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Students' Conceptions about Climate Change: Using Critical Evaluation to Influence Plausibility Reappraisals and Knowledge Reconstruction

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STUDENTS' CONCEPTIONS ABOUT CLIMATE CHANGE: USING CRITICAL
EVALUATION TO INFLUENCE PLAUSIBILITY REAPPRAISALS AND
KNOWLEDGE RECONSTRUCTION

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ABSTRACT

Students' Conceptions about Climate Change: Using Critical Evaluation to Influence Plausibility Reappraisals and Knowledge Reconstruction

by

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The Intergovernmental Panel on Climate Change (2007) reported a greater than 90% chance that human activities are responsible for global temperature increases over the last 50 years, as well as other climatic changes. The scientific report also states that alternative explanations (e.g., increasing energy received from the Sun) are less plausible than human-induced climate change. These climate scientists have made their plausibility judgment—which I define as the relative potential truthfulness of alternative explanations—based on the evaluation and coordination of multiple lines evidence with competing theoretical perspectives.

Climate change is a highly relevant and gravely serious topic; in an educational setting, climate change also presents an opportunity for students to learn about fundamental scientific principles and how scientists construct knowledge. However, students may be neither naturally evaluative when learning about controversial topics, such as climate change, nor reflective while engaging in judgments about knowledge and knowing (King & Kitchener, 2004), such as plausibility judgments. The purpose of this

study was to examine how plausibility judgments and knowledge about human-induced climate change transform during instruction that promotes critical evaluation abilities.

An instructional scaffold—called a model evidence link (MEL) diagram— was used in this study. The MEL allowed students to weigh the strength of connections between two alternative models of climate change (i.e., the scientifically accepted model of human-induced climate change and a popular skeptics’ model that climate change is caused by increases in the Sun’s energy). The results revealed that treatment group participants who used the MEL diagram experienced a significant shift in their plausibility judgments toward the scientifically accepted model. This shift was accompanied by significantly greater postinstructional knowledge of human-induced climate change, with treatment group participants demonstrating reconstruction of knowledge about the causes of climate change to be more consistent with scientific understanding. Moderate to large effect sizes characterized these changes in treatment group participants’ plausibility perceptions and understanding. A comparison group of students who experienced a climate change activity that is part of their normal curriculum did not experience statistically significant changes.

The results from this dissertation study, along with previous studies that I and my colleagues have conducted (see, for example, Lombardi & Sinatra, 2012), helped to inform the development of a model on the role of the plausibility judgment in conceptual change. This model has the potential to guide further research that will help educators better understand the mechanisms in conceptual change and guide instructional practices to promote knowledge reconstruction on scientific topics of great societal importance, such as climate change.

DEDICATION AND ACKNOWLEDGEMENTS

This dissertation is dedicated to Janelle Bailey, without whom this study would not have been possible. Janelle is an accomplished science education researcher and her insights have been critical to the ideas that I present in this dissertation. She is also a fabulous writer and has read and re-read this manuscript to ensure clarity, consistency, coherency, and quality. Most importantly, Janelle has been my dedicated companion on this journey, providing me strength during periods of personal weakness and believing in me when no one else did. Her good humor, patience, and love have been my guiding star.

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CHAPTER 1

INTRODUCTION

The scientific process is a mystery to many individuals. Misconceptions persist about how scientists construct knowledge, as well as the actual knowledge scientists have constructed, despite the widespread presence of both topics in elementary and secondary curricula. Many individuals tend to view science as an objective body of knowledge that is independent of theory. However, science is quintessentially a socio-cognitive, collaborative process. Communities of scientists create questions and analyze data about observed phenomena to construct knowledge that they deem reliable and valid. Furthermore, these communities evaluate their constructed knowledge to gauge the quality of observed and analyzed data (von Glaserfeld, 2001). It is through evaluation that some scientific knowledge gains greater status, to the point of being considered a broadly accepted theoretical framework to guide further theorizing and research (e.g., the Second Law of Thermodynamics; T. Kuhn, 1962). The process of evaluation may render some scientific knowledge false, particularly as individuals collect and analyze new data. Constructed scientific belief structures (e.g., hypotheses, theories) must adhere to a falsifiability criterion, where evaluations of incoming evidence may invalidate these structures (Popper, 1963; Stanovich, 2007). Whereas, individual scientists might not adhere to the falsifiability criterion, the scientific community will ultimately eliminate a scientific knowledge construction when its evidentiary failures are satisfactorily explained by a rival construction (Lakatos, 1970).

Researchers have extensively documented the existence and persistence of students' misconceptions (see, for example, Chi, 2005; Posner, Strike, Hewson, &

Gertzog, 1982; Vosniadou & Brewer, 1992). Recently, Sinatra and Chinn (2011) have argued that in order to improve understanding of science, students need to reconstruct both their conceptual understanding and epistemic cognitive processes. The former (reconstruction of conceptual understanding) is a theoretical perspective commonly referred to as conceptual change (Dole & Sinatra, 1998). The latter (reconstruction of epistemic cognitive processes) is called epistemic conceptual change (Sinatra & Chinn, 2011). Kitchener (1983) defines epistemic cognition as the cognitive processes involved in making judgments about knowledge and knowing. Therefore, epistemic conceptual change involves transformation of students' epistemic cognition from less-sophisticated "prereflective" thinking (i.e., scientific knowledge is absolute and accumulated solely through observation and experimentation) to more sophisticated "quasi-reflective" thinking (scientific knowledge is uncertain and subjective, and one theory may be as valid as another), and ultimately to "reflective" thinking (scientific knowledge is constructed via evaluation of evidence obtained through scientific inquiry) (King & Kitchener, 2004). Essential to the development of more sophisticated epistemic cognition are the thinking processes that provide an understanding of how various knowledge domains are justified and the use of that understanding in reasoning and problem solving (Green, Azevedo, & Torney-Purta, 2008). In other words, an important component of epistemic conceptual change is for students to become more critically evaluative of knowledge sources.

Students' critical evaluation of their knowledge may also be an important component of conceptual change. Ohlsson (2009) has proposed that individuals engage in a process of competitive evaluation between two alternative conceptions to undergo

knowledge reconstruction. For conceptual change to occur, students must gauge the scientifically accurate conception with their experience and background knowledge, which are often at odds. Under such a scenario, the two countering conceptions may cause cognitive conflict and individuals implicitly evaluate the usefulness of each competing knowledge structure. Ohlsson calls this usefulness “cognitive utility,” which relates the value of a knowledge structure or conception to how well it supports efficient cognitive processing (i.e., “low cognitive load, fast task completion, and high goal satisfaction”; Ohlsson, 2009, p. 29). Individuals may employ inferences in the process of evaluating the cognitive utility of competing concepts. These inferences are often abductive in nature, where individuals select the explanation deemed as the most plausible from a group of alternatives. Thus, as postulated by many researchers, students’ plausibility judgments appear to be an integral component of conceptual change (see, for example, Chi, 2005; diSessa, 1993; Dole & Sinatra, 1998; Posner et al., 1982). Furthermore, higher quality plausibility judgments may be dynamically linked to critical evaluation, and therefore, facilitate epistemic conceptual change (i.e., shifting from thinking processes associated with knowledge subjectivity to evaluative processes of knowledge construction based on evidence).

Working Definition of Plausibility in Conceptual Change

This dissertation study focuses on conceptual change learning. As a working definition for this study on conceptual change, plausibility is a judgment on the *relative potential truthfulness* of incoming information compared to our existing mental representations. This definition is based on Nicholas Rescher’s (1976) theory of plausible reasoning, where Rescher argues that “the ‘acceptance’ of a proposition as a potential

truth is not actual *acceptance* of it at all, but a highly provisional and conditional epistemic inclination towards it, an inclination that falls far short of outright commitment” (Rescher, 1976, p. 9, emphasis in original). Rescher is a prolific American philosopher of science who has developed his ideas of pragmatic idealism based on the philosophical tradition of Gottfried Leibniz and Immanuel Kant, specifically that science validates “a plausible commitment to the actual existence of its theoretical entities” (Marsonet, 2009, Para. 3). Using Rescher’s plausible reasoning theory as a guide and incorporating an educational perspective of constructivism, this definition of plausibility reflects a pragmatic constructivist philosophy (Bickard, 1997; Dewey, 1922).

Plausibility judgments can be a subcategory of epistemic judgments when they are comparative and qualitative about knowledge. Plausibility judgments do not rely on absolute definitions of and distinctions between knowledge and belief. In the broader category of an epistemic judgment, a belief is based on some kind of information that an individual connects to that belief (Kalderon, 2009). For example, a person may believe that climate is changing because she has experienced an unusually warm summer. Without a situation of cognitive dissonance or evaluating competing explanations, she may consider her belief to be true and greatly plausible. She has moved outside of the tentative and comparative nature of the plausibility judgment because she has decided that her belief is true knowledge. Therefore, she has made an epistemic judgment, but not a plausibility judgment.

An individual’s epistemic stance on knowledge and belief probably influences her plausibility judgments, but she makes these judgments within whatever epistemic perspective she currently has. For example, if an individual thinks an objective reality

exists and that people acquire knowledge from this objective reality, then she probably makes her plausibility judgments accordingly. On the other hand, if she views knowledge as a social construction, she probably makes her plausibility judgments through this lens. Epistemic perspectives, however, can potentially change through critical evaluation, or what Rescher (1976) calls “retrospective reappraisal of the standards of datahood and plausibility” (p. 118). Evolution of an epistemic stance may result in changes to an individual’s process of making plausibility judgments. Most importantly, if an individual transitions to a stance where critical evaluation (i.e., analyzing how evidentiary data support a hypothesis and its alternatives) informs her plausibility judgments, the individual elevates what her “truth” means to a more analytical level.

Purpose and Overview of the Study

Problems facing our society require a citizenry that can critically evaluate incoming information and make reasoned decisions about the plausibility of this information. For example, with global climate change issues, individuals are exposed to statements from both scientific experts and novice but vocal pundits, and may not understand the basic differences between the qualities of their two opposing arguments (Lombardi & Sinatra, 2012). Therefore, as educational researchers, we must explore effective methods to engender changes in students’ epistemic cognition to be more critically evaluative of hypotheses and theories in order to increase their plausibility perceptions of scientific claims. In this way, we may be able to assist teachers in bringing their students to the most advanced state of reflective judgment, where “conclusions are defended as representing the most complete, plausible, or compelling understanding of an issue on the basis of available evidence” (King & Kitchener, 2004, p. 7).

The purpose of this dissertation study was to examine how plausibility perceptions and knowledge about human-induced climate change transform during instruction that potentially promotes critical evaluation abilities. In examining the relationship between critical evaluation, plausibility perceptions, and knowledge restructuring, this study also investigated epistemic conceptual change, a process that is critical for promoting greater understanding of science and abilities to engage in scientific reasoning.

Research Questions and Hypotheses

The following research questions and hypotheses guided this dissertation study in accomplishing its purpose.

1. Does explicit instruction designed to promote evaluation of competing climate change theories—specifically, human-induced climate change (i.e., the scientifically accurate model; Intergovernmental Panel on Climate Change, 2007) versus an increasing amount of solar energy received by Earth (i.e., a popular model used by skeptics of human-induced climate change; Cook, 2010; Ellis, 2009)—result in changes to:
 - a. plausibility perceptions of climate change,
 - b. knowledge of human-induced climate change, as well a basic understanding of the distinctions between weather and climate, and
 - c. beliefs about climate change evidence?
2. What is the relationship between students' comparative plausibility perceptions of competing climate change theories (human-induced climate change versus

increasing solar irradiance) and their perceptions about which of these theories they think is correct, and how does this relationship change with instruction?

3. Are model plausibility ratings of these two competing climate change theories related to the seven responses theorized by Chinn and Brewer (1993) as ordered categories (i.e., very low plausibility is associated with ignoring and rejecting data and high plausibility is associated with individual theory change)?

In response to the first research question, I hypothesize that explicit instruction promoting evaluation of the two climate change models will result in both greater critical evaluation abilities (H_{1A}) and increased plausibility perceptions about climate change (H_{1B}). I also hypothesize that these increases in plausibility perceptions will result in a greater degree of conceptual change about human-induced climate change, weather and climate distinctions, and beliefs about climate change evidence. (H_{1C}).

As for the second research question, I hypothesize that even though students may consider competing climate change theories to be plausible, the one with the greater plausibility will correspond to the theory that students think is correct (H_{2A}). I further hypothesize that students who use the instructional scaffold will rank the plausibility of the scientifically accepted conception (human-induced climate change) higher than the alternative conception (increasing solar irradiance) (H_{2B}).

My hypothesis for the third research question is that that there will be a discernible relationship between model plausibility ratings and response to anomalous incoming information (H_3). For example, students who rate human-induced climate change as implausible will reject or ignore evidence related to this scientifically accurate model and students who rate human-induced climate change at a relatively high

plausibility level will demonstrate a greater degree of conceptual change about climate change.

Methods

This study used a quasi-experimental design to analyze the research hypotheses. One hundred sixty-nine grade 7 students served as participants. In the school district where the study was conducted, the curriculum first exposes students to climate concepts in grade 7. As a quasi-experimental design, the study included a treatment group and a comparison group, with 7 classes randomly assigned to the treatment and 7 classes randomly assigned to the control. Treatment group participants experienced an instructional scaffold designed to help them evaluate competing climate change theories. Comparison group participants engaged in an activity from their normal curriculum, which involves analysis of climate change evidence and prediction of future climate change. Participants completed instruments measuring plausibility perceptions of climate change, knowledge of human-induced climate change and weather and climate distinctions, beliefs about climate change evidence, and perceptions of model plausibility and correctness prior to and just after instructional activities.

Results

The results indicated that treatment group participants experienced a significant shift in their perceptions of model plausibility and correctness towards the scientifically accepted model of human-induced climate change. The treatment group participants also demonstrated significantly greater understanding of human-induced climate change at postinstruction, and also, conceptual change about the climate change causes. Moderate to large effect sizes showed that these treatment group transformations were also of

practical significance. Comparison group participants did not reveal any significant changes in model plausibility and correctness perceptions or understanding about human-induced climate change.

Both treatment and comparison participants experienced a significant change in overall perceptions about the plausibility of climate change. These overall perceptions encompass not only plausibility of human-induced climate change, but also plausibility perceptions about evidence for current climate change. The study was inconclusive in changes in understanding about weather and climate distinctions and beliefs about climate change evidence because scores on these measures lacked reliability. The results were also inconclusive about associations between model plausibility perceptions and psychological responses to anomalous data. However, treatment group participants did show a significant association between their level of critical evaluation and model plausibility ratings, specifically when evidence contradicted a model claim.

Organization

In this chapter (Chapter 1), I have provided a brief overview of this dissertation study. In Chapter 2, I present a review of the literature that has informed the development of a theoretical model of plausibility in conceptual change and perspectives from the literature which provide the justification for this study's purpose. The methodology for the dissertation study is presented in Chapter 3. I discuss the results and analyses in Chapter 4, and finally, I conclude the dissertation with an overall discussion of this dissertation study, including limitations, modification to my theoretical model on plausibility perceptions and conceptual change, and implications for instruction and future research in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

This literature review has two related components. The objective of Part 1 is to provide a theoretical framework for plausibility judgments situated within the broader context of theory and research in conceptual change and epistemic cognition. More simply, Part 1 features a model for plausibility judgments in conceptual change that I have developed. The model emerges from philosophical and cognitive theories of plausibility reasoning, as well as through theoretical perspectives on plausibility's role in conceptual change. During my discussion of the model, I will overview epistemic cognitive processes that influence plausibility judgments. Part 2 of this literature review is an application of this proposed plausibility model in conceptual change about a controversial topic: human-induced climate change. The research questions and hypotheses for this dissertation study flow from this application of the model.

Part 1: Plausibility Judgments and Conceptual Change

Plausibility judgments are cognitive actions used to compare the relative potential truthfulness of mental representations. Plausibility comes into play in a situation of cognitive dissonance (Rescher, 1976), where individuals experience dissatisfaction as a negative intrapersonal state when encountering information that is inconsistent with their background knowledge (Festinger, 1957). According to Piaget (1954), when experiencing a state of dissatisfaction, individuals attempt to reconcile contradictory ideas through a process of assimilation (i.e., incorporating the idea into their existing mental representations) or accommodation (i.e., changing their mental representations so that the new information is no longer contrary). Learning is different under dissonance because

background knowledge and prior experiences act as a barrier rather than creating a pathway toward understanding. This is specifically the case if individuals assimilate information into existing mental representations that are not consistent with scientific understanding. Through comparison of the incoming information to the current mental representation, plausibility influences the cognitive decision whether to assimilate or accommodate information during a cognitive dissonance situation.

It is important to note that students could experience cognitive dissonance even if they have little or no prior knowledge. In such a situation, an individual may encounter two or more alternative ideas that relate to a given scenario or situation. The classic example is in law adjudication, where a judge or jury must decide between the claims of the two opposing parties (e.g., the prosecution and the defendant). Similarly, the scientific community may develop comparably plausible but competing hypotheses to explain a phenomenon. For example, in the 1970s, two hypothetical explanations of rising global temperatures were (a) a natural increase in solar radiation and (b) human emissions of greenhouse gases. Climate scientists developed these alternative hypotheses from limited data, which may have resulted in some level of cognitive dissonance within the climatology community. A limited number of climate scientists also considered a third hypothesis at this time that predicted an early ice age (i.e., global cooling; Peterson, Connolley & Fleck, 2008). Despite the lack of scientific consensus, the global cooling hypothesis was popularized by the national media, which again, may have promoted dissonance.

Walton (2004) addresses such cases of competing hypotheses with abductive inference (Peirce, 1958), where individuals think a conclusion is plausible if they deem

the supporting claims to be true. Plausible reasoning has the characteristics of (a) selecting from a set of alternatives that are (b) “relativized to a given body of evidence” (Walton, 2004, p. 31). In other words, plausible reasoning often involves two or more alternative explanations of a phenomenon that are based on the same evidence. Furthermore, these characteristics may be independent of background knowledge. The process of abductive inference might also involve evaluations of competing explanations and the plausibility judgment model that I will present in this literature review is specifically focused on knowledge reconstruction situations between incoming information that is anomalous with background knowledge. This review will therefore focus on cognitive dissonance situations where incoming information conflicts with background knowledge and leads to the operational definition of plausibility in conceptual change that I have discussed in more detail in Chapter 1. As a reminder, plausibility is a judgment on the *relative potential truthfulness* of incoming information compared to our existing mental representations.

Prior Models of Plausibility Judgments

As shown in Figure 1, Rescher’s (1976) model of plausible reasoning is relatively straightforward. Raw data (i.e., incoming information) is pre-processed first, where an individual applies a qualitative plausibility index to the incoming data based on the potential truthfulness of the information. A high index value means that a proposition has greater plausibility than a proposition with a lower value. Rescher (1976) maintains that a plausibility index is a function of source reliability, where an information source is “understood in a very wide sense” (i.e., including people, text, rules of logic and

probability, and/or validating principles). Individuals base reliability on their experiences and in terms of questioning “how solid and trustworthy” the source is (p. 7).

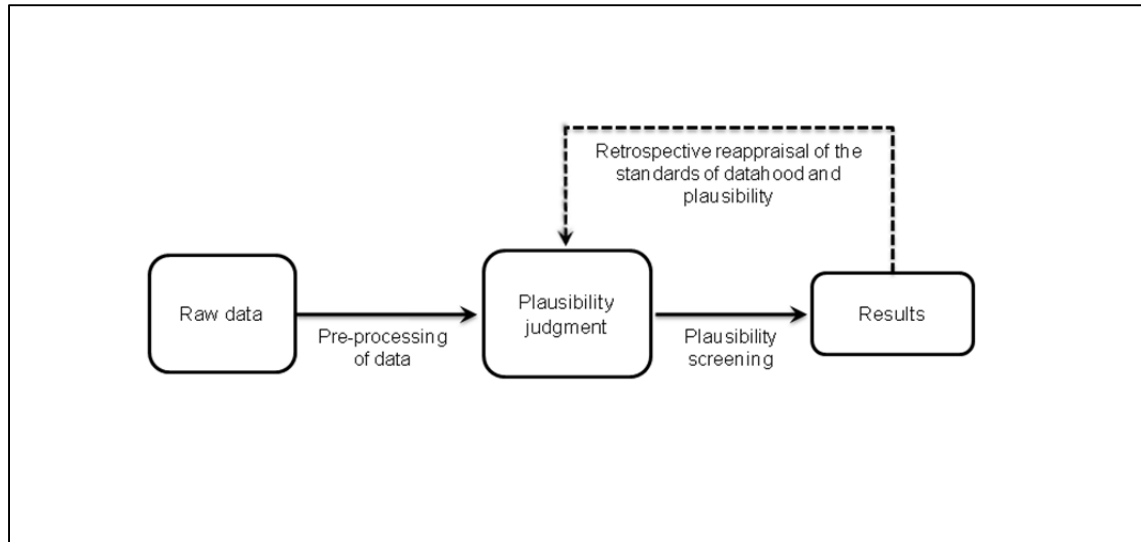


Figure 1. The systematic structure of plausibility analysis. By Rescher, N. (1976).

Plausible reasoning: An introduction to the theory and practice of plausibilistic inference. Amsterdam: Van Gorcum Ltd, p. 118.

Rescher’s (1976) notion of pre-processing is consistent with other perspectives on plausible reasoning. According to Walton (2004), plausibility is one mode in which individuals judge the connection between a proposition and its derived set of premises. Walton (2004) states that a proposition is plausible if that proposition “seems to be true based on appearances” and plausibility increases if the proposition is “consistent with other propositions that seem to be true” (p. 35). Furthermore, individuals associate greater plausibility to propositions supported by evidence.

