since the other graphs all have rising things, it
probably shows that the greenhouse effect could be real…definitely.

In these post data, Bono revealed after the unit that not only could he infer patterns from the
graphs, but that he could extrapolate from them to future probabilities. He also linked the graphs
together to find common patterns, and again showed a tendency towards the current consensus in
climate change science by indicating that humans are definitely contributing to it. One thing that
may be problematic from his data is that he hints that the greenhouse effect could be the
problem. This indicates a limitation on his understanding of the science, as the greenhouse effect
is seen by scientists as a definite background phenomenon, which is likely made worse by the
addition of anthropogenic greenhouse gases. Bono‘s understanding, although advanced, was
lacking in this critical nuance. It is also important to note that his post data showed a complete
lack of support for the sunspot/solar radiance hypothesis that he advocated in his pre-test.
Bono‘s confidence in graphs is very high after the unit. When I prompted him for the most
important sources to understand things like climate change, this was the exchange (Bon post int,
p. 2):
Bono: Probably scientific evidence in graphs.

BG: So things that you know right now about climate change, where do you think you learned all that from?

Bono: Well I hear a lot on the news, and I’ve seen a lot of scientific evidence in graphs. I mean the news, they can say anything—that doesn’t really prove it, but the graphs do.

Obviously, Bono placed a great value on graphs as transmitters of scientific information. Even though he showed signs of this prior to the GCC unit, his understanding of how to interpret the graphs in hand improved drastically, even to the extent of changing his reported view about the major cause of climate change. I note also that the above quote wherein Bono says the graphs prove warming supports the notion that he sees scientists’ roles as providers of proof of scientific ideas. It is now necessary to examine the role of affective factors in shaping Bono’s overall conceptual growth.

*Bono’s affective factors*

Although Bono reported that science was not his favorite subject (world cultures was the favorite), he seemed to have watched a lot of science on television, and had a keen interest in science. His interest in science seemed to be an affective issue that helps explain much of what Bono knew and understood about science. In other words, his interest in science led him to learn more science, often through channels alternate to the official school curriculum. This refers not only to his understanding of science, but to his epistemology as well. In his pre interview, he claimed to watch a lot of the Science channel and History channel, two cable television channels that feature much programming on issues related to science (p. 3):

BG: When it comes to a science issue, where do you get your information, and why do you trust these sources?

Bono: I get my information from different channels such as Science but I’ll watch more than one thing about a subject to make sure that it’s not just one. Science channel, things like History channel, all those things. Ummm…National Geographic.

BG: So if you see something strange and interesting on one channel, you don’t necessarily believe it until you see it somewhere else?

Bono: Yeah. Same things somewhere else. I’ll like to see it 3 or 4 times before I can prove, before I…
BG: Before you’re convinced?
Bono: Yeah. Even then I won’t be completely convinced, but I’ll be more convinced. While he clearly emphasized the importance of such sources, Bono’s answer to the question—What are the most important sources for you to understand about patterns in global climate change?” is revealing in his pre interview (p. 3):

Bono: Maybe looking at scientific graphs from someone who doesn’t have a certain point of view. Because I know that some people do believe in global warming, and some don’t.

Clearly, the above passages established the fact that Bono’s interest in science-related television had greatly influenced his understandings and that he entered the science unit already prioritizing the information contained in scientific graphs. This has influenced his epistemology as well, in that he likes to—watch more than one thing about a subject” (Bon pre int, p. 3). So Bono did not trust any one such source, but saw multiple sources as necessary to buttress the point being made.

Another affective element present in Bono’s thinking reflected concern for animals. However, this was something that manifested itself only in the data collected after the unit. Animals were never mentioned in his pre data, except as targets of dissection. However, he inserted his concern for animals in his delay post interview, even while describing what was convincing to him about evidence for climate change (Bon delpost, p. 2):

Well that normally it wouldn’t really happen in the earth. I mean we’ve gone through ice age and stuff, but it doesn’t seem like a natural thing to have all this stuff that other animals need to be melting, cause the world was kind of in balance and everything. All these arctic animals need all this ice and it’s melting, it doesn’t seem like a natural thing. Later in the delay-post interview, Bono again expresses concerns about animals, this time attached to the Gulf oil spill then in the news (p. 3):

I’ve seen a lot of news. I think the recent oil spill could probably be affecting global warming. I’m thinking that the oil gives off a lot of fumes. But also could be heating up ocean because oil is like a black, kind of brownish dark substance, and I know that the sun heats up dark substances, and would cause a lot more fish to die, because there’s less oxygen, and they need more, so they’ll start just dying and suffocating. I know that could be a pretty big global warming thing, so…
These passages made it clear that for Bono, concern for animals was something that he had internalized at least partially as a result of his experiences in the GCC unit.

When asked in the delayed post interview – “What was the portion of the unit that you found most helpful?” Bono expressed that he valued the round-robin portion the most (Bonodelpost int, p. 2):

BG: What were the most helpful aspects of it, what helped you learn the most?
Bono: Ummm…well I think what helped me learn most was the when we made the boards and we looked at other people's ideas cause we could learn more ‘why’ sort of information instead of just information from one source.
BG: So..I think you're referring to when you put your arguments on poster board, and you had practice arguing with each others‘ teams, is that right? (→yeah-round robin”) so what about the round robin itself made it helpful?
Bono: You get more than one idea from different people that have done different tests, well not different tests, but have gotten different results from the tests.

Overall, the major affective components necessary to understand Bono’s development include the sources that he valued (scientific graphs and science-related television shows), the concern for animals which seemed to develop as a result of the unit in question, and the fact that he most valued the portion of the unit in which he was able to hear the views of others. The relationship of these factors will be addressed fully in the conclusions.

Bono’s synthetic GCC framework after the unit shows significant conceptual change. Many factors appear to have been involved in this conceptual growth. First, Bono’s epistemological sense grew in that he moved from a vague emphasis on experiment and evidence to provide proof towards a more robust understanding that suggests scientific evidence is needed to support claims. Bono also invokes modeling as a central element of his synthetic epistemology, even though he mistakes the model for the evidence. Much of Bono’s epistemological growth was likely buttressed by the fact that his epistemic values already emphasized scientific evidence and graphs. It was as his understanding of the evidence, particularly that contained in the graphs, grew, that his understandings grew. This growth is intimately connected to his growth in analytical ability. As described above, Bono originally interpreted the sunspot graph as showing a causal pattern, simply because the two graph lines were →usually similar”. Later, Bono grew to not only infer appropriate patterns from graphs, but
to infer patterns across similar graphs, and to invoke causality from graphic data. And lastly, the affective components also allowed Bono’s understanding to grow. First, Bono’s epistemic values already privileged graphic data, as described above. Second, he watched a lot of science-related television shows such as —Mythbusters”, which often focuses on the scientific testing on popular culture references to science, such as —Do cell phones cause gas station fires?” Third, Bono apparently learned to express concern for animals. References to animals are nowhere to be found in his pre-test, pre-interview, or concept map interview. However, in his delayed post interview, and in his writing assignment, Bono expressed concern for animals in terms of their needing ice and the world’s being out of balance, etc. He also expressed concern for the recent oil spill, its connection to climate change, and its effect on the ocean and sea life. In these aspects, it appeared that Bono had actually learned that there is an affective component to climate change, that climate change may result in negative consequences for animals and ecosystems. I contend that this affective aspect of climate change was learned by Bono as a process of the social discourse associated with the argumentation pedagogy. That is, that in two rounds of argumentation, in which he both expressed his views and listened to the views of others, Bono certainly heard others express concern for animals. The fact that he may have lent credence to this aspect is supported by the fact that Bono himself said that the Round-Robin portion of the unit was his favorite, as he was able to —look at other people’s ideas” (Bon delpost int, p. 2).

**Summary of Bono’s conceptual change**

Bono’s conceptions about GCC grew substantially during the course of the instructional unit. His GCC science framework was initially open to the possibility of climate change, and to a mechanistic role of greenhouse gases in producing warming. However, Bono thought that this connection to anthropogenic causes was —just a theory” and —unproven”. This was tied to his original stance that Global warming was an idea requiring that one buy into an entirely anthropogenic cause. Since that had not yet been proven, and was hence in need of further testing, Bono said initially that he therefore did not believe in GW, at least not as something caused by humanity:

I’m not sure I completely believe everything. I believe some it but not completely.

Because the earth has gone through times of different climate changes, like the ice age
and stuff like that. It might be partly natural. It probably has some impact on it, but not as much as one might think. Because proof they have is not solid proof that humans are the only ones causing it.

This was tied to his naive statement that the warming was caused by sunspots. In Bono’s mind, the lack of proof of human-caused warming necessitated another cause being found. The Solar radiance graph provided this for him. Over the course of the unit, however, his skepticism on that stance waned notably, to the extent that he acknowledged that GW was caused by GHG’s such as CO$_2$, which, he noted, traps heat in the atmosphere. Signs of outright skepticism towards anthropogenic warming had disappeared completely by the unit’s end. This indicates that Bono’s GCC views were more in concert with those of consensus climate science.

Related to Bono’s gains in conceptual understandings is a gain he made in ontological categorization. Prior to the unit, he showed conflation of GCC, GW, and general environmental issues. For example, he noted that the GHE was “not good for the ozone” (Bon pre int, p. 3) and that in order to remedy the ozone hole, people should drive more hybrid vehicles. This showed that Bono made some false connections between GCC and a largely unrelated issue, the ozone hole, and connected it to GCC by virtue of assigning it to a cognitive category of the environment. By unit’s end, however, Bono’s invocation of general environmental themes disappeared completely, having not mentioned such issues as ozone or hybrid vehicles. This disappearance can best be explained by the collaborative argumentation aspects of the designed unit. That is, that as Bono and his peers developed explanations for the data, holding each other accountable for those ideas, extraneous issues that were not reflected in the data, such as ozone holes and hybrid vehicles, were either selected against, or not selected for. That is, in acting as their own “epistemic agents” (Miyake, 2008), students such as Bono could not maintain the expression of those ideas not epistemically supported by the data at hand.

However, at the unit’s end, Bono still held onto his naïve conception of scientific modeling. As described above, he conflated the physical model for the ideational scientific model. In other words, Bono felt that the model-based lesson that he engaged in was an actual test of the greenhouse effect, and that therefore, the greenhouse effect was in fact real, and accounted for the phenomenon of warming. In this, he missed out on the key idea that the model lesson was in fact a mental model for how the GHG’s act as a barrier to escaping heat of certain
wavelengths. Bono's failure to grasp this idea meant that he was unable to eventually recognize that the greenhouse effect is not the blame for any global warming effect, but that it is the enhanced greenhouse effect, as a net process added to by anthropogenic factors, that results in a higher equilibrium temperature than just the greenhouse effect alone. Because of the limits of Bono's interpretation of the mental model of the greenhouse effect, he failed to categorize GCC as an emergent/equilibrium process (Chi, 2008), instead viewing it as a discrete entity, caused by the greenhouse effect.

Figure 11 Bono's conceptual change (blue = naive; green = synthetic)
**DARKO: Scientist as Explorer**

Darko initially conceived of science as information directly gathered by explorers who searched out information in various corners of the Earth. To him, the way to knowledge was to have these explorers either directly collect the data or else have them ask people who live there. The use of scientists-as-explorer makes sense as an extension of Darko’s privileging of anecdotal data.

**Darko’s understanding of GCC Science**

In terms of understanding the science of GCC, Darko started out with room for a great deal of improvement. For example, Darko showed a conflation of climate and weather, while invoking the anecdotal mode seen above (Drk pre int, p. 2):

BG: What can you tell me about climate patterns around the world? First, do you know what climate is?

Darko: I don’t know the exact definition—isn’t it the weather type…?

BG: It does have to do with the weather…

Darko: Climate has been cold recently.

BG: Cold where, when?

Darko: It’s been really cold in Florida. And it’s kinda been cold night and day. But recently it’s only been cold at night. It’s gotten warmer during the day.

Given that Darko started by conflating weather and climate, his understanding of more complicated aspects of GCC may have been precluded. When asked if he had heard about climate change, Darko responded (Drk pre int, p. 2): —uhh….not exactly. Unless you’re talking about global warming.” One interesting aspect of the above answer is that Darko brought up the term ‘global warming’ well before I did. When I asked him what he knew about that, Darko continued (p. 3):

Not that much. All I know is that they’re saying the climate, the weather, temperature is getting so hot it is starting to melt in the arctic and animals are starting to die because they don’t live in the water, they live on ground.
In his elaboration, Darko indicated that his knowledge of global warming was limited to the general sense that things are getting hotter in the Arctic and that it's connected to animals dying off. Here, Darko reflected an affective element seen elsewhere in this research: concern for animals. During his concept map interview, Darko elaborated on the greenhouse effect and its relation to global warming (Drk C-M int, p. 4):

Darko: Global warming involves greenhouse gases because...the how the greenhouse gases are affecting the earth.
BG: Okay. And how is that?
Darko: That's the part when I get stuck at...what would you say exactly causes global warming? Because I am kind of on...I kind of believe yet I kind of don't believe in global warming. Because technically they're saying GLOBAL (his emphasis) warming, but the whole entire globe isn't warming, so I kinda don't believe in it. Only a certain part of the globe is warming. Because in (Southern city), LAST YEAR it was warmer during winter than it was during summer. This year it's been freezing cold, below freezing, almost snowed. So it's not exactly global warming. It's part of the globe warming. But I can kind of say that global warming is caused by greenhouse gases.

<table>
<thead>
<tr>
<th>GCC Science Framework Category</th>
<th>Pre-instruction/naïve Framework</th>
<th>Post Instruction/Synthetic Framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics of GCC</td>
<td>Climate is changing (pre-T, pre-int); Temp increasing (pre-T); Ice melting (pre-int); Issues of scale abundant (pre-int, C-M int); Climate/Weather confusion (“now it’s cold &amp; rainy”, “climate has been cold recently”) (pre-int, C-M int)</td>
<td>Climate changing (post-T, post-int, delpost int);</td>
</tr>
<tr>
<td>Characteristics of GW</td>
<td>Doesn’t believe in (C-M int);</td>
<td>GW is happening, however: Doesn’t believe in the ‘global’</td>
</tr>
</tbody>
</table>
In the above passage, Darko indicated great uncertainty about his understanding of global warming. Indeed, while he was thinking about it, he was actually asking me about the causes. Then he focused on the fact that he did not believe in global warming, because of the ‘global’ part of that term. Here, he again invoked anecdotal reasoning by saying that to qualify as global, every part of the Earth must be warming. And in his anecdotal experience, his home town did not fit that pattern. Interestingly, the pattern that he anecdotally remembered, the winter being hotter than the summer, was not the case. He further confused the matter by then saying that greenhouse gases —kind of— cause global warming. It is clear from these contrasting statements that Darko held contradictory ideas in his understanding of global warming. Although the
warming wasn’t ‘global’” to him, he conceded that greenhouse gases did help cause whatever warming there may be.

In his interview conducted after instruction, Darko again invoked his anecdotal experience to explain his thinking (Drk post int, p. 1):

BG: What do you know about climate change?
Darko: Well, from the amount of CO₂ increasing, the…climate has also been changing. Also the temperature.

BG: How has the temperature been changing?
Darko: For us in (Southern town in Florida), the climate has decreased and now it is increasing but in the arctic it has been increasing.

BG: What has been increasing?
Darko: The temperature – climate change. The climate’s changing in the arctic by the ice melting, and…

BG: What did you say about the climate here in Florida?
Darko: The climate as well the temperature-can I say that? The temperature decreased a lot into the 20’s and now it’s increasing into the 60’s 70’s and 80’s.

In this interview after the unit it appeared that Darko was not only invoking his own anecdotal experience to possibly trump other sources of information, but that he was getting confused as to what scale to invoke for climate change. That is, Darko started by invoking a weather pattern that was accurate, i.e., the period of research did feature an unusually cold winter, which was followed by a period of noticeable warming. So the pattern he called attention to was covering the time span of weeks or months, as opposed to the time span invoked for scientific purposes of understanding climate change, which is on the timescale of years, decades, centuries, and millennia. Therefore, he struggled with what I will call the ‘appropriate attention to scale’” color much of his overall conceptual change. The post interview continued from the above portion (p. 2):

BG: Do you think that’s connected to what’s going on in the arctic for example or Antarctic?
Darko: The arctic is…mainly increased and the temperature is mainly increasing. Here the temperature has decreased and then increased.

BG: What makes you say the temperature has decreased here in Florida?
Darko: Outside it has almost snowed. It has been below freezing. Ice on the ground, or frost.

The evidence Darko invoked above not only continued to rely heavily upon his own personal experience (in addition to a reference to the Arctic), but again, it did not resonate well with the actual temperature record during the time in question, as the area never experienced frost during that winter.

Darko’s emphasis on anecdotal data is manifest in the following data as well: (Drk delpost, p. 1):

Darko: I’m conv—well, the thing that doesn’t convince me is that global warming is a part of that. I don’t really believe in global warming. And...

BG: Okay—back track for just a second. You’re saying that global warming is a part of climate change? It’s a part that you don’t believe in?

Darko: Yeah. I don’t believe in global warming, but…I’d say it’s like half global warming, because only half of the globe is warming. Now Tallahassee is warming, but during when we were learning about global warming, (our Southern city) was in the 20’s and 30’s.

BG: Right. We were in winter at the time. So you don’t believe the earth is warming?

Darko: I believe the earth is warming. I just don’t believe that all the earth is warming. Places like where it’s really snowy, like…Greenland, and…Antarctica. Antarctica is…warming…but I mean, I don’t know very much about Greenland, all I know is it’s very ice (sic) there, and there’s a lot of snow.

BG: How do you know that Antarctica is warming?

Darko: Because I’ve seen movies and videos of the ice melting. There was a graph like that, showing that the ice core is lowering.

In the above passage from his delayed post interview, Darko again relied upon anecdotes for much of his understanding, much clouded by issues of scale. He noted accurately that his city was in winter during the research time, but confused the seasonal warming that would subsequently be normal with global warming. In this case, the particular issue of scale that he showed confusion in was temporal. In addition, he was confused on the spatial scale. His strong statements of disbelief in global warming were embedded within his claim that the entire globe was not warming. This again reflects an issue regarding the proper scale, although this time a
spatial emphasis is needed in reference to the questions “Where is the earth warming?” and “Where should the earth be warming?”

In his final writing assignment (p. 1), Darko explained “My argument is CO$_2$ is mainly causing the climate change because in some of the graphs it shows when the temperature raises the CO$_2$ rises.” This statement indicates that Darko concedes the power of graphic data to demonstrate the likely cause of climate change. However, he remained unconvinced of the idea that warming was occurring globally. For example, he said the following in the delayed post interview (p. 2):

Darko: Yeah. I don’t believe in global warming, but…I’d say it’s like half global warming, because only half of the globe is warming.

While his conceptual framework did develop by the unit’s end, such as the role of greenhouse gases as a causal agent in warming, his overall growth was limited by his struggles with the notion of proper scale.