Rescher’s (1976) idea of source reliability and plausibility indexing is supported by a plausibility model developed by Connell and Keane (2004; 2006). In their model which was developed and calibrated using empirical data, Connell and Keane view

plausibility judgments as cognitive mechanisms through which “some concept, scenario, or discourse is plausible if it is conceptually consistent” with other knowledge (Connell & Keane, 2006, p. 96). Plausibility increases if an incoming idea has many corroborating connections with background knowledge and if these connections minimize complexity and conjecture, as expressed in the following two equations:

$$\text{implausibility} = \frac{\text{complexity}}{\text{corroboration} - \text{conjecture}}$$

$$\text{plausibility} = 1 - \text{implausibility}$$

Therefore, an idea “will be...plausible...if [it]...has minimal complexity and conjecture, and...maximal corroboration” (Connell & Keane, 2006, p. 99).

Individuals may often use validating principles to establish source reliability (Connell & Keane, 2006; Rescher, 1976; Walton, 2004). Rescher claims a simple idea has a greater plausibility index compared to a more complex idea, when other source factors are equivalent. This is similar to Connell and Keane’s equation where minimizing complexity increases plausibility. Likewise, if an individual perceives an idea as definite, the idea may receive a greater plausibility index than one that is uncertain (i.e., a conjecture). Large amounts of evidence may provide greater validity to an idea, and subsequently, a greater plausibility index. For example, human-induced climate change may be particularly implausible because the topic has large degrees of complexity (i.e., many scientific concepts are involved) and perceived conjecture (i.e., statements of uncertainty associated with predictive models may lead students to believe that scientists are guessing), and a low degree of corroboration (i.e., scientific evidence may have few connections with students’ prior experience).

However, as Rescher (1976) points out, validating principles are only one component on which individuals base source reliability. Plausibility indexes may be determined primarily based on the person giving the information. If that person is not a trusted expert, the plausibility index will be relatively low. For example, a member of Political Party A may view all information from Political Party B with low source reliability. If the Political Party A member also equates scientific claims about human-induced climate change as Political Party B claims (e.g., Political Party B supports public funding of climate science, therefore climate scientists must be members of Political Party B), then the Political Party A member could assign a lesser plausibility index to any scientific ideas about climate change.

Source reliability may also be based on background knowledge and personal experiences. In this way, individuals may employ heuristics in assigning a plausibility index similar to heuristics used when assessing probabilities and quantifying uncertainty. One of these is the availability heuristic, in “which people assess the...probability of an event by the ease with which instances or occurrences come to mind” (Tversky & Kahneman, 1974, p. 1127). For example, an individual may experience several unusual blizzards in a short period, and when judging the plausibility of global warming, may assign low source reliability to that idea because they will use these recent blizzards to predict long-term climate trends.

Source reliability may also share similarities to the representativeness heuristic, “in which probabilities are evaluated by the degree...to which [an effect] resembles [a potential cause]” (Tversky & Kahneman, 1974, p. 1124). If a potential cause closely resembles an effect, then an individual may think that a causal relationship exists. For

example, an individual may think a single record high temperature is representative evidence of climate change because greater temperatures resemble the idea that the planet is warming over the long term. However, an individual may assign lower probability to a greater frequency of extreme events (e.g., blizzard and tornadoes) as evidence for climate change because of a lower degree of representativeness.

Tversky and Kahneman (1974) argue that availability and representativeness, as well other heuristics (e.g., adjustment and anchoring) violate the rules of probability and lead to judgment biases. These heuristics, however, may not violate the tenants of plausibilistic reasoning because such biases may be strongly influenced by source reliability. In other words, plausibility reflects “a more basic (or primitive) level of analysis than the calculus of probability” (Rescher, 1976, p. 38). Furthermore, individuals may rely on the more primitive plausibility judgment much more often because of lower level of cognitive resources required and only engage in probabilistic judgments when they are required (and able) to do so (Stanovich, 2010).

Distinctions between probability and plausibility. Cognitive determination of source reliability and assignment of a comparative plausibility index to the incoming information leads to what Rescher (1976) calls “plausibility screening” (see Figure 1). This screening involves what Rescher says is a “cardinal rule” of plausibility: “in cases of conflict, never make the more plausible give way to what is less so; by all means retain the more highly plausible thesis” (p. 14). In the case of conceptual change, plausibility screening will weigh the plausibility of the incoming information to our existing mental representation. If our existing representation has greater plausibility than the new information, conceptual change might not occur. Change might not occur even if the

individual considers the new information to be plausible, but still less plausible than an existing representation (Dole & Sinatra, 1998).

This idea—that individuals may assign a high plausibility index to both an incoming conception and an existing mental representation—makes the plausibility judgment fundamentally different from probability. In reflecting on the theoretical frameworks of Rescher (1976) and Walton (2004), Nussbaum (2011a) states that there are two appreciable distinctions between plausibility and probability: (a) “opposing propositions can both be plausible, even highly plausible, but both cannot be highly probable” and (b) plausibility is gauged on an ordinal scale (i.e., a comparative ranking between two or more alternatives), whereas probability is gauged on an interval scale (p. 90). Friedman and Halpern (2001) claim that a plausibility judgment is often a default reasoning mechanism through which probabilistic reasoning is subsumed. Individuals may evaluate the strength of competing arguments when probabilistic reasoning is understood and properly employed through evidentiary analysis (Nussbaum, 2011a), and thus would more carefully parameterize the likelihood of the arguments. However, if probability is not used, then a plausibility judgment based on less precise information may be the cognitive default. This idea is similar to the fuzzy trace theory of decision-making, where “decision makers seek the lowest level of precision in [a] hierarchy of gist that can be used to accomplish a task” (Reyna, Adam, Poirier, LeCroy, & Brainerd, 2005, p. 81).

Thagard and Findlay (2011) argue that for controversial topics where strong emotions are involved, such as global climate change, probabilistic reasoning is cognitively impractical, even in simple cases involving only a hypothesis and an

alternative. Specifically, Thagard and Findley state that “probability theory should be used whenever appropriate for statistics-based inference, but applying it to qualitative cases of causal reasoning such as climate changes obscures more than it illuminates” (p. 340). Thagard and Findley specifically reference statements made in a major report made by an international team of climate scientists (Intergovernmental Panel on Climate Change, 2007), where the scientists qualitatively classified causes and future impacts of climate change in order for more effective communication and understanding. For example, one statement in the report says “climate change is *likely* to lead to some irreversible impacts.” (Intergovernmental Panel on Climate Change, 2007, p. 13, emphasis theirs). Similarly, Mukherjee (2010) postulates that judgments made primarily through automatic and affective cognitive processes is “insensitive to probabilities” (p. 245). In situations of strong affect, a coarser plausibility judgment may play a dominant role in evaluating incoming information that conflicts with background knowledge.

Limitations of prior plausibility models. We can classify the plausibility reasoning models of Connell and Keane (2006) and Rescher (1976), as well as the model of abductive reasoning of Walton (2004), as part of the family of *cold cognitive processing* (Pintrich, Marx, & Boyle, 1993; Sinatra, 2005). In general, cold cognition focuses on relationships and processing between knowledge structures (e.g., storage of knowledge in long-term memory, processing of information in working memory, attention on information, etc.), with little emphasis on the “warmer” constructs of affect, motivation, and social context (Sinatra, 2005). Whereas both Rescher and Walton acknowledge that uncomfortable feelings associated with cognitive dissonance can initiate plausibility judgments, there is virtually no mention of other emotions, nor

individuals' goals and intentions, epistemic motives and dispositions, or the social context. However, in a recent study, Lombardi and Sinatra (2011) found a significant relationship between plausibility perceptions that humans are contributing to global climate change and science educators' angry feelings about teaching climate change. The relationship was negative, where lesser plausibility perceptions were associated with greater feelings of anger. Evidence from this empirical study suggests that extra-rational constructs may be dynamically and reciprocally related to plausibility judgments.

Rescher's (1976) model of plausibility reasoning also implies that individuals engage in explicit processing when making a plausibility judgment. Researchers describe explicit processing, sometimes called Type 2, as cognition that is "controlled, voluntary, and effortful" (Kahneman & Klein, 2009, p. 519). On the other hand, implicit or Type 1 cognitive processes are associated with automatic and unconscious judgments (Kahneman & Klein, 2009). When individuals engage in Type 1 thinking, they are regularly employing the use of heuristics and acting as "cognitive misers" (Stanovich, 2010). Because Type 1 processes require a much lower expenditure of cognitive resources, students probably make plausibility judgments implicitly.

One empirical investigation supports this idea that plausibility is often an implicit cognitive process. In examining the use of plausibility judgments in solving simple multiplication problems, LeMaire and Fayol (1995) asked the study participants to verify if answers were true or false. Specifically, the researchers measured verification times in problems with a single multiplier (a), multiplicand (b), and product (c) (i.e., $a \times b = c$). LeMaire and Fayol used two sets of four equations, where one set was categorized as easy and the other difficult based on Ashcraft's difficulty indexes (Koshmider &

Ashcraft, 1991). For more difficult problems, the researchers found that both children and adults initially use a false estimation process by comparing the odd-even status of c to both a and b . Shorter verification times are needed to conclude that the answer is false when a and/or b is even and c is odd (e.g., $9 \times 6 = 55$). In other words, the answer is implausible. However, if both a and b are odd and c is odd (e.g., $9 \times 7 = 61$), then longer verification times were measured as the subjects engaged in more elaborate calculation procedures. In this case, the answer is plausible; therefore, additional steps are necessary for verification. LeMaire and Fayol propose that this estimation process is a plausibility judgment individuals use to avoid longer procedures and lower cognitive load during retrieval. Plausibility perceptions may therefore be similar to other cognitive processes, including “planning, monitoring, and evaluation, [which] may not be conscious or explicit in many learning situations” (Schraw, Crippen, & Hartley, 2006, p.114). However, it may be possible to make the plausibility judgment explicit through instruction, which I will discuss in some detail below.

Because Rescher’s (1976) model does not include either (a) mechanisms for both implicit and explicit processing and (b) the warmer constructs of affect, motivation, and social context, we have a need to reconceptualize a model for plausibility in conceptual change situations, which includes these components. Critical to this model’s development are some of the ideas found in conceptual change research; specifically relevant are ideas about how researchers treat plausibility in several perspectives of conceptual change.

The Role of Plausibility in Conceptual Change

My operational definition for conceptual change—reconstruction of conceptual understanding—is based on the philosophical underpinnings of (a) scientific revolutions,

which have been used as an analog to conceptual change (Chinn & Brewer, 1993; Feyerabend, 1962; T. Kuhn, 1962; Posner et al., 1982), as well as (b) psychological learning theories involving reconstruction of knowledge (Chi, 2005; Dole & Sinatra, 1998; Vosniadou & Brewer, 1992). From this perspective, conceptual change implies that an individual has an existing mental representation (e.g., propositions stored in long-term memory, schema, mental model, or naïve theory) that is not consistent with scientific understanding. Conceptual change occurs when those types of knowledge structures are reformed to represent scientifically accurate knowledge.

Many conceptual change researchers are currently engaged in an active debate about the degree of coherency in students' misconceptions. On one side are those suggesting that misconceptions reside in memory structures that are relatively coherent (see, for example, Carey, 1999; Vosniadou, Vamvakoussi, & Skopeliti, 2008). Those on the other side claim that naïve ideas most often exist as fragmented pieces of elemental knowledge, which lack cognitive structure (diSessa, 2008). Researchers call this latter perspective "knowledge in pieces," where misconceptions are ephemeral because students construct concepts from elemental information based on the situation and context provided by the environment (diSessa, Gillespie, & Esterly, 2004).

From the knowledge in pieces perspective, a student learns about a concept because she has taken fragmented knowledge and organized it into a coherent structure (Mayer, 2002). Change occurs in how knowledge is organized (i.e., fragmented to coherent), but not as a shift from one coherent mental model to another. This notion is quite different from the reconstruction of knowledge notion present in many other conceptual change theories (Carey, 1999; Chi, 2005; Dole & Sinatra, 1998; Ohlsson,

2009; Vosniadou, Vamvakoussi, & Skopeliti, 2008). Students integrate naïve knowledge fragments and evaluate which fragments create a more complex and scientifically accurate mental representation (Mayer, 2002). Evaluation of naïve knowledge fragments involves a judgment that diSessa (1993) calls “mutual plausibility” (p. 116). However, the knowledge in pieces perspective is much more akin to concept development (see for example, Gellman, Coley, & Gottfried, 1994; Mandler, 2008) than conceptual change. Furthermore, this perspective gives plausibility only a very superficial treatment. Therefore, I have not used knowledge in pieces to inform the model’s development.

Responses to anomalous information. Chinn and Brewer (1993) discussed what happens when students experience scientific evidence that disagrees with their naïve theories. According to Chinn and Brewer, there are seven outcomes when students experience “anomalous data:” (1) ignore (discard data with no explanation), (2) reject (discard data with explanation), (3) exclude (place data outside the domain of their existing conception), (4) hold in abeyance (deal with the data later), (5) reinterpret (incorporate data into the domain of their existing conception), (6) modify peripherally (make a superficial change to their existing conception), or (7) reconstruct theory (undergo strong conceptual change so that their understanding is consistent with scientific knowledge).

Plausibility judgments play a critical factor in determining which of these seven responses occurs (Chinn & Brewer, 1993). Specifically, Chinn and Brewer argue that a new theory that accurately accounts for the anomalous data must be plausible. Because Chinn and Brewer strongly associate individual conceptual change with the history of science, they say, “the essential ingredient in a plausible theory is a plausible physical

mechanism” (p. 21, emphasis theirs). From my earlier example, scientists did not have a unique explanatory physical mechanism for increasing global temperatures until the 1980s. Before that time, increasing solar activity and/or increased human emissions of greenhouse gases were both reasonable explanations. Solar activity began to decrease in the 1980s, but human emissions of greenhouse gases continued to increase. At this point, human-induced greenhouse gas emissions became a more plausible explanatory mechanism for climate change (at least among climate scientists).

The classic conceptual change model. Chinn and Brewer (1993) based their analysis of plausibility on the classic conceptual change model of Posner et al. (1982). In this model, Posner et al. proposed that conceptual change proceeds in a linear fashion analogous to the process that occurs within scientific revolutions. First, the student has dissatisfaction with his existing conception. Then, the student must find the competing conception to be intelligible and appear initially plausible. The conceptual change will occur if the new conception also “leads to new insights and discoveries” (Posner et al., 1982, p. 222) when applied to a broader perspective (i.e., the new conception is fruitful). When discussing initial plausibility, Posner et al. viewed it “as the anticipated degree of fit of the new conception into an existing conceptual ecology” (p. 218). Their idea of plausibility is different from mine (i.e., plausibility is a judgment on the relative potential truthfulness of incoming information compared to our existing mental representations). Instead of a comparative and ordinal judgment, Posner et al. view plausibility as a wellness of fit between the new information and existing mental representation. However, their notion of plausibility is incomplete because it fails to address how students reconstruct their conceptual ecology when the degree of fit is not good.

Despite their limited perspective on plausibility, Posner et al. (1982) made several important recommendations about instructional strategies to promote conceptual change. With regard to plausibility, Posner et al. say, “any available metaphors, models, and analogies should be used to make a new conception more intelligible and plausible” (p. 224). This idea of associating intelligibility (also called message comprehensibility) and plausibility is found in many subsequent discussions of conceptual change. However, Lombardi and Sinatra (2012) state that “comprehensibility is related to the coherency and consistency of the message (i.e., is the message understandable)” (p. 4). Consequently, even if students comprehend the incoming information, they may still find the message implausible. For example, “students may understand that scientists are measuring increased temperatures around the world and that humans are emitting a large quantity of greenhouse gases in the atmosphere..., [but] students may feel that it is implausible that human activity could influence global climate” (Lombardi & Sinatra, 2012, p. 204).

Whereas Posner et al. (1982) tend to fuse intelligibility and plausibility, their insight into the instructional use of analogies is consistent with Rescher’s (1976) notion that plausibility is a comparative and qualitative evaluation of competing conceptions. Clement (1993) argues that experts often use “qualitative physical intuition schemas” and not “formal” (p. 1252) quantitative strategies to create bridging analogies in solving problems. These bridging analogies “may therefore be important plausible reasoning strategies for developing and refining physical intuitions” (Clement, 1993, p. 1252). Analogical reasoning may also promote an inference to understand a relationship between the source and target analog (Holyoak, 2005). Subsequently, analogical and plausibilistic reasoning may be connected if the inference used in making an analogy is

abductive in nature. This analogical/plausible mechanism may be involved when individuals shift their categorization of ideas from one ontological category to another, which is another major perspective on how conceptual change occurs.

Ontological shift. Chi (2005) stated that students naturally categorize concepts into ontological categories, which are formed by a mutually exclusive set of plausible attributes (i.e., an attribute that a category member may plausibly, but does not necessarily, have). For example, anything within the object ontological category may plausibly have the attribute of color, even though some objects may be colorless (e.g., air). However, color would not be a plausible attribute of the process ontological category (e.g., melting of Antarctic ice sheets would not plausibly possess the attribute of color). Because conceptual change occurs when a student shifts a concept from one ontological category into another, plausibility plays a central role in Chi's model. In other words, for a shift to occur, the concept must be reliably consistent with the ontological attributes that the student may have assigned to that category.

The ontological perspective, along with the conceptual change theories of Chinn and Brewer (1993) and Posner et al. (1982), were established using the framework of cold cognitive processing. As I have discussed earlier, we need to consider the “warmer” extra-rational processes, such as motivation, affect, and social context to gain a more complete understanding of plausibility's role in conceptual change.

Integrating Conceptual Change and Plausibility into a Warmer Cognitive Arena

A major shift in conceptual change research occurred with a seminal article by Pintrich et al. (1993). These researchers posited that conceptual change is not necessarily analogous to history of science because learner characteristics (e.g., motivation) and the

social environment in the classroom strongly influence conceptual change. In other words, conceptual change may not necessarily be an overly rational process for the student. Furthermore, Pintrich et al. proposed that when students seek plausibility in a new mental representation, they may undergo a deeper level of cognitive processing through elaboration and organization, which “facilitate encoding and learning” (p. 174). This is consistent with the work of LeMaire and Fayol (1995) discussed earlier, where shorter verification times (i.e., indicating a superficial level of processing) are associated with quick implausibility judgments and longer verification times (i.e., indicating deeper processing) are associated with a more deliberate determination of plausibility.

Dole and Sinatra’s (1998) cognitive reconstruction of knowledge model (CRKM) embraced the viewpoint of Pintrich et al. (1993) by postulating an interaction between the qualities of a student’s existing conceptions (i.e., the strength of, coherence of, and commitment to the existing conception), his motivation to process new information, and the incoming “message” conflicting with the existing conception. Dole and Sinatra claim that plausibility is one of four critical aspects of an incoming message, along with degrees of comprehensibility, coherency, and compelling rhetoric. Two of these aspects, comprehensibility and plausibility, were theoretical holdovers from Posner et al.’s (1982) conceptual change model.

Plausibility and coherence. Dole and Sinatra (1998) claim that the incoming message must have explanatory coherence. Thagard (1989, 2006) presents the idea of explanatory coherence as an evaluation of explanations between two or more competing hypotheses. In making the cognitive evaluation of alternatives, explanatory coherence examines the fit of evidence to the alternatives, as well as the how well the two

alternatives fit with each other. In his theory of explanatory coherence, he claims that individuals accept an alternative based on its degree of coherency (Thagard, 2006). In the case of conceptual change, knowledge reconstruction would occur because the existing mental representation has lower explanatory coherence than the new, incoming message.

In the explanatory coherence model, evaluation of explanations relies on plausibility perceptions (Ranney & Schank, 1998). However, explanatory coherence primarily concerns the degree of corroboration with background knowledge, which I have noted above is only one aspect of validating principles that result in plausibility indexing. Explanatory coherence also dichotomously categorizes the perceived complexity and conjecture in the connections between the incoming message and background knowledge (e.g., hypothetical versus evidentiary). These dichotomous categories are somewhat similar to the plausibility factors discussed by Connell and Keane (2006), but lack the breadth of Rescher's (1976) source reliability.

An expanded explanatory coherence model does take into account the influence of emotions on cognitive judgments (Thagard, 1998, 2006; Thagard & Finley, 2011). In running simulations of this expanded model, Thagard and Finley (2011) show how emotions can interfere with belief revision by undermining hypotheses that are better supported by the evidence. Yet, explanatory coherence lacks the power of the plausibility judgment because one source may override all the others. Coherence may describe how an explanation aligns into a conceptual whole, but plausibility explains how students qualitatively compare dissonant information to background knowledge in order to apply a relative potential truthfulness value. Some researchers have noted this limitation in

Thagard's theory (Adams, 2002) when compared to the broader utility of the plausibility judgment (Chinn & Brewer, 2001).

Plausibility and compelling rhetoric. The last message variable in Dole and Sinatra's (1998) model is compelling rhetoric, which emerges from the social psychology literature on persuasive text (see, for example, Petty & Cacioppo, 1986). Dole and Sinatra claim that "some individuals may be more compelled [toward conceptual change] by an impassioned and emotional speech" given by an authority figure (p. 120). Compelling rhetoric may then interact with plausibility judgments if we consider the idea of source reliability from Rescher's (1976) model. An individual who is deemed highly reliable (e.g., a well-respected politician) could deliver a message with compelling rhetoric, and consequently, individuals could give the message a high plausibility index. On the other hand, a person could deliver compelling rhetoric, but individuals could consider the person to be unreliable (e.g., a politician who is deemed untrustworthy). In this case, the source reliability and the associated plausibility index will be low despite the persuasiveness of the speaker.

Dole and Sinatra (1998) do express a major difference from Rescher's (1976) model of plausible reasoning by making the following claim: when individuals make a plausibility judgment about the message, they weigh the probability of evidence by deciding on the probability of its usefulness. Probability demands that when one alternative is highly likely, the other alternative must be unlikely. This is counter to the idea of simultaneously considering two opposing alternatives to be plausible. Unlike probability, a plausibility judgment is not an "either or" proposition, but a relative and ordinal ranking of alternatives. My model will hold to Rescher's general perspective on

plausibility, and therefore, will deviate somewhat from Dole and Sinatra. However, many elements of Dole and Sinatra's CRKM have informed my model of plausibility in conceptual and epistemic change, which I have detailed in the next section.

Model of Plausibility Judgments in Conceptual Change

Figure 2 is my model of plausibility judgments in conceptual change. The structure of the model is similar to Rescher's (1976) model of plausible reasoning. However, the details in the boxes have been expanded to reflect Dole and Sinatra's (1998) model, which has influenced the warming trend in conceptual change, as well as Chinn and Brewer's (1993) theoretical framework on students' responses to anomalous data and Connell and Keane's (2006) model of plausibility. Perspectives on epistemic cognition have also contributed to the processes involved in the critical evaluation feedback loop, as well as the degree of evaluation in the plausibility judgment. I consider this critical evaluation feedback to be a sociocognitive route because plausibility reappraisal would likely be initiated via interactions with other people or information sources (e.g., texts and video), whereas the initial pathway (i.e., from anomalous incoming information to the plausibility judgment to the result) is primarily cognitive. The model then heeds the call made by Sinatra and Mason (2008) for researchers to pay attention to both the socio-cultural and cognitive perspectives of conceptual change.

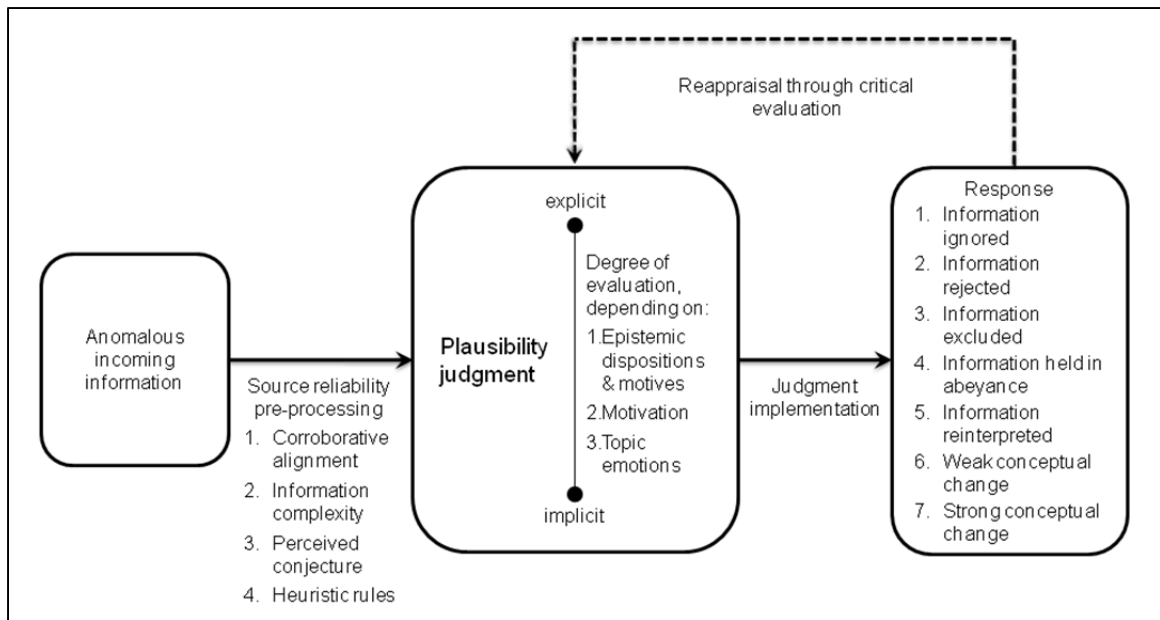


Figure 2. A model of the role of plausibility judgment in a conceptual change situation initiated by cognitive dissonance.

Pre-processing of anomalous incoming information. Incoming information that is anomalous to background knowledge can result in cognitive dissonance and dissatisfaction. Students pre-process this anomalous incoming information in order to establish source reliability. Because of the importance placed on validating principles in Connell and Keane's (2006) model, I have highlighted three screening principles as key factors in establishing a plausibility index: (a) corroborative alignment of information with background knowledge, (b) complexity of the incoming information, and (c) perceived degree of conjecture or uncertainty. I call the fourth screening principle heuristic rules (e.g., representativeness, availability, and anchoring; Tversky & Kahneman, 1974). As I have discussed earlier, source reliability may be influenced by these heuristics, where biases that are contrary to the laws of probability, but not to the tentative judgment of plausibility, are cognitively activated.

Plausibility judgments and the degree of evaluation. Central to the model is the actual plausibility judgment (see Figure 2), where individuals compare the incoming information to their existing mental representation. The plausibility judgment may involve some degree of implicit processing (i.e., Type 1, with low awareness and low cognitive effort) and explicit processing (Type 2, with high awareness and high cognitive effort). Because of students' proclivity toward Type 1 cognition (i.e., acting as "cognitive misers"; Stanovich, 2010), the plausibility judgment might often be implicit. I have represented the degree to which the plausibility judgment is implicit or explicit as a continuum, which I am calling the *degree of evaluation*. This evaluation would only be critical and reflective if the plausibility judgment is (a) primarily an explicit comparison of the connection between evidence and alternatives, (b) based on skilled intuition developed through expertise in a particular domain (e.g., a theoretical physicist may implicitly use critical evaluation when considering the validity of new theory on subatomic particles; Kahneman & Klein, 2009), or (c) representative of individuals' dispositions to think deeply, and possibly their motivations toward and emotions about the topic.

Epistemic dispositions and motives. Research on epistemic dispositions and motives emerges from the social psychology literature that, in part, helped to form Dole and Sinatra's cognitive reconstruction of knowledge (CRKM) model. In particular, epistemic dispositions are associated with relatively stable personality traits relating to our views about knowledge and/or its acquisition. Dole and Sinatra specifically identify need for cognition in their model, which is a disposition toward engaging deeply in topics because of enjoyment (Cacioppo, Petty, Feinstein, & Jarvis, 1996). Individuals with a

high need for cognition tend to appreciate complexity and do not seek closure on an issue prematurely, and therefore may be more implicitly evaluative in making plausibility judgments. In a study involving undergraduate students, Sinatra, Southerland, McConaughy, and Demastes (2003) found “that willingness to entertain knowledge change intentionally (the central theme of the dispositional scales) affects acceptance of evolution” (p. 521). In such a case, the initial plausibility judgment could place a relatively high index on complex and controversial incoming information, but only if the individual has a tendency to be more explicitly evaluative.

Epistemic motives are an individual’s inclination toward a particular view of knowledge, such as seeking or avoiding closure (Kruglanski, 1989). Epistemic motives may also be dispositional in that they are relatively stable for extended periods. In a recent study, Lombardi and Sinatra (2011) found that decisiveness (a need for closure subcomponent; Webster & Kruglanski, 1994) and anger about teaching about climate change were significant predictors of an individual’s plausibility perceptions about human-induced climate change. In this study, greater decisiveness predicted lower plausibility, potentially indicating that individuals with an urgent desire to decide may tend to evaluate information heuristically (i.e., as theorized by Dole & Sinatra, 1998, p. 117). This tendency could assign a comparatively greater weight to existing mental representations, and because of this decisiveness, the plausibility judgment could favor background knowledge over new, incoming information.

Sinatra, Kardash, Taasobshirazi, and Lombardi (2011) found that another need for closure subcomponent, specifically close-mindedness, was related to undergraduates’ willingness to commit to actions that would mitigate climate change. Greater levels of

close-mindedness predicted a lower degree in commitment to act. Whereas, Sinatra et al. did not measure plausibility perceptions, we may speculate that one reason for the lack of willingness may have been because the participants did not consider human-induced climate change to be plausible.

Motivation. Students' motivation would also influence the degree of evaluation. In their conceptual change model, Dole and Sinatra (1998) list several motivational factors, including students' (a) "stake in the outcome," (b) "interest in the topic," and (c) "self-efficacy about the topic" (Dole & Sinatra, 1998, p. 119). These motivational factors may also influence the plausibility judgment implicitly. For example, students with low interest about the incoming anomalous information may rank this information's source reliability lower than that of their background knowledge, which may hold greater interest. This could result in a lower comparative plausibility perception of the incoming anomalous information. For example, an individual may have little interest in protecting the environment for future generations, but have a strong interest in racing monster trucks. In this case, the interest in truck racing may promote a strong belief in drilling for oil in environmentally sensitive areas to maintain lower gasoline costs. An interest in truck driving could also create a strong desire to rebut the anomalous information. Therefore, this individual may place greater source reliability on climate change skeptics who are supported by the oil industry because of their interest in racing over that of climate scientists who may be considered "environmentalists" (and by association, of much lower interest).

Recent research in motivation and conceptual change reveals that students' goal orientation (e.g., mastery versus performance) interact with "awareness, knowledge, and

the intentional reconstruction of knowledge” (Sinatra & Mason, 2008, p. 565). Students with a mastery orientation could provide a greater ranking to incoming information even though it is anomalous just because of their desire for greater understanding.

Furthermore, mastery goals may result in more explicit and critical evaluation of the incoming information, thereby changing the comparative plausibility judgment.

Topic emotions. Emotions based specifically on the topic of instruction may also influence the plausibility judgments’ degree of evaluation. Topic emotions may potentially interfere with motivation and cognition in a reciprocal fashion, similar to the way that general academic emotions interfere with motivation and cognition (Pekrun, Frenzel, Goetz, & Perry, 2007). In an overview of recent research on emotion in education, Linnenbrink (2007) states that current research is converging on “the view that there are bi-directional, reciprocal relations among motivation, affect, and cognition” (p. 311). From the conceptual change perspective, an individual’s feelings about a particular topic may affect the comparative judgment of the anomalous information to the existing mental representation. Lombardi and Sinatra (2012) showed that teachers who expressed anger about teaching about climate change (as well as an epistemic motivation toward decisiveness) found the idea of human-induced climate change implausible. However, despite this initial evidence, the direction of the plausibility and topic emotion is still uncertain. Gregoire (2003) argues that affective appraisals, such as threat and stress, “happen automatically before characteristics of the message [e.g., plausibility] are seriously considered and that message characteristics may never be fully processed on the basis of appraisals made” (p. 168). The potential reciprocal nature of plausibility judgments and topic emotions could provide a fruitful arena for future research.

Result of the plausibility judgment. As shown in the model (Figure 2), the plausibility judgment would be implemented through some degree of implicit and explicit processing and would result in one of the seven responses to anomalous information (i.e., as theorized by Chinn & Brewer, 1993). Chinn and Brewer's use of the term "data" actually represents a wide variety of scientific information, including ideas that we can consider hypotheses and theories. For example, to support the idea of weak conceptual change (i.e., peripheral theory change), Chinn and Brewer recount early astronomers' reactions to Galileo's discovery of lunar mountains. According to the prevailing astronomical theory, celestial objects were considered perfect spheres. The astronomers made a weak (and still incorrect) modification to their theory by allowing mountains to be embedded within a perfect crystalline sphere (Chinn & Brewer, 1993, p. 11).

The idea that plausibility is a judgment on the *relative potential* truthfulness of incoming information compared to our existing mental representations aligns with these seven responses. Incoming information that students perceive to be essentially impossible (i.e., because the source reliability is virtually zero) would be ignored because the existing mental representation would certainly have a greater plausibility. Similarly, students may assign incoming information a low plausibility index due to topic emotions that generate adverse feelings and they would reject this information because the current conception would usually have a greater comparative plausibility. When students exclude the incoming information or hold it in abeyance, they might assign the information a somewhat greater plausibility index because they accept the information as potentially truthful. However, due to greater explanatory power, existing conceptions would retain greater plausibility. Incoming ideas with still greater plausibility would require some

level of change, depending on the strength of the source reliability. A student may reinterpret the information in order to assimilate it into the existing conception, resulting in weak restructuring. Only when the plausibility of the new information is greater than the current mental representation would knowledge reconstruction occur. The process does not necessarily end with these results because the plausibility judgment would be tentative and reappraisal of the judgment could occur (Rescher, 1976).

Reappraisal of the plausibility judgment. Interactions, which are sociocultural in nature, may facilitate reappraisal of students' plausibility judgments and subsequent disposition of the incoming information (see Figure 2). Dole and Sinatra (1998) state that "a host of social contexts," such as "students in a group discussion, may be motivated to consider new or conflicting information that they have disregarded in the past because they value their peers' viewpoints" (p. 119-120). Sociocultural interactions could also include reading text or watching video from a highly reliable source. This could then change the new information's plausibility index. If the change is great enough, the new information may result in knowledge reconstruction (i.e., if the plausibility of the incoming message is now greater than the existing mental representation). However, these interactions most likely require critical reflection and evaluation to result in plausibility change, such that students "are reflective about what they are thinking and why" (Dole & Sinatra, 1998, p. 121).

Critical comparison of the incoming information to the existing mental representation may be more apt to lead to strong and enduring conceptual change. This evaluation can be thought of as a problem solving process, where "students would...engage in metacognitive reflection, rethinking their old beliefs and comparing

them with the new ideas in order to judge the new ideas as more plausible and fruitful” (Pintrich et al., 1993, p. 174). Similarly, Dole and Sinatra (1998) call this critical comparison *high metacognitive engagement*. Rescher (1976) states that when the comparative reappraisal “happens systematically ...we are in the position to reevaluate—and revise—the existing criteria of plausibility themselves” (Rescher, 1976, p. 118). The challenge then is to promote strong conceptual change through epistemic cognitive processes, which in turn leads to systematic plausibility reappraisal. In other words, the use of critical evaluation may move the plausibility judgment from implicit to explicit thinking. Instruction may be one way to facilitate explicit cognition in making the plausibility judgment. If students can undergo epistemic conceptual change through instruction that promotes critical evaluation, they may develop the ability to reappraise their plausibility judgments and criteria in light of the several factors influencing the judgment.

Epistemic Cognition and Critical Evaluation

Cognitive development researchers often view epistemic cognition in discrete stages. For example, D. Kuhn and colleagues’ developmental model of critical thinking has four levels of epistemological understanding (D. Kuhn, 1999; D. Kuhn, Cheney, & Weinstock, 2000). The realist and absolutist levels are the first two stages, where “knowledge is certain” and critical thinking is minimal (D. Kuhn, 1999, p. 23). Likewise, in the third level (multiplist stage), “critical thinking is irrelevant” because knowledge is based solely on opinions of equal weight and value (D. Kuhn, 1999, p. 23). However, critical thinking is essential in the evaluative level, which is the most advanced stage in Kuhn’s model. In this stage, individuals use reasoned criteria to compare and evaluate

alternative assertions. Furthermore, the evaluative level exhibits similarities to King and Kitchener's (2004) notion of reflective thinking. Having an evaluative epistemological understanding introduces the idea of judgments based on argument, evidence, and criteria. Therefore, with regard to scientific knowledge, one theory would have preference over another based on the strength of evidence and collaborative understanding. D. Kuhn and Pearsall (2000) view this as a "coordination of theory and evidence in a consciously controlled manner" (p. 114), and classify mature scientific thinking as a metacognitive process.

Whereas the development of such mature scientific thinking may be a conscious and explicit cognitive process, expert scientists may conduct such coordination implicitly, with little metacognition. Mayer (1992) claims that physics experts categorize schematic knowledge through structural similarities (as compared to superficial similarities used by novices). In problem solving, expert physicists examine data through a theoretical perspective (e.g., Newton's Laws of Motion) rather than the type of problem (e.g., inclined plane). The physicists demonstrate that they have a theory-based procedural schema through which they interpret data. Thus, theory and data coordination may become part of intuitive judgment process, which is a characteristic of Type 1 thinking (Kahneman & Klein, 2009). These intuitive judgments form via experience, rather than relying on more simplified heuristics characteristic of novices (e.g., use of superficial similarities). Instruction could potentially provide the necessary experience for students to coordinate data and theory intuitively, and therefore, develop mature scientific thinking. This may then move students' epistemic cognition toward a more naturalistic and critical type of evaluation. Cognitive development researchers acknowledge that

instruction can result in such transformations, but they provide a limited amount of detail on how to do so. Fortunately, research in science education and educational psychology provides some insight.

Sinatra and Chinn (2011) claim that science education researchers have been investigating epistemic cognition by examining students' learning about the nature of science. Included as a content area in the *National Science Education Standards* (NRC, 1996), nature of science covers the ideas that (a) science is a dynamic sociocognitive process of knowledge construction, (b) the history of science illuminates this process, and (c) knowledge constructed through the scientific process has unique characteristics. This latter idea directly concerns epistemic cognition, where scientific knowledge “distinguishes itself from other ways of knowing...through the use of empirical standards, logical arguments, and skepticism, as scientists strive for the best possible explanations about the natural world” (NRC, 1996, p. 200). Arriving at the best possible explanation implies that analyses, evaluations, and arguments are central to the scientific process. In Part 2 of the literature review, I will provide more details on promoting critical evaluation through instruction and how such instruction may result in plausibility appraisal, and ultimately, conceptual change.

Part 2: Applying the Model to Students' Conceptions About Climate Change

Global climate change is receiving increased attention as a classroom topic. Recently, the U.S. National Oceanic and Atmospheric Administration and the American Association for the Advancement of Science developed a guide to promote greater understanding of climate change (U.S. Global Change Research Program, 2009). The guide lists four abilities of a climate literate person, including (a) demonstrating

knowledge about the “essential principles of Earth’s climate system,” (b) understanding “how to assess scientifically credible information about climate,” (c) communicating “about climate and climate change in a meaningful way,” and (d) being “able to make informed and responsible decisions with regard to actions that may affect climate” (U.S. Global Change Research Program, 2009, p. 3). This literature review will focus on the first three aspects, particularly how students and teachers understand the fundamental scientific concepts related to climate change, and how students and teachers develop epistemic cognitive processes needed to think scientifically about climate change.

Climate change science is complex. Developing understanding about Earth’s climate requires fundamental knowledge in many domains, including physics, chemistry, geology, astronomy, meteorology, and ecology. Many of these scientific ideas are counter to students’ existing mental representations. Often called misconceptions, these alternative or naïve mental representations may be present at birth or very early in infancy (see, for example, Carey, 1992; Gellman, Coley, & Gottfried, 1994; Mandler, 2008) and also form via experiences with the natural world, as well as experiences at school, church, and other everyday interactions (see, for example, diSessa, 1993; Vosniadou & Brewer, 1992). Many misconceptions are notoriously robust to change and can act as a barrier to learning scientifically accurate ideas (Chi, 2005). To reconstruct knowledge structures into correct conceptions, Dole and Sinatra (1998) have theorized a complex interaction between characteristics of (a) students’ existing mental representation and their motivation to change and (b) the incoming, scientifically accurate message that teachers present to students.

The question of why scientists think Earth's climate is changing is also complex. In addition to understanding scientific principles, students also need to engage in epistemic cognitive processes that reflect scientific reasoning used to understand complex topics (Sinatra & Chinn, 2011). Students' underlying epistemological assumptions about knowledge and how they gain knowledge influences their epistemic cognition (Kitchener, 1983). Of particular importance to understanding climate change, students need to deepen their ability to critically evaluate the quality of scientific information and weigh alternative explanations in a reasoned manner. This will help them to construct knowledge consistent with the scientific community. Such knowledge construction (i.e., via evaluation of evidence obtained through scientific inquiry) would be a characteristic exhibited by reflective thinkers. Unfortunately, few high school graduates demonstrate reflective thinking (King & Kitchener, 2004). Therefore, to facilitate improved understanding of climate change and other complex science topics, students need to reconstruct their epistemic cognition processes to be more evaluative and reflective, as well as their conceptual understanding (Sinatra & Chinn, 2011).

Plausibility judgments may be an important way in which students evaluate an incoming message. In situations of cognitive dissonance, plausibility judgments comparing the incoming information to the existing conception would influence if and how much conceptual change may occur (Dole & Sinatra, 1998; Pintrich et al., 1993; Posner et al., 1982). Plausibility judgments may often be implicit and automatic cognitive processes, influenced by students' epistemic dispositions and motives, topic emotions, and motivations. However, a plausibilistic comparison may be reappraised through explicit and effortful critical evaluation as I have discussed in more detail in Part 1 of this

literature review. Given the association between potentially robust misconceptions and complex concepts, topics such as climate change may need an explicit reappraisal of plausibility for students to reconstruct their knowledge successfully. Furthermore, the consensus among climate scientists is that human activities are the primary cause of recent increases in global average temperatures (Doran & Zimmerman, 2009). This is a controversial stance outside of this scientific community, where non-climate scientists may view competing theories with greater plausibility. The controversial nature of human-induced climate change may therefore contribute to a lower comparative plausibility of the scientific conception.

Based on these circumstances, my underlying thesis in Part 2 of the literature review is that critical evaluation of competing climate change models would increase plausibility perceptions of human-induced climate change. This in turn would result in a greater degree of conceptual change about the topic. The remainder of this section will discuss the nature of misconceptions related to climate change, potential importance of plausibility judgments in conceptual change, connection between critical evaluation and plausibility reappraisal, and emergence of research questions that may reveal insights into instructional methods that facilitate deeper understanding of climate change and science learning in general.

Climate Change Misconceptions

Table 1 lists several misconceptions that students have about climate change, along with the associated scientifically accurate understanding. This is an update to Lombardi and Sinatra's (2012) list, which I have modified using recently published information (Choi, Niyogi, Shepardson, & Charusombat, 2010). The table shows two

categories of misconceptions, evidence-related and cause-related. The single evidence-related misconception concerns student confusion about weather and climate distinctions (see, for example, Gowda, Fox, & Magelky, 1997; Lombardi & Sinatra, 2012; Papadimitriou, 2004; Pruneau, Gravel, Courque, & Langis, 2003).