**Darko’s epistemological understanding.**

Now I turn to an examination of non GCC science-based factors in order to help understand Darko’s conceptual growth. Darko’s epistemological understanding began as somewhat naïve. While improvement was shown, some naïve elements remained in his understandings after the GCC unit. Initially, Darko’s epistemological views included an emphasis on “finding things”, as shown in this exchange (Drk pre int, p. 1):

BG: Ok. How do scientists know dinosaurs really existed?

Darko: Scientists know that dinosaurs existed because when…they…well technically they found dinosaur bones and they were able to put them together and make a full dinosaur skeleton.

BG: ok. So…they know they existed not because they found them, but because they could put them together?

Darko: It’s both. If they just found bones, it could just be anything, it could be maybe humans were back then. If they couldn’t put together the bones, they wouldn’t exactly know…they wouldn’t know what it was, kind of. Because a T-Rex you…a human…the head shape, the structures of the bones…see but if all we found was the long necked dinosaurs, what if they were just giraffes?
Above, Darko showed a tendency to accept that scientists know dinosaurs existed because the bones have been found, as most in this research indicated. It is important that he included the criterion that the bones can be put back together, indicating that he understood that some sense-making is necessary on the part of the scientists doing the discovery. More insight into the naïve nature of his naïve epistemological views are revealed when climate change became the subject, as shown here (Drk pre int, p. 3):

BG: When scientists discuss climate change, or global warming, how valid an explanation do you think that is?
Darko: It could be…do you mean like the importance of it?
BG: What I mean by valid is how do they know that they’re right?
Darko: They’ve had…I don't know what they’re called. I call them explorers that go down there and check it out. They’re still scientists, but they explore the area.
BG: They explore the arctic, for example?
Darko: Yes, sir.
BG: And when they do that exploring, what is it that they do?
Darko: When they explore, you could say ‘camp out’, they have kind of like a tent, but bigger. They would probably walk around the area, and see. They might ask people who live there how what the temperature or climate has been changing, or if it’s been staying the same…

Here, Darko has revealed some insights into his initial epistemological understandings. As with the dinosaur answer above, his emphasis was clearly on ”finding” the evidence in a physical manner. Instead of finding the bones, his answer now became one of sending explorers to the Arctic to determine the temperature. He suggested that these explorers could even ask those who live in the Arctic what the temperature has been. But it is clear that Darko had placed the emphasis on personal discovery or fact-finding as the way in which knowledge is gained. In this regard, Darko’s initial epistemological understanding could be considered to be naïve (Kuhn, 1993).

In his post interview, Darko held onto the same epistemological understanding, with a modification, as illustrated in the following exchange (Drk post int, p. 2):

BG: What is scientists’ main evidence for climate change?
Darko: They have had people travel to the arctic and umm….camp out and stay there, and travel around the world, and see how the temperature or climate has been changing.

BG: What do you think are the best scientific explanations for why temperature has been changing?

Darko: Their best reason or explanation?

BG: Well both. You just tell me what you think.

Darko: They collected data from when they traveled to different places, they put it in graphs, charts, tables,…

Above, Darko revealed how he believed scientists acquired the data to put into the scientific graphs in question. They had scientific explorers travel to the areas, collect the data, then put them into graphs. This is an idea that seems naïve on its face, yet has some potentially accurate aspects to it. In order for scientists to get data from a polar region, they would need to send a team there to collect the appropriate data from, say, ice cores. This would in fact have the effect of essentially having scientists “camp out” for extended durations in order to collect the necessary data. Such data do indeed eventually get represented in graphs and charts. However, Darko’s emphasis seems to be on the personal exploration aspect, the need for an individual to see with his/her own eyes, as opposed to the need to collect data via instruments, etc.

Another extremely important aspect of Darko’s epistemology involved his emphasis on personal anecdote as a valued means of understanding the world, as opposed to a more systematic means of study (Allchin, 2011). During his mid-unit interview, Darko was in the midst of explaining why he does not believe in global warming when he invoked anecdotal reasoning (Drk C-M int, p. 5):

Only a certain part of the globe is warming. Because (In his Southern city), LAST YEAR it was warmer during winter than it was during summer. This year it’s been freezing cold, below freezing, almost snowed. So it’s not exactly global warming. It’s part of the globe warming. Here, Darko showed that he thought that the local place he experienced personally did not fit the pattern that he thought was global warming. Therefore this allowed him to be dismissive of the entire idea of global warming. In his post interview, Darko became very explicit about how he weighed the relative value of personal experience versus data in graphs, etc. (Drk p. 1):
BG: Let me go back for a second. You said some people, like one of your parents and your sister don’t believe in global warming, but others do? How do you decide for yourself?

Darko: Well I don’t exactly follow everything my parents say, but…I mean, I’m not a bad child or anything. Ummm…I’ve basically, you don’t have to look at graphs or data tables to figure out if the globe is…it if the temperature is increasing or decreasing. You can kind of just go outside and say ‘oh I’m gonna need to wear a tee-shirt today, or a sweatshirt, or a heavy coat/jacket.

In the above passage, Darko showed strong signs of having expressed “belief identification”. Belief identification is a construct invoked by many scholars (Cederblom 1989; Sa, West, & Stanovich, 1999; Southerland, Sinatra, & Mathews, 2001) to refer to an idea which an individual simply identifies his or her beliefs with their self-concept to the extent that it makes him/her “happy and proud when someone holds the same beliefs that I do” or he/she seeks to hold the same beliefs as their parents or family members (Sa et al., p. 501). Such an individual may not be willing commit to belief in evolution, or global warming if it conflicted with their past beliefs or beliefs of their family. Darko in fact showed just such signs of belief identification in regards to being opposed to global warming. He himself volunteered during his concept map interview and during his post interview that he did not believe in global warming, because his father and sister do not so believe in it.

Even after the GCC unit, Darko clearly still privileged personal experience over data given in other more forms such as graphs. To determine whether or not temperature is increasing, all that was necessary for him was to go outside and see for himself.

Darko’s Analytical understandings

In a surprising contrast, Darko did show significant growth in regards to his ability to understand data displayed in graphs. In his pre and mid-unit interviews, he was limited to sheer descriptions of graph labels, as opposed to interpretation of the data contained therein. This idea remained well into the lesson, as captured during the concept map interview, as he pointed to the graph showing temperature and time over the last 130 years (Drk C-M int, p. 2):

Darko: And the time/temperature graph-last..hundred years…Deals with the temperatures…
He continued to describe several graphs in one short passage (Drk C-M int, p. 3):

Then carbon dioxide…and there’s carbon dioxide/time graph to show the amount, and there’s another graph with the last 300 thousand years to show amount too! and the fossil fuels…and then the temperature of what is being affected by warming, …

Clearly, Darko’s ability to infer patterns and causality from graphs was limited, fairly well into the GCC unit. At this point, he began to refer to graphs differently (Drk post int, p.2):

Darko: …but the whole globe hasn’t exactly been warming.

BG: Okay. What does…what kind of data do you have to back up that argument?

Darko: I’ve looked at graphs that Ms. Octane gave me and that you gave me, and…data tables and charts. Time data tables from 30,000 years ago…

BG: Some of these data tables show the world temperature is going down—is that what you are saying? I’d love to look at that if you happen to have that on you.

Darko: No. It was what you gave me one thing that showed that like temperature decreasing, like 110,000 years ago I believe. It rised and decreased a lot.

Here, Darko has done something radically different from his previous usages of graphs. He has invoked them as a form of evidence to support an argument. What makes this doubly interesting is that the graphic data he referred to were the graphs given during the GCC unit, which clearly do not support his overall argument that the warming does not show a global trend. He was correct in noting that the historical temperature of the Earth’s surface has fluctuated, but he has ignored other highly relevant aspects of the graph shown, including the connection between temperature and CO\(_2\), and the current spike of CO\(_2\), indicating (perhaps) that a temperature increase may follow.

Darko’s use of the graphic data which ostensibly opposes the position he tried to invoke calls upon the need to explain his invocation of anomalous data. Darko chose to respond to it in ways consistent with the description by scholars of reactions to anomalous data (Chinn & Brewer, 1998). Darko responded to the anomalous data by invoking two of the many strategies available: by rejecting the data; and by accepting the data to make minor revisions. This notion will be returned to below.

So while Darko discounted the graphic data with respect to anecdotal, he still has shown a shift in his understanding of the graphic data just by invoking it as to buttress his argument. This represents a clear shift in his understanding of graphs. In fact, he grew enough in his
understanding after the GCC unit that he then looked for the weaknesses in graphic data to support his argument against global warming (Drk delpost int, p. 2):

Darko: I believe the earth is …it is warming, but…it’s just global warming isn’t very too convincing.
BG: Okay. Can you tell me what is it about this graph, for example, that’s not convincing? The one that shows the earth’s surface temperature changing?
Darko: Is it the WHOLE earth?
BG: It’s averaged over the whole earth, yeah.
Darko: Averaged over the whole earth, okay. But this is only earth’s surface temperature changes from 1880 to 2003, not to 2010.
BG: Right. Ummm-hmmmm.
Darko: So it’s not 100%. They should have done it to 2010. And if it shows rising, I’d be more on the earth’s rising side, but since…

Darko had indeed grown in his understanding of graphs. While he did not always interpret them in ways that are consistent with those of climate researchers, at the end of the unit he not only invoked them to support his arguments, but he actually looked for weaknesses in the graphs to undermine opposing arguments (Chinn & Brewer, 1998). He then dismissed the other arguments by pointing out that the data were not inclusive enough for his tastes, i.e., that it did not include current data.

**Darko’s affective factors**

Several affective notions influenced Darko’s conceptual change in this unit. The most striking factor was Darko’s personality. He was very shy, speaking rarely, and quietly when he did so. However, when he felt he had something to add to the class discussion, he would eagerly raise his hand to volunteer an answer. But when he did speak, he did so quietly. In addition, Darko claimed his favorite subject to be math, and never positioned himself as a “star” student of science. In speaking to adults, Darko invoked an air of respect for authority, complete with the use of “Yes, ma’am” and “No, sir” in almost every case.

The other salient affective aspect of Darko’s journey involved the influence of family members. Although Darko did include his parents among his source of trusted information, like
most of the participants, the extent of this influence did not become apparent until collection of
post data, particularly in the passage below (Drk post int, p. 2):

BG: Ok. What are the most important sources for you to understand about things like
climate change?
D: Like what teaches you about it?
BG: Yeah. Like everything that you know about it-where did you learn it from?
D: I learned it from school. I learned some from my parents. I heard it on the news
sometimes. But mainly it has been from my parents or school.
BG: Do you think you learned the same things about it, or do you think you’ve learned
totally different versions?
D: Well my…parents and my sister do not believe in global warming I’m kind of on the
track that they are. In school a lot of people like my friends have said –Oh global
warming is definitely warming is definitely real.’ But I mean it’s called „global warmin‘
but the whole globe hasn’t exactly been warming.
And while he had been clear in this opinion since the start of the research, this is the first direct
statement he had given as to the views of his family members, and the relative role being played
by it in regard to the GCC unit. It should be noted that while the other students generally
invoked their parents as sources of information, none of them specifically cited the views of their
parents on the issue of global warming. Darko, in the conversation above, showed signs of a
strong belief identification in regards to global warming.

However, while his belief in the idea of global warming did not waver, his understanding
of the scientific basis actually did improve, as discussed above. The difference between his
initial and synthetic views is that in the latter, he claims evidence for is lack of belief in global
warming, i.e., the lack of the –global” nature of it. Besides that, he accepts the idea that warming
may be going on.

Darko’s affective issues

Several affective factors conspired to have a curious effect on Darko’s group project. On
the final group argument, designed to answer the question –What are the likely causes of the
climate change patterns?”, his group’s argument reflected a confused hodge-podge of an answer.
Their explanation read (Drk adi 2):
The CO₂ is rising, but even though it’s rising, the surface temp. is lowering frequently. Oil makes the most CO₂ since 1880. The natural gas makes the least amount of CO₂. Coal has the same most of the time. The total rises the whole time. The temp from 300,000 to 100,000 years ago is almost the same as today. 200,000 years ago it was very low. The temp rises and lowers and rises again.

In this explanation, the group argument seemed to reflect Darko’s reading of the graphic data without inferring causal patterns, and also seemed to imply an argument against global warming. Despite his shy personality and his relative lack of apparent involvement in the construction of the group argument, the socially constructed argument did in fact seem to be very consistent with Darko’s views as evinced in the data above.

**Summary of Darko’s conceptual change.**

In conclusion, Darko did experience some moderate conceptual change regarding GCC science. His scientific understanding improved in the sense that he evolved from a limited, disconnected view of climate change, to one that focused on the greenhouse effect as a mechanism for warming. Darko also learned to value what scientific data in the form of graphs could contribute to his understanding. However, his synthetic understanding of global climate change featured a fascinating dichotomy, in that he understood some things about the mechanism of warming, while denying that the warming was global. A crucial factor in understanding his change, and the limits of that change, concern his strong belief identification. Darko early on identified his beliefs as consistent with those of his family’s. As subsequent information came in that was contrary to his understandings, Darko chose to respond to it in ways consistent with the description by scholars of reactions to anomalous data (Chinn & Brewer, 1998). Darko responded to the anomalous data by invoking two of the strategies: by rejecting the data; and by accepting the data to make minor revisions. It may seem at first glance that these ideas are contradictory. However, each has an element that speaks to Darko’s claims, detailed above. First, he accepted the data and scientific phenomena in terms of greenhouse gases causing warming. However, he rejected not the entire data set, but its applicability to the notion of its being “global”. Therefore, it appears that Darko in fact rejects the applicability of the data to the theory of global warming, as he saw it. It may be no accident that his struggled to understand the appropriate level of scale emerged in exactly the perceived weakness that Darko seized upon. This became a constraint
upon Darko's ability to accept the scientific framework in front of him. In other words, his belief identification, combined with his inability to overcome the issue of scale, constrained his ability to understand the context of climate change. The unique outcome of this is that Darko held two simultaneous ideas which were conflicting. That yes, warming is happening, and that the greenhouse effect, CO₂, and extant data account for this, but that global warming is not happening, because it is not “global”, i.e., not happening everywhere. Previous conceptual change researchers have found that students can simultaneously hold two oppositional ideas (Vosniadou, 2001, 2003). In her research involving elementary school children, she found that students could simultaneously hold a mental model of the Earth that was flat, along with the mental model of a round Earth, existing in space.

A summary of Darko's conceptual change is given below, in Figure 13:
NIGELLA: Scientists as Theory-Makers

Nigella began the unit with a fairly well-developed idea of scientific knowledge building which included the idea that scientists had to invent theories in order to test their understandings. She also emphasized the idea that evidence must be found to support such theories. One limitation on her initial understanding was that she did not initially invoke the idea that individuals need to subjectively make sense of the evidence at hand.

Nigella’s Understandings of GCC Science
Nigella underwent significant development in her understanding of climate science as a result of the unit. In her pre unit interview data, her shyness came to the fore, allowing her to reveal very little of what she understood concerning climate change (Nige pre int, p. 2)

BG: Have you ever heard of the greenhouse effect?
Nigella: Maybe a little bit, but I don’t know exactly what it is.
BG: Do you have any idea what it pertains to at all?
Nigella: Not really! (sounding exasperated)

Clearly, Nigella’s understanding of GCC science concepts was not substantial enough in her mind to warrant responding to such questions. While no students are “blank slates”, Nigella tried to pose herself as such, pre-instruction, in this regard. However, Nigella’s naive framework of GCC science, summarized below in Figure 14 (taken from her pre test and her pre-instruction interview), indicates that she did understand some characteristics of climate change, namely that climate change was occurring (Nige pre-T, pre-int), that temperature was increasing (Pre-T, pre-int) and that glaciers were melting (Pre-T, pre-int). Her view of a causal mechanism overlapped with a general environmental model in that she said that pollution caused climate change, specifically from CO\textsubscript{2} (Pre-int). Although she did have a vague idea that CO2 was the culprit behind climate change, she did not elaborate on any causal mechanism. Instead, she invoked a metaphor for the need for more evidence concerning climate change, claiming that scientists need to get more data, like testing a medicine (Nige pre-int). However, she did indicate specifically early on that sunspot data could not be invoked as a causal agent in climate change. Her reasoning was that the graph did not say it dealt with causes (Pre-T).

<table>
<thead>
<tr>
<th>GCC Science Framework Category</th>
<th>Pre-instruction/naive Framework</th>
<th>Post Instruction/Synthetic Framework</th>
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<tbody>
<tr>
<td>Characteristics of GCC</td>
<td>Climate is changing (Pre-T); Confused by scale (climate/weather/daily cycles (Pre-int); Infers fluctuations from graphs, no specific trends</td>
<td>Climate change different from GW, but can’t relate how (Post-int);</td>
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<tr>
<td>Characteristics of GW</td>
<td>T is increasing (Pre-T); Sunspots not cause due to graph not discussing causes (Pre-T);</td>
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<tr>
<td>Characteristics of Environment</td>
<td>Infers pollution from T/CO2 graphs (Pre-int); GHE caused by pollutants from cars &amp; factories (Post-int); Confused about above (delay post);</td>
<td>\</td>
</tr>
<tr>
<td>Evidence for above</td>
<td>Glaciers melting (Pre-T); Cites graph showing T/CO2 changes over time (pre T, pre int); Sci’s need to get more data like testing a medicine (Pre-int); Sci’s need to make models (Post-int); Ice melting in photos (Post-T); T rising in graphs (Post-T);</td>
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<tr>
<td>Mechanisms of above</td>
<td>Fossil fuels as cause of GCC (Pre-T); Low self-efficacy: unwilling to share views on GHE, mechanisms (Pre-int); GHE as half natural, half man-made (Post-int); CO2 causing T to rise (re: graph) (Post-int); Infers patterns across graphs (increases) (Post-int); GHG’s blocking heat from rising (DEL POST); Misses potential sources of CO2 (Del Post); Favors CO2 as cause in graph b/c it explains a bit better</td>
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</table>
However, her understanding of climate change concepts showed rapid growth over the course of the unit. In her mid-unit interview, Nigella elaborated on details of the greenhouse effect that stumped her previously (Nige C-M int, p. 2):

BG: Could you be more specific the part greenhouse gases may play in global warming?
Nigella: By like trapping the …kind of like the cover saran wrap, trapping the heat in, like heat usually rises.
In her post interview, her answer to the greenhouse effect question is:
Nigella: I guess I would say it’s the carbon dioxide in the atmosphere that’s causing, you know how heat rises? Well it’s causing it.
BG: Okay, is that a natural thing, the greenhouse effect?
Nigella: I guess I’d say so it’s half-natural, and half man-made.
BG: Can you tell me more about how half of it is not natural?
Nigella: I’d say that half of it was natural and half of it was not natural because half of it was from what we caused to do, all the gases and things, the pollutants we put in the air and things from like factories and cars, vehicles.
BG: Any particular pollutants?
Nigella: Not that I can think of…I guess I learned greenhouse gases, exactly what they were, and how like different places/different times, that the heat was rising in different places, not just like…here.