Cause-related misconceptions include (a) attributing global warming to increasing solar irradiance (i.e., the amount of solar energy received at the top of the Earth's atmosphere) (see, for example, Boyes & Stanisstreet, 1993; Pruneau et al., 2003), (b) stratospheric ozone depletion (i.e., the ozone hole) causing either increased amounts of energy to reach the Earth's surface or allowing more of Earth's energy to escape out to space (see for example, Andersson & Wallin, 2000; Boyes & Stanisstreet, 1994; Keller, 2006; Österlind, 2005), (c) a gas or dust layer at the top of Earth's atmosphere behaving similarly to a glass roof on a greenhouse (see, for example, Andersson & Wallin, 2000; Pruneau et al., 2003), and (d) some form of pollution (i.e., pollution other than greenhouse gas emissions) contributing to global warming (see, for example, Gowda et al., 1997; Keller, 2006; Papadimitriou, 2004; Read, Bostrom, Morgan, Fischhoff, & Smuts, 1994). We used conclusions from an international team of climate scientists for the table's comparative listing of scientifically accurate conceptions (Intergovernmental Panel on Climate Change, 2007).

Table 1

Comparisons of Some Student Misconceptions and Scientific Conceptions about Global Climate Change

| Student misconceptions | Scientific conceptions |
|--|--|
| <i>Evidence-related</i> | |
| <ul style="list-style-type: none"> • Short-term and local weather events are evidence of global climate change. | Long-term observations show a statistically averaged and global-wide warming trend. |
| <i>Cause-related</i> | |
| <ul style="list-style-type: none"> • Increasing amounts of solar irradiation because the Sun is releasing more energy or the Earth is getting closer to the Sun. | Whereas the amount of solar radiation from the Sun varies, in the past 30 years, the Earth has been receiving slightly decreasing amounts of solar energy. |
| <ul style="list-style-type: none"> • Stratospheric ozone depletion causes significant increases in global temperatures. • A gas or dust layer at the top of the atmosphere is trapping Earth's energy similar to the glass roof covering a greenhouse. | Increased atmospheric concentrations of greenhouse gases (primarily carbon dioxide) are resulting in increased global temperatures. These greenhouse gases are mainly located in the lowest layer of Earth's atmosphere and generally well mixed throughout this layer |
| <ul style="list-style-type: none"> • Pollution (e.g., smog, acid rain, nuclear waste) is directly linked to global climate change. | Human activities are causing increasingly greater concentrations of atmospheric greenhouse gases |

Note: Adapted from "College students' perceptions about the plausibility of human-induced climate change," by D. Lombardi and G. M. Sinatra, 2012, *Research in Science Education*, 42, 201-217, and "Do earth and environmental science textbooks promote middle and high school students' conceptual development about climate change?: Textbooks' consideration of students' misconceptions," by S. Choi, D. Niyogi, D. P. Shepardson, and U. Charusombat, 2010, *Bulletin of the American Meteorological Society*, 91, p. 890.

Researchers have studied other climate change misconceptions, which are outside the categories of "evidence related to" and "causes of" climate change (see, for example, Choi et al., 2010; Moxnes & Saysel, 2009; Shepardson, Niyogi, Choi, & Charusombat, 2011). These misconceptions, along with the cause-related misconceptions concerning stratospheric ozone depletion, a gas and dust layer, and other forms of pollution are beyond the scope of this review. Understanding these misconceptions probably has

implications for climate change education, but for the purposes of gaining better understanding about the relationship between plausibility judgments and critical evaluation, I will limit my focus to the first two misconceptions listed in Table 1 (confusion about weather and climate distinctions and attributing climate change to increasing amounts of solar irradiation). These two misconceptions are especially relevant to initial learning about climate change (i.e., at the middle school level) based on learning progressions implied by the *National Science Education Standards* (NRC, 1996).

Confusion about weather and climate distinctions. Scientists use localized and short-term weather events to determine regional climate trends, and periods of 30 years or greater are the classical time spans for determining climatic averages and extremes (National Climatic Data Center, 2008). Unlike climate scientists, students and the public sometimes use unique weather events to make conclusions about climate change. For example, two blizzards hit Washington, D.C. within one week during the winter of 2010 and President Obama nicknamed these events as “Snowmageddon” (Silva, 2010). During that snowstorm, “Oklahoma Republican Sen. James Inhofe, an outspoken skeptic of global warming...mocked Al Gore” [Nobel Prize winner for his work on informing the public about potential climate change impacts] by showing images of him and his family “building an igloo near the Capitol, with a sign that read ‘Al Gore’s new home’” (Page, 2010). The inference here is that these short-term blizzards invalidated predictions about increasing global temperatures associated with long-term climate change.

Lombardi and Sinatra (2012) summarized three research studies documenting confusion about weather and climate distinctions occurring in members of the public,

high school students, and preservice teachers. These survey studies found that individuals (a) used “local weather excursions” (e.g., extreme storms) to make judgments about climate trends (Read et al., 1994, p. 974), (b) claimed that “climate often changes from year to year” and to have personally experienced climate change by witnessing a “memorable weather event” (Gowda et al., 1997, p. 2236), and (c) cited recent weather events (e.g., extremely hot summer days) as evidence of climate change (Papadimitriou, 2004). Lombardi and Sinatra (2012) used this information to develop the Distinctions between Weather and Climate Measure (DWCM), a 13-item dichotomous choice instrument, where students classify statements as pertaining to weather or climate. Prior to this study, we administered the DWCM to 83 undergraduate students, 40 secondary science teachers, and 45 preservice elementary teachers, with average overall correct responses of 61% (students at semester’s beginning) and 48% (teachers). Semester-long geoscience instruction, with at least some coverage of weather and climate distinctions, significantly increased undergraduate students’ understanding of these distinctions (increasing to 71% correct responses; Lombardi & Sinatra, 2012). These results show that students and teachers had an appreciable level of misunderstanding about weather and climate distinctions, which persisted somewhat after instruction.

Attributing climate change to increasing solar irradiance. The Sun is the predominant energy source for Earth’s weather and climate. Recent paleoclimate studies have shown a strong association between solar activity and global temperatures over the past 11,000 years (Solanki, Usokin, Kromer, Schüssler, & Beer, 2004). However, “correlations between the Sun’s behavior and the Earth’s climate have completely failed since the 1970s” (Priest, Lockwood, Solanki, & Wolfendale, 2007). Solar activity has

been decreasing since that time, and in the absence of an enhanced greenhouse effect caused by human activities, this lessening solar irradiance should have resulted in slightly lower global temperatures (Lockwood, 2010).

Despite these recent scientific observations, the increased solar activity argument has been popular with those who are skeptical of human influences on climate (Cook, 2010). For example, a blog called the Dakota Voice misinterpreted a NASA study by claiming “we have still more evidence that any warming occurring on planet earth is coming from natural sources [i.e., the Sun] and is cyclic in nature” (Ellis, 2009, p.1). Educational researchers have also found that students hold misconceptions about the connection between climate change and solar irradiance. For example, Boyes and Stanisstreet (1993) found that 59% of secondary students ($N = 128$) incorrectly thought, “the greenhouse effect is made worse because too many of the sun’s rays get to the earth” (p. 538). Pruneau et al. (2003) surveyed 39 teenage students prior to instruction and found that two believed that climate change is occurring because “the planet gets closer to the sun and gets warmer” (p. 437). Although this is a very small percentage, this ranked as the third most popular explanation because 67% of the students responded that they did not know what caused climate change.

Both the blogger’s and students’ irradiance misconception may be related (at least in part) to the judgment that increased solar energy output is more plausible than implicating human emissions of invisible greenhouse gases. Similarly, it may seem plausible that short-term weather events are indicative of long term climate changes, thus muddling weather and climate distinctions. To examine this relationship in more detail,

we now turn to a discussion of studies showing the connection between plausibility perceptions and climate change conceptions.

Empirical Evidence of Plausibility Judgments in Conceptual Change

Theorists have long included the plausibility judgment as a critical component in knowledge reconstruction (Dole & Sinatra, 1998, Posner et al, 1982); however, plausibility has received little empirical attention in conceptual change (Dole & Sinatra, 1998). Treagust and Duit (2008) reported on a series of three studies conducted from the early 1990s to the early 2000s, where the classical conceptual change model of Posner et al. (1982) was examined using qualitative interviews. These studies support the idea that students must first comprehend the incoming message before they can make plausibility judgments. Interestingly, intentional learners (i.e., students with the goal of mastering the material) engaged in deeper levels of processing, which resulted in more reflection when making their plausibility judgment (when compared to learners who did not have a mastery goal). Beyond these studies, conceptual change researchers have not engaged in collecting data about plausibility perceptions until our recent research (Lombardi & Sinatra, 2012).

Plausibility judgments and reconstructing conceptions of climate change. We conducted a study with 83 undergraduate students and found that plausibility perceptions about human-induced climate change accounted for statistically significant changes in knowledge about weather and climate distinctions over semester-long instruction, above and beyond their existing background knowledge (Lombardi & Sinatra, 2012). We also found that plausibility perceptions did not significantly change during instruction, even though one of the courses involved in the study focused on climate science for the entire

semester. There might have been no significant changes in students' plausibility judgments because the courses did not explicitly weigh "the plausibility of geoscientists' claims with alternative claims" (Lombardi & Sinatra, 2012, p. 212). This suggestion helped inform the preliminary development of a model of plausibility judgments (see Figure 2), specifically on the potential importance of the "plausibility appraisal through critical evaluation" feedback loop. If the students had engaged in critical evaluation, their plausibility perceptions about human-induced climate change may have increased, with a subsequently potential greater increase in the knowledge of weather and climate distinctions. This is a speculative, but these results point toward the need for more research.

Factors influencing the degree of evaluation in plausibility judgments. In a follow up study, we examined some factors relating to teachers' initial plausibility judgment (Lombardi & Sinatra, 2011). This study involved 40 secondary science teachers attending a summer workshop that discussed air quality and climate change, and 45 preservice elementary teachers enrolled in a science methods course. Study participants completed five questionnaires: (a) emotions about human-induced climate change (and teaching about climate change), (b) knowledge of weather and climate distinctions (i.e., the DWCM), (c) plausibility perceptions of human-induced climate change, and (d) need for cognition and (e) need for closure. Need for cognition is an epistemic disposition that is relatively stable over time, indicating the extent to which individuals engage in and enjoy effortful cognitive activities. The epistemic motive of need for closure is also somewhat dispositional and represents individuals' "motivation with respect to information processing and judgment" (Webster and Kruglanski, 1994, p. 1049).

We found two significant predictive relationships in the follow-up plausibility study (Lombardi & Sinatra, 2011). The first regression model included individuals' topic emotions about climate change, but not their topic emotions about teaching climate change. Of the several emotions that we measured, anger and hopelessness about human-induced climate change were significant predictors, with greater anger predicting lower plausibility perceptions and greater hopelessness predicting greater plausibility perceptions. In this model, background knowledge and needs for cognition and closure did not significantly contribute to students' prediction of plausibility. The second regression model included individuals' emotions about teaching climate change, but not their emotions about the topic per se (as was the case in the first model). Anger about teaching climate change and decisiveness (a need for closure subcomponent) were significant predictors, with both greater anger and greater decisiveness resulting in lower plausibility perceptions of human-induced climate change. Similar to the first model, background knowledge and need for cognition did not significantly contribute to prediction of plausibility.

Our study was limited because we did not measure conceptual knowledge post instruction, and therefore, were unable to determine if any conceptual change occurred (i.e., either during the week-long workshop for the secondary science teachers or over the course of semester-long instruction for the preservice elementary school teachers) (Lombardi & Sinatra, 2011). However, the study did provide some tentative evidence for the degree of evaluation that occurs in the plausibility judgment and potential contributing factors—in this case, topic emotions of hopelessness and anger, and the epistemic motive of decisiveness. We can speculate that if these participants had engaged

in critical evaluation, they may have reappraised their plausibility judgment and potentially had greater plausibility perceptions about human-induced climate change.

Critical evaluation may have been particularly effective in the case of one teacher who participated in the study (Lombardi & Sinatra, 2011). In follow-up interviews, one secondary science teacher focused almost exclusively on plausibility perceptions of scientific statements in general, and human-induced climate change specifically. About her understanding of scientific knowledge, the teacher said,

I have a network of people that I can go to and I am not afraid to pick of a phone and say, 'I don't understand this.' So, I will call people. I will ask questions. I am not afraid to go to the experts. You know I enjoy reading the primary source, the primary references.

Just after this comment, the teacher related how she heard that many of the world's glaciers are actually advancing and not receding as reported by scientific statements.

When I asked her about the source of this information, she said,

I read it online...I haven't found the primary source for that yet. I am still looking for those primary sources. I was told that there was this think-tank in DC where a lot of this information is coming out of, but my first question is: who are they being funded by...who's paying their salary?

Toward the end of the interview, the teacher seemed extremely agitated by a recent mistake in a scientific report on global climate. Her reaction to apologies made by scientists when the mistake was discovered was:

Oh yeah, [the scientists] lied about it... Well, you just discredited yourselves! Well, now how am I supposed to believe you when you then

come out with another statement...are you lying again? My question then becomes what is your agenda?

It seems that this teacher is directing her anger squarely at scientists and their claims about climate change. Her plausibility judgment may have been influenced by the low source reliability she places on the scientists and the scientific report. However, had she conducted a more thorough and careful critical evaluation of the mistake, as well as considered the preponderance and quality of evidence in the report, she may have been less angry. Consequently, her plausibility judgments may have changed.

Researchers have found that instruction can dampen topic emotions. Broughton, Sinatra, and Nussbaum (2010) examined emotions of elementary students in association with the scientific reclassification of Pluto from a major to a dwarf planet. In their study, Broughton et al. found that during interviews, three out of the four students reported that they felt “kind of sad..., mad and frustrated” (p. 29), but also, that these feelings diminished after reading a refutational text (a text designed to promote conceptual change, see Sinatra & Broughton, 2011) and participating in a collaborative, peer-to-peer discussion. This study shows that students brought these feelings of anger, frustration, and sadness into the learning environment. However, this instruction was also able to muffle these feelings such that these students were more willing to engage with the scientific viewpoint. Although Broughton et al. did not measure plausibility perceptions, their study does suggest that reappraisal of the plausibility judgment could occur, in this case by explicit and critical evaluation, with associated reductions in adverse topic emotions.

Reappraising Plausibility through Critical Evaluation

Halpern (2007) lists many attributes of critical thinking and specifically states that critical thinking, “involves evaluating the thinking process—the reasoning that went into the conclusion we’ve arrived at or the kinds of factors considered in making a decision” (p. 5). However, as I have discussed earlier, to employ critical evaluation, an individual must examine the connection between evidence and an explanation, as well as connections between the same evidence and alternative explanations. Critical evaluation is likely a single construct (i.e., without subcomponents) that is often an explicit and effortful process that requires considerable cognitive resources. Stanovich (2010) calls such explicit thinking a Type 2 cognitive process, with implicit and low effort cognition being Type 1. In this dual process view of cognition, individuals often resort to Type 1 thinking because of the limited amount of cognitive resources required. The plausibility judgment may often be implicit, as I have detailed earlier in this review. To reappraise our plausibility judgments, Type 2 thinking and specifically critical evaluation may be necessary.

The need for explicit evaluation. Students may be naturally curious about scientific topics, but are not necessarily evaluative as they consider hypotheses and theories. Chinn and Buckland (2012) state that some students adopting a creationist perspective on biological evolution may engage in non-collaborative argumentation tactics that bias evidence. Such a stance may prevent learning about “the ontological conceptions of species, populations, variation, and extinction” (Chinn & Buckland, 2012, p. 7), tenants central to biological evolution. To overcome this bias and promote deeper learning of evolution, Chinn and Buckland argue that students should gain a coordinated

understanding of both the (a) theory's ontological conceptions and (b) scientists' epistemic practices. Scientific judgments about the strength of the theory of biological evolution are based on a large body of evidence. Furthermore, these judgments have emerged from an environment of argumentation that has co-considered alternative explanations (e.g., creationism and intelligent design).

An individual's bias toward a particular perspective may be reflective of their stance on controversial issues. In a recent experimental study, Kahan, Jenkins-Smith, and Braman (2010) found significant disagreement on the state of scientific consensus about global climate change based on an individual's cultural values. Individuals who are more egalitarian (i.e., those who value equality in politics, economics, and society) and communitarian (i.e., those who place greater value on contribution to the community compared to individual gain) were much more likely to think that expert scientists agree that global temperatures are increasing than those who are hierarchical (i.e., those who value graded authority in politics, economics, and society) and individualistic (i.e., those who place greater value on individual gain compared to contribution to the community). Conversely, hierarchical-individualistics were much more likely to think that expert scientists are divided about increasing global temperatures.

Kahan et al. (2010) found similar differences between the two value orientations regarding the evidence for human-induced climate change. These findings provide additional support to the wider body of research on confirmation bias (discussed in detail by Nickerson, 1998). However, Kahan et al.'s (2010) experiment also revealed that judgment about "whether an individual of elite academic credentials, including membership in the [National Academy of Sciences], was a 'knowledgeable and

trustworthy expert” depended “on the fit between the position the...expert was depicted as adopting and the position associated with the subjects” values (p. 21). Because students are not predisposed to critically evaluate data and data sources (Schraw et al., 2006), it may be particularly important for students to reflect metacognitively on their epistemic practices when the topic is controversial. Therefore, students should experience instructional practice that develops their critical evaluation skills.

Critical evaluation involves understanding how evidence can potentially support both an idea (e.g., an argument, a scientific model) and its alternatives (e.g., a counterargument, a contrary hypothesis). Furthermore, through critical evaluation an individual seeks to weigh the strengths and weaknesses in the connection between the evidence and the ideas. Mere critique is not sufficient. For example, people can exhibit a disconfirmation bias, “where when faced with evidence contrary to their beliefs, people try to undermine [this incoming] evidence” (Edwards & Smith, 1996, p. 6). Such evidence undermining is almost certainly a Type 2 process because Edwards and Smith (1996) have shown that individuals who display a disconfirmation bias engage in a deliberative memory search. The purpose of this undermining memory search is to “retrieve material [e.g., stored beliefs] for use in refuting the position advocated” (Edwards & Smith, 1996, p. 18). However, this disconfirmation bias is not necessarily evaluative because less cognitive processing is involved when individuals agree with a particular position. Therefore, critical evaluation must try to find fault with both the existing idea and the alternative, gauged on the level of support provided by evidence. In this way, critical evaluation embraces the scientific standard of falsifiability.

Instruction promoting critical evaluation. Students' classroom use of critical evaluation should mimic that used by scientific experts (Duschl, Schweingruber, & Shouse, 2007). By publishing their work in research journals and participating in symposia, panels, and presentations, the scientific community engages in collaborative argumentation, defined by Nussbaum (2008) as a constructive and social process where individuals work together to compare, critique, and revise conceptions. Collaborative argumentation is different from adversarial argumentation, where opponents attempt to reduce one another's viewpoint to a point of uselessness. Individual scientists may engage in adversarial argumentation; after all, scientists are human too. However, as a community, science thrives due to collaborative argumentation, which is an inherently constructive process (Osborne, 2010).

Nussbaum (2008) stresses that students can use collaborative argumentation to achieve deep understanding through cognitive elaboration; thereby, making multiple connections with their background knowledge. Collaborative argumentation should also examine alternative ideas presented through the group discourse, which promotes critical thinking and evaluation of alternative ideas. Nussbaum, Sinatra, and Poliquin (2008) found that students with an evaluativist epistemological stance engage in deeper and more critical argumentation. Enhancing "students' willingness to be critical of scientific theories and awareness of inconsistencies in their own thinking" may result in strong conceptual change (Nussbaum, Sinatra, & Poliquin, 2008, p. 1994). However, students may not naturally be critically reflective when engaging in collaborative argument, and therefore, "students need tools to evaluate arguments" (Nussbaum & Edwards, 2011, p. 447).

Nussbaum and Edwards (2011) examined the combined use of critical questioning and argumentation and found that when middle school students or the teacher “asked critical questions, it helped move the discussion to...productive ground, where arguments could be evaluated.” (p. 481). The study took place in a social studies classroom; however, some of the information and discussion implicitly touched upon scientific principles (e.g., conservation of energy, energy efficiency, and energy transformation in association with fossil fuel emissions and global climate change). In particular, some of the critical questions used by Nussbaum and Edwards had a distinctly scientific flavor, including “What’s the likelihood?” and “How do you know?”(p. 457). Nussbaum and Edwards used these questions as effective guides to help students critically evaluate each other’s arguments.

The use of critical questions as guides may help students develop what Glassner and Schwarz (2005) call “the antilogos ability,” a term which comes from classical Greek philosophy and means “the art of contradiction” (Glassner & Schwarz, 2005, p. 354). In terms of students’ argumentation skills, Glassner and Schwarz (2007) define antilogos as “the ability to critically evaluate whether specific information may support different claims” (p. 11). Glassner and Schwarz (2005) measured antilogos ability in 173 secondary school students through an activity in which students figured out as many reasonable flaws as they could in two claims: one supporting the death penalty and the other opposed. The results of the study indicated that the number of flaws increased with age (i.e., high school students were able to figure out more flaws compared to middle school students). However, two manipulations lessened results due to age differences. One manipulation gave students a worked out example showing a claim with a list of

identified flaws. The worked out example provided an instructional scaffold that cued students to be more critically evaluative. A second manipulation involved having students construct their own argument for or against the death penalty prior to the antilogos activity. Glassner and Schwarz (2005) speculate that construction of their own argument led to greater processing of different perspectives and promoted evaluation.

Argument construction does not necessarily promote greater critical evaluation. A study conducted by Nussbaum and Kardash (2005) showed that when students were given a persuasion goal, they generated fewer counterarguments in their writing. In other words, trying to persuade led to more one-sided thinking. Nussbaum and Kardash also found a connection with the intensity of students' beliefs about a topic and their ability to generate counterarguments, where more extreme attitudes led to fewer counterarguments. Whereas Nussbaum and Kardash were not specifically examining the idea of a disconfirmation bias, where individuals seek to undermine arguments counter to their own by disregarding contrary evidence (Edwards & Smith, 1996), their results may provide some evidence for this tendency. Nevertheless, Nussbaum and Kardash recommend that further research be conducted that specifically examines how explicit instruction can promote "deeper, but more balanced reasoning" (p. 165).

Critical questions, the ability to find flaws in both a hypothesis and alternative, and generation of counterarguments on both sides of an issue may then stimulate critical evaluation in collaborative argumentation, but science may involve additional complexities for learning. Specifically, students encountering science topics in a school setting often possess existing mental representations that conflict with scientific understanding, and often, these naïve understandings seem more plausible than the

correct conception. For students to be able to critically judge plausibility when comparing competing models (naïve vs. scientific), they could engage in both (a) collaborative argumentation and (b) a method that allows them to weigh evidentiary data (Chinn & Osborne, 2010).

Using model-based reasoning to promote critical evaluation. Chinn and Buckland (2012) report on the recent use of an instructional scaffold, called the model-evidence link (MEL) diagram, which assists students in making arguments based on relative weighting of evidence that support an explanatory model and an alternative. In MEL diagrams, students draw different types of linking arrows between evidentiary data and alternative models. Students draw arrows in different shapes to indicate relative weight of the evidence. Straight arrows indicate that *evidence supports the model*; squiggly arrows indicate that *evidence strongly supports the model*; straight arrows with an “X” through the middle indicate the *evidence contradicts the model*; and dashed arrows indicate the *evidence has nothing to do with the model*. Students then use these MEL diagrams in collaborative argumentation and explanatory tasks to critically evaluate their links and construct understanding.

In a year-long study involving middle school life science students, Chinn, Duschl, Golan Duncan, Buckland, & Pluta (2008) found that the treatment group (724 students using MEL diagrams to assist in their argumentation) made “substantially greater advances in their ability to effectively coordinate models and evidence” than the comparison group (1,961 students who did not use the modeling scaffold) (p. 2). The year of instruction was broken down into units that discussed fundamental life science concepts. For each unit, treatment group participants constructed a MEL diagram in

coordination with argumentation and other instructional activities designed to develop deep understanding. The MEL diagrams featured two models (e.g., the naïve stress model of ulcer inducement versus the scientific bacteria model of ulcer inducement). Students would gather evidentiary data during the instructional activities (e.g., reading a passage about a scientific experiment) and collaborate on constructing MEL diagrams.

Participants in the control group completed the same argumentation and other activities, but did not use the MEL diagrams. Many of these units involved topics for which students typically have robust misconceptions (e.g., photosynthesis, cellular respiration, and mitosis). Pre and post testing for each unit demonstrated that treatment group participants experienced a greater degree of conceptual change than control group participants (Chinn & Buckland, 2012).

The Present Study

In this literature review I have presented a model of plausibility judgments in conceptual change and discussed how this model might be applied to transforming students' conceptions about climate change. Although the model is grounded in philosophical and theoretical perspectives, the empirical evidence supporting the model is limited. I have made some assertions that are speculative and require further research. Of particular importance to me is the plausibility reappraisal feedback loop, which represents a "terra nova" in science education. Through this loop, teachers may potentially engender both conceptual change, where students reconstruct their knowledge to be consistent with the current scientific understanding, and also epistemic conceptual change, where students transform their way of thinking to be more critically evaluative and cognizant of

how they are making plausibility judgments about information that conflicts with their background knowledge.

Many instructional methods may result in an explicit plausibility reappraisal; however MEL diagrams may be particularly useful because this instructional scaffold presents an opportunity for students to compare competing models. Subsequently, use of MEL diagrams raises some interesting questions. For example, would use of MEL diagrams increase students' critical evaluation skills? Chinn et al. (2008) showed better coordination of evidence and models with diagram use, but did not report any increases in students' ability to evaluate two competing explanatory models critically. Furthermore, plausibility judgments were not the focus of their research, but the greater degree of conceptual change in the treatment may be due—in part—to increased plausibility perceptions about scientific conceptions (i.e., per the model of plausibility judgments in conceptual change that I have proposed earlier). If the students were more critically evaluative while comparing competing models, did this change their plausibility judgment about the scientific conception? Finally, Chinn and Buckland's (2012) list of life science topics covered included only non-controversial topics (e.g., biological evolution was not included). How then would students' critical evaluation and plausibility judgments change when the topic is controversial (e.g., human-induced climate change)? Would the explicit reappraisal of plausibility judgment be great enough to overcome the more implicit topic emotions, cognitive dispositions, and motivations that shape the plausibility indexing of existing, naïve conceptions? Finally, if critical evaluation promotes changes in plausibility perceptions, does conceptual change also occur?

Research Questions

The research discussed in this literature review demonstrates that it may be possible to strengthen students' critical evaluation of competing climate change models and subsequently increase plausibility perceptions of human-induced climate change. With increased critical evaluation and the ability to reappraise plausibility judgments, students may experience knowledge reconstruction about human-induced climate change and associated scientific principles (e.g., weather and climate distinctions). Furthermore, with increased critical evaluation and explicit plausibility reappraisal abilities, students may also experience epistemic conceptual change because they have achieved greater understanding of how scientists construct knowledge. The following research questions and hypotheses have emerged from this review.

1. Does explicit instruction designed to promote evaluation of competing climate change theories—specifically, human-induced climate change (i.e., the scientifically accurate model; Intergovernmental Panel on Climate Change, 2007) versus an increasing amount of solar energy received by Earth (i.e., a popular model used by skeptics of human-induced climate change; Cook, 2010; Ellis, 2009)—result in changes to:
 - a. plausibility perceptions of climate change,
 - b. knowledge of human-induced climate change, as well a basic understanding of the distinctions between weather and climate, and
 - c. beliefs about climate change evidence?
2. What is the relationship between students' comparative plausibility perceptions of competing climate change theories (human-induced climate change versus

increasing solar irradiance) and their perceptions about which of these theories they think is correct, and how does this relationship change with instruction?

3. Are model plausibility ratings of these two competing climate change theories related to the seven responses theorized by Chinn and Brewer (1993; see Figure 2) as ordered categories (i.e., very low plausibility is associated with ignoring and rejecting data and high plausibility is associated with individual theory change)?

Hypotheses

In response to the first research question, I hypothesize that use of MEL diagrams as an instructional tool will increase students' plausibility perceptions of human-induced climate change (H_{1A}). This hypothesis stems from the model of plausibility judgments I have presented earlier in the review, where explicit reappraisal of the plausibility judgment may be induced through instruction promoting critical evaluation, as well as previous research that Lombardi and Sinatra (2012) have conducted on students' plausibility perceptions of human-induced climate change. I also hypothesize that increases in plausibility perceptions of human-induced climate change will result in reconstruction of students' knowledge about human-induced climate change, conceptual change about a fundamental scientific principle related to climate change—weather and climate distinctions, and beliefs about climate change evidence (H_{1B}). I have based this hypothesis on the theoretical conceptual change model of Dole and Sinatra (1998), empirical research by Lombardi and Sinatra (2012), and the model of plausibility judgments (see Figure 2).

My hypothesis for the second research question is that even though students may consider competing climate change theories to be plausible, the one with the greater

plausibility will correspond to the theory that students think is correct (H_{2A}).

Furthermore, I hypothesize that students who use MEL diagrams will rank the plausibility of the scientifically correct conception (human-induced climate change) higher than the alternative conception (increasing solar irradiance) (H_{2B}). I have based this hypothesis on the model of plausibility judgments in conceptual change, which I presented earlier in this review (see Figure 2).

As for the third research question, I hypothesize that there will be a discernible relationship between model plausibility ratings and response (H_3). This hypothesis is based on Chinn and Brewer's (1993) theoretical framework on responses to anomalous data during knowledge acquisition, in which they have categorized seven responses ranging from ignoring and rejecting data to strong theory (i.e., conceptual) change. For example, students who rate human-induced climate change as implausible will reject or ignore evidence related to this scientifically accurate model and students who rate human-induced climate change at a relatively high plausibility level will demonstrate a greater degree of conceptual change.

CHAPTER 3

METHODS

Participants and Setting

Middle school students from a large urban district in the Southwestern USA were the participants in this study. In the state where this district resides, science education standards specify that teachers should introduce climatic concepts at the middle school level (i.e., grades 6-8). Weather concepts are also taught to middle school students, but weather is introduced much earlier, i.e., in the primary (kindergarten to grade 2) band. One middle school standard explicitly addresses weather and climate, saying, “By the end of the [6-8] grade band, students...understand the relationship between the Earth’s atmosphere, topography, weather, and climate” (Nevada Department of Education, 2005). Under this standard, three benchmarks specify what middle school students should understand about climate: (a) “Students know how the processes involved in the water cycle affect climatic patterns,” (b) “Students understand the composition of Earth’s atmosphere, emphasizing the role of the atmosphere in Earth’s weather and climate,” and (c) “Students know the difference between local weather and regional climate” (Nevada Department of Education, 2005). This last benchmark concerning student understanding of weather and climate distinctions is the one addressed in this study.

The school district involved in this study teaches the weather and climate distinction benchmark during grade 7, when all students are required to take an Earth science class. Study participants were drawn from an entire middle school’s grade 7. These participants were enrolled in grade 7 Earth Science and were taught by one of four grade 7 science teachers. At the time of the study, 429 students were enrolled in grade 7

science and I invited all to participate in the study. About 63% ($N = 269$) of the students provided both parental consent and self-assent, and just under two-thirds ($N = 169$) fully participated in the study—I defined “full participation” as being present for the study’s instructional activities and completing instruments in a manner that allowed me to ascertain meaningful information (e.g., ensuring the a participant’s name was on a questionnaire and that a participant did not leave many blank items on a questionnaire). Of the 169 students who participated in the study, 108 (64%) were Hispanic, 29 (7%) were White (17%), 19 (11%) were African American, and 13 (7%) were Asian/Pacific Islander (7%). Eighty-seven participants (51.5%) were male. Eighteen (11%) of the participants had individualized education plans, 36 (22%) had limited proficiency in the English language, and 79 (47%) were eligible for free or reduced-cost lunch.

Design and Materials

The study was conducted toward the end of the school year’s first quarter. At this time, the grade 7 students were completing an introductory unit on the nature of Earth science. The instructional activities occurred over two class periods (about 90 minutes of instructional time total). Fourteen total classes were involved in the study (three different teachers were instructors for four classes each and one teacher was the instructor for two classes). I randomly assigned half of the classes to the treatment condition (i.e., using an instructional activity promoting critical evaluation of two competing climate change models) and the other half of the classes to the comparison condition (i.e., using regular curriculum materials that discuss climate change). The study design is shown in Figure 3, with details on instrumentation below.

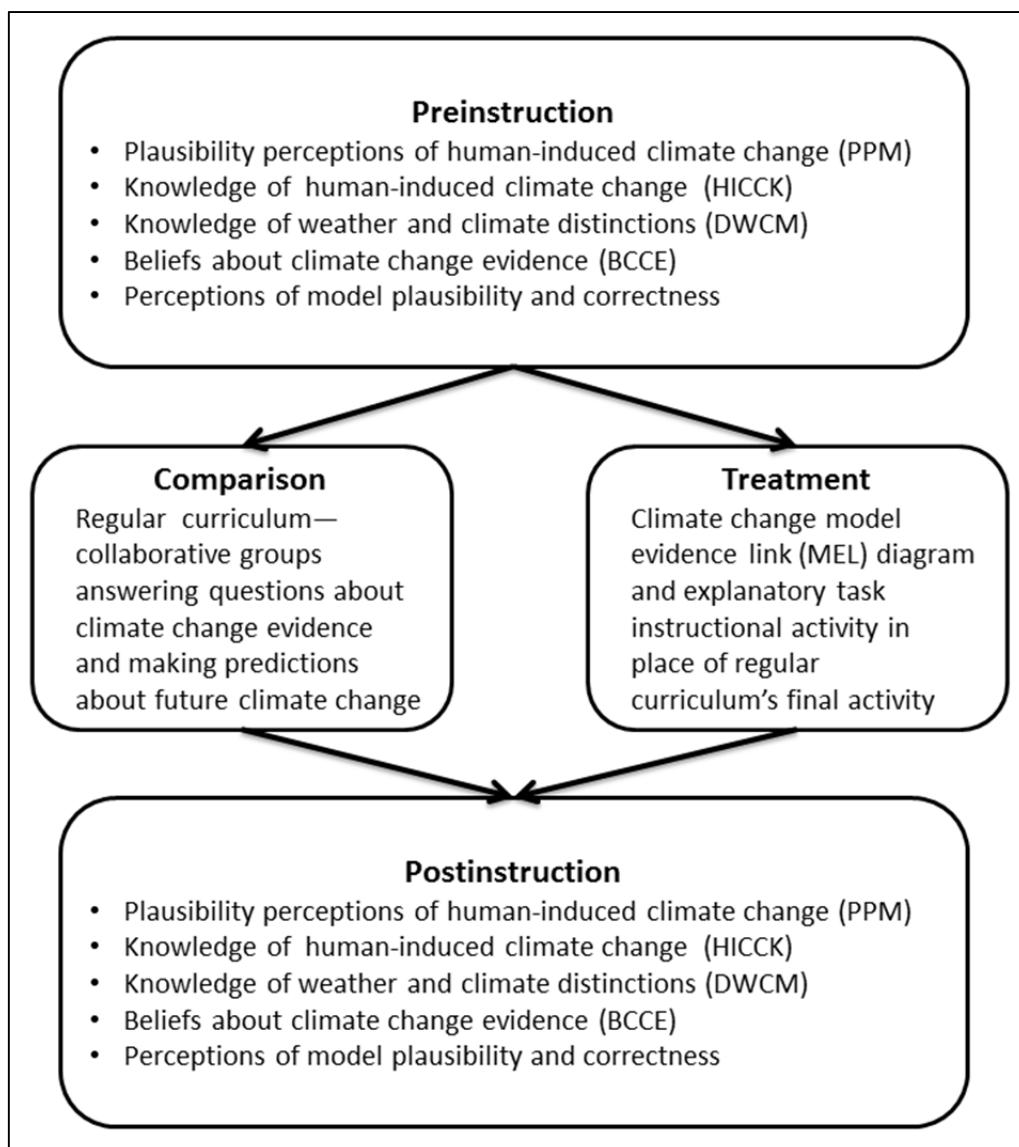


Figure 3. Study design.

Plausibility Perceptions of Climate Change

To measure participants’ plausibility perceptions of climate change, I used the Plausibility Perceptions Measure (PPM) (Lombardi & Sinatra, 2012). The PPM has eight statements about climate change based on the latest summative report produced by a United Nations’ expert panel (Intergovernmental Panel on Climate Change, 2007). In the version used by Lombardi and Sinatra, the PPM’s statements matched the major conclusions made in the report, including, for example, the following: “Warming of the

climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level” (Intergovernmental Panel on Climate Change, 2007, p. 2). Lombardi and Sinatra (2012) report that “that the PPM’s readability [is] at the college level” (p. 207). Because of the advanced reading level, I used a modified version of the PPM (see Appendix A), which is at a grade 7 reading level based on the Flesch-Kincaid formula. For example, the statement above was modified to “The Earth is warming. Rising air and ocean temperatures, melting glaciers, and rising sea levels are evidence of this warming.”

Participants rated each statement on a 0–10 plausibility scale (0 = greatly implausible or even impossible and 10 = highly plausible). In previous studies with adult and undergraduate participants, the PPM’s coefficient alpha values have been good to excellent ($\alpha \geq .8$; Lombardi & Sinatra, 2012, 2011; George & Mallery, 2009). Stability measurements (e.g., test-retest reliability) have not been reported for the PPM. However, a science education expert examined the PPM for evidence of face and “content validity and we revised the instrument based on her comments” (Lombardi & Sinatra, 2012, p. 208). The same science education expert reviewed the PPM that I modified to be at a lower reading level and I made all of her suggested revisions. This revised version is shown in Appendix A.

Prior to taking the PPM, classroom teachers conducted a short discussion with the participants about judgments made using plausibility perceptions, with one or two practice items that did not relate to the concepts of weather and climate. Participants then

engaged in a classroom discussion to ensure they understood the meaning of plausibility and then took the PPM.

Knowledge of Human-induced Climate Change

I used a 34-item instrument to measure participants' knowledge of human-induced climate change (HICCK), both prior to and after instruction. I created this instrument to measure correct and incorrect conceptions about human-induced climate change, based on a recent study that surveyed American citizens on their understanding of scientific phenomena related to global warming (Leiserowitz & Smith, 2010), the latest summative report produced by a United Nations' expert panel (Intergovernmental Panel on Climate Change, 2007), and common misconceptions about human-induced climate change (Choi et al., 2010). The participants rated each item on a 5-point Likert scale gauging the level of agreement that they thought *climate scientists* would indicate for each statement, ranging from 1 = strongly disagree to 5 = strongly agree. As DeVellis (2003) recommends, HICCK items were strongly worded, unambiguous declarative statements without jargon. The Flesch-Kincaid formula indicates that readability of HICCK items are slightly below the grade 7 level, on average. Seven of the HICCK items directly address misconceptions reported in the literature and summarized by Choi et al. (2010). The HICCK is shown in Appendix B, with "misconception" items indicated by asterisks.

I administered a shorter, 18-item version of the HICCK to grade 7 students in a pilot study. This shorter version used a dichotomous true/false scale rather than a 5-point Likert scale. Coefficient alpha values of the shorter version ranged from .48 (preinstruction) to .57 (postinstruction), both below the acceptable threshold of .7

(George & Mallery, 2009). Therefore, the instrument was extended to include an additional 16 items and increase reliability by more fully exploring the construct (i.e., more fully exploring participants' understanding of human-induced climate change). A follow up pilot study with the 34-item instrument revealed that the coefficient alpha value was .64, which is still below the acceptable threshold. However, by eliminating five items that exhibited a negative corrected item total correlation, the coefficient alpha value exceeded the acceptable threshold ($\alpha = .73$).

Weather and Climate Distinctions

The Distinctions between Weather and Climate Measure (DWCM; Lombardi & Sinatra, 2012) was used to measure participants' understanding about a topic that is fundamental to understanding global climate change: weather and climate distinctions. Both students and adults exhibit misconceptions about these distinctions (Gowda et al., 1997; Lombardi & Sinatra, 2012; Papadimitriou, 2004). As I have discussed in the literature review, individuals sometimes use weather events, which are localized and short term, to make conclusions about the potential for climate change, which would occur regionally over much longer time periods—30 years or greater (National Climatic Data Center, 2008).

The original form of the DWCM contained 13 single-sentence statements that individuals classified as being either weather or climate (Lombardi & Sinatra, 2012). Based on the results of our first research study (i.e., specifically, the unsatisfactory reliability of the measure, with coefficient alpha values less than .6), we have now developed a longer form containing 35 single-sentence statements (see Appendix C). In the longer version, individuals who take the test continue to classify each statement as

either weather or climate; therefore, both the short and long forms are dichotomous measures similar to a true/false test. The first 13 items of the longer form are identical to the original form.

The statements included in both the shorter (13-item) and extended (35-item) DWCM versions reflect the results of research into students' confusion about weather and climate (Gowda et al., 1997; Papadimitriou, 2004). For example, the first statement says, "There was a heat wave last summer." This statement reflects a memorable weather event that may confuse individuals about being a predictor of future climate changes. Some of the statements examine other aspects of weather and climate that—to my knowledge—researchers have not studied empirically. For example, in the extended form we now include the following statement, "Strong and dry winds have contributed to an active fire season." This statement includes the phenomenon of wind and is correctly classified as weather. Perhaps past misconceptions researchers did not consider winds to be a salient feature of weather and climate, and therefore, omitted wind from their research studies. However, we felt that the extended version of the DWCM should include wind and other weather and climate phenomena in order to explore the construct more fully (e.g., ocean currents, glaciers, topography, as well as precipitation and temperature).

We also developed the DWCM for use with a wide range of ages (middle school to adult). Therefore, we worded the DWCM items as unambiguous declarative propositions in the form of short simple statements without jargon (DeVellis, 2003). In the short form, the statements were easy to read, with the Flesch-Kincaid formula indicating readability was at or below the sixth grade level. A panel of three science

education experts and one climate scientist reviewed the extended version. The panel examined the extended DWCM for scientific accuracy and precision, comprehensibility and clarity, and face validity. We used all review comments to modify the longer form.

Forty-seven preservice elementary school teachers (Lombardi & Sinatra, 2011) and 98 middle school students (in a pilot study) have completed the extended DWCM. A one-way univariate analysis of variance revealed that the mean DWCM score for the preservice elementary teachers ($M = 25.1$, $SD = 3.83$) was significantly greater than middle school students ($M = 18.23$, $SD = 4.24$), $F(1,143) = 88.1$, $p < .001$, $\eta^2 = .38$ (note that the maximum score would be 35). The extended DWCM's coefficient alpha value for both groups combined was .72, which exceeds the acceptable reliability level (George & Mallery, 2009). The extended version of the DWCM is more reliable than the shorter version due to the increased length and associated additional sampling of the construct, as well as using a more heterogeneous sample (i.e., preservice elementary teachers and middle school students) (Osterlind, 2010). Finally, there is a strong association ($r = .73$, $p < .001$) between short version scores (i.e., the first 13 items of the form) and the remaining extended version items. This provides some evidence for concurrent validity the two versions of the DWCM.