What is striking about the above exchange is that Nigella, by mid-unit, went from someone unwilling to elaborate on GCC science, posing herself as a blank slate, to offering not only an adequate explanation of the greenhouse effect, along with sources of greenhouse gases,
but with an answer which involved something akin to the consensus view on climate change. That is, she explained that the earth is warming on average due, at least partially, to the human-enhanced greenhouse effect. She carefully nuanced that some of this change may be natural, again something that climate scientists concede may be happening. However, it also must be noted that part of her explanation invokes an inaccurate scientific conception akin to that of Bono. That is, the notion that heat rises. In this case, Nigella intended to convey the idea that hot air tends to rise, but nonetheless this is a source of potential concern in that she came away from the GCC unit with a fairly well developed scientific understanding in some respects, while keeping the notion of heat rising as part of her causal mechanism. In fact, she expanded on exactly this in her delayed post interview, saying that “I remember like the CO₂ up in the air that’s blocking heat from like going up because heat rises….and it’s making it hotter!” This indicates that six weeks after the unit, her understandings of the mechanism were even more tightly bound to the notion that heat rises.

It should be noted that Nigella’s interpretation of rising heat being blocked as a causal mechanism would be an accurate interpretation of the cause of the rising heat in the model employed in the lesson. That is, the rising hot air was blocked by the Saran wrap, which modeled the effect of CO₂, making that bottle hotter. Thus, her correct interpretation of what was occurring in the model may have prevented her from grasping a more general understanding of the atmospheric greenhouse effect. Just like Bono, Nigella also confused the physical model for the desired mental model (Cartier, et al., 2001; Grosslight et al., 1991), therefore preventing her from making a shift to an entirely accurate ontological model of GCC as an emergent or equilibrium process (Chi, 2008).

**Nigella’s epistemological understanding**

Nigella’s naive epistemological understandings were characterized by an emphasis on finding evidence. In her pre unit interview, Nigella did show some epistemological sophistication (Nige pre int, p. 1):

BG: How do scientists know that dinosaurs actually existed?

Nigella: Because they find evidence. That there actually was dinosaurs, their bones, different like things that ….they have to like make a theory and then back it up with evidence.
I assert that this was fairly sophisticated for a 6th grader in that she prioritized evidence, and suggested that theory-making is a critical part of the scientific process, and also that theories need to be backed with evidence. However, her sophistication pre-GCC unit is limited as shown in the following exchange (Nige pre int, p. 1):

   BG: Could you talk a little about how they go from finding bones to how to make a theory about that?
   Nigella: They find evidence like maybe a footprint or a fossil you could examine it to figure out their lifestyle things…then…this happened to this dinosaur, like how it died or something.

What the above passages show is that while Nigella valued evidence initially, she had a limited feel for the subjective nature of the interpretation of evidence. Some scholars have suggested that the subjective interpretation of evidence is a key aspect of the Nature of Science that needs to be taught in K-12 schools more explicitly (Abd El-Khalick & Lederman, 2000; McComas, 1998). In other words, she seems to have the idea that the evidence supplies its own interpretations of the theory at hand. This indicates that although her epistemological understanding may be quite advanced for her age or grade, she has room for growth to achieve a more nuanced view in terms of an understanding of science more aligned with that of NOS scholars.

   After the unit, Nigella did show signs of greatly increased epistemological sophistication. This is her post interview response to the question of how scientists know that dinosaurs existed (p. 2):

   Well I guess that usually seeing is believing. So it would help to see it, but they probably would have to make a model or something of what they think it would look like. And then see if they could make up a way to actually figure it out..

Later, she elaborated when the question was particular to climate change:

   Nigella: Cause you need to know exactly what you’re talking about. And what you’re explaining to people. Cause if you’re like a scientist, and you come up with a theory it’s kind of true because people most likely are going to believe you if you have evidence and you need to know exactly what you’re talking about and make sure like you’re interpreting the evidence correctly.
The above demonstrated that although Nigella’s naive epistemological understandings were fairly advanced, especially in that she had already internalized the need for scientists to make theories, she still managed to improve significantly during the GCC unit. She began the unit by invoking the need for evidence and theory-making. She finished at a point in which she continued to advocate the same, but with the added nuances that models need to be made as a means of testing theories, evidence needs to be interpreted correctly, and the need for evidence as a means of convincing others. This highly nuanced viewpoint situates Nigella in the realm of a sophisticated epistemological understanding. According to the psychologist Deanna Kuhn, the most sophisticated or evaluativist level of epistemological sophistication consists of “—claims, which require support in a framework of alternatives, evidence, and argument.” (Kuhn, 2001, p. 5). Such notions were absent in her pre-data. Therefore, the extent of the development of these notions provide evidence of epistemic conceptual change in Nigella, in that her already strong epistemological understandings grew yet more as a result of the instructional unit.

**Nigella’s analytical understandings**

Nigella’s initial attempts at analysis of the data focused on simple descriptions of the graphs involved. At first, she, like most others, tended to look at the graphs in question and simply describe what she could about the graphs, making little to no inferences about their meanings. In her pre interview, this pattern was seen in Nigella’s attempt to explain two different graphs (Nige interview, p. 3):

(re: graph one): What I see basically is that with the earth surface that the temperature is like rising increasingly by like…years over the years. It keeps getting hotter in Celsius degrees.
(re: graph two): Seems like the temperature is very wavery. It’s not staying put or not going straight up. It’s like up and down.

When I specifically asked her about any connections between the various graphs, this was her reply (Nige interview, p. 4):

Well they all do have to do with similar topics, things like…some of them are about pollution.

These responses imply that Nigella’s understanding of reading and interpreting graphs was somewhat limited, at least in reference to the ones she looked at. She resorted to simply
describing what she saw in general terms and non-specific fluctuations, as opposed to focusing on causality or detection of patterns. However, as a result of this unit, she improved mightily in these aspects. In her post interview, Nigella elaborates on the sunspot graph (p. 3):

THIS graph shows that I would say, that sunspots aren’t, or solar radiance, isn’t really causing the earth’s surface temperature to go up, because right here, (pointing to recent 27 years of graph, where temperature & sunspot lines diverge dramatically) it’s not exactly following it. And then the end the temperature and solar radiance are going in basically the opposite directions.

What is fascinating about that answer is that it shows Nigella examining a graph, inferring patterns in it and offering a causal explanation for those patterns. Indeed, in her delayed post interview, Nigella answers with much nuance (Nige delpost int, p. 2):

BG: If you look at these graphs together, what do they mean to you?
Nigella: Ummm…the temperature’s rising, and the different things that are causing it.
BG: What tells you what might be causing that temperature rise?
Nigella: Kind of all the graphs play a part and this shows this might be causing that, because if THIS goes up this also goes up.
BG: Okay-so what is the THIS in that graph that might be causing temperatures to go up?
Nigella: The natural gases, coal, and oil, that might have that effect.

Overall, Nigella showed tremendous growth in her ability to analyze graphic data. Her initial attempts at such analysis were characterized by simply reading labels and units, while later efforts revealed her detection of patterns, including patterns drawn from the examination of multiple graphs, and even invoking causal arguments from graphs.

**Nigella’s affective factors**

Accounting for affective dimensions are particularly important in order to understand Nigella’s conceptual change. The most salient aspect was her own shy, mostly withdrawn personality. She tended to sit quietly in class, without talking unless she deemed her input necessary, especially if she perceived the class to be stuck. Her short answers to the pre instruction interview questions also buttress the idea of her relative shyness. However, Nigella was one of only two to note that science rivaled mathematics as her favorite subject. During the unit, her understanding of the science involved was certainly one of the most advanced in the class. However, despite this, her views were not well-represented in her group’s final socially
constructed argument. At the end of the first ADI lesson, designed to answer the question “What are the patterns of climate change we can detect?”, Nigella’s group came up with an argument very consistent with the available data. Their argument’s explanation, drawn from their group-derived whiteboard, read (Nige ADI 1):

We think the earth is warming because of the photos we studied in our climate change lesson. We concluded this because in the picture of the ice land masses (North Pole) is shrinking….The line graphs shows global temperature have been rising.

The above group explanation makes it clear that the group was adopting an argument consistent with consensus GCC science in several ways. For example, they conclude that global temperatures are rising, and that ice masses are melting, an observation consistent with warming. They appropriately call attention to relevant pieces of evidence, such as graphic temperature data, as well as photographs showing glacial retreat. They had not yet tendered an explanation for the causes as of that time, as they had not yet been asked to supply the causes.

In the second ADI lesson, designed to understand the causes of climate change patterns detected, the students were assigned by the teacher to new groups. The resulting argument from Nigella’s new group invoked a causal explanation that is at odds with consensus science views as described in chapter one. The explanation given for the causes of the climate change patterns read (Nige ADI 2):

We think the recent cause of temp. change is due to sunspots. We think this because the graph shows that when there is more sunspots the temp. is warmer. Also, the use of coal, oil, and natural gases is making it warmer. We also think greenhouse gases has an effect on the climate.

The explanation above is at odds with Nigella’s own GCC views as described above, in which she had explained by mid-unit that warming was half “man-made” and that greenhouse gases and other pollutants were the likely cause (Nige CM int, p. 2). At no point past the pre-test had Nigella demonstrated any sort of commitment to the viability of sunspots as a causal mechanism. The above passage makes it clear that Nigella participated in a group argument whose causal explanation was opposed to Nigella’s own highly sophisticated personal understandings. One factor that may help to explain Nigella’s lack of assertion in the group is that the new group included “Carmen”, a very assertive female. As this group was trying to decide what to write for their group argument, their exchanges often included terms like “let’s just put THIS down” (Day
3 notes cam 2). Carmen did not say anything that might indicate she was fervently devoted to the idea that the earth was not warming due to human causes. Rather, she seemed a combination of assertiveness along with the inability to infer appropriate causal patterns from the graph in question. So she led the group discussion, to the exclusion of Nigella. One other group member mounted a relatively feeble defense of greenhouse gases as making the Earth warmer. Therefore, their final argument initially invoked Carmen’s sunspot hypothesis, then explained that greenhouse gases also are causes. In other words, Nigella’s group finally ended with a simple relativistic inclusion of all possible causes as being plausible. Nigella, while having a more sophisticated understanding of the climate science, and of the associated evidence, as well as the ability to infer causality from the graphic data, was relatively uninvolved with her group argument as depicted on the white board.

**Summary of Nigella’s conceptual change**

Nigella’s conceptual change was substantial. This was particularly so given the extent to which she gave detailed accounts of the need to use evidence to convince others, and her generally sound understanding of the interplay between GHG’s and warming. However, the inaccurate aspects of her understanding of the greenhouse effect and rising heat, which were clearly learned as a result of the intervention, are difficult to account for. As discussed above, it is likely that Nigella was entirely accurate in her understanding of the actual model she experienced. That is, the reason that the two liter bottles in the modeling lab had different temperatures really was that the Saran wrap prevented the hot air from rising out of one bottle, and not the other. Her difficulty was in her extrapolation of that model to the actual greenhouse effect. While the lesson emphasized the modeling aspect as a metaphor for a natural phenomenon, Nigella struggled to make that connection, as did Bono. In other words, both Nigella and Bono failed to recognize the limits of the model being used for the greenhouse gases. In this case, the model greenhouse gas, the Saran wrap, literally prevented the heated air from rising out of the bottle, thus trapping the hotter air in the bottle. This differs from the heat trapping mechanism thought to be present in the CO$_2$ gas molecules, which are thought to simply capture particular wavelengths of re-radiated energy coming from the Earth. The main conceptual difference between the model and the actual effect is that the model works by
blocking a batch of hot air, whereas the greenhouse gases work by capturing not parcels of air, but particular pieces of energy.
Shania’s initial understandings of science focused on notions of proof and (especially) dis-proof. Mentioning that facts are needed in order to attempt to disprove scientific explanations, her ideas bore some resemblance to Karl Popper’s notion of falsification.

Shania’s understandings of GCC Science

Shania’s naive science framework (see Figure 16) included a wide diversity of information across a variety of topics. She at first understood that climate was changing, temperatures were rising, without giving specific examples. However, her initial framework was
also characterized by general environmental principles such as deforestation, mercury poisoning, overfishing, interdependence of organisms, and ozone holes. In her pre instruction interview, she revealed the extent of her understanding of climate change science (p. 2):

BG: Changing subjects, what can you tell me about current climate patterns around the world?
Shania: Current climate patterns…oceans are rising, the temperature is getting hotter, and then in the winter, it’s getting much COLDER than it was in the past. So it’s like in the hot times, it goes PHOOM! Way up! And in the cold times it plummets! It’s almost like instead of being this nice, regular way, it goes CHING! SHEONG! It just climbs and then dramatically falls into pits.
Shania: It’s a complete change from what we’ve seen in the past. There’s also less oxygen in the air because trees are going away. That doesn’t help us either!

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<tr>
<th>GCC Science Framework Category</th>
<th>Pre-instruction/naive Framework</th>
<th>Post Instruction/Synthetic Framework</th>
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</thead>
<tbody>
<tr>
<td>Characteristics of GCC</td>
<td>Climate is changing (pre-T, pre int);</td>
<td>Sea levels rising, T inc (Del post int);</td>
</tr>
<tr>
<td></td>
<td>Clim change is the rapid change in E’s T (Pre-int);</td>
<td>Clim change is the warming of E due to inc in GHG’s in atmos. (Post-int);</td>
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<tr>
<td></td>
<td>Climate patterns getting weirder (Pre-int);</td>
<td>Clim change, GW exactly the same (Post int);</td>
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<tr>
<td></td>
<td>Climate change not good [because of interdependence of plants &amp; animals] (Pre-int);</td>
<td>Did not catch onto ice cores (Delpost int);</td>
</tr>
<tr>
<td></td>
<td>Science television (Mythbusters, etc) (Pre-int)</td>
<td>The ADI lesson “thoroughed” her belief in GW (C-M int);</td>
</tr>
<tr>
<td>Characteristics of GW</td>
<td>GW same as climate change (C-M int);</td>
<td>GHE creates protective blanket that protects us from</td>
</tr>
<tr>
<td>Characteristics of Environment</td>
<td>Fossil fuel use $\rightarrow$ ozone hole (Pre-T p. 1, 5); Clim change includes sudden changing of tectonic plates (Pre-int); Seismic activities (Pre-int); Polar bears struggling (Pre-int); GW related to ozone and mercury (Pre-int); Concern for marine animals-overfishing, mercury, dolphin/tuna issue (pre-int); Pollution.</td>
<td>UV &amp; keeps sun's heat in (Post int); Science as CSI investigation to solve &quot;murder of our planet&quot; (Post int); Infers cause from CO2 spike (Post int); Confused by deadly nature of CO2 (Post in, p. 6); CO2 levels have risen due to increased driving, air pollution, usage of fossil fuels (Sha, writ p. 1).</td>
</tr>
<tr>
<td>Evidence for above</td>
<td>Glacial melt photos (Pre-T, pre int, C-M int); Charts showing t fluctuations=most powerful (Pre-int); Pictures taken from helicopters (Pre-int);</td>
<td>Polar melting (Post int); Temp spike on graph (Post-int); Graphs most important source (Post int); Also feels to be getting hotter (Post int); Sci’s on TV (Post int);</td>
</tr>
<tr>
<td>Mechanisms of above</td>
<td>CO2, Methane emissions (Pre-T, pre int, C-M int); Fossil fuels (Pre-T, Pre-int); Concern for animals welfare tied to oil spill (Del post int).</td>
<td>CO2 levels have risen due to increased driving, air pollution, usage of fossil fuels (Sha writ, p. 1); CO2 traps heat inside it (Sha writ, p. 2);</td>
</tr>
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</table>
Shania's understanding of GCC science seemed to rely on an emphasis not on overall or average warming, but on increased extremes in both summer and winter. Her statement that winters were getting colder seemed to preclude an understanding that the overall average surface temperature of the earth is getting warmer. In addition, Shania invoked deforestation to conclude that there is less oxygen in the air as a result of climate change. In fact, she continued later in the interview to invoke tectonic activity changing, as if it too was tied to climate change:

I know that climate change is the rapid changes in the earth’s temperature. [note to self: maybe a theme that avoiding the term global warming is more confusing to s’s and precludes them from understanding overall temperature trends? And the ummm...changing of the tectonic plates, ummm, where they are,.....and they’re moving around, causing some things to just disappear into the ocean, and other things to just POW! It's right there, and it wasn’t there yesterday!

The above passage is an example, along with her mention of deforestation, of Shania's lack of a systematic, refined category of climate change. Instead, she seemed to focus on issues that were of dubious connection to climate change, as long as they were of an environmental nature.

Shania elaborated in revealing ways when asked –Have you heard of the greenhouse effect?": (Sha pre int, p. 3)

Shania: Yes I have.

BG: What does that mean?

Shania: The greenhouse effect, is ummm...greenhouse gases that are in our atmosphere are ...there’s a mass of them, and they’re getting much higher, like CO₂, and methane and after actual studies, and scientific things they've done, and looking at the effects of methane and CO₂ on ice, and plants, and...other things that we need...and all that stuff...the ice melts extremely quickly under methane and CO₂. But in oxygen, it basically just sits there. And there's also UV rays that aren't escaping anymore, and they're getting in through holes in the ozone layer because of what we're doing. Now the
UV rays come in, and they get stuck. They can’t get back out. So now it’s heating up our planet even more.

BG: Is there a connection between the greenhouse effect and maybe global warming related to the ozone layer?
Shania: I believe it is. It is directly related, actually. We put out these things like CO₂ and methane right over cities when they look at the ozone layers above it, the ozone starts to go away. When they put out tons of methane and CO₂ and mercury and all these different things.

BG: Now what happens with the uv rays?
Shania: They get in through holes in the ozone layer. That’s what keeps it out.
BG: Do they only get in through the ozone hole? Is all the UV blocked by…
Shania: Not all of it. The majority of the UV that gets trapped in here comes in through holes in the ozone layer. Some of it will eventually penetrate through it. Of course it doesn’t help to have a giant hole there.

In this exchange, Shania revealed that her understanding of the role of CO₂ is such that she thought that the CO₂ was causing the increased heat, directly, as opposed to the indirect means of blocking in heat. Also, she seemed to conflate the ozone hole with greenhouse effect by saying that the UV gets into the atmosphere through the ozone holes. Also, she included general pollutants like mercury with climate change, in an ambiguous way. In other words, her naïve understandings were characterized by the tendency to place all things concerning climate change into a category of general environmental events or items.