Beliefs about Climate Change Evidence

To measure participants' beliefs about climate change evidence (BCCE), I developed a short 6-item instrument, with statements reflecting major observations of Earth's changing climate (Appendix D). For example, the first item says that "Global temperatures have increased over the past 100 years." These statements mirror those that were used in the climate change model-evidence link diagram (MEL) activity

experienced by treatment group participants only. Similar to the other instruments that I used in this dissertation study, the BCCE statements are unambiguous and declarative statements just below the grade 7 reading level. Participants rated each statement using a 5-point Likert scale gauging their level of agreement, ranging from 1 = strongly disagree to 5 = strongly agree. Note that this is different from the scale used in the knowledge instrument (HICCK), where students rated the degree to which they *thought* climate scientists would believe these statements. With the BCCE, participants indicated their own beliefs.

Perceptions of Model Plausibility and Correctness

Two items measured the comparative plausibility evaluation of Model A (human-induced climate change) and Model B (solar irradiance causing climate change), as well as which of the models participants perceived to be correct (see Appendix E). The first item, which measured comparative plausibility, uses the same 0–10 scale as the Plausibility Perceptions Measure (PPM), where 0 = greatly implausible or even impossible and 10 = highly plausible. To determine which model participants perceive to be correct, I used a five category scale, spanning from “very certain that Model A is correct” to “very certain that Model B is correct.” These two items are new for this study, with results used to test the potential interaction between the two models’ comparative plausibility weightings and perceived correctness (i.e., directly examining my second hypothesis). Participants completed these two items at the end of a one page text discussion of the two alternative models. These items and associated discussion are found in Appendix E.

Instructional Scaffold

The treatment group used the model-evidence link (MEL) diagram activity to promote critical evaluation and potential changes in participants' judgments about human-induced climate change (Appendix F). On the MEL, participants drew different types of arrows linking evidentiary data to the two alternative models of climate change (Model A: human-induced and Model B: solar irradiance). Participants drew arrows in different shapes to indicate the relative weight of the evidence. Straight arrows indicated that evidence supports the model; squiggly arrows indicated that evidence strongly supports the model; straight arrows with an "X" through the middle indicated the evidence contradicts the model; and dashed arrows indicated the evidence has nothing to do with the model.

I have conducted two pilot studies using different versions of the MEL. In the first pilot study, participants used a MEL with six evidence statements, and I examined changes in the knowledge about human-induced climate change (HICCK) scores, as well as perceptions of model plausibility and correctness. I used the nonparametric sign test to measure changes from preinstruction to postinstruction. Note that the nonparametric sign test was an appropriate analysis because of the relatively small sample size ($N = 35$) and the highly kurtotic nature of the examining within-subjects changes in pre- and post-HICCK scores, which are interval data, as well as model plausibility and perceived model correctness, which are ranked ordinal data (Nussbaum, 2011b). The null hypothesis for the sign test is that within-subjects' scores are the same at both preinstruction and postinstruction.

Results from this first pilot study showed significantly greater knowledge (HICCK) scores postinstruction compared to preinstruction, $z = -2.68, p = .007$. About 60% of the participants had a greater score postinstruction, with only 25% having a lower score postinstruction. The percentage difference between those that gained knowledge (60%) to those that and those that did not (25%) was appreciable (i.e., about 35%) indicating a large effect size. However, the sign tests for model plausibility ratings and perceived model correctness did not reveal significant differences preinstruction to postinstruction (all $ps > .7$).

The first pilot study results showing no advantage for plausibility ratings of the scientifically correct model higher was likely due to problems with the preliminary version of the MEL used. I suggest that the six evidences in the MEL may have resulted in cognitive overload as students attempted to critically evaluate the strength of each of the evidences supporting each model. Therefore, for the second pilot study I used a MEL with only four evidence statements, corresponding to items 3-6 in the beliefs about climate change evidence (BCCE) instrument. This version of the MEL is shown in Appendix F.

To analyze for differences in the second pilot study, I used the nonparametric Wilcoxon signed ranks test. Results of this test showed that both model plausibility ratings and perceived model correctness changed significantly from preinstruction to postinstruction. The difference in percentage of participants who rated the plausibility of the scientifically correct model greater (51%) from pre to post to those who rated the alternative model greater (22%) was 29%, $z = -2.86, p = .004$. The difference in percentage increase in participants who perceived the scientific model to be correct

(46%) to those who rated the alternative model greater (12%) was 34%, $z = -3.79$, $p < .001$. Based on these significant gains, the adjustments I made in the MEL may have reduced cognitive overload and allowed for clearer connections between evidentiary data and the models.

Procedures

Table 2 shows the timeline of instrument administration and the quasi-experimental activity. Details of these activities follow the table.

Table 2

Schedule of instrument administration and instructional activities

| Activity | Duration |
|--|-------------------|
| Preinstruction instrument administration <ul style="list-style-type: none"> • Plausibility Perceptions Measure (PPM) • Human-induced Climate Change Knowledge (HICCK) instrument • Distinctions between Weather and Climate Measure (DWCM) • Beliefs about Climate Change Evidence (BCCE) instrument • Ratings of model plausibility and correctness | Two class periods |
| Quasi-experimental phase (note that normal classroom instructors taught both the treatment and comparison groups) <ul style="list-style-type: none"> • Treatment group: Climate change model-evidence link (MEL) diagram activity • Comparison group: Normal instruction (Investigation 8 of the weather and climate module) | Two class periods |
| Postinstruction instrument administration <ul style="list-style-type: none"> • Plausibility Perceptions Measure (PPM) • Human-induced Climate Change Knowledge (HICCK) instrument • Distinctions between Weather and Climate Measure (DWCM) • Beliefs about Climate Change Evidence (BCCE) instrument • Ratings of model plausibility and correctness | Two class periods |

Preinstruction Phase

Two class periods prior to the instructional activity, participants completed the Plausibility Perceptions Measure (PPM), Human-induced Climate Change Knowledge

(HICCK) instrument, Distinctions between Weather and Climate Measure (DWCM), Beliefs about Climate Change Evidence (BCCE) instrument, and climate change model ratings of plausibility and perceived correctness.

Quasi-Experimental Phase

Participants in the treatment group engaged in a model-evidence link (MEL) diagram activity (Appendix F) that was taught by their regular classroom teacher. Part A of the activity is titled “How do scientists change their plausibility judgments.” This helped students understand how scientists weigh connections between evidence and scientific ideas (e.g., scientific models). Specifically, Part A asked students to rank the importance of the following four types of evidence connections in changing plausibility judgments:

1. The evidence supports an idea.
2. The evidence strongly supports an idea.
3. The evidence contradicts (opposes) an idea.
4. The evidence has nothing to do with the idea.

Note that these statements correspond to the four types of errors that the participants used when they developed their MELs (Part C).

After making their initial rankings, the students read a short paragraph discussing falsifiability, and specifically, how evidence that contradicts an idea has a large influence on how scientific knowledge changes. After reading this paragraph, students re-ranked the four types of evidence. At the end of Part A, teachers conducted a short discussion with the class on their rankings and directly reinforced that contradictory evidence generally does have the greatest weight in changing scientists’ plausibility judgments.

In Part B, the instructor had the participants individually read short (about one page) expository texts discussing each piece of evidence (Appendix F). These pages also included graphs and figures. The instructor asked the students if they had any questions about the evidence texts and figures to clear up any confusion or misunderstandings. In Part C, treatment group participants evaluated the four evidentiary statements and link them to each model using different arrows for the weighting scheme. Participants developed their MEL diagrams, completed their associated explanatory tasks, and then rated each model's plausibility and correctness individually.

Comparison group participants used instructional materials from *Integrating Earth Systems* (IES) Weather and Climate module (Smith, Southard, & Mably, 2002). The weather and climate module has eight investigations. I specifically used the Investigation 8, titled "How is Global Climate Changing," for the comparison activity. In this activity, comparison group participants were initially asked the following guiding questions: "Do you think the world's climate is changing? If so, what will happen in the future? What will the climate be like for you, your children, and your grandchildren?" Comparison group participants then read about evidence related to past and current climate change, and then make predictions about future climate change as a collaborative group.

The investigation was adapted so that comparison group participants would read and use the same four pieces of evidence used in treatment activity (see Appendix F). These evidence texts were used to answer questions throughout the investigation so that comparison group participants could evaluate these evidences. For example, two questions ask the participants to consider "What parts of the four evidences support your

final prediction? What parts of the four evidences do not support your final prediction?”

Whereas such questions are evaluative, Investigation 8 did not ask the participants to weigh evidence between two competing models. This is the critical difference between the comparison task and the treatment task (i.e., the MEL diagram activity). The time needed by comparison group participants to complete Investigation 8 was the same amount of time spent by the treatment group participants in the MEL diagram activity (i.e., two class periods).

Postinstruction Phase

At the end of the learning module, treatment and comparison group participants completed the same measures as in the pre instruction phase. One minor difference in post instruction measurement was that treatment group participants completed the two items measuring comparative plausibility and the model that participants think is correct at the end of the MEL diagram activity (see Appendix F). Comparison group participants completed these two items at the end of a one page text discussion of the two alternative models (i.e., the same instrument used in the preinstruction phases; see Appendix E).

CHAPTER 4

RESULTS AND ANALYSES

This chapter discusses the quantitative and qualitative analyses, with associated results, that I used to address this study's three research questions. As a reminder, research question 1 asked: Does explicit instruction designed to promote evaluation of competing climate change theories—specifically, human-induced climate change (i.e., the scientifically accurate model; Intergovernmental Panel on Climate Change, 2007) versus an increasing amount of solar energy received by Earth (i.e., a popular model used by skeptics of human-induced climate change; Cook, 2010; Ellis, 2009)—result in changes to (a) plausibility perceptions of climate change, (b) knowledge of human-induced climate change, (c) understanding of weather and climate distinctions, and (d) beliefs about climate change evidence? My hypotheses for research question 1 were the following:

- H_{1A} : explicit instruction promoting critical evaluation of the two climate change models (i.e., instructional use of model-evidence link diagrams) will result in increased plausibility perceptions about human-induced climate change.
- H_{1B} : increases in plausibility perceptions will result in a greater degree of conceptual change about human-induced climate change, weather and climate distinctions, and beliefs about climate change evidence.

Research question 2 asked: What is the relationship between students' comparative plausibility perceptions of competing climate change theories (human-induced climate change versus increased solar energy output) and their perceptions about

which of these theories they think is correct, and how does this relationship change with instruction? My hypotheses for research question 2 were the following:

- H_{2A} : Even though students may consider competing climate change theories to be plausible, the one with the greater plausibility will correspond to the theory that students think is correct.
- H_{2B} : Students who use the instructional scaffold will rank the plausibility of the scientifically accepted conception (human-induced climate change) higher than the alternative conception (increasing solar irradiance).

Research question 3 asked: Are model plausibility ratings of these two competing climate change theories related to the seven responses theorized by Chinn and Brewer (1993) as ordered categories (i.e., very low plausibility is associated with ignoring and rejecting data and high plausibility is associated with individual theory change)? My hypothesis for research question 3 was the following:

- H_3 : There will be a discernible relationship between model plausibility ratings and response to anomalous incoming information. Prior to detailing the results and analyses for these three research questions, I describe the study participants.

Participants

One hundred sixty nine ($N = 169$) grade seven students fully participated in this study. These participants were from an available pool of 429 students enrolled in grade 7 science at a public middle school located in the southwestern United States. I invited all 429 to participate in the study, but only 63% ($N = 269$) of the students provided both parental consent and self-assent. Of those providing assent and consent, just under two-

thirds ($N = 169$) fully participated in the study, where I defined “full participation” as being present for the study’s instructional activities and completing instruments in a manner that allowed me to ascertain meaningful information (e.g., ensuring the a participant’s name was on a questionnaire and that a participant did not leave many blank items on a questionnaire).

Participants reflected the demographics of their school, which is located in a large, urban school district of predominantly Hispanic ethnicity. About 64% of the participants were Hispanic ($N = 108$), with 17% White ($N = 29$), 11% African American ($N = 19$), and 7% Asian/Pacific Islander ($N = 13$). Just over half ($N = 87$, 51.5%) of the participants were male. Furthermore, about 11% ($N = 18$) of the participants had individualized education plans, 22% ($N = 36$) had limited proficiency in the English language, and 47% ($N = 79$) were eligible for free or reduced-cost lunch.

The participants were enrolled in science classes taught by four different teachers. Three of the these teachers taught four grade 7 science classes and one teacher taught two grade 7 science classes. I randomly assigned participants to the treatment and comparison groups at the class level, with an even number of treatment and comparison classes taught by each teacher (i.e., three of the teachers taught two treatment classes and two comparison classes, and the other teacher taught one treatment class and one comparison class). The total number of participants in the treatment classes ($N = 86$) was nearly equal to the number in the comparison classes ($N = 83$).

Analyses of Research Questions 1 and 2: Pre to Postinstruction Changes

Of the three research questions that motivated this dissertation study, research questions 1 and 2 related to participants’ changes from pre to postinstruction. Whereas

the analyses differ for the two research questions, the data for both questions are the same; therefore, the following section covers both research questions 1 and 2, and specifically, the changes that occurred in these variables from pre to postinstruction. This section first details the preliminary data analyses. I then discuss analyses that I used to determine group (treatment and comparison) differences pre to postinstruction. Finally, I demonstrate how these differences relate to the nature of the instructional activities and not to individual effects from the classroom teachers.

Preliminary Data Analysis

Data outliers. I used Mahalanobis distance to calculate multivariate outliers, which is a multidimensional measure representing the distance of a particular case from the centroid of all variables and other cases (Tabachnick & Fidell, 2007). Mahalanobis distance values for all but two cases were from 1.3 to 18.9. However, two cases were separated from the others with relatively high Mahalanobis distances of 24.2 and 22.3. According to Tabachnick and Fidell (2007), “Mahalanobis distances at $p < .001$...are evaluated using χ^2 with degrees of freedom equal to the number of variables” (p. 99). For this analysis there were four dependent variables, measured at pre and postinstruction, yielding a $df = 8$ and a critical $\chi^2(8) = 26.13$. Therefore, these two cases were not multivariate outliers. There were also no univariate outliers in any of the cases (i.e., z -values for all variables and participants were less than an absolute value of 3).

Reliability of instrument scores. I used classical test theory to inform my evaluation of reliability in participants’ scores of plausibility perceptions of climate change (PPM), knowledge of human-induced climate change (HICCK), understanding of weather and climate distinctions (DWCM), and beliefs about climate change evidence

(BCCE). In this way, I conceptualized reliability as an important component of validity evidence based on Osterlind's (2010) premise that reliability is "properly interpreted only in the framework of a particular" measure (p. 123).

I calculated coefficient alpha values for all measures pre- and post-activity to ascertain reliability. Coefficient alpha values for the DWCM and BCCE were unacceptable (i.e., well below the .5 threshold; George & Mallery, 2009), with all < 0.41 both pre and postinstruction. Therefore, I excluded these measures from the remainder of the analyses because scores measured by these instruments do not reliably reflect student understanding of weather and climate distinctions or beliefs about the climate change evidence. Without a reliable estimate of these constructs, further analysis and subsequent conclusions would not have validity.

The coefficient alpha value for the PPM was .51, preinstruction, which is a marginal value. However, the postinstruction PPM alpha value was .71, a value that exceeds the acceptable threshold of .7 (George & Mallery, 2009). The marginal reliability prior to the activity may have been due to the sensitivity of the coefficient alpha calculation to homogeneity of the participants (Thompson, 2003). The 7th grade participants in this study probably had limited understanding of the meaning of plausibility prior to instruction because this word is typically introduced formally into the lexicon (i.e., via instruction) in the middle school grades (see, for example, Snow, 2010). Therefore as a sample, participants may have been homogeneous in their limited experience with the concept of plausibility judgments, and therefore, responded somewhat randomly. The participants became more familiar with plausibility judgments while completing subsequent preinstructional instrumentation and engaging in the study's

instructional activities. As students became more familiar with plausibility judgments, reliability increased. I will discuss the potential implications of the marginal preinstruction PPM reliability later in this chapter.

Preinstruction coefficient alpha values for the HICCK were initially equal to .37. However, removing seven items (specifically, Items 5, 8, 9, 10, 26, 29, and 33; see Appendix B), increased coefficient alpha values to .58. Furthermore, with these seven items removed, postinstruction coefficient alpha values for the HICCK were .71, again above the acceptable threshold. Following the same argument that I have made with the PPM above, the HICCK appears to be a reliable measure of participants' developing understanding of human-induced climate change with these seven items removed. Furthermore, removal of these seven items had little impact on measurement of participants' understanding of human-induced climate change. Items 5 and 10 are very similar to items 21 and 22; therefore removal of item 5 and 10 did not result in a reduction of full construct examination. Items 8 and 9 are only peripherally aligned with the concept of climate change. Items 26, 29, and 33 represent sophisticated and subtle aspects of climate change knowledge that require understanding and experiences that are likely well-beyond the grade 7 level. Therefore, removal of items 8, 9, 26, 29, and 33 did not prevent examination of participants' basic understanding of human-induced climate change.

I calculated perceptions of relative model plausibility as the difference between participants' plausibility ratings of Model A and Model B (i.e., the difference in perceived plausibility between human-induced and Sun-induced climate change). Recall that as a working definition, I view plausibility as a judgment on the *relative potential*

truthfulness, and therefore, the difference in plausibility ratings is appropriate when looking at relationships involving conceptual change. In terms of reliability, model plausibility perceptions are only two items and calculation of model plausibility score reliability would have little meaning. Likewise, model correctness perception is a single item and classical reliability calculations are not meaningful.

Bivariate correlations. Table 3 shows Pearson bivariate correlations between all the measures, both pre and postinstruction. For all but model correctness perceptions, there were medium to large positive correlations ($r = .3$ to $.6$; Cohen 1988) within a specific variable pre to postinstruction (e.g., model plausibility perceptions preinstruction were significantly correlated to model plausibility perceptions post), with all p -values less than $.01$. Model correctness perceptions had a small to medium positive correlation ($r = .24, p < .01$) pre to postinstruction.

Table 3

Bivariate Correlations for the Study Variables (N = 169)

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|-----------------|-------|-------|-------|-------|-------|-------|-------|---|
| 1. Mplaus-pre | — | | | | | | | |
| 2. Mplaus-pst | .30** | — | | | | | | |
| 3. Mcorrect-pre | .73** | .20** | — | | | | | |
| 4. Mcorrect-pst | .25** | .71** | .24** | — | | | | |
| 5. HICCK-pre | .26** | .12 | .18* | .26** | — | | | |
| 6. HICCK-pst | .22** | .28** | .17* | .32** | .55** | — | | |
| 7. PPM-pre | .25** | .23** | .20** | .31** | .40** | .38** | — | |
| 8. PPM-pst | .26** | .28** | .26** | .29** | .47** | .44** | .52** | — |

* $p < .05$, ** $p < .01$

Note. Mplaus-pre = perceptions of model plausibility preinstruction; Mplaus-pst = perceptions of model plausibility postinstruction; Mcorrect-pre = perceptions of model correctness preinstruction; Mcorrect-pst = perceptions of model correctness postinstruction; HICCK-pre = knowledge of human-induced climate change preinstruction; HICCK-pst = knowledge of human-induced climate change postinstruction; PPM-pre = plausibility perceptions about climate change preinstruction; PPM-pst = plausibility perceptions about climate change postinstruction.

Small to large positive correlations ($r = .2$ to $.7$) existed between the preinstruction variables (e.g., model plausibility perceptions preinstruction were significantly correlated to model correctness perceptions pre), with all p -values less than .01. Similarly, medium to large positive correlations ($r = .3$ to $.7$) existed between the postinstruction variables, with all p -values less than .01. The only non-significant correlation existed between model plausibility perceptions postinstruction and knowledge of human-induced climate change scores preinstruction, with $p > .05$. Furthermore, no bivariate correlations exceeded a value of 0.8, which reduced the possibility of multicollinearity (i.e., that variables were redundant measures of each other).

This correlation analysis partially addresses the first part of question 2 (i.e., what is the relationship between students' comparative plausibility perceptions of competing climate change theories). A significant and strong relationship existed among participants' perceptions of model plausibility and correctness prior to instruction ($r = .73, p < .01$) and after instruction ($r = .71, p < .01$).

Group Differences Pre to Postinstruction

Table 4 shows the means and standard deviations for perceptions of model plausibility (Mplaus) and model correctness (Mcorrect), knowledge of human-induced climate change (HICCK), and plausibility perceptions of climate change (PPM). The table shows means and standard deviations by time period (pre and postinstruction), as well as group (treatment and control).

Table 4

Means and Standard Deviations (in Parentheses) for the Study Variables ($N_{treatment} = 86$, $N_{comparison} = 83$, $N_{total} = 169$)

| Variable | Group | Preinstruction | Postinstruction |
|----------|------------|----------------|-----------------|
| Mplaus | Treatment | -0.30 (3.99) | 1.60 (2.82) |
| | Comparison | 0.04 (3.85) | -0.19 (3.61) |
| | Total | -0.14 (3.91) | 0.72 (3.34) |
| Mcorrect | Treatment | 2.97 (1.35) | 3.79 (0.97) |
| | Comparison | 3.11 (1.24) | 2.90 (1.17) |
| | Overall | 3.04 (1.30) | 3.36 (1.16) |
| HICCK | Treatment | 92.3 (8.65) | 95.5 (10.1) |
| | Comparison | 91.5 (8.27) | 90.7 (8.84) |
| | Overall | 91.9 (8.45) | 93.2 (9.77) |
| PPM | Treatment | 53.8 (8.94) | 55.4 (9.38) |
| | Comparison | 51.0 (9.40) | 53.4 (10.8) |
| | Overall | 52.4 (9.25) | 54.4 (10.1) |

Note. The possible score ranges were: (a) perceptions of model plausibility (Mplaus) = -9 to +9; (b) perceptions of model correctness = 1 to 5; (c) knowledge of human-induced climate change (HICCK) = 34 to 170; and (d) plausibility perceptions of climate change (PPM) = 8 to 80.

Assumptions testing. To address research questions #1 and 2, I performed a repeated measures multivariate analysis of variance (MANOVA) to assess changes pre to postinstruction, with group (treatment and comparison) as the between-subjects variable, time (pre and postinstruction) as the within-subjects variable, and Mplaus, Mcorrect, HICCK, and PPM as the dependent variables. To gauge applicability of the normality assumption inherent in MANOVA designs, I examined outliers (as discussed earlier), as

well as skewness and kurtosis values. All skewness and kurtosis values were less than an absolute value of 1.1, and with no outliers in the data, the normality assumption was held.

I also examined the basic MANOVA assumptions of linearity and homogeneity of the variance-covariance matrices. Scatterplots for pair combinations of the dependent variables did not reveal any concern regarding linearity. Similarly, scatterplots of standardized residuals for each of the dependent variables revealed no concerns regarding linearity. This analysis also met the assumption of homogeneity of the variance-covariance matrices based on Box's *M* test, with $F(36, 93595) = 1.49, p = .029$ (a *p*-value greater than .001 indicates homogeneity with the relatively conservative Box's *M* test; Tabachnick & Fidell, 2007).

Potential class effects. Individual participants were nested in classrooms creating possible statistical dependencies among students within these classrooms. For example, the possibility existed that participants in one classroom talked to each other about the topic more than another classroom. I therefore calculated the intra-class correlations (ICC) to ascertain levels of statistical independence among the observations. I specifically calculated the ICC for each of the four dependent variables retained in the study: perceptions of model plausibility (Mplaus), perceptions of model correctness (Mcorrect), knowledge of human-induced climate change (HICCK), and plausibility perceptions of climate change (PPM). The ICC "describes the...similarity of individuals within a group compared to the similarity of people belonging to different groups" (Cress, 2008, p. 73). Therefore, the ICC measures potential classroom effects because a high absolute ICC value would indicate that participants in a particular classroom setting (i.e., participants clustered by teacher) have relatively strong within-group dependency.

In addition to phenomena such as teacher effects, ICC can be used to ascertain the effects of participation in collaborative groups (Cress, 2008).

A common way to determine ICC is to calculate the proportion of variance explained by group membership. Kashy and Kenny (2000) developed the following formula for calculating ICC using one-way analysis of variance (ANOVA) parameters:

$$ICC = \frac{MS_B - MS_W}{MS_B + (m - 1)MS_W}$$

where MS_B is the mean sum of squares between cluster groups, MS_W is mean sum of squares within, and m is the cluster size. When clusters are unequal in size, Kashy and Kenny advise using the mean cluster size for m . To determine the p -value for the calculated ICC (i.e., to ascertain whether potential cluster effects are significant), Kashy and Kenny recommend using Fisher's r -to- z transformation (Fisher, 1928), replacing the Pearson bivariate correlation (r) with the calculated ICC value, using this value and the mean cluster size to calculate the test statistic (z), and then determining the p -value from the test statistic.

Table 5 shows the ICC values that I calculated for the four dependent variables (all using postinstruction scores), with associated one-way ANOVA parameters (with teacher as the independent variable category) and calculated z - and p -values. The ICC values ranged from .00024 (Mcorrect) to .17 (PPM), with all p -values greater than .4. Cress (2008) states that “only if the ICC is significant must a multilevel model be used...so, if the ICC is not significant, we can apply a standard regression without any concern, because there is no group effect in the data” (p. 79). Furthermore, only ICC values greater than or equal to .2 are generally considered large enough to require multilevel modeling in educational research (Snijders & Bosker, 1999). Therefore

because all dependent variables had no significant ICC values and were less than .2, the participants in a particular teacher cluster did not have significantly greater similarity than the overall similarities in the treatment and comparison groups; thereby indicating that potential differences between the treatment and comparison groups (see subsequent analyses in this section) are most likely the result of the study's instructional activities and are not due to potential classroom effects. In other words, this analysis supports the assumption in ordinary-least squares analyses, such as repeated measures MANOVA, of independence in observations.

Table 5

Intra-class Correlation Coefficient (ICC) Values for the Study Variables Clustered by Teacher, with $N_{teacher} = 4$, and m (Mean Cluster Size) = 21.13

| Variable | MS_B | MS_W | ICC | z | p -value |
|----------|---------|--------|--------|--------|------------|
| Mplaus | 5.218 | 8.035 | 0.0169 | 0.0719 | 0.943 |
| Mcorrect | 0.939 | 0.944 | 0.0003 | 0.0011 | 0.999 |
| HICCK | 285.827 | 95.317 | 0.0864 | 0.3689 | 0.714 |
| PPM | 401.781 | 76.481 | 0.1676 | 0.7203 | 0.473 |

Note. Mplaus = perceptions of model plausibility; Mcorrect = perceptions of model correctness; HICCK = knowledge of human-induced climate change; PPM = plausibility perceptions about climate change; MS_B = mean sum of squares between clusters; and MS_W = mean sum of squares within.

Multivariate effect. The repeated measures MANOVA revealed a significant interaction between group and time for the combined scores of perceptions of model plausibility and model correctness, knowledge of human-induced climate change, and plausibility perceptions of climate change, with $F(4,164) = 7.76, p < .0001$. There was also a medium to large effect size, with $\eta_p^2 = .16$ (Tabachnick & Fidell, 2007).

Follow-up univariate analyses on significant interaction effects. Follow-up univariate analyses of variance indicated that interactions between time and group were significant for perceptions of model plausibility, $F(1,167) = 10.89, p = .001, \eta^2 = .061$ (small to medium effect size); perceptions of model correctness, $F(1,167) = 21.90, p < .0001, \eta^2 = .12$ (medium to large effect size); and knowledge of human-induced climate change $F(1,167) = 9.26, p = .003, \eta^2 = .053$ (small to medium effect size). There was no significant interaction between group and time with participants' plausibility perceptions of climate change, with $p = .57$. These three analyses were run concurrently, and to properly account for family-wise error, I used a Bonferroni adjusted critical value ($\alpha = .013$) as a conservative gauge of significance.

Simple effects analyses. For the three variables that showed a significant interaction in the follow-up univariate tests, I conducted an additional simple effects analysis to determine the exact nature of the group differences at both preinstruction and postinstruction. There were no significant differences preinstruction between the treatment and comparison groups in any of the three variables, with all p -values $> .47$. However at postinstruction, treatment group scores were significantly greater than the comparison group scores in all three variables, with $F(1, 167) = 13.09, p < .001, \eta^2 = .073$ (medium effect size) for participants' perceptions of model plausibility; $F(1, 167) = 28.99, p < .0001, \eta^2 = .15$ (medium to large effect size) for perceptions of model correctness; and $F(1, 167) = 10.67, p = .001, \eta^2 = .060$ (small to medium effect size) in scores of knowledge of human-induced climate change.

The simple effects analysis also showed that there were no significant differences in any of the comparison group scores, pre to postinstruction, with all p -values $> .19$.

However when comparing each variable from preinstruction to postinstruction, the treatment group has statistically greater scores in perceptions of model plausibility and correctness, and knowledge of human-induced climate change (all p -values < .001; see Table 4 for means and standard deviations, as well as graphical representations of means in Figures 4 through 6).

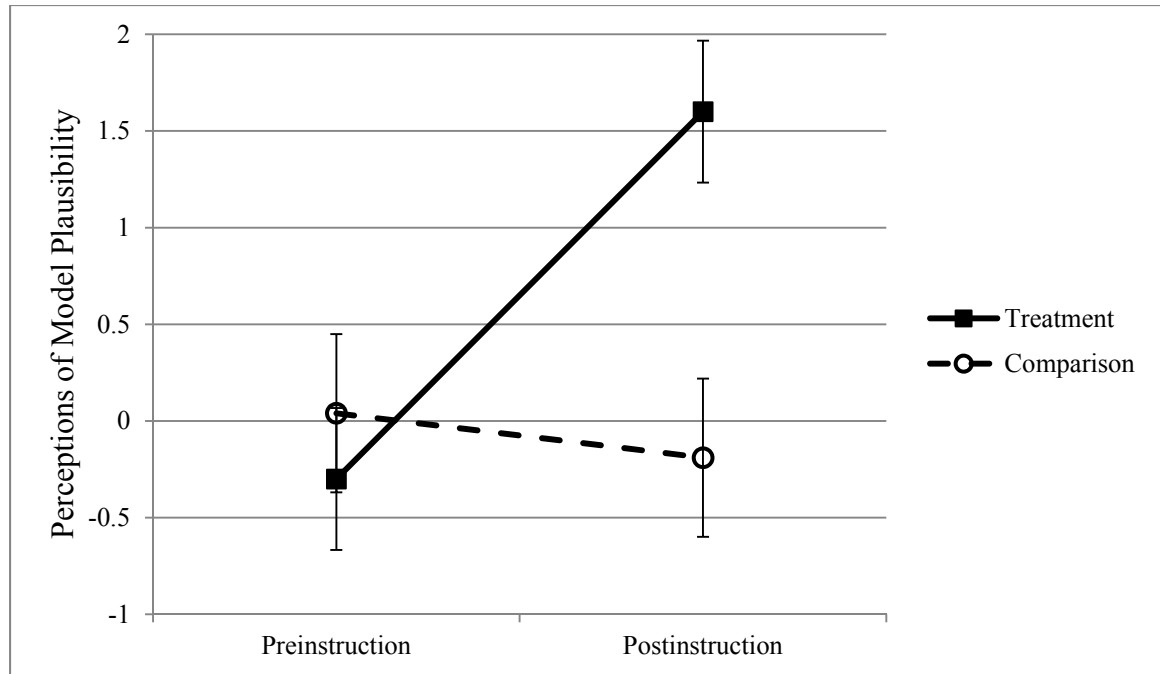


Figure 4. Pre to postinstruction scores of model plausibility perceptions for the treatment and comparison groups, with bars showing standard errors.

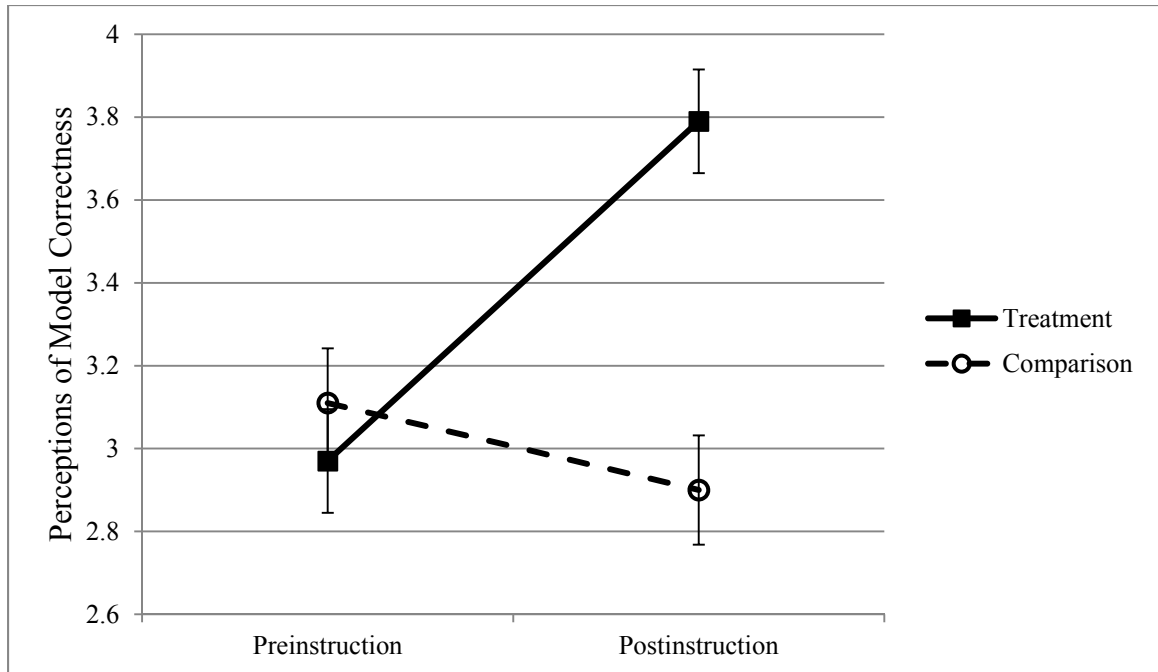


Figure 5. Pre to postinstruction scores of model correctness perceptions for the treatment and comparison groups, with bars showing standard errors.

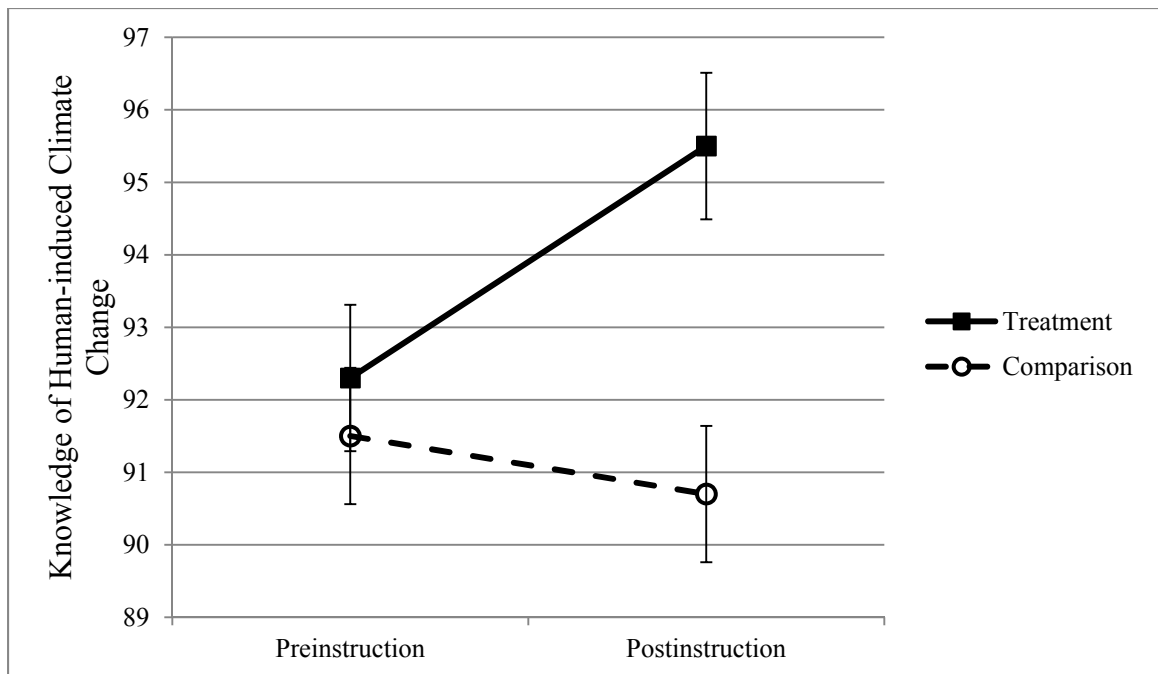


Figure 6. Pre to postinstruction knowledge of human-induced climate change (HICCK) scores for the treatment and comparison groups, with bars showing standard errors.

Main effects analysis. Whereas the interaction between time and group was not significant for plausibility perceptions of climate change (PPM, with $p = .57$), there was a significant main effect with time, $F(1,167) = 7.28$, $p = .008$, $\eta^2 = .042$ (small to medium effect). As shown in Table 4 and Figure 7, all participants had significantly greater PPM scores postinstruction than at preinstruction.

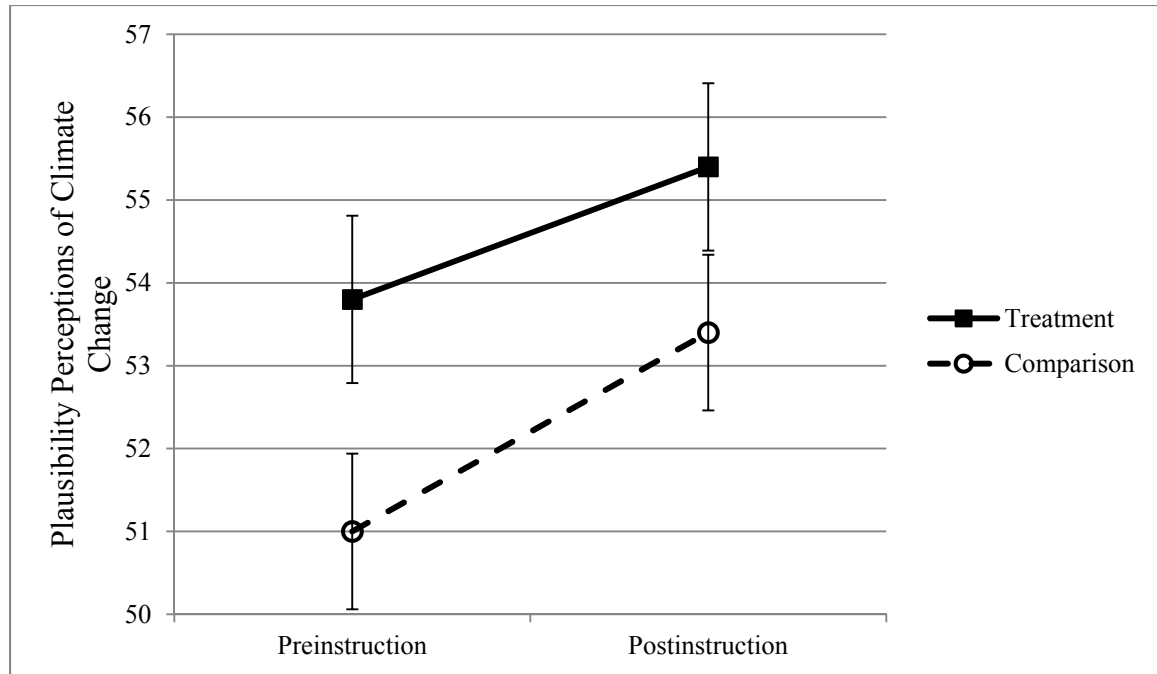


Figure 7. Pre to postinstruction scores of plausibility perceptions of climate change (PPM) for the treatment and comparison groups, with bars showing standard errors.

One potential reason for the lack of interaction between the treatment and comparison groups may be the marginal reliability of PPM scores at preinstruction. Lower reliability could mean greater attenuation of scores at preinstruction, and therefore, relatively greater error in measurement. With greater error, potential differences between the treatment and comparison groups are harder to ascertain.

Another reason for a lack of interaction may be due to the breadth of the PPM's statements relative to the instructional activities. For example, one item specifically asked participants to measure the plausibility of the statement saying, "Human caused global warming will lead to some impacts that are abrupt or irreversible, such as massive polar ice melt." Such a statement reflects the notion of a "tipping point," where Earth cannot easily return back to its earlier condition. Both the treatment and comparison instructional activities focused on causes of current climate change and not future impacts. Because the PPM measured plausibility perceptions of a wider range of climate change issues, it is possible that the effects of the treatment activity may have not been precisely measured. It is also possible that instruction promoting critical evaluation of future climate change impacts, which would directly follow the MEL activity used in this study, could lead to greater increases in overall plausibility perceptions of climate change as measured by the PPM. Such a sequence of instruction may therefore result in an interaction in a future follow up study to this dissertation.

Focused Analyses Related to Questions 1 and 2

An overall purpose of this study is to examine conceptual change and epistemic conceptual change through plausibility reappraisal. The following two analyses provide a focused look at these two phenomena.

Indicators of conceptual change. Conceptual change involves reconstructing cognitive knowledge structures. Teachers often desire to transform preexisting conceptions that are inconsistent with scientific understanding (often referred to as misconceptions) into those that are consistent with scientifically accepted knowledge. In this study, the knowledge of human-induced climate change (HICCK) instrument

measured participants' understanding about the causes of climate change, and as I discussed above, treatment group participants experienced a significant change in understanding from pre to postinstruction, whereas comparison group participants did not. Inasmuch as overall HICCK scores showed a transformation in treatment participants' understanding and may have represented significant conceptual change, six of the items on the HICCK directly examined knowledge about the causes of current climate change and the potential for a conceptual shift in understanding about these causes. One of these items reflected the scientific model that humans are the current cause of climate change (i.e., the correct conception). The other five items looked at misconceptions about the causes of climate change; i.e., current climate change is caused by (a) an increase in the Sun's energy, (b) the ozone hole, (c) changes in Earth's orbit around the Sun, (d) volcanic eruptions, and (e) increasing dust in the atmosphere (Choi et al., 2010).

Figure 8 shows how participants changed their conceptions on these six items, pre to postinstruction. Change is shown for the treatment and comparison groups for each item and is expressed as the mean gain score (mean postinstruction score minus mean preinstruction score). The treatment group had positive gains scores on all six items; however these gains were only significant on two items as measured by dependent measures *t*-tests. On the item measuring understanding of the scientific model, postinstruction scores ($M = 3.70$, $SD = .94$) were significantly greater than preinstruction scores ($M = 3.28$, $SD = 1.24$), $t(85) = -2.75$, $p = .007$, (Cohen's $d = .30$, a small effect size; Cohen, 1988). This result shows that treatment group participants' experienced significant conceptual change toward a view that is consistent with that of climate

scientists. Treatment group participants also had significantly greater postinstruction scores ($M = 3.16$, $SD = 1.17$) on the item measuring the misconception that climate change is caused by variations in Earth's orbit around the Sun, $t(85) = -2.74$, $p = .007$ (Cohen's $d = .29$, a small effect size), compared to preinstruction scores ($M = 2.76$, $SD = 1.20$). For this misconception, a greater score indicates both a greater understanding and a lesser degree of misunderstanding. Therefore, in the case of variations in Earth's orbit around the Sun, treatment group participants significantly lessened their misconceptions, again indicating the occurrence of conceptual change.