After the instruction, Shania’s synthetic GCC understandings had been greatly scaffolded, as shown in the exchange below (Sha post int, p. 1):

BG: What can you tell me about climate change?
Shania: Climate change-fascinating subject! Climate change is the warming of the earth due to increase in greenhouse gases such as methane and carbon dioxide in the atmosphere. They are creating somewhat of a blanket that allows the heat in, but then traps it in and…in quantities that are getting beyond what the planet needs. It’s overheating the planet, and also the gases themselves are…in mass quantity, deadly. Especially carbon dioxide.
Shania went on to explain that she understood that carbon dioxide was deadly because a television program on the History Channel depicted a case where a bubble of carbon dioxide killed people and livestock near a volcanic crater in Africa. She did seem to capture the role of greenhouse gases in the atmosphere, in terms of trapping heat in. However, two aspects of her post explanation appear to still need some modification toward the scientific conception. The first is that she defined climate change as the warming of the earth. Therefore, she seemed to be conflating climate change and global warming.

In addition, Shania seemed to be emphasizing the deadly nature of carbon dioxide in reference to humans and animals, something that is not particularly relevant to climate change itself. Her emphasis of this is despite the fact that her understanding of the role of carbon dioxide in trapping gases in the atmosphere is highly developed. Her focus here may have been the product of her particular love of and concern for animals. For example, in her pre unit interview, Shania elaborated (p. 4):

And there’s polar bears out there scrambling to live, and everyone is just like all the animals up there that live on the ice...they’re just scrambling around, trying to live, but they can’t because the things they need aren’t there.

And in the post unit interview, that idea was still a foremost concern for Shania (p. 2):

I’m really concerned about polar bears, and plus, with the oil getting spilled, then that heats up the water which kills more animals, beyond just the oil coating them to death.

Indeed, Shania’s great concern for animals, expressed throughout the research, was constantly emerging from the data. This fact makes it reasonable to infer that Shania’s concern for the well-being of animals had a role in shaping her understanding of the GCC science.

In regards to the greenhouse effect itself, Shania’s post answers were revealing (Post int, p. 3):

BG: Okay. What’s the greenhouse effect?
Shania: The greenhouse effect is when ummm…it’s when greenhouse gases are in the atmosphere that create a protective blanket that A) keeps out, blocks out a majority of UV rays that harm us. And B), the ummm...keep in the sun’s heat so that…it stays warm but let enough of it out so that it doesn’t start happening like it’s happening now.
BG: Okay. And…what exactly is happening is happening now, to change this?
Shania: As we emit more greenhouse gases, it fills up the atmosphere, therefore making it thicker and thicker, and it allows IN the heat, and it traps in more of the heat, making it hotter. And…I do think that it’s possible that the climate will go…the temperature will go up and up and up and up until finally it plateaus, but I think it’s gonna take a LONGGGG time. A VERY long time.

It is important to recognize that Shania’s understanding of the greenhouse effect was much more consistent with the scientific understanding after the unit. However, in this case, it may be more important to underscore what is not said by Shania in the passage above (post instruction). At no point does she invoke the ozone hole as something related to climate change. In fact, her synthetic understanding seems to have nearly dissolved the general environmental confluations that characterized her naive framework. She also seemed to invoke only the appropriate role for greenhouse gases, in terms of blocking and trapping in heat, as opposed to themselves directly contributing to the heat. While her post-understandings of GCC science were far from complete, they did grow considerably from her prior understandings.

**Shania’s epistemological understanding**

Shania’s epistemological understanding before the GCC unit was focused on "proof" as illustrated below (pre int, p. 1):

BG: What is science to you?
Shania: To me science is the study of the things around us, whether we can explain them or not. That is the point of science. Figure it out, explain it, and then…try and disprove what you’ve what you’ve found. If you disprove it, well, you’ve disproved it. If you prove it again, you try to disprove again and you prove it again, and it’s like okay every time I do this, I get the same result. Facts!
BG: Is that important for science to keep doing things again and again?
Shania: Yes! It’s very important! Cause things might change! One of the natures of science-things change!
BG: Okay…ummm, what do you mean by "natures of science"? That’s an interesting term!
Shania: Ummm…the natures of science…the living things around us, is one of my examples. They can adapt so we say them we find them as this ONE way, and then when
they’re in another habitat, we study them again, and they’re totally different. They just change. The main part of science, and nature, and all this stuff put together, it proves that science can change, as does nature.

Above, Shania seemed to understand that evidence is critical to scientific understanding. While she invoked the term “natures of science”, which sounds similar to the Nature of Science as widely discussed in scholarly circles in science education (Abd El Khalick, et al., 2000; Southerland, et al., 2006), her elaboration on that term indicates that her labeling of it is incidental to the NOS literature. She seemed to imply only that science is akin to nature. She also focused on the need to “prove” or more particularly, to attempt to disprove, what scientists have found, in the sense of replicating scientific results, or failing to do so. It was her perspective that the net result of this process is to produce facts, although she did seem to understand that scientific understandings may be prone to change. In these respects, Shania’s views are akin to those of the Austrian philosopher Karl Popper, who posited the role of science to propose hypotheses which could then be potentially falsified by the search for appropriate evidence (Popper, 1965).

In this exchange, Shania elaborated on her climate change understanding (pre int, p. 3).

BG: When scientists discuss climate change, how valid a scientific explanation do you think that is?

Shania: Ummm…depends on who’s saying it, and what they are saying. If it were this world-renowned climate change expert, and they’re saying how the vast amounts of CO\textsubscript{2} are increasing the temperature and then the next thing they see is Mythbusters actually showing how CO\textsubscript{2} melts ice really fast! And how methane does it too. And then…I’m going ‘Okay-I see that’s very valid. That makes sense!’ Then other scientists say ‘Climate change doesn’t exist! CO\textsubscript{2} isn’t in the air! Then ‘blah blah blah and hubbub’ about nothing. And then…you look at other people’s data and it’s like ‘Dude you’re wrong!’ Things are changing.

Above, Shania again asserted the changing nature of scientific understanding. She also invoked the need to look at others’ data, indicating that her views of science were advanced enough to include the notion that the sharing of data provided more powerful scientific understandings. Interestingly, she stated here the need to be skeptical even of highly renowned experts, in the face of evidence, in this example, with her invocation of the famous show “Mythbusters”, a cable
television show which tests and often debunks “myths” related to popular science. In other words, Shania invoked “Mythbusters” as an archetype of skepticism that was her model for how to be skeptical, until “proving” claims true or not.

After the Climate Change unit, Shania held onto these ideas, but in a more nuanced and accurate fashion, as shown in the exchange below (Post int, p. 2):

BG: Okay. Umm… When scientists talk about climate change, do you think that’s a valid scientific explanation?
Shania: Yes, I do. I think it’s a quite valid scientific explanation.
BG: How so? What makes an explanation valid, scientifically?
Shania: When other people can look at the evidence, think about it rationally, and it still makes sense, and then go out and do tests that other people did, and come out with the same results. This is how we check other people’s things. Like when the man claimed he figured out how to stop breast cancer, when really all his patients had been dying! Insane whacko!

While Shania had the idea of the necessity of fact-checking others’ data prior to the unit, this time, she emphasized the idea that it is necessary to actually make sense of the evidence, in addition to simply doing the same tests. This indicates that Shania’s epistemological understandings had shifted somewhat. Shania was actually invoking elements of the Nature of Science as posited by science education scholars, in that scientific knowledge is considered to be subjective, socioculturally embedded, and the product of human imagination and creativity (Abd-El-Khalick, et al., 2000; Khishfe & Lederman, 2005). The following exchange further illustrates Shania’s adoption of more sophisticated ways of viewing scientific knowledge:

BG: So do you think it’s important to understand evidence for things like climate change?
Shania: Yes. I think it’s important to understand evidence about the issues because when you understand the evidence. It’s like interpreting the evidence in a crime scene investigation, you need to be able to understand the evidence in order to piece it together enough to figure out the problem and a way to solve that problem. Of course, in… crime scene investigation, it’s finding murderers. (Laughs)
BG: That is kinda similar, isn’t it?
Shania: Yeah—the murder of our planet!
The above passage illustrates that Shania had undergone significant growth epistemologically. She began her journey with a focus on proof and disproof in a Popperian sense, and after the instructional unit, she showed a much more nuanced view of science invoking a murder investigation as an analog for how science happens. This shift seems to be consistent with a shift from a positivist towards a post-positivistic view of science. In this view, scientific research is seen as “A fallible enterprise that attempts to construct viable warrants or chains of argument that draw upon diverse bodies of evidence and that support any assertions that are being made.”(Phillips, 2000, p. 17). Postpositivism, therefore, is a way of thinking of scientific knowledge (and indeed other types of research-based knowledge) as a branch of human understanding that is not limited to experimentally-derived data, but instead is open to supporting assertions that link arguments to varied bodies of evidence. Shania, in the course of this unit, made a shift in her understanding in that direction.

**Shania’s Analytical understanding**

Shania’s initial attempts to analyze the data before her were revealing. Before the unit, she seemed more comfortable than most of her peers in inferring patterns from graphs, although like most of them, she did not proceed to infer causality. This exchange illustrates this comfort (Pre int, p. 5):

**BG:** I’m going to ask you to look at these graphs. The first one first...so take a minute to figure out what’s going on in that first graph. When you’re ready, tell me what you think it’s showing.

Shania: I can tell you right now!

**BG:** Go ahead!

Shania: It’s showing the dramatic increase in the temperature. It used to be right here, kinda low, truckin’ right along, then it shoots up!

**BG:** What about graph two?

Shania: Graph two...ice core in Antarctica...hmmmm....CO₂ temperature...hmmm ...what I see is...the ummmm...the pattern of the CO₂ and temperature levels in Antarctica, and how it will spike right before...ummm...the...mark of the next 100,000 years, then drop, then spike, and then drop.
Shania’s relative comfort with graphs is shown by her eagerness to begin discussing the graph (“I can tell you right now!”) and her readiness to describe patterns she saw in the graphic data. Shania readily caught onto the idea that graph one (showing temperature change since 1880) showed an overall pattern of increase. But she was unable to make much sense of graph two, showing the cyclical nature of temperature over 300 thousand years, and its connection to carbon dioxide. Later on in the pre interview, Shania showed a more developed skill in pattern detection (p. 6):

Because of the spike in the use of oil and coal. And…then…beneath that…above that, I can see how the spike in coal and oil and total would…make the graph above it spike and now that I’m looking at it, it has almost exactly the same pattern! That’s weird! There’s the difference…That’s really weird!

While she caught readily onto the patterns across the different graphs, before the unit she was unable to offer any elaboration. Her post-unit explanations were of a different sort altogether (SAD post int, p. 4):

Shania: Here. Umm…I see a spike in the ummm… temperature. t’s almost an exact match ummm….When you get to around 1950, and moving on, almost an exact match that of the global fuel carbon dioxide emissions. So the link right there is…around the same time, both are experiencing the same thing, and they’re both spiking.

B: Okay. What about these 2 pages? (Referring to the Temperature/CO2 graphs)
Shania: okay. Ummm…this one, I see the huge jump in the CO₂ emission beyond what it has been in the past 350,000 years, and…I see that the temperature appears that it is about to follow it.

B: How do you know that the temperature is about to follow it?
S: That’s basically been the pattern for the past 350,000 years, even if it doesn’t immediately follow, the temperature does follow the CO₂ emissions.

Her discussion above indicates that Shania, after the unit, was looking at the graphic data and analyzing it, as opposed to simply reading it. Not only did she infer patterns, but she also inferred causality and extrapolated into the future. She continued in regards to the sunspot graph (SHA POST int p. 4):

BG: Cool. What about that?
Shania: What I see is...umm...spike in solar activity, sunspot activity. Temperature dropped. But though they both traveled together for some time, they will go like this-bam!

BG: What does that mean that they go like that? What does it mean that they separate?

Shania: Right around 1995, there's a drop in the sunspot activity and at the exact same time, a spike in temperature. So I don't think that sunspot activity is what's causing the climate change. I don't that the increase in sunspot activity is what's causing climate change.

In her explanation of the sunspot graph offered after the unit, Shania carefully explained how the graph indicated that the solar activity could not be the cause of the earth's temperature increase. This represents a dramatic improvement from her naive framework. Also improved was her ability to understand the significance of the data given in the photographs presented at the unit's start, as illustrated below (SHA post int, p. 5):

Shania: And these photographs...I see...ice disappearing...umm...over time due to...ummm...heat and CO₂ concentration.

BG: Okay. Umm...Do you know from those photos what it's due to? Why are you so confident in saying that it's due to increase CO₂ for example?

Shania: Umm...If I were just to look at these, and not know any of this, I'd think ―wow! Ice is melting-I wonder why!‖ So anyone can tell, ice goes bye bye! But...reason I can say with such confidence that it is the CO₂ emissions and increase in temperature is because I've seen THIS, and...I've seen it on TV, and all over the place about CO₂ going up, and temperature going with it, therefore, what else could it lead to other than melting of ice? 'Cause when temperature goes, up, ice goes away. Basically, something-anyone who has ever left a piece of ice on the floor would know!

The above passage from Shania is important in that it illustrates the source of much of her thinking. For her, the data alone were not the most convincing part; instead, the data in conjunction with her own viewing of a TV program, and her own sense-making in uniting these different sources were all key drivers of her understanding. It should be noted that her invocation of science programs on television did not always lead to increasingly accurate views of science. As discussed below, one program that she viewed, about the effect of a CO₂ bubble bursting out of a volcanic region, led Shania to conclude that the main concerns about CO₂ were
its direct role as an agent of not only death, but of direct heating of the atmosphere (as opposed to simple capture of certain wavelengths of energy).

**Shania’s affective factors**

To understand Shania as a learner of GCC, it is critical to examine some affective components of critical importance. First, Shania was the only student in the research to state that science was, by itself, her favorite subject. She stated that her intention was to become a Marine Biologist, because she loved animals. She invoked several television shows of a science theme that she watched regularly, including “Mythbusters”. She was very confident in her own ideas, especially concerning science. For example, when I asked her initially to examine some graphs, “Take some time to think, then tell me what you think”, she quickly interjected “I can tell you right now!” (Sha pre int, p. 6). Such exclamations were very common for Shania, indicating that she had a very high sense of self-efficacy in regard to science. Self-efficacy refers to “beliefs in one’s capabilities to organize and execute the courses of action required to produce given attainments” (Bandura, 1986, p. 2-3). Shania demonstrated continually that her self-efficacy was high in regards to her perceived ability level in school in general, and in science in particular. To buttress this idea, she often discussed the fact that she is a “gifted” child in a matter-of-fact way (“they put me in the gifted program in the second grade” (Sha, post int, p. 5).

It is also important to note that Shania had extreme difficulties in relating to her fellow students. While she often provided correct answers in ways that seemed to validate her self-evaluation, she did not engage with her peers often, unless forced to by virtue of the unit design. When forced by virtue of class requirement, such as collaborating to develop an argument for this unit, social problems often emerged. For example, during the first ADI lesson, Shania tried to argue her point to her group, who were unwilling to listen. Frustrated, Shania stormed off into the corner of the classroom, with arms folded and an angry scowl adorning her face. She also mentioned (frequently) that she considered herself a “perfectionist” who often was frustrated at dealing with the foibles of others in class. For example, in her concept map interview, Shania said that she interrupted other people to make sure that they “don’t get burnt down (p. 3)”.

The third strong affective component necessary to explain Shania involves her strong love of animals. She volunteered this at the end of the pre-interview (p. 6):
BG: Okay. The last question I have for you. Is there anything else you'd like to add that I didn’t ask you about?
Shania: Actually, yes. It actually has to do with marine animals. And what we're doing. What we all just end up doing. We are not only affecting the water temperature, which is killing off reefs and animals. But we emit things into the water like mercury and other toxins, and it will kill animals, like plastic bags in the water will kill turtles and choke penguins. It's just hideous! Then dolphins will eat plankton eat mercury, fish eat the plankton, bigger fish eat the fish, dolphins eat the big fish, people in Japan slaughter the dolphins, sell it off as exotic whale meat, then when people eat it, they get mercury poisoning! One of the most heinous things is that they kill dolphins! And to think they're not even protected by the global oceanic whale protector people—I can’t remember the entire name.
BG: Yeah, those things are known to harm animals. Does that particularly relate to climate change?
Shania: It actually does! Because when you think about it, when we put all that stuff in the water, it's polluting the water. And if we pollute the water, that directly affects climate change because we're changing the climate of the ocean. When we do that, it not only affects the animals who live there, it affects US. It affects everything!
The above data clearly depict Shania's love of, and concern for, animals. Also before the unit Shania already understood some aspects of science relating to the effect of toxins on animals, possibly providing an understanding that unfortunately conflated some aspects of GCC understanding for her. After the GCC unit, her love of animals was still emphasized, except she now combined that love with the then-dominant topic in the news, the Gulf Oil spill (Delpost int, p. 2):

Shania: I’m really concerned about polar bears, and plus, with the oil getting spilled, then that heats up the water which kills more animals, beyond just the oil coating them to death.
BG: How would the oil heat up the water?
Shania: Well because the oil is darker in color, it keeps in more heat. And so…as the oil is floating around in the water, the sun’s rays beat down on it, it collects more of the heat
than just water, and so it heats up the water around it. Plus, if it got onto a dolphin, and it was hot enough, it might actually burn them.

Not only was Shania's love for animals intact after the GCC unit, it seemed to provide an impetus to express concern for another scientific subject which had a direct bearing on the welfare of animals. For her, the Gulf Oil Spill, and its effect on marine life, served as a nexus for her love of animals and her love of science, and also allowed her to make connections to the climate change science that she had recently been learning. I note that her colleagues Bono and Beyonce also invoked the Gulf Oil spill in their post-unit interviews.

The affective factors described above help explain much of Shania's development in terms of GCC-related understanding. Her lack of ability to get along with her peers, combined with her high ability in science (acknowledged by group peers) may help explain the fact that her group's written argument on whiteboard did not reflect the depth of understanding held individually by Shania. The group did acknowledge that CO$_2$ was the likely cause of global warming, but stopped at elaborating on the evidence for that assertion in a way that Shania was effusive about. In other words, her lack of social “polis” may have ostracized her and her ideas from her group mates. However, the group argument was at least broadly consistent with Shania's thinking.

**Summary of Shania’s conceptual change**

Shania grew conceptually during the course of the unit, in some ways that were different in extent from her peers' growth. Initially, Shania shared the same ontological conflation as Beyonce, in that her discussions of climate change were couched within a general environmental framework. In this regard, Shania was qualitatively different from Beyonce and others, however. For example, Shania included mentions of the horrors of general pollution, litter, dolphin meat being captured with tuna, overfishing, and tectonic activity in general. For her more than any others, the ontological category she invoked was first and foremost an environmental framework, into which the issues of GCC and GW were subcomponents. Additionally, Shania grew epistemologically in that her previously positivistic emphases upon proof, facts, and disproof, evolved to the point of invoking a CSI model for how science works, at least in terms of finding the “murderer of the planet”.
In terms of her analytical abilities, Shania grew substantially as well. Initially, she read graph labels, like her peers, with some modest amounts of pattern interpretation. However, she grew in this regard to the extent that she interpreted patterns across the graphs, and inferred causality from the graphic data as well. For example, Shania, in reference to the CO₂/temperature graph derived from ice core data, said that “We have already seen that what is happening is not natural. CO₂ is like...higher than it has been for the last 350,000 years! (Sad post int, p. 4)” In pointing out that aspect of the graph, she is in fact citing the cause of warming. Later on, she verified that the sunspots were not the cause of warming: “Right around 1995, there’s a drop in the sunspot activity and at the exact same time, a spike in temperature. So I don’t think that sunspot activity is what’s causing the climate change. I don’t think that the increase in sunspot activity is what’s causing climate change (Sad post int, p. 5).”

Shania’s particular affective issues were also important in helping to explain her growth. Her high self-efficacy in science ensured that she was highly interested and capable of learning this material. This is particularly so in that her interests in the environment and animals in general were activated by the unit in question, thus motivated Shania even more. She entered into the unit with an understanding that climate change was happening and that it was a bad thing.
Summary of Chapter V

In order to explain the growth shown by each student from their naïve to their final synthetic view of GCC, four major categories were necessary to account for: Ontology, Epistemology, Analytical, and Affective factors. The relationship between the factors is given in Figure 18 below.

Figure 17: Shania's conceptual change. Blue = naïve; green = synthetic
Ontology proved important in that students had trouble initially in placing their knowledge about GCC into a category that was separate from any other environmental issue that they knew something about. As was discussed above, the development of such a category served as an Ausubelian organizer, scaffolding further conceptual growth in the students. Ideally, that growth would culminate in the understanding that GCC reflects an equilibrium process as opposed to a discrete entity (Chi, 1997, 2008).

Epistemology was a critical factor to examine in order to understand students’ conceptual change. This was particularly so in regard to the scaffolding of the students’ epistemic values towards those consistent with scientists’ epistemic values. By adopting the value of graphic data, for example, over their own anecdotal experience, these students quickly made epistemological gains.

Students’ ability to analyze data served as another important focus of conceptual change. Getting Beyonce, Darko, and the others to participate productively in the culture of science

Figure 18: Factors affecting conceptual change about GCC
(Duschl et al., 2007) entailed their improvement in the area of making inferences from graphic data in particular.

The last factor, affect, was as important as the other three, in unique ways to each student. While each student presented a unique affective landscape to examine, one finding that proves to be salient is the idea that middle school students’ love of animals may prove a useful scaffolding tool with which to build understandings of related scientific ideas upon. In fact, some authors have noted the need to take advantage of the public focus on particular sub-sets of animals, the “charismatic megafauna” (Barney, Mintzes & Chiung-Fen, 2005). The charismatic megafauna are those animals such as whales, wolves, and dolphins, i.e., large mammals whose imagery is associated with a broad sense of emotional appeal.

The graphic detailing the interaction of factors to explain the students’ conceptual change should not be interpreted as placing ontology as of primal importance as compared, say, to affect or analytical understandings. The graphic is simply meant to convey the idea that in order to explain the shifts made (or not made) in each student’s GCC understanding, an examination of those four factors is critical.

In this chapter, I have described the results seen for each of the five research participants. The first concept examined was the naive GCC science framework held by each student. These frameworks generally broke down into five categories: characterizations of climate change, characterizations of global warming, characterizations of the environment, evidence for those characterizations, and mechanisms of them. Their naive GCC understandings were then compared to their final, or synthetic understandings. Areas of growth or difficulty were noted. I then described other sets of factors that proved salient in their learning: ontological understanding, epistemological understanding, analytical understanding, and affective issues. Each of those sets of issues proved different for the students involved. Students’ overall conceptual change was then explained in terms of how those factors help to account for the specific changes that they underwent. Below is a discussion of some trends or unique aspects found in each area.

GCC Science frameworks

One trend in their GCC Science understandings that was immediately apparent is that at the beginning of the research, most of the students had at least a vague idea that climate change
is occurring, in the form of increased temperatures, sea level rise, and/or melting ice. Although all had heard of the greenhouse effect, none besides Shania could give more than a cursory account of how it worked, and even Shania had a major misconception in her understanding. Indeed, Shania had many incorrect ideas and/or conflations of other environmental ideas present in her understandings. That these students had poorly constructed understandings of the science of GCC supports the work of other scholars (Boyce & Stanistreet, 1993; Shepardson et al, 2008;) who found that particulars of the greenhouse effect are difficult for young students of elementary and middle school age to comprehend.

Several students began the unit with a conflation of GCC science issues with general environmental issues, such as pollution and concern for animals. That is, when asked to describe aspects of GCC and/or GW, several students described other environmental issues which were of limited relation to GCC. For example, the ozone hole was mentioned by two students, and the need to drive more fuel efficient vehicles was mentioned by two as well. Faulty connections to tectonic activity were given by Beyonce and Shania, with Shania giving a robust account of extraneous environmental aspects, including dolphin meat. For example, Shania said this while discussing the impacts of climate change:

People in japan slaughter the dolphins, sell it off as exotic whale meat, then when people eat it, they get mercury poisoning! One of the most heinous things is that they kill dolphins!

Shania went on to discuss pollution in general:

When you think about it, when we put all that stuff in the water, it’s polluting the water. And if we pollute the water, that directly affects climate change because we’re changing the climate of the ocean. When we do that, it not only affects the animals who live there, it affects US. It affects everything!

While the above data illustrate the trend towards the conflation of environmental and GCC issues in some students, at least three students were prone to errors of scale on either temporal and/or spatial dimensions. These students had trouble in making the leap from their own understandings of the scale of space and time that they were used to the scale needed to appropriately understand issues of climate change. For example, Beyonce and Darko each invoked their own anecdotal experience initially in order to justify their understandings, or lack thereof, of GCC. Each
indicated that they had not noticed any warming, and that the weather was then currently cold, so what warming was there?

Additionally, these three students also had misconceptions as to the unit of time in terms of what cycle of warming was being invoked, as to seasonal warming heading into the summer, etc. These understandings were further undermined by a focus on their own region. To Darko especially, the weather phenomenon encountered by him personally, at his locale, was used to undermine the notion of global warming. Interestingly, he subsequently admitted that warming was real, and the effect of GHG’s, but then denied it at the scale of being global. He conceded that the effects may be real, but that they did not apply to the entire world. Some scholars have noted that young students struggle in efforts to incorporate accurate representations of scale both spatially (Tretter, Jones, & Minogue, 2006), and temporally, especially the concept of deep time (Dodick, 2007).

After the GCC unit, students’ understandings of the science were greatly enhanced in many aspects, although with each student showing major weaknesses in their conceptions. All eventually understood in some sense that greenhouse gases lead to increased warmth through the greenhouse effect. Several students showed an understanding of the greenhouse effect afterwards, with at least three students approaching the scientific consensus at least in one regard, that there are both natural and anthropogenic factors in global warming. Two of the more high-performing students in the research revised many of their incorrect understandings by the end, or at least showed little to no sign of them in their interviews or written explanations. One explanation is that these students were able to successfully categorize their areas of learning, with several letting go of their overall environmental category. That is, students such as Shania were able to refine their understandings of GCC in such a way that allowed them to more clearly constitute a GCC category that was clearly distinct from the category of general environmental phenomena. This was likely a needed ontological shift towards the direction of thinking of GCC not as an entity unto itself, but rather as an emergent process, with complex causality (Chi, 2008).

However, some incorrect scientific ideas were either retained by the unit’s end or else were learned by the unit’s end, including the idea that heat rising was a major factor in the greenhouse effect, and that the way scientists know of the greenhouse effect is because they have done the modeling lesson that these students were engaged in. In other words, some of the
students have conflated the physical model for the more important mental model. In investigating using a model of the greenhouse effect, these students failed to make the fullest ontological shift possible because they failed to master the mental model as opposed to the physical model. Therefore, no students emerged from the unit with the desired understanding that the greenhouse effect was a background phenomenon, and that its enhancement by anthropogenic causes is the major concern. Instead, even the highest performing students interpreted the greenhouse effect as the problem and cause of warming, with Bono even claiming that he had done the “experiments” that proved this. This means that even high-performing students such as Bono and Nigella failed to learn critical portions of the science content because their experiences in the unit either created or reinforced the naïve conception that the greenhouse effect was the net cause of global warming. Additionally, these students’ conceptions were limited in that they perceived to understand a model of the greenhouse effect that was inaccurate.

**Epistemological trends**

Most of these students began the unit as empiricists in that they placed emphasis on finding evidence, placing them broadly in the camp of empiricism, a philosophy which privileges empirical methods (Phillips & Burbules, 2000). While they could be broadly classed in that category, they also simultaneously valued anecdotal data, which would seem to conflate with a sense of empiricism. Two students, Beyonce and Darko, placed a great emphasis, initially, on anecdotal data. That is, they invoked data that they either personally witnessed or personally could witness. As described above, at least one scholar has suggested a reformulation of the NOS literature in a way that specifically privileges the idea that scientific models value the systematic observations of nature, as opposed to anecdotal data (Allchin, 2011). Each of these students, with the possible exception of Darko, moved somewhat along the spectrum of empiricist to post-positivist. In general, they did not place an emphasis on the subjective interpretation of that evidence until after the unit, if then. Also, they initially emphasized certain types of evidence that they eventually evolved away from.

Other differences were of a more individual nature. One trend that analysis of the data makes obvious is that the epistemological thinking generally grew to a point where the students invoked the need to evaluate evidence, that is, that the evidence did not speak for itself. In other words, these students learned some aspects of the Nature of Science, in that scientific knowledge
is the result of subjective human experience, is the product of particular socio-cultural influences, and is the product of human imagination (Abd-El-Khalick & Lederman, 2000; Khishfe & Lederman, 2005). At least two students noted in post interviews that model-building is a necessary component of scientific understanding. And each student reached a point where they saw the need to invoke graphic data to buttress their arguments, even for Darko, whose view was against the scientific consensus (and the classroom consensus).

Analytical trends

Many scholars have noted that while science has placed great reliance upon inscriptional data, including graphs (Latour, 1987; Lynch & Woolgar, 1990), students often struggle to understand such sources (Lemke, 1998; Wu & Krajcik, 2006). While the students in this study were at varying levels in regard to their ability to make sense of graphic data, some trends were present. First, their initial attempts to make sense of the graphs consisted largely of reading the labels and the units affixed to the graph. Some attempted varying and limited levels of pattern recognition. Second, each of the students improved somewhat in their ability to understand these graphs, as shown by their subsequent inclusion of either pattern recognition, sometimes across multiple graphs, and/or invoking of graphic data as evidence for interpreting (or not) causality. And third, each of the five students at least attempted to incorporate graphic data into the explanations. This occurred regardless of the particular stance of or beliefs held by the individual. Even Darko, whose belief identification in opposing global warming was strong, used graphic data to buttress his views, and attacked perceived weaknesses in graphic data displayed. In doing so even in a somewhat unjustified manner, Darko made progress in the manner of productively participating in the discourse of science (Duschl & Schweingruber, 2007). In learning to value graphs and to include them in discussions as to the relevance of scientific data, Darko made somewhat of a shift in this regard. However, as discussed above, Darko never showed himself able to accurately make use of the graphic data.

Affective trends

Given that each of these students were individuals, fewer trends were noted across the affective domain. Also, while some changes were noted from pre to post, the idea that their
affective understandings somehow would necessarily change could not be assumed nor expected. However, one trend that was very salient was that four of the five students expressed a concern for animals at some point in the research. One of these four, Bono, expressed this only in the post data. This high degree of concern for animals reinforces the call by some scholars to focus on charismatic megafauna as a means to enhanced environmental and climate change education (Kollmuss & Agyeman, 2002). Such animals seem a logical choice for educational focus in these areas because of their emotional appeal, and the fact that their wide territorial ranges lend themselves to an interpretation as a world-wide phenomenon (Kollmuss & Agyeman, 2002). I argue that climate change educators should focus on charismatic megafauna that are obviously connected to climate change. For example, polar bears are certainly well-recognized exemplars of charismatic megafauna. Polar bears’ connection to disappearing sea ice, and the arctic food webs impacted their presence or absence would be a likely topic to focus upon. The students researched in this study certainly invoked polar bears as an iconic animal to center their concern around.

Two of the five students mentioned that science was their favorite subject, something surprising given that they are all in a science magnet program. They were very different in regard to their apparent self-efficacy, as some were very low indeed (Nigella) while others (Shania) were high to an extent that often proved unbearable for her colleagues. Two of the higher-performing students indicated that a great source of information was their constant watching of scientific-oriented television, such as Mythbusters. While each student mentioned the importance of family and teachers, only one, Darko, indicated that his views on GCC science were in fact the same as those of his family. In doing so, Darko explicitly invoked pride in stating his beliefs, and holding the same belief as his family, a phenomenon described by scholars as “belief identification” (Cederblom 1989; Sa, et al, 1999; Southerland, et al, 2001). Also, some values seem to have in fact been learned by some students. First, all of them showed some degree of having learned the epistemic values associated with science. That is, by the end of the intervention, each student, to a varying degree, invoked scientific data to support their arguments, regardless of their stance. For some this was a more marked trend than for others. For example, for Beyonce and Darko, this was a stark contrast because their initial references to evidence focused on anecdotal sorts of evidence. Two students, Bono and Beyonce, attached negative value to climate change, specifically saying that it is bad, whereas they initially did not
combine those two aspects. This was an issue with feet in both the epistemic and the affective categories. That is, the learning of the epistemic values of science, i.e., placing a premium on rational, logically coherent arguments which best explain sets of data, is directly an epistemological issue and at the same time, an affective issue. In other words, at some point in the process of the GCC unit, these students had to not only learn these epistemic values, but to choose to value them. In fact, each student did in fact choose to place value upon those epistemic criteria, as evidenced by the extent to which they in fact modified their arguments to favor data-based explanations.

One thing that stands out about the students’ adoption of epistemic criteria of science is that the original unit design did not explicitly emphasize these as goals. Instead, the unit may implicitly addressed some of these aspects in the course of student-student and teacher-student interactions. Some scholars have identified some characteristics of good epistemic criteria for scientific models to include conceptual coherence; compatibility with other theories; parsimony; consistence with empirical evidence; and a history of making novel empirical predictions (Pluta, Chinn, & Duncan, 2011, p. 486). Of those criteria, consistency with empirical evidence was the only aspect explicitly emphasized in the GCC unit. While that consistency with evidence also is the aspect which most obviously shows in the data, coherence also seems to have played a role in these students’ development, particularly in regards to their adoption of different ontological categories. In particular, several students started the GCC unit with a mental category covering general environmental factors, as opposed to one separately governing climate change specific issues. In the course of learning about GCC, some shifts were necessary, in one case (Beyonce), an Ausubelian shift (1978) was described in that she needed a new category in which to place her understanding, one in which things other than environmental issues were the key element. Each and every student’s shift had elements of the Ausubelian shift, in that a new category was necessary in which to invoke their new learning. However, I argue that an Ausubelian type shift is not enough to completely understand a complex subject such as GCC. In fact, failure to go beyond this shift helps to understand the lack of success encountered by the highest performing students as to the mechanisms of global warming. To appropriately understand such a phenomenon, based on a current equilibrium temperature that is thought to be enhanced by anthropogenic greenhouse gases, the subject of GCC must be thought of as an emergent or equilibrium process (Chi, 1997, 2008). That is, GCC is not an entity unto itself, so much as a
process that cannot be understood with reference to a simple causal mechanism. In other words, an appropriate and robust understanding of GCC would entail an appreciation of not only the greenhouse effect, but how that greenhouse effect acts a background effect, which might be enhanced (or reduced) by other factors.

**Summary of conceptual change**

In general, each of the students researched did show enhanced understandings of the associated epistemology, science, and graphing. However, their strong affective components help to determine where they were in regards to those categories, and how much growth was possible, or likely. The most prevalent results included that:

1) The students did show epistemological growth during the unit, in terms of showing more nuanced views of what counts as scientific evidence, and invoking that evidence appropriately;

2) They did show growth in terms of their understanding of the science of GCC, particularly in regards to what the greenhouse effect is, and what kind of evidence exists in this field. In general, these students all made progress toward the consensus framework of GCC, with 3 students specifically pointing out the fact that both natural and anthropogenic factors may be at play in GCC;

3) Students struggled to understand the greenhouse effect. This particular intervention included a lesson modeling that greenhouse effect in which students took their own data, and then discussed how the situation modeled the atmosphere. The net result of this is that none of the students mastered the idea that it is human-accelerated factors that are thought to amplify the already-existing greenhouse effect. In fact, two of the most high-performing students instead internalized the model as the evidence or as the actual atmospheric phenomenon;

4) Tremendous leaps were made in their abilities to analyze graphic data. Most dominant was the idea that students initially simply described the graphs as opposed to making sense of them. By unit's end, students generally inferred patterns and causality from graphs, largely absent initially. This trend towards a more sophisticated understanding and recognition of causality (or recognizing a non-causal relationship) and recognizing patterns in graphic data lend themselves to an interpretation of conceptual change. Some
scholars have noted the importance of providing students with opportunities to identify patterns in data and infer causal models from (Duschl, et al., 2007).

5) Students, to varying degrees, had to develop some categories to help them compartmentalize and learn about GCC. In particular, one obstacle to naive understanding was their conflation of GCC aspects with other, general environmental aspects, such as pollution, ozone, and concern for animals.

6) The affective factors strongly influenced each of the other factors. To truly understand the conceptual change in this unit, it is critical to examine the interaction of the individual affective factors along with the other three categories.

In the next chapter, some concluding remarks will attempt to synthesize the important aspects of these results, and some implications will be examined, both for purposes of further research and for classroom learning.
CHAPTER SIX

CONCLUSIONS AND IMPLICATIONS

In this research, I learned much about how middle school students process complex scientific information, and about how they make sense of it. This chapter will focus on what conclusions can be drawn from this research, and what the implications are.

I begin this chapter by looking again at the conceptual change theory that drove this research. Then I will examine how this study situates within the overall conceptual change research literature. I then describe the positioning of these findings within the climate change education literature. I conclude this chapter with an examination of some implications that this study’s findings portend for K-12 education.

Conceptual Change Theory

This work used the framework theory approach to conceptual change (Vosniadou (2003, 2007a, 2007b). This conceptual change theory invokes a view of learning that positions the student learning which needs changing as not the students’ misconceptions, but instead the –naïve, intuitive, domain-specific theories constructed early in childhood, on the basis of everyday experience under the influence of lay culture” (Vosniadou, 2007b, p. 4). These naïve frameworks are thought to be relatively coherent bodies of knowledge which help students explain, but fall short of rising to the level of a coherent scientific theory (Vosniadou, 2007b, p. 11).

Vosniadou’s framework theory of conceptual change (2003, 2007b) posits a shift from the students’ naïve frameworks towards a more scientifically accurate framework, culminating in a synthetic framework. While it is ideal for the student to not fall short of the fully accurate scientific model in question, a model which results from the synthesis of the student’s initial, or naïve framework, and his or her immersion in the more scientifically accurate model is an expected result.

Many findings in this study support the conceptual change literature in general and the framework theory in particular. For example, extra rational factors were of critical importance for each student, albeit in different ways. Also, ontological and epistemological understandings
were instrumental in driving the conceptual change for several students. However, there were some findings that promise to augment the literature, including some that seem to directly contrast with aspects of the conceptual change literature.

**Trends in the students’ conceptual change**

While the students in this study each had vastly different views and understandings of climate change, in addition to different experiences, some trends were apparent. The first such trend is that four of the five students’ basic views of climate change/global warming remained intact. Darko was the only student who explicitly stated a belief that global warming was not happening. As described above, he fit the description of belief identification (Southerland et al., 2001) in this regard. Over the course of the research, his understandings of the science of climate change showed significant improvement. However, at the end of the study, Darko remained explicitly opposed, at least to the idea that global warming truly is a global phenomenon. I emphasize this point to underscore an important focus of emphasis. While I contend that the evidence revealed that each of the five students underwent some conceptual change, none of them totally changed their beliefs or stated understanding as to the big picture of climate change/global warming. When I use the term “conceptual change,” I am using it to describe significant changes in student understanding in ways pursuant to the framework theory of conceptual change (Vosniadou, 2007a). Given that the framework approach to conceptual change is a comprehensive theory of conceptual change that focuses on epistemic, ontological, and other factors, an examination of the changes in these factors, if changes are found, are tantamount to describing conceptual change at some level. Therefore, a complete, global shift in understanding and acceptance of a scientific topic is not necessary to claim that conceptual change was experienced. Instead, I back away from such claims of global/total change and simply describe any salient gains made in these students’ understanding, within the framework theory of conceptual change. For example, while Darko did not shift in his stated acceptance of GCC/GW, he actually invoked graphic evidence to support his anti-global warming views towards the end of the study. This in itself represented a tremendous change in his conceptual awareness, beyond what could be posed as a mimicking of others’ verbiage. To further support the idea that this was learning on a level beyond such parroting or other rote learning, the triangulation of data sources make it clear that Darko did in fact change conceptually with respect to his epistemic understandings, and in other ways. Belief identification seemed to
merge with one of Darko’s constraints in order to guarantee that standpoint. Darko showed confusion in dealing with matters of scale, throughout the research. At first, this seemed to account for his privileging of anecdotal data. However, by the unit’s end, Darko was still claiming that while warming was happening, as evidenced in the data, that it was not global, in that it was not happening everywhere.

Bono’s views, on the surface, did appear to undergo an overall change, in that he was openly skeptical of global warming at the outset of the research. However, this idea does not survive careful analysis, because Bono initially believed that global warming implies that either one subscribes to the idea that global warming is entirely natural or that it is entirely anthropogenic. His skepticism was based upon his mistaken assumption that climate scientists are saying that belief in global warming implies that humans totally cause the warming. Therefore, once this false distinction fell away, his skepticism fell away. Beyonce entered into the research with an understanding that climate change was indeed happening, even though her understanding of the science was poorly structured. She maintained this stance throughout the research. Nigella, and Shania, likewise, each started out as accepting of climate change as a reality, and their acceptance of this did not apparently waiver. This was the case despite much variation in the extent to which each of them mastered the nuances of climate change science.

A second trend in the data is that many students understood some basic facts about climate change even at the outset of the research. While these parcels of knowledge may have been relatively unconnected to a greater theory of climate change, they do indicate that students came into the unit/research with a greater grasp of some pertinent information than perhaps might have been expected. For example, 4 of the 5 students initially understood that either the Earth’s temperature is increasing, and/or sea levels are rising, and/or that ice is melting (Beyonce, Bono, Shania, Darko). This may be particularly surprising given the young age of the students and their lack of curriculum particular to this field of science. This may imply that, as indicated above, students develop much of their knowledge base of climate science through other sources, such as parents, friends, and television.

Another trend that became apparent is that each student initially had ideas about climate change which could be described as scientifically inaccurate. This trend holds regardless of the performance levels of the students concerned. Beyonce’s understandings initially included the idea that natural disasters are a part of climate change in addition to poor understandings of the
greenhouse effect and the distinction between weather and climate. Bono’s understanding of climate change included the notion that one must believe in global warming must either be anthropogenic OR natural, not a combination of each. Darko was initially confused by issues of scale, in both temporal and spatial senses, in addition to having climate/weather confusion. Nigella initially had extremely rudimentary understandings of the greenhouse effect, while she conflated climate change with tectonic activity. The single most glaring aspect of climate change that was not robustly understood by the students at the outset was the greenhouse effect. Several students had heard of it, and invoked it initially. At least two students (Darko and Shania) even specifically mentioned CO₂ initially. However, none of the students had anything close to a robust understanding of the greenhouse effect or of the specific role of greenhouse gases in the atmosphere. This is true even at the most basic level, in that no students adequately differentiated global warming from climate change.

One trend emerged to be salient for several students concerning environmental knowledge. That is, Shania and Bono in particular each initially showed a wide range of knowledge about environmental issues. They seemed to conflate the two notions, mentioning such things as pollution, dolphins, ozone holes, and SUV exhaust gases. I contend that these students held onto a large mental notion that consisted of a big category of general environmental phenomena, under which climate change fell. Therefore, when asked to relay their understandings of climate change, their responses naturally included phenomena such as mercury poisoning and electric cars. For each of these 3 students, these environmental concepts seem to fade as they proceeded through the unit. I argue that their initial categorization fits nicely into the Ausubelian (1978) idea of subsumption theory, described above.

Despite the fact that understanding of climate change was initially incomplete to poor in each student, another trend was that each student did improve in their understanding of GCC science in several ways. Each of the five students discussed the role of CO₂ as a greenhouse gas by the end of the intervention. While none of the five students showed a completely accurate understanding of the greenhouse effect even at the study's end, it is striking that at the end of the research, at least each student mentions CO₂ and the greenhouse effect in relation to climate change. One striking aspect of many students' improvement is that their final understandings of GCC show that they improved much in the direction of GCC science consensus views, in terms of anthropogenic versus natural contributions to warming & climate change. As described
above, consensus climate science documents (IPCC, 2007) indicate that current warming & other climate trends are thought to be a function of both natural AND anthropogenic changes. This research indicates that some students (Bono) may be confused greatly by a misunderstanding about this, which may serve as a barrier to learning more scientifically accurate notions of climate change.

It may be surprising at first that some students appeared to learn scientifically inaccurate understandings of climate change as a result of the classroom intervention. Interestingly, this seemed most salient for the higher-performing students. Nigella, over the course of the unit, started to include the term ―heat rises‖ to explain the greenhouse effect. In her view, the heat could not escape the atmosphere because of the fact that greenhouse gases were trapping the heat in the atmosphere. It appears that Nigella was guilty of using the modeling component of the lesson, involving the two 2 liter bottles, one of which has Saran wrap covering the bottle. Taking that modeling lesson into account gives an appreciation for the sophistication in Nigella's thinking because her interpretation of the model was actually correct. The Saran wrap actually did prevent the hot air from rising out of the bottle, thereby making that bottle measurably hotter than its unwrapped cohort. She seemed to combine this understanding with other knowledge she had, such as the phrase ―heat rises‖, to put together an overall explanation. It should be noted that Nigella is not entirely accurate to say that heat rises, although in the modeling lesson at hand, the ―hot air‖ does rise, and is then blocked by the Saran wrap, causing its bottle to become hotter. In essence, then, Nigella used the model not as a model, but as the actual device it was meant to model. Bono made a similar inference in reference to the model. When asked how scientists know about global warming and the greenhouse effect, Bono answered that they have ―done the experiment‖ that he did in the class, therefore ―they know‖. While these high-performing students definitely benefitted from the use of the model, it should be noted that there are perils to such an approach, in that students can easily take them as the literal example.

Affective issues also played a role in each student’s conceptual change. While affective issues were composed of different sub-factors for each child, playing a complex role within their personalities, one such trend was a factor for four of the five students. That concerns the importance of animals in their GCC thinking. Animals became prominent in one of two ways. The role of animals in their conversations was usually one of expressing concern for the welfare of animals who might be harmed as a result of climate change. Also, often at the same time,
students expressed that animals’ dying off was itself evidence for climate change. Only one student, Nigella, failed initially to mention the role of animals in climate change. Bono, on the other hand, did not mention animals early in the research, but expressed concern for animals in his post interview. It is perhaps possible that given the argumentation format used as pedagogical strategy, that Bono may have learned this concern from his peers. One student, Shania, expressed a concern for animals to an extent which extended into outright advocacy. Shania stated that she intended to become a Marine Biologist. She expressed concern for dolphins, while showing contempt for the fact that they sometimes become caught in tuna nets. For some students, the role of parents, teachers, and others becomes a particularly salient factor. For Darko, his father and sister’s stance against global warming was adopted by him explicitly because they had that view, thereby giving him a belief identification, which then merged with his poor understanding of scale. Beyonce claimed that her views were heavily influenced by her mathematics teacher, who used climate data (related to sea level rise) to teach basic math concepts. Each student had a unique interplay of affective components that helped to explain their particular conceptual change, as describe in the previous chapter. However, it is important to note that even if no general trend was available to explain each student’s conceptual change, that these factors were present and influential for each student.

Another trend concerns the epistemological understandings of the students in this research. That is, these students' epistemological understandings and/or values appeared to grow somewhat over the course of the research. While these students' initial epistemological understandings showed a valuing of gathering evidence, they grew in that each student eventually included graphic data as a source of evidence. Each one of the five grew in this regard. Perhaps the most interesting example is Darko. He was one of two students (Beyonce is the other) who showed an early tendency towards valuing anecdotal data. However, Darko, at the end of the research, was citing scientific graphs in order to support his claims. It turns out that he was inaccurately assessing or remembering the graph in question, but it is of interest that even the one student who was steadfast in his opposition to global warming showed an improvement in epistemology such that he valued graphic data by the unit’s end.

**Conceptual change**

There is one idea pertinent to conceptual change that appears to be a new contribution of this research. This concerns the idea of *epistemic scaffolding*. That is, that some students’
learning of a complex science such as climate change was greatly scaffolded by the opening up of new epistemic space in their understandings. Beyonce in particular, began the unit with an epistemological emphasis upon anecdotal data. Her reference frames tended to focus upon what she herself experienced. By the unit’s end, Beyonce had recognized not only that relying on her own particular experiences may be limited, but that scientific data in graphs may actually provide awareness of things that she might not notice personally. I argue that her epistemic evolution from anecdote-centeredness towards awareness of the meaning of scientific data held in graphs represents a quantum leap in improvement. Beyonce’s shift from focus on anecdotal to a more systematic view fits with the call of Allchin (2011) to move towards a more nuanced view of the NOS. This improvement in her epistemic awareness also figured prominently in the vast improvement in her understanding of the climate change science.

Another finding may compel a re-examination of one aspect of the framework theory of conceptual change. That is, the framework theory posits that the naïve theoretical frameworks held by students based upon their daily experiences, etc., serve to help them make predictions about associated phenomena. This idea implies at least a certain minimum of robustness in these ideas such that these naïve frameworks may not easily be shifted. In the case of this research, some of the students' naïve ideas were in fact easily shifted. The best case of this was Bono. Initially, Bono’s framework for GCC/GW included the notion that global warming implied that humans were causing all of it. That is, if in fact one claimed that the warming was not 100% human-caused, then one was not an adherent of global warming. Bono in fact readily abandoned this position in the course of the unit. In fact, that idea of the dichotomy of causes of GCC (discussed below, in detail), that either it was entirely human-caused or entirely natural, seemed to be a key misconception that, once dispensed with, allowed Bono to make great progress in his understanding. Once he was convinced that that dichotomy did not in fact exist, his GCC views quickly became consistent with a consensus view of GCC science.

In addition to the above notion of epistemic scaffolding described above, many aspects of conceptual change uncovered in this research support the extant literature on learning theory. First, the idea that learning in general, and conceptual change in particular, that learning involves more than just rational factors. Early models of conceptual change themselves focused only upon these purely rational aspects (Posner et al., 1982). Subsequent scholars (Pintrich et al.,
1993; Sinatra & Dole, 1998; Vosniadou, 1999) have emphasized the importance of extra-rational factors such as learning dispositions, motivation, belief identification, and more. In the present research, many extra-rational factors were found, as described above. These elements included belief identification, the importance of animals in the worldview of sixth grade students, and self-efficacy. In particular, Darko showed a definite belief identification opposed to the consideration of global warming, with that view remaining intact despite much evidence of learning. Several students, including Shania, notably, expressed a concern for animals’ welfare that played into their overall learning of GCC science. And self-efficacy was a notable factor especially in Nigella’s case, in that her low self-efficacy prevented her from contributing significantly to her group product, despite the fact that her understanding of the science was at least as robust as any other student in the group. I emphasize, however, that where any extra rational factors played a role in the student’s particular learning, that it did not necessarily translate into an inability to learn more of the science. In Darko’s case, his opposition to the idea of anthropogenic global warming did not preclude him from learning meaningful scientific aspects of global warming or climate change.

While conceptual change is generally perceived to be something that requires a great commitment of time (Vosniadou, 2003), this research supports the notion that sometimes conceptual change is not always characterized by slow, steady, gradual processes. Instead, some authors (Mintzes & Quinn, 2006) indicate that conceptual change may be marked by long periods of stasis and/or weak restructuring, interspersed with rapid, irregular, and explosive bursts of strong restructuring, in which higher-order concepts are replaced and integrated into cognitive structure” (p. 303). Mintzes and Quinn cite Eldredge and Gould’s punctuated equilibrium model of evolution as their model. In punctuated evolution, the idea that evolution works only by a gradual, consistent process is discarded, in favor of an idea in which periods of stasis are punctuated by periods of rapid evolution (Eldredge & Gould, 1972). In considering the present research, which was conducted with a central intervention lasting about two weeks, the initial claim that any conceptual change was experienced may be considered immediately controversial. However, I argue that by focusing this two-week experience on an argumentation-based format served as an increased selection pressure, in essence facilitating conceptual change in some directions. The specific factors that provided this selection pressure include the fact that student ideas were made explicit, followed by opportunities which compelled students to
articulate and defend their scientific ideas with appropriate evidence at hand. I contend that the students in this research did experience varying degrees of conceptual change, although none of them ended the study with robustly accurate views of the mechanisms of global warming. But their growth in understanding was indeed substantial, particularly given the relatively short span of time given for this learning.

**Climate Change Education**

Next, I examine the findings concerning climate change education. Again, I highlight what aspects of this research stand out as new contributions to the field of climate change education. One such finding is that facilitating students' understanding of the sense of scale pays dividends in helping them to understand the complex nature of GCC science. I then reveal what aspects of this research are consistent or inconsistent with that literature. For example, one previous finding was supported by this research: that students have a difficult time understanding the greenhouse effect.

These findings of this research are of interest to the literature on climate change education. Some notions found appear to be new to this literature, or at least partly new. One finding that constitutes a new contribution to this literature is that for many/some students, to ask them to elaborate on their views on climate change or global warming asks them to activate a category that does not exist for them. Instead, they seem to invoke a mental model of “general environmental things”. In this general environmental category, students seem to hold onto any concepts that seem remotely environmental. For these students, such as Shania and Beyonce, many things may be activated, including natural disasters, ozone holes, factory pollution of the atmosphere, general pollution of mercury and other things into the environment, concern for dolphins getting into tuna supplies, and more. For them, climate change simply fit into that “general environment” category, therefore eliciting these other environmental concerns. These students improved massively in their GCC understandings over the course of the research to the extent that post-intervention, their discussions of climate change did not invoke ancillary environmental issues. I argue that this makes sense especially in light of the Ausubelian notion of subsumption theory (Ausubel, 1978). That is, in subsumption theory, a learner is thought to subsume information in accordance to pre-existing structures with which to hold this information. Ausubel argued that *advance organizers* are necessary as pedagogical tools in order to help students categorize new information in accordance with what they already understand. It
may be greatly helpful for teachers of climate change to understand this, and therefore help their students understand that the category of “general environment” is accurate, but too generic to be useful. Instead, perhaps the “general environment” category can be expanded to include subcategories such as “Earth’s climate” and “Earth’s biosphere”. While these are not mutually exclusive categories, perhaps this is a useful way to break down general environmental concerns into concerns about climate as opposed to sympathy for biota. In other words, researchers and teachers should be aware that students may come with their own de facto advance organizer, “general environment”, and plan accordingly.

In addition to the applicability of the “general environment” versus “climate change” ontological categories, I must examine the relative failure of the students to fully achieve an understanding of GCC as an emergent process. Climate change is an example of a construct that lends itself to the notion of an emergent or equilibrium process (Chi, 2008). Emergent processes are those whose causal agents are multiple, wherein no single causal determinant is thought to be at play. Additionally, local patterns may be seen which are ignorant of the greater global patterns, whose changes may be proportional to the causal agents, instead of incremental. That is, feedback mechanisms may result in increases/decreases in the system to the extent that small changes in causal agents may result in relatively large systemic outcomes. This emergent process fits climate change because it is a complex process whose causal nature is multiple, in that the greenhouse effect has a key role, but operates against a background of multiple other factors that need to be accounted for. Anthropogenic greenhouse gases are but one factor, while greenhouse gases may be emitted from other sources as well, from cows to volcanoes. Also, other factors, such as variations in solar cycles, Milankovitch cycles, and other aspects all play a part in a complex mosaic. A robust understanding of climate change would imply the ability of a student to understand the role of anthropogenic GHG’s against that mosaic of other complicating factors, and grasp the idea that the causality may not in fact be simple. Because of the lack of these students’ success in attaining this “emergent process” view of climate change, they were held up by such notions as the greenhouse effect and the lesson meant to model it. The two highest performing students, Bono and Nigella, because they saw GCC as an entity, or simple process at best, quickly seized upon the model as THE cause of climate change. Therefore, they left the unit with the misconception that the greenhouse effect was THE cause of global
warming, as opposed to understanding that it was the amplification of that greenhouse effect by other factors, including anthropogenic causes that might be the cause.

Another finding that represents a contribution to climate change education literature is that some students perceive a strict “either/or” dichotomy concerning global warming. That is, such a student may have a bias such that he or she thinks that global warming or climate change must be either entirely a natural or entirely a human-caused event. As discussed above, consensus science indicates that there are constant background changes in the natural record (IPCC, 2007). Much of the complexity in climate change science involves the detection of signal that indicates an anthropogenic contribution, which is distinguished from that natural background. In other words, climate scientists understand that climate change as being experienced right now has both natural and anthropogenic components. Students who have the bifurcated “either/or” stance in regard to this may struggle to understand climate science until this is resolved. In this research, Bono represents this standpoint. He initially voiced his skepticism of global warming based on his assumption that it had to be one or the other causes. Once he understood the nature of this false dichotomy, his views quickly evolved towards one more consistent with the scientific consensus.

Another finding that portends something not addressed in climate change literature is the notion of scale/proportion and its criticality to an effective understanding of climate change. That is, students must develop a more accurate understanding of scale in terms of both temporal and spatial scale in order to generate a robust understanding of climate change. Other literature has in fact noted the problematic aspects of students learning about deep time (Dodick, 2007). In other words, children whose reference frames are in single numbers of years can scarcely be expected to automatically understand concepts like evolution and climate change, whose required time often exceeds hundreds of thousands of years. In the case of climate change, it is important to grasp the temporal and the spatial scales accurately. In invoking the term “global warming”, there are some implied questions that are unanswered, including “warming over what time period?”, “warming over how much of the globe?” While climate scientists and science teachers may already understand the varying timescales over which this science is set, students likely do not. When they are asked “is the Earth warming?” they rightly are confused, as they could answer in different ways that would be simultaneously accurate. For example, a student asked this question at 9am in April (in the northern hemisphere) might answer “Yes, it’s
warming, as the sun is getting higher in the sky”, or “yes it’s warming, as it’s getting closer to summer”. That is, the student may be answering accurately, yet not invoking the appropriate scales of time or space, in that they’re focused on a daily temperature change or a seasonal change.

In addition to the issue of temporal scale, the student is focused on what is going in the location that he/she is in, as opposed to considering the Earth’s surface on average. Two of the students in this research, Beyonce, and Darko, were confused on this point. One concept that seemed to dovetail with the confusion over scale was their particular epistemological focus. The evidence they seemed to value, at least initially, was largely anecdotal. Both Beyonce and Darko invoked justifications such as “it’s a cold winter, so therefore there’s no warming”, or “it’s not warming everywhere,…” so the “global” part of global warming just does not make sense. It makes sense that a student privileging anecdotal data should have just such confusions about both temporal and spatial scale. The second notion of which may be particularly salient for poor and working-class students who have not traveled out of their areas, and so whose spatial reference frames are limited. It is instructive to note that of these two students, Beyonce showed signs of overcoming her limited focus on anecdotal information, later on indicating that scientific data in graphs may even trump anecdotal information.

One aspect of climate change education that stands out in this research is the blurred distinction between the terms global climate change and global warming. The student participants in this research were poor at making the distinction between the two concepts. In fact, some equated the two as exactly or essentially the same things, even at the end of the intervention (Shania). I have posed the distinction between the two, according to consensus science documents, as climate change being the larger, more inclusive category, which subsumes global warming as a category. That is, that global warming is one aspect of climate that may change. However, there are other potential changes in climate, which may include changes in precipitation amounts, changes in oceanic circulation patterns, and more. That, within the greater concept of global climate change, the notion of global warming really is meant to indicate that the temperature of the Earth’s surface is increasing, not in total, but as an average (IPCC, 2007). However, these distinctions are quite difficult for middle school students to effectively understand and communicate.
These research findings also support much of the extant literature on climate change education. In particular, my findings reinforce the notion that students have a difficult time understanding the greenhouse effect (Boyes, Stannistreet 1993; Shepardson et al., 2007). Given the centrality of the greenhouse effect in a robust understanding of the mechanism for anthropogenic warming, this difficulty is particularly vexing. Even the higher-performing students in this research either conflated the greenhouse effect with global warming (Bono, Shania) or else misconstrued a vital aspect of such greenhouse gases in terms of “heat rises” (Nigella). As noted above, the modeling lesson so integral to the present unit actually resulted in the students’ creation of inaccurate mechanisms. None of the five students involved in this research ended the intervention with a robust and accurate interpretation of the greenhouse effect, despite that most knew the role of CO$_2$ as a contributor to the effect.

Another aspect mentioned in the climate change education literature is the conflation of the ozone hole with climate change and global warming. Many authors have suggested this to be a problem (Boyes, et al, 1993). Meanwhile, other authors more recently found that this was not problematic in their research students (Shepardson, et al, 2007). In this study, only one student held that conflation (Shania), and she quickly let go of that particular misconception. It makes sense that some students may mention this, particularly if they have a mental model which equates to a “general environmental” model, including all things they perceive to pertain to the environment, not just climate change-specific issues. However, I argue that it makes sense that this misconception may be waning, as the ozone hole has recently been considered to be a problem which is in the process of being addressed, due to the banning of chlorofluorocarbons internationally in the Montreal protocol of 1987. Therefore, students now in K-12 classrooms may simply not have heard as much about ozone depletion in classes and the media as students in the past.

Additionally, this research also supports the notion that Shepardson et al. (2007) discuss regarding the mental models that K-12 students have of the environment. In a study spanning classrooms from higher elementary to high school levels, the researchers had students draw conceptual diagrams of their environmental models. They found that most students drew models in which humans were unconnected to the environment. That is, the environment was something that existed “out there” and unattached to humanity. These comprised models 1 and 2. However, they also found that some, particularly urban students, were more likely to invoke a
mental model of the environment which featured human interactions with the environment, particularly if there were negative effects of human interactions. I argue that this version, model 3, was salient for several students, particularly Shania, who explicitly recognized the aspect of humans polluting the environment, particularly concerning animals in the environment. Such student concern for animals underscores the potential utility in devising climate change curricula around charismatic megafauna such as polar bears.

**Implications for future research**

The present study implies many avenues of focus for both research and K-12 pedagogy. One fruitful avenue for further research would be to further investigate the extent to which students’ initial “general environment” models impact their understandings of climate change, with reference to how they develop models based on an emergent process of climate change. The process of epistemic scaffolding shows promise as a tool with which to examine conceptual change, by examining how students’ epistemic values grow in concert with their learning of science content such as climate change. Also, given the relative failure of these students to learn a robust model of the greenhouse effect, despite an explicit model devoted to this, future research may investigate the question of how to accelerate students’ learning of the mechanism of global warming. Also of interest would be more investigation exploring the possibilities of punctuated models of conceptual change. Given the ever-expanding nature of pressures upon K-12 teachers, the idea that relatively short time intervals can yield dramatic increases in understanding could be an exciting avenue for further research and potential pedagogical strategy.
APPENDIX A

FLORIDA NEXT GENERATION SUNSHINE STATE SCIENCE STANDARDS ADDRESSED IN THIS UNIT

At least 20 of these standards are applicable to GCC within secondary grades. Twelve of the standards are overtly related by content, either by direct reference to GCC, or by reference to critical ideas within Earth/Space science upon which any GCC lesson/unit must stand, and eight others by connections with the Nature of Science (NOS). Listed below are the particular benchmarks from these standards, along with the subject areas they are for, as well as the Big Ideas that they fall under. The content standards are:

SC.6.E.7.2 Benchmark Description: Investigate and apply how the cycling of water between the atmosphere and hydrosphere has an effect on weather patterns and climate. Subject Area: Science  Grade Level: 6  BODY OF KNOWLEDGE: Earth and Space Science  Big Idea: Earth Systems and Patterns - The scientific theory of the evolution of Earth states that changes in our planet are driven by the flow of energy and the cycling of matter through dynamic interactions among the atmosphere, hydrosphere, cryosphere, geosphere, and biosphere, and the resources used to sustain human civilization on Earth.

SC.6.E.7.6 Benchmark Description: Differentiate between weather and climate. Subject Area: Science  Grade Level: 6  BODY OF KNOWLEDGE: Earth and Space Science  Big Idea: Earth Systems and Patterns - The scientific theory of the evolution of Earth states that changes in our planet are driven by the flow of energy and the cycling of matter through dynamic interactions among the atmosphere, hydrosphere, cryosphere, geosphere, and biosphere, and the resources used to sustain human civilization on Earth.

C.6.E.7.3 Benchmark Description: Describe how global patterns such as the jet stream and ocean currents influence local weather in measurable terms such as temperature, air pressure, wind direction and speed, and humidity and precipitation. Subject Area: Science  Grade Level:
The scientific theory of the evolution of Earth states that changes in our planet are driven by the flow of energy and the cycling of matter through dynamic interactions among the atmosphere, hydrosphere, cryosphere, geosphere, and biosphere, and the resources used to sustain human civilization on Earth.

SC.6.E.7.5 Benchmark Description: Explain how energy provided by the sun influences global patterns of atmospheric movement and the temperature differences between air, water, and land. Subject Area: Science Grade Level: 6

SC.6.E.7.6 Benchmark Description: Differentiate between weather and climate. Subject Area: Science Grade Level: 6

SC.6.E.7.2 Benchmark Description: Investigate and apply how the cycling of water between the atmosphere and hydrosphere has an effect on weather patterns and climate. Subject Area: Science Grade Level: 6

SC.912.E.7.9 Benchmark Description: Cite evidence that the ocean has had a significant influence on climate change by absorbing, storing, and moving heat, carbon, and water. Subject
Area: Science   Grade Level: 912   BODY OF KNOWLEDGE: Earth and Space
Science   Standard: Earth Systems and Patterns - The scientific theory of the evolution of Earth
states that changes in our planet are driven by the flow of energy and the cycling of matter
through dynamic interactions among the atmosphere, hydrosphere, cryosphere, geosphere, and
biosphere, and the resources used to sustain human civilization on Earth.

SC.912.E.7.7 Benchmark Description: Identify, analyze, and relate the internal (Earth system)
and external (astronomical) conditions that contribute to global climate change. Subject Area:
Science   Grade Level: 912   BODY OF KNOWLEDGE: Earth and Space Science   Standard:
Earth Systems and Patterns - The scientific theory of the evolution of Earth states that changes in
our planet are driven by the flow of energy and the cycling of matter through dynamic
interactions among the atmosphere, hydrosphere, cryosphere, geosphere, and biosphere, and the
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our planet are driven by the flow of energy and the cycling of matter through dynamic
interactions among the atmosphere, hydrosphere, cryosphere, geosphere, and biosphere, and the
resources used to sustain human civilization on Earth.
SC.912.L.17.4 Benchmark Description: Describe changes in ecosystems resulting from seasonal variations, climate change and succession. Subject Area: Science  Grade Level: 9-12  BODY OF KNOWLEDGE: Life Science  Standard: Interdependence -

A. The distribution and abundance of organisms is determined by the interactions between organisms, and between organisms and the non-living environment.

B. energy and nutrients move within and between biotic and abiotic components of ecosystems via physical, chemical and biological processes.

C. Human activities and natural events can have profound effects on populations, biodiversity and ecosystem processes.

SC.912.L.17.8 Benchmark Description: Recognize the consequences of the losses of biodiversity due to catastrophic events, climate changes, human activity, and the introduction of invasive, non-native species. Subject Area: Science  Grade Level: 9-12

A. The distribution and abundance of organisms is determined by the interactions between organisms, and between organisms and the non-living environment.

B. energy and nutrients move within and between biotic and abiotic components of ecosystems via physical, chemical and biological processes.

C. Human activities and natural events can have profound effects on populations, biodiversity and ecosystem processes.

The science standards invoking critical aspects of the Nature of Science are:

SC.6.N.2.2 Benchmark Description: Explain that scientific knowledge is durable because it is open to changes as new evidence or interpretations are encountered. Subject Area: Science  Grade Level: 6  BODY OF KNOWLEDGE: Nature of Science  Big Idea: The Characteristics of Scientific Knowledge -
A: Scientific knowledge is based on empirical evidence, and is appropriate for understanding the natural world, but it provides only a limited understanding of the supernatural, aesthetic, or other ways of knowing, such as art, philosophy, or religion.

B: Scientific knowledge is durable and robust, but open to change.

C: Because science is based on empirical evidence it strives for objectivity, but as it is a human endeavor the processes, methods, and knowledge of science include subjectivity, as well as creativity and discovery.

SC.7.N.2.1 Benchmark Description: Identify an instance from the history of science in which scientific knowledge has changed when new evidence or new interpretations are encountered.

Subject Area: Science   Grade Level: 7   BODY OF KNOWLEDGE: Nature of Science   Big Idea: The Characteristics of Scientific Knowledge -

A: Scientific knowledge is based on empirical evidence, and is appropriate for understanding the natural world, but it provides only a limited understanding of the supernatural, aesthetic, or other ways of knowing, such as art, philosophy, or religion.

B: Scientific knowledge is durable and robust, but open to change.

C: Because science is based on empirical evidence it strives for objectivity, but as it is a human endeavor the processes, methods, and knowledge of science include subjectivity, as well as creativity and discovery.

SC.6.N.1.1 Benchmark Description: Define a problem from the sixth grade curriculum, use appropriate reference materials to support scientific understanding, plan and carry out scientific investigation of various types, such as systematic observations or experiments, identify variables, collect and organize data, interpret data in charts, tables, and graphics, analyze information, make predictions, and defend conclusions.   Subject Area: Science   Grade Level: 6   BODY OF KNOWLEDGE: Nature of Science   Big Idea: The Practice of Science -

A: Scientific inquiry is a multifaceted activity; The processes of science include the formulation of scientifically investigable questions, construction of investigations into
those questions, the collection of appropriate data, the evaluation of the meaning of those
data, and the communication of this evaluation.

B: The processes of science frequently do not correspond to the traditional portrayal of
"the scientific method ."

C: Scientific argumentation is a necessary part of scientific inquiry and plays an
important role in the generation and validation of scientific knowledge.

D: Scientific knowledge is based on observation and inference; it is important to
recognize that these are very different things. Not only does science require creativity in
its methods and processes, but also in its questions and explanations.

SC.6.N.1.4   Benchmark Description: Discuss, compare, and negotiate methods used, results
obtained, and explanations among groups of students conducting the same
investigation.   Subject Area: Science   Grade Level: 6   BODY OF KNOWLEDGE: Nature of
Science   Big Idea: The Practice of Science -

A: Scientific inquiry is a multifaceted activity; The processes of science include the
formulation of scientifically investigable questions, construction of investigations into
those questions, the collection of appropriate data, the evaluation of the meaning of those
data, and the communication of this evaluation.

B: The processes of science frequently do not correspond to the traditional portrayal of
"the scientific method ."

C: Scientific argumentation is a necessary part of scientific inquiry and plays an
important role in the generation and validation of scientific knowledge.

D: Scientific knowledge is based on observation and inference; it is important to
recognize that these are very different things. Not only does science require creativity in
its methods and processes, but also in its questions and explanations.
SC.6.N.1.5 Benchmark Description: Recognize that science involves creativity, not just in designing experiments, but also in creating explanations that fit evidence. Subject Area: Science   Grade Level: 6   BODY OF KNOWLEDGE: Nature of Science   Big Idea: The Practice of Science -

A: Scientific inquiry is a multifaceted activity; The processes of science include the formulation of scientifically investigable questions, construction of investigations into those questions, the collection of appropriate data, the evaluation of the meaning of those data, and the communication of this evaluation.

B: The processes of science frequently do not correspond to the traditional portrayal of "the scientific method ."

C: Scientific argumentation is a necessary part of scientific inquiry and plays an important role in the generation and validation of scientific knowledge.

D: Scientific knowledge is based on observation and inference; it is important to recognize that these are very different things. Not only does science require creativity in its methods and processes, but also in its questions and explanations.

SC.6.N.3.1   Benchmark Description: Recognize and explain that a scientific theory is a well-supported and widely accepted explanation of nature and is not simply a claim posed by an individual. Thus, the use of the term theory in science is very different than how it is used in everyday life. Subject Area: Science   Grade Level: 6   BODY OF KNOWLEDGE: Nature of Science   Big Idea: The Role of theories, laws, Date Adopted or Revised: 02/08   Date of Last Rating: 05/08   Cognitive Complexity: Moderate   - What does this mean? Status: State Board Approved

SC.6.N.2.1   Benchmark Description: Distinguish science from other activities involving thought. Subject Area: Science   Grade Level: 6   BODY OF KNOWLEDGE: Nature of Science   Big Idea: The Characteristics of Scientific Knowledge -
A: Scientific knowledge is based on empirical evidence, and is appropriate for understanding the natural world, but it provides only a limited understanding of the supernatural, aesthetic, or other ways of knowing, such as art, philosophy, or religion.

B: Scientific knowledge is durable and robust, but open to change.

C: Because science is based on empirical evidence it strives for objectivity, but as it is a human endeavor the processes, methods, and knowledge of science include subjectivity, as well as creativity and discovery.

SC.6.N.2.2 Benchmark Description: Explain that scientific knowledge is durable because it is open to change as new evidence or interpretations are encountered. Subject Area: Science Grade Level: 6 BODY OF KNOWLEDGE: Nature of Science Big Idea: The Characteristics of Scientific Knowledge -

A: Scientific knowledge is based on empirical evidence, and is appropriate for understanding the natural world, but it provides only a limited understanding of the supernatural, aesthetic, or other ways of knowing, such as art, philosophy, or religion.

B: Scientific knowledge is durable and robust, but open to change.

C: Because science is based on empirical evidence it strives for objectivity, but as it is a human endeavor the processes, methods, and knowledge of science include subjectivity, as well as creativity and discovery.
# APPENDIX B

## OVERVIEW OF INSTRUCTIONAL UNIT (USING ARGUMENT-DRIVEN INQUIRY ABOUT CLIMATE CHANGE)

<table>
<thead>
<tr>
<th>Step:</th>
<th>When/duration</th>
<th>Comments</th>
<th>For further details:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Pre-interviews</td>
<td>Week prior to start of unit (Feb); interview duration about 30 mins each.</td>
<td>With Purposefully selected sample (maximum diversity of ability levels, views, backgrounds)</td>
<td>See interview probe, Appendix C</td>
</tr>
<tr>
<td>2: Pre-Assessment</td>
<td>Day prior to start of unit. Assessment should take 1 class period</td>
<td>Includes all students in class who submitted assent &amp; consent forms.</td>
<td>See assessment, Appendix D.</td>
</tr>
<tr>
<td>4. Historical Climate Data:</td>
<td>2 days:</td>
<td>Present Students with photos and graph data showing:</td>
<td>See Appendix F</td>
</tr>
<tr>
<td>5. Causal Mechanisms of Climate Change</td>
<td>3 days: Does the evidence support either a CO$_2$ or a sunspot causal phenomenon?</td>
<td>Show students different forms of data, including the Keeling curve (CO$_2$ versus time) and sunspot activity over time. Which mechanism is better supported by data? Whiteboard session as well. Homework assignment to create an explanation which best fits data.</td>
<td>See Appendix G for specific data given to students.</td>
</tr>
<tr>
<td>6. Post-Assessment</td>
<td>1 day</td>
<td>Similar assessment task as pre-assessment. (extension activity makes it different)</td>
<td>See Appendix D</td>
</tr>
</tbody>
</table>
1. What can you tell me about current climate patterns around the world?

2. Some scientists talk about a phenomenon called Climate Change. Do you know anything about that? What is their evidence for this phenomenon?? How do they explain this phenomena? How do you?

3. When scientists discuss climate change, how valid a scientific explanation do you think this is? What makes the explanation valid? Invalid?

4. What is the most powerful evidence supporting or negating scientific explanations of climate change?

5. What are the most important sources for you to understand about patterns in Global climate and their change?

6. Have you ever heard of the Greenhouse Effect? (Explain) What does it mean?

7. When it comes to a scientific issue, where do you get your information? Why do you trust these sources? What makes a source of scientific information trustworthy?

8. Do you think it is important to understand scientific evidence for issues like Climate Change? Why/why not?

9. Take a look at this graph. What do you think this graph shows? (Any trends?) [ask for time-temp graphs]
10. Is there anything else you’d like to add that I did not ask you about?
APPENDIX D

ASSESSMENT TASK
Name: __________________________  Date: __________ Class Period:_____

Global Climate Change Argumentation Assessment:

Part A: Earth’s Climate Change

Reference Section
This section contains data that may help you to answer the questions about the Earth’s Climate Change.

Climate: Definition ~average temperatures of Earth’s surface

The greenhouse effect is seen when the Earth’s atmosphere traps some of the Sun’s heat in. Much of the Sun's energy is radiated away by the Earth’s surface. If not for certain gases in the atmosphere, such as CO₂ and water vapor, which trap solar energy in the atmosphere, then the Earth’s surface would be much colder than it is. We call these gases greenhouse gases.

The Earth’s atmosphere contains many gases. The chart below shows the four most common, in order:

<table>
<thead>
<tr>
<th>Gas</th>
<th>What percent of <del>air</del> the gas is:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>78%</td>
</tr>
<tr>
<td>Oxygen</td>
<td>21%</td>
</tr>
<tr>
<td>CO₂</td>
<td>.25%</td>
</tr>
<tr>
<td>Other <del>trace</del> gases (Argon, H₂O vapor, etc)</td>
<td>.75% combined</td>
</tr>
</tbody>
</table>

The Industrial Revolution is a period of time beginning around the start of the 1800’s, extending into modern times. This was a major turning point in the history of humankind, characterized by the development of industrialization. While industrial expansion helped improve lives in many ways, the increase in factories also led to more pollutants being released into the atmosphere. An important pollutant is Carbon Dioxide(CO₂), a greenhouse gas.

In 1955, a scientist named Charles Keeling went around the world taking atmospheric measurements of a gas called CO₂. Every year from then on, he took more measurements. Here is a graph showing the results:
A glacier is a river made of ice. These 4 photos were taken of two different glaciers from nearly the same position, at different periods of time.
These photos are taken, in 1979 and in 2003, of the North Pole from a satellite.

**Ice cores.** Scientists sometimes drill into large ice sheets to get ice cores (see photo). When they do this, they get access to air that is up to 600,000 years old. They can then analyze the bubbles of air trapped within the ice to see what the atmosphere was like long ago.
Graph showing connection between Temperature and CO₂ levels for last 350,000 years. 

Temp Data & Ice Ages Connection
Galileo was one of the first scientists to discover sunspots. Sunspots are dark spots that appear on the sun’s surface. They reoccur in cycles of about 11 years. Some scientists have said that sunspots, not human-caused CO$_2$, have caused the recent warming of the Earth. The graph below shows sunspot data since 1885. Sunspot activity is shown by the red line, with the Earth’s surface temperature indicated by the blue line.

**Questions Section about Earth’s Climate Change:**

1. What do you think the temperature average would most likely be, in 2020 in Earth? ______________

2. What data do you think supports your answer? ______________
3. How exactly do the data you mention lend support to your answer?
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

4. If the climate of the earth is changing, what do you think is the major cause of climate change on the Earth? Please explain, citing as much data as possible. (Be sure to indicate whether or not the climate change is cooling or warming).
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

6. Do the sunspot data indicate that the sunspots may be causing the temperature changes? What is the evidence to support your answer?
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Please answer the following questions. Indicate either SA, A, U, D, or SD:

<table>
<thead>
<tr>
<th>Statement</th>
<th>SA</th>
<th>A</th>
<th>U</th>
<th>D</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(strongly disagree)</td>
<td>(disagree)</td>
<td>(unsure)</td>
<td>(agree)</td>
<td>(strongly agree)</td>
</tr>
</tbody>
</table>

11. There is an intense date among scientists regarding whether global climate change is really occurring.

12. Recent global climate change is due, at least in part, to human activities (i.e. the consumption of fossil fuels, deforestation, etc.).

13. Recent global climate change is due only to natural climate fluctuations that have occurred on the earth.

14. Global warming is caused primarily by changes in solar radiation.

15. The earth’s climate has warmed and cooled for millions of years, since long before humans appeared on the scene.

16. There’s very little doubt that increases in the atmospheric concentration of carbon dioxide and other greenhouse gases strengthens the natural greenhouse effect and contributes to global warming.
17. At the present time, the levels of CO$_2$ in the atmosphere appear to be higher than they have been in the last 100,000+ years.
APPENDIX E

LESSON: THE GREENHOUSE EFFECT

Question: Does the temperature change faster in a 2 liter bottle wrapped in saran wrap than a bottle without the wrap? Why/why not?


Materials Needed:

<table>
<thead>
<tr>
<th>What</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Liter Bottles</td>
<td>2 per group</td>
</tr>
<tr>
<td>Scissors</td>
<td>Several pairs per class</td>
</tr>
<tr>
<td>Light bulbs</td>
<td>1 per group</td>
</tr>
<tr>
<td>Saran Wrap</td>
<td>1 box per class</td>
</tr>
<tr>
<td>Soil</td>
<td>1 small bucket per class</td>
</tr>
<tr>
<td>100 mL graduated cylinders</td>
<td>1 per group</td>
</tr>
<tr>
<td>White boards</td>
<td>1 per group</td>
</tr>
<tr>
<td>Dry erase markers</td>
<td>1 per group</td>
</tr>
<tr>
<td>Rubber bands</td>
<td>Several per group</td>
</tr>
<tr>
<td>Thermometers</td>
<td>2 per group</td>
</tr>
</tbody>
</table>

[Invoke GEMS lesson’s built-in questions to prompt discussion (quoted from Hocking, Sneider, Erickson, and Golden (1990, pg 20):

1. Point out that the atmosphere is a large and complex system, so experiments and measurements concerning it are difficult to perform.
2. As the class to suggest experiments or ways of measuring the average temperature of the Earth’s atmosphere. [Averaging lots of temperature measurements; finding places with long histories of records; analyzing data from isolated places, such as islands, which are less affected by other changes that can affect the climate.]

3. Ask what difficulties scientists might have in determining whether or not the average temperature of the Earth is heating up. [It’s difficult to: find long-term historical data; regularly measure the temperature at sea and at the polar ice caps; distinguish long-term changes in average temperature from short-term variations; take into account differences in temperature between seasons and between places; and find locations that are unaffected by local factors, such as urban development and deforestation]

4. Remind students that the greenhouse effect and global warming are new areas of study, and scientists do not have all the answers, partly because of the difficulties the class has just discussed.

5. If your students have not already done so, point out that one way to test theories about climate change is to build a model of the atmosphere, and to experiment with the model. That what the class will be doing in this session.

6. Explain that before they build their models, they need to have a clear idea of what the atmosphere is like.

7. Tell class they are going to make a model of the atmosphere, and explore what happens when light shines on it.

8. Assemble students into groups of 3-4. Ask “what is going to model the sun?” (light bulb);

9. Demonstrate the set-up of the thermometer inside the 2 liter bottle with soil;

10. Explain that one of the bottles will be the control.

11. Pass out equipment.

12. Ask students if all the thermometers should read the same at the beginning.
13. Have students start the experiment when all are ready.

14. Tell students to collect thermometer data in a chart. The teacher will call out every minute to collect a reading.

15. When done, they are to use the chart data to make a time-temperature graph, with time on the X axis.

16. When done graphing, ask class to summarize what happened between the control and experimental bottles.

17. Use these questions to help the discussion:
   a. Why did the temperature in each bottle go up?

   b. Why did the temperature in both bottles level off?

   c. Why did the temperature of the closed bottles level off at a higher temperature than the open bottles?

   d. How did the equipment used in this experiment correspond to the real earth?

   e. What things were different between this experiment and the real world?

Conclude by explaining that scientists think something is trapping heat in the Earth's atmosphere, causing the temperature to go up. However, it is not a solid barrier like plastic.

*Why GEMS? GEMS is a set of curricula designed from the outset as a means to address the efforts of the National Reform documents (AAAS, 1993; NSES, 1996) within a framework incorporating pedagogies based on a learning cycle model (Sneider, 1997). Also, there is a body of literature extant which confirms the educational efficacy of GEMS (Sneider and Pulos, 1983; Eratuuli and Sneider, 1990; Sneider, et al., 1984).
Purposes of Greenhouse effect activity:

To allow all students to develop baseline understanding of greenhouse effect & warming effect it has on Earth;

To allow all students to develop some understanding of graphs, especially those involving time and temperature;

To allow all students to become acquainted with talking together and developing scientific explanations in groups.
Questions: Is the Earth presently cooling or warming? What have the historical patterns of climate change on Earth been?


<table>
<thead>
<tr>
<th>Materials Needed</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Sheets</td>
<td>1 per group</td>
</tr>
<tr>
<td>White boards</td>
<td>1 per group</td>
</tr>
<tr>
<td>Dry Erase Markers</td>
<td>1 per group</td>
</tr>
</tbody>
</table>

Look at the photographs of the glaciers and of the polar ice:

![Columbia Glacier c. 1980](image1)
![Columbia Glacier 2005](image2)
![Arapaho Glacier 1898](image3)
![Arapaho Glacier 2003](image4)
A glacier is a river made of ice. These 4 photos were taken of two different glaciers from nearly the same position, at different periods of time.

These photos are taken, in 1979 and in 2003, of the North Pole from a satellite.

What patterns, if any, do you notice?

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Look at the time-temperature graphs below.
Photo of an Ice Core

Graph showing connection between Temperature and CO$_2$ levels for last 350,000 years. These data were taken from an ice core in Antarctica. Scientists drill deeply into the ice, then take the resulting cores and analyze the air that is trapped within. This is how they understand what gases were present in an ancient atmosphere. 

What trends do you notice in the graphs?
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

Do the two graphs agree with each other?(please explain, using data)
______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

In your groups, use your white board to create an explanation for the information given in the graphs and in the photos. In your explanation, use as much data as possible.

Use the following format for your evidence-based explanation:

<table>
<thead>
<tr>
<th>Group members</th>
<th>Goal of investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(What were you trying to do?)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Your explanation</th>
<th>Your evidence and Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>(How do you explain the phenomenon under investigation?)</td>
<td>(how can you be sure?)</td>
</tr>
</tbody>
</table>
APPENDIX G

CAUSES OF CLIMATE CHANGE LESSON

**Question:** Can we analyze data to detect a possible cause for the current patterns in the earth’s climate?


<table>
<thead>
<tr>
<th>Materials Needed</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Sheets</td>
<td>1 per student</td>
</tr>
<tr>
<td>White boards</td>
<td>1 per group</td>
</tr>
<tr>
<td>Dry Erase Markers</td>
<td>1 per group</td>
</tr>
</tbody>
</table>

Now that we understand something about historical and current climate change, let’s examine some data that may help us understand what some possible causes are. The graphs below give some information that may help to understand these causes.

![Graph: Global Fossil Fuel Carbon Dioxide Emissions 1880-2004](image)

- Coal
- Oil
- Natural Gas
- Total
Graph showing connection between Temperature and CO₂ levels for last 350,000 years. 

Temp Data & Ice Ages Connection

Photo of Sunspots
Galileo was one of the first scientists to discover sunspots. Sunspots are dark spots that appear on the sun’s surface. They reoccur in cycles of about 11 years. Some scientists have said that sunspots, not human-caused CO₂, have caused the recent warming of the Earth. The graph below shows sunspot data since 1885. Sunspot activity is shown by the red line, with the Earth’s surface temperature indicated by the blue line.

After analyzing the information above, construct an explanation (as a group) on your white board, that answers the following question:

What is the most likely cause of the current global climate change?

In your answer, make sure that you explain, using evidence, why you say so. You must indicate why each piece of evidence agrees with your explanation. Please also note where, exactly, any information presented does not agree with your explanation.

Again, please use the following format for your whiteboards:

<table>
<thead>
<tr>
<th>Group members</th>
<th>Goal of investigation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(What were you trying to do?)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Your explanation</th>
<th>Your evidence and Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>(How do you explain the phenomenon)</td>
<td>(how can you be sure?)</td>
</tr>
</tbody>
</table>
Once you have completed your whiteboard explanation, visit other groups and discuss their explanations with them. When done, complete the homework assignment:

Homework assignment: After consulting with other groups, you have had an opportunity to examine how many others have interpreted the data. Now, write your own explanation of what the current trend in climate change is, and what the likely cause is. As always, invoke as much data as possible in your response. You may turn this in tomorrow, on regular paper.
APPENDIX H: HUMAN SUBJECTS COMMITTEE APPROVAL MEMORANDUM

Office of the Vice President For Research
Human Subjects Committee
Tallahassee, Florida 32306-2742
(850) 644-8673, FAX (850) 644-4392

APPROVAL MEMORANDUM

Date: 2/23/2010

To: Barry Golden

Address: [Redacted]

Dept.: SCIENCE EDUCATION

From: Thomas L. Jacobson, Chair

Re: Use of Human Subjects in Research
Student Conceptual Change concerning Global Climate Change

The application that you submitted to this office in regard to the use of human subjects in the research proposal referenced above has been reviewed by the Human Subjects Committee at its meeting on 02/10/2010. Your project was approved by the Committee.

The Human Subjects Committee has not evaluated your proposal for scientific merit, except to weigh the risk to the human participants and the aspects of the proposal related to potential risk and benefit. This approval does not replace any departmental or other approvals, which may be required.

If you submitted a proposed consent form with your application, the approved stamped consent form is attached to this approval notice. Only the stamped version of the consent form may be used in recruiting research subjects.

If the project has not been completed by 2/9/2011 you must request a renewal of approval for continuation of the project. As a courtesy, a renewal notice will be sent to you prior to your expiration date; however, it is your responsibility as the Principal Investigator to timely request renewal of your approval from the Committee.

You are advised that any change in protocol for this project must be reviewed and approved by the Committee prior to implementation of the proposed change in the protocol. A protocol change/amendment form is required to be submitted for approval by the Committee. In addition,
federal regulations require that the Principal Investigator promptly report, in writing any unanticipated problems or adverse events involving risks to research subjects or others.

By copy of this memorandum, the Chair of your department and/or your major professor is reminded that he/she is responsible for being informed concerning research projects involving human subjects in the department, and should review protocols as often as needed to insure that the project is being conducted in compliance with our institution and with DHHS regulations.

This institution has an Assurance on file with the Office for Human Research Protection. The Assurance Number is IRB00000446.

Cc: Sherry Southerland, Advisor [ssoutherland@fsu.edu]
HSC No. 2010.3982
Dear Parent(s),

Your child’s teacher is participating in a research project designed to help teachers provide more effective science instruction so we are asking all of the students in your child’s class to participate. Understanding how children make sense of complex scientific topics as global warming is an increasingly important issue. We are conducting research which aims to learn more about how children develop such understandings. As a part of this, we have designed a research program which will attempt to make use of scientific argumentation in order to effect student learning in this area. Here is what will happen during this research:

We will visit your child’s classroom during the fall semester in order to make some observations. Near the end of the semester, we will begin observing every day during the (approximately) 2 week unit on global warming/climate change. Prior to the beginning of this unit, we will select several students with which to conduct periodic interviews. These interviews are aimed at trying to understand what the child is thinking at that point in time. Also, during the argumentation-based lessons, the students will be grouped. Each group during this phase will be filmed. This is for the purpose of making detailed transcripts later on, so that we may come to understand how students interacted, and how these interactions led to the final product of the group: a well-argued scientific explanation of the phenomenon of global warming.

Your participation, as well as, that of your child in this study is voluntary. You and your child have the right to withdraw from the study at any time without consequences.

If you have any questions now or in the future, please contact me at Florida State University at (or by email, Should you have questions regarding your rights as a participant in research, please contact the Behavioral Sciences Institutional Review Board, (850) 644-8633.

All information obtained during the course of this study will remain confidential to the extent allowed by law. The participants’ name or school’s name will not be associated in any way with the data gathered or the findings of the research. The results or findings will be used for the purpose of this study only. If the results are published, the participants’ name or school’s name will not be used. Once the study is completed, all documents and/or data will be destroyed.

Researcher Signature                     Date

I GIVE consent for my child (print child’s name here) to participate in the above study.

________________________________________________________
Signature of child’s parent or guardian / Date

I DO NOT GIVE consent for my child (print child’s name here)

to participate in the above study.

________________________________________________________
Signature of child’s parent or guardian / Date
APPENDIX J: STUDENT ASSENT FORM

Investigator: Barry W. Golden.

Why are we doing this research?

In order to learn how to best teach students about complex scientific topics.

What will happen in the research?

In this research you will discuss and learn about global warming. You may be videotaped during the lesson, and interviewed later on.

What are the good things that can happen from this research?

This research will help us understand how students can learn best about global warming.

What are the bad things that can happen from this research?

There are no risks associated with this research. Any information that we collect in the classroom will be locked up. Your name will never be used.

What else should you know about the research?

Being in the research is your choice. You can say yes or no. If you say Yes and change your mind later that is OK. You can stop being in the research at any time. If you want to stop, please tell the research investigator.

Take the time you need to make your choice. Ask us any questions you have. You can ask questions any time.

Child’s Statement

The researchers have told me about the research. I had a chance to ask questions. I know I can ask questions any time. I want to be in the research.

Signature of child____________________________________ Date__________________
REFERENCES


American Association for the Advancement of Science. (2007). *Communicating and learning about climate change: an abbreviated guide for teaching Climate Change*. AAAS publications


Golden, B. W. (2009). *Emphasis given to climate change in state science standards: Are states warming up to the science?* Poster to be presented at the annual meeting of the National Association for Research in Science Teaching (NARST), Culver City, CA.


BIOGRAPHICAL SKETCH

Barry W. Golden is currently the project manager for an NSF-funded research project which examines the effects of RET programs on science teachers’ notions and practices of inquiry-based science teaching. Prior to that, he taught various science courses at Maclay School in Tallahassee, Florida. He received his Master’s degree in Science Education from Florida State University in 2000, and his B.S. degree in Psychology from FSU in 1993.

Barry decided to make a career change in the mid to late 90’s, after what he deemed an “existential crisis”. In a move to find an occupation which would fill his need to contribute to society, he entered Florida State University to pursue teacher licensure, along with a Master’s in Science Education. After teaching for nine years, he decided to re-enter graduate school to pursue a PhD in Science Education. With this degree, and his new position as an assistant professor at the University of Tennessee, he hope to contribute to the field of science education both through the excellent preparation of teachers and through the creation of new understandings of teaching and learning.

Barry has been married to Shari Buckingham since 1999. Shari is a Court Operations Consultant for the State Supreme Court of Florida.