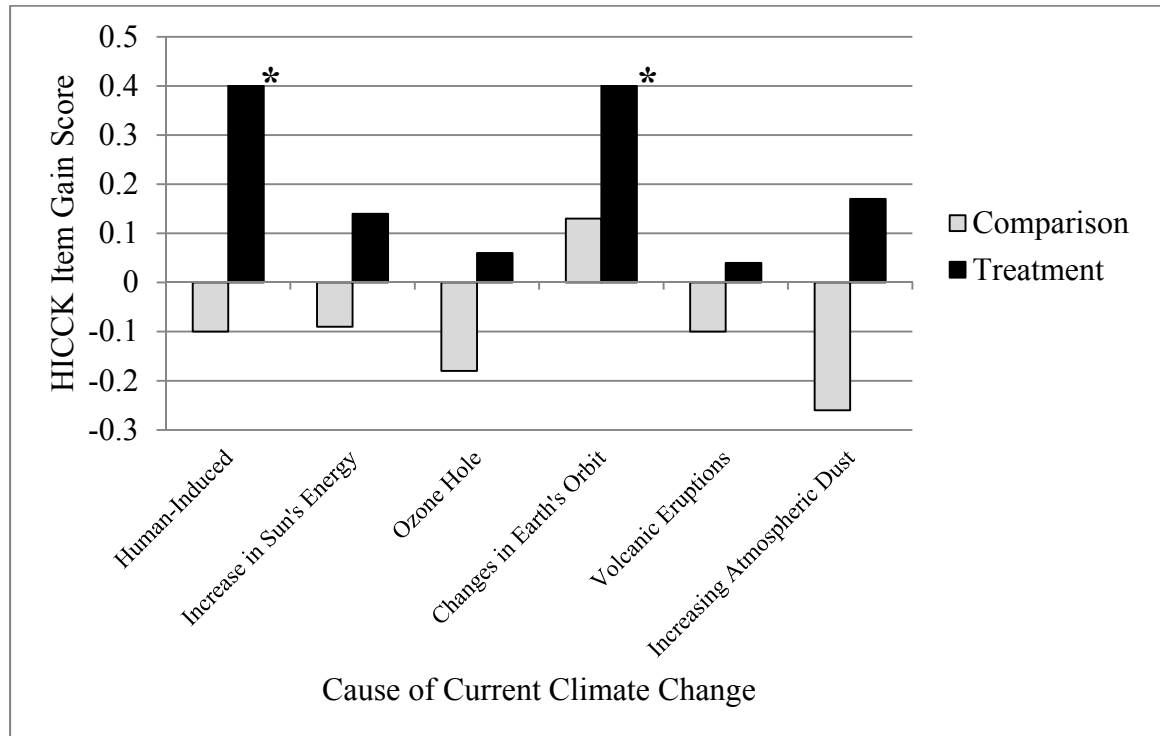


Figure 8. Gain scores (postinstruction – preinstruction) on six items from the knowledge of human-induced climate change (HICCK) instrument relating to causes of current climate change. The two treatment group gain scores with an asterisk (*) are statistically significant gains scores (assuming $\alpha = .05$), with both p -values = 0.007.

None of the other postinstruction gains made by treatment group participants were statistically significant for preinstruction, with all p -values $> .19$. Of particular interest is that treatment group participants did not show conceptual change about the misconception that current climate change is caused by increasing energy from the Sun, (i.e., the alternative model in the treatment activity). The question directly asked participants if “current climate change is caused by an increase in the Sun’s energy.” Whereas treatment group participants showed changes in plausibility and correctness perceptions away from this model, this alternative may still have seemed to be at least a partial cause of current climate change because participants’ understood (correctly) that the Sun is the primary energy source for Earth’s climate. Of course with the treatment activity only being a relatively short intervention and representing a single science lesson, I did not anticipate appreciable conceptual change in all areas of understanding. Likewise, it is interesting to note that treatment group participants did experience change about the misconception of Earth’s orbit, revealing that they were refining their understanding of the Sun’s role in global climate.

Comparison group participants had negative gain scores on all but one of the items. However, these negative gains were not significantly different pre to postinstruction.

Indicators of epistemic conceptual change. Participants’ reappraisal of plausibility judgments is an indicator of epistemic conceptual change, which is the transformation from less-sophisticated thinking that is absolute or subjective to scientific thinking based on critical evaluation. As discussed above, results from the repeated measures MANOVA show that treatment group participants reappraised their perceptions

of model plausibility, whereas comparison group participants did not. These results also show that both treatment and comparison group participants experienced changes to their overall plausibility perceptions of climate change as measured by the plausibility perceptions measure (PPM). Specifically, the PPM measures participants' plausibility perceptions about (a) evidence for current climate change (first two items), (b) connection between current climate change and human activities (next three items), and (c) future impacts of climate change (last three items). In order to gain a better understanding of the difference in plausibility perceptions between the treatment and comparison groups, I examined responses for each item on the PPM.

Figure 9 shows changes in the eight PPM items, pre to postinstruction. Similar to Figure 8, change is shown as the mean gain score (mean postinstruction score minus mean preinstruction score). The treatment group had positive gain scores for items 1, 3, 4, 6 and 8, with slightly negative scores on items 2 and 5, and a greater magnitude of negative gain on item 7. The comparison group had positive gain scores on items 1, 2, 3, 4, 5, and 6, with a slightly negative gain on item 8, and a greater magnitude of negative change on item 7.

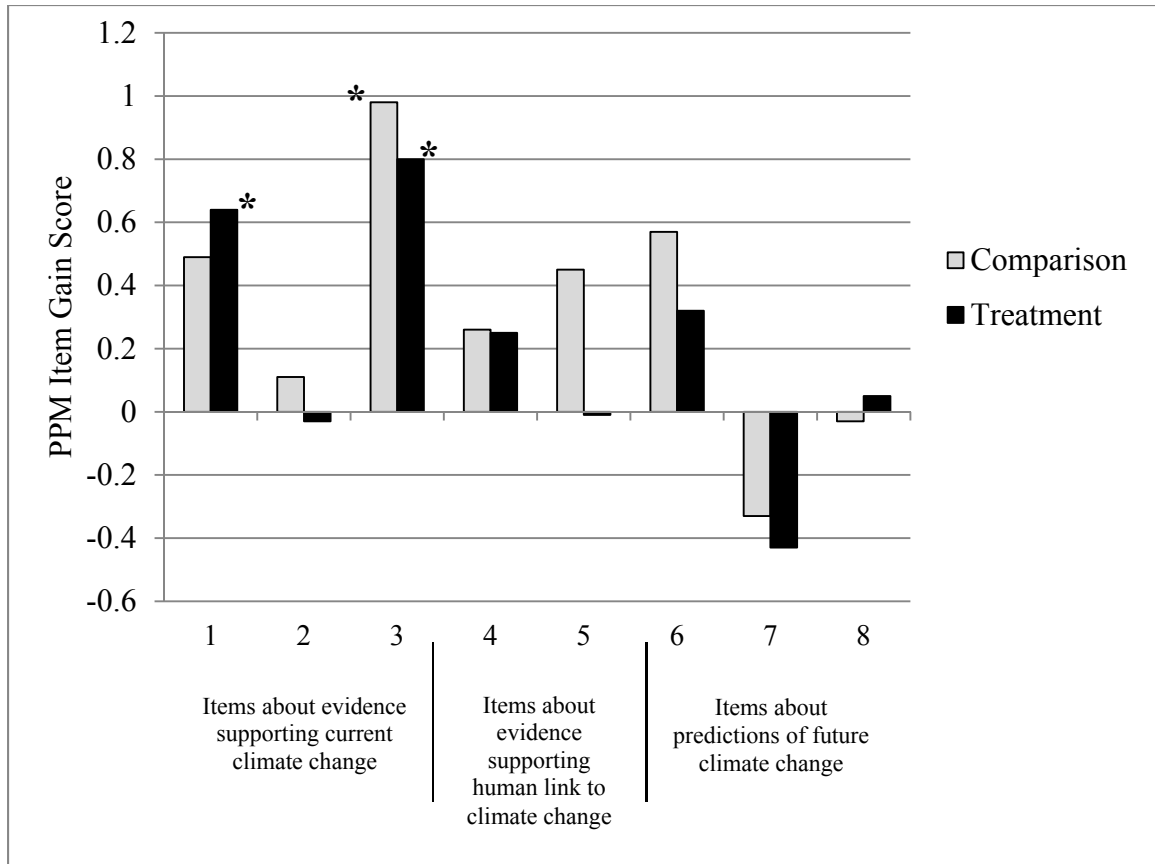


Figure 9. Gain scores (postinstruction – preinstruction) on eight items from the plausibility perceptions measure (PPM). The two treatment group and one comparison group gains scores with an asterisk (*) are statistically significant gains pre to postinstruction (assuming $\alpha = .05$), with all p -values ≤ 0.017 .

I conducted a dependent measures t -test for each item to determine statistically significant differences in each item pre to postinstruction. Treatment group participants had significantly greater postinstruction scores on item 1 ($M = 8.00$, $SD = 1.94$) compared to preinstruction scores ($M = 7.36$, $SD = 2.18$), with $t(85) = -2.43$, $p = .017$ (Cohen's $d = .26$, a small effect size; Cohen, 1988). This item asks participants to rate the plausibility of the statement that Earth is warming, with rising air and ocean temperatures, melting glaciers, and rising sea level evidence of this warming. Unlike comparison group

participants who did not experience significantly greater plausibility perceptions of this item pre to postinstruction ($p = .093$), treatment participants showed significant changes in plausibility perceptions about evidence of current climate change. The treatment activity had participants weigh evidence-to-model connections and may have resulted in plausibility reappraisal.

For item 3, both treatment ($M = 7.57$, $SD = 1.81$) and comparison group ($M = 6.82$, $SD = 2.18$) participants had significantly greater postinstruction scores compared to preinstruction scores (treatment : $M = 6.77$, $SD = 2.48$; and comparison: $M = 5.84$, $SD = 2.52$), with treatment $t(85) = -2.47$, $p = .015$ (Cohen's $d = .27$, a small effect size; Cohen, 1988) and comparison $t(82) = -1.70$, $p = .017$ (Cohen's $d = .37$, also a small effect size). Item 3 asked participants to rate the plausibility that concentrations of greenhouse gases are increasing in Earth's atmosphere and human industry has caused these increases, which is perhaps the least controversial of the items. Therefore it is not surprising that both the treatment and comparison group participants found this significantly more plausible, especially because both groups engaged with evidence that discussed these increased emissions. Participants also did not have significantly greater postinstruction scores on items 2, 4, 5, 6, 7 and 8, with all p -values $> .10$.

These results show that the only significant changes occurred with the items examining the plausibility perceptions about evidence of current climate change (treatment group only) and that humans are increasing greenhouse gas concentrations in the atmosphere (both groups). However, there was no significant change in items 4 and 5, which measure the plausibility perceptions that link humans to current climate change. This is somewhat surprising because treatment group participants showed a significant

shift in plausibility perceptions toward the scientifically accepted model of human-induced climate change. The last three items measure plausibility perceptions of future climate change, which was not the topic of this study. Finally as a reminder, PPM scores at preinstruction were of marginal reliability. This may attenuate preinstruction scores, increase potential error, and therefore make it more difficult to determine differences in individual items from pre to postinstruction.

Analysis of Research Question 3: Results of the Plausibility Judgment

Research question 3 asks about the association between participants' plausibility reappraisal (i.e., the postinstruction plausibility judgment) and their psychological response to anomalous data, as theorized by Chinn and Brewer (1993). These responses fall into seven categories relating to how individuals respond "when they encounter scientific information that contradicts their" preinstructional theories (Chinn & Brewer, 1993, p. 1) and are:

1. ignore the anomalous data;
2. reject the anomalous data;
3. exclude the data from the domain to the preinstructional theory;
4. accept the data, but hold the data in abeyance;
5. accept and reinterpret the data while retaining the preinstructional theory;
6. accept and reinterpret the data while making peripheral change to the preinstructional theory; and
7. accept the data and change their preinstructional theory.

In this section, I present the results of my coding analysis and the subsequent development of a rubric to score treatment group participants' written explanations. I

then discuss the results of the scoring and associations between the variables that emerged from the coding analysis.

Content Analysis of Written Explanations

To address research question 3, I specifically examined the explanatory task responses generated by treatment group participants at the end of the model-evidence link (MEL) diagram activity (see Appendix F). This task asked the participants to select three (out of a possible eight) evidence-to-model links that they had made on their MEL diagram. In their explanations, participants identified each end of the link, with an evidence (numbered 1, 2, 3, or 4; see Appendix F) at one end and the model (A: human-induced model of climate change or B: sun-induced model of climate change) at the other. Participants then wrote their judgment about the weighting of link's strength between an evidence and a model (i.e., the evidence *strongly supports* the model, the evidence *supports* the model, the evidence *has nothing to do with* the model, or the evidence *contradicts* the model). The participants also provided a justification for their weighting of link strength, starting with the provided prompt "because." For example, a full explanation from one participant said that "Evidence #1 strongly supports Model A because atmospheric greenhouse gases have been rising for the past 50 years because of humans."

I conducted a content analysis to examine participants' explanations, which is a technique for systematically coding large amounts of text to create a small number of content categories (Stemler, 2001). I read through the explanations multiple times until I had categorized all the explanations and no new relationships emerged. One major issue emerged during coding: The structure of the task did not allow me to explicitly identify

whether explanations about evidence-to-model links were psychological anomalies of participants' preinstructional theories about climate change. In other words, I was not able to find direct evidence of any of Chinn and Brewer's (1993) responses because the explanation task did not specifically query participants to determine if their preinstructional theories were at conflict with either of the two models in the MEL diagram.

However during coding, one phenomenon emerged that appeared to closely relate to participants' reappraisals of their plausibility judgments. Specifically, participants' explanations reflected a range of cognitive processing, elaboration, and reflection, from low to high. This range is similar to the continuum of engagement hypothesized by Dole and Sinatra (1998), where low cognitive engagement results in little or no conceptual change and high cognitive and metacognitive engagement is required for enduring and strong conceptual change. Greater engagement would require more critical evaluation of the evidence-to-model link, and therefore, a higher potential for plausibility reappraisal.

The content analysis revealed that explanations fell into four well-defined categories reflecting the levels of participants' critical evaluation and the potential for them to reappraise their plausibility judgments. Whereas, these categories do not directly address research question 3, which asked about participants psychological responses to anomalous data, they do help to answer the broader question of the role of critical evaluation in plausibility reappraisal, and specifically how this can be facilitated through instruction. The four categories are discussed in more detail below.

Category 1: Incorrect explanations. Many participants had incorrect explanations about evidence-to-model links. For example, one participant said that

Evidence #2 strongly supports Model B because the evidence “talks about the Sun’s energy and the temperature rising and Model B talks about energy released from the Sun.” However, Evidence #2 states that solar activity has been decreasing since 1970 and that Earth has received less energy from the Sun, while Earth’s temperatures have continued to rise. The participant was clearly incorrect because Evidence #2, which reveals that solar activity has been decreasing, contradicts Model B, which states that our current climate change is caused by *increasing* amounts of energy released from the Sun.

Table 6 shows correct and incorrect evidence-to-model links based on participants’ judgments about the weighting of a link’s strength (i.e., strongly supports, supports, has nothing to do with, or contradicts). The table combines the weights of strongly supports and supports because from the perspective of correctness, it was not possible to differentiate between these two. I determined correct and incorrect responses based solely on the information provided in the evidence and the cause/effect statement made in a model. Whereas, someone with a sufficient amount of background knowledge (i.e., an expert in climate science) could argue that other correct options exist, such nuances are beyond the level of these middle school participants, who were clearly novices in the area of climate science. Table 6 also shows if correct links are weak or strong, which relate to the next three categories (see below).

Table 6

List of Correct (C) and Incorrect Responses (I) for Evidence-to-model Links (+ Indicates a Strong and Correct link and – Indicates a Weak and Correct Link) Based on Participants' Judgments

| Evidence-to-model link | Link Weight | | |
|------------------------|----------------------------|------------------------|-------------|
| | Strongly supports/supports | Has nothing to do with | Contradicts |
| E1_MA | C+ | I | I |
| E1_MB | I | C- | I |
| E2_MA | I | C- | I |
| E2_MB | I | I | C+ |
| E3_MA | C+ | I | I |
| E3_MB | I | C- | I |
| E4_MA | I | C- | I |
| E4_MB | C+ | I | I |

Note. En-Mx = evidence-to model link for evidence *n* (1, 2, 3 or 4) and model *x* (A or B).

Category 2: Correct with weak links. Many of the participants' explanations discussed how certain evidence had nothing to do with a particular model. In many cases, these explanations were correct, but represent a weak level of cognitive processing because they demonstrate no elaboration, reflection, or metacognition. Without these deeper cognitive processes, the participants may have engaged in a low level of evaluation, which was not sufficient for plausibility reappraisal and conceptual change (Chinn & Brewer, 1993; Dole & Sinatra, 1998). For example, one participant wrote "Evidence #3 has nothing do with Model B because the evidence is about satellites and greenhouses, and Model B is about energy released from the Sun." These types of

explanations share some similarity to Chinn and Brewer's (1993) psychological response of excluding the data from the domain of the theory. When data are excluded, "they obviously do not lead to any theory change" (Chinn & Brewer, 1993, p. 8), and therefore reflect minimal amounts of critical evaluation and reappraisal.

Category 3: Correct with strong links and superficial explanations. Many of the participants had correctly discussed links that had strong connections (i.e., contradicts, supports, or strongly supports) a particular model. These were signs of a deeper level of processing by indicating commitment (i.e., taking a definite positional stance), which in some cases could lead to a greater potential for conceptual change (Dole & Sinatra, 1998). These explanations concurrently reflected superficial explanations lacking depth of analysis and evaluation. Such a response was given by one participant who said that "Evidence #1 strongly supports Model A because Evidence #1 talks about greenhouse gases just like Model A." This explanation was typical of many participants, who often made their judgments based on the similarities of words used in the evidence text to words used to describe the model, but did not reveal deeper thinking or analysis about the context of the connection. At best, strong links with superficial explanations reflect a low to moderate level of engagement because even though participants are making meaningful connections between evidence and a model, they are still not elaborating or reflecting beyond surface details. Superficial connections may be somewhat akin to peripheral cues that are most often associated with low cognitive engagement, but "has the potential to draw an individual into high engagement with the issues and arguments" (Dole & Sinatra, 1998, p. 122).

Category 4: Correct with strong links and robust explanations. Some explanations of strong evidence-to-model links expressed a greater degree of elaboration and reflection than in other types of explanations. For example, one participant indicated that “Evidence #3 strongly supports Model A because the satellites are measuring energy being absorbed by greenhouse gases, which makes the Earth’s climate change.” This participant provided a causal statement about increasing energy absorbed by greenhouse gases as a mechanism for climate change, which in turn corresponded to Model A. This causal statement does not necessarily indicate any change to the participants’ preinstructional theory, but it does reveal deeper thinking about the evidence-to-model link, and a greater potential for plausibility reappraisal and possibly conceptual change.

Scoring Rubric for Written Explanations

From the results of the content analysis, I created a scoring rubric for student explanations (Table 7). The four categories in the rubric represent a natural ordering of levels of critical evaluation and potential for plausibility reappraisal—from no or minimal potential (incorrect responses) to low potential (correct explanations of weak link) to low-moderate potential (correct but superficial explanations of strong links) to moderate-high potential (correct and explanations of strong links). Again it was not directly possible to know if participants viewed any of the evidence as psychological anomalies so I am unable to use this scoring rubric to answer research question 3. However, this scoring rubric provides a meaningful instrument to examine the relationship between critical evaluation and plausibility reappraisal.

Table 7

Scoring Rubric for Explanatory Tasks.

| Category | Description | Score |
|--|--|-------|
| Incorrect explanations | Explanation contains an incorrect model-to-evidence link and/or is mostly inconsistent with scientific understanding. | 1 |
| Correct explanations of weak links | Explanation is correct, but the evidence-to-model link weight states that the evidence has nothing to do with the model. | 2 |
| Correct but superficial explanations of strong links | Explanation is correct, with an evidence-to-model link weight of strongly supports, supports, or contradicts as appropriate. However, the explanation is superficial, demonstrating only surface similarities between evidence and model. | 3 |
| Correct and robust explanations of strong links | Explanation is correct, with an evidence-to-model link weight of strongly supports, supports, or contradicts as appropriate. The explanation also reflects deeper cognitive processing that elaborates on an evaluation of evidence and model. | 4 |

I scored participants' explanations using this rubric (Table 7). Each treatment group participant was asked to provide three explanations at the end of the Model-Evidence Link (MEL) diagram activity. With 86 treatment group participants, a maximum of 258 explanations were possible. However, a few participants left some explanations completely blank, and therefore I was not able to score six explanations, yielding a total of 252 scored explanations. A science education expert also scored participants' explanations independently. Initial rater scores were at a high level of agreement ($r = .94, p < .01$). We discussed differences in our initial scores and ultimately reached full consensus on every explanation.

Figure 10 shows the frequency of scores for each evidence-to-model link. Participants wrote the greatest number of explanations ($N = 74$; 29.4% of the total explanations) for the link between Evidence #1 and Model A. Evidence #1 describes how atmospheric carbon dioxide concentrations have increased over time, and how carbon dioxide emissions due to human activities have also increased over time (see Appendix F for more details). Model A is the human-induced model of climate change. For this evidence-to-model link, the predominant score was 3 (correct but superficial explanation of a strong evidence-to-model link; $N = 62$). This indicates that most of the participants' explanations discussed only the similarity in wording between Evidence #1 and Model A.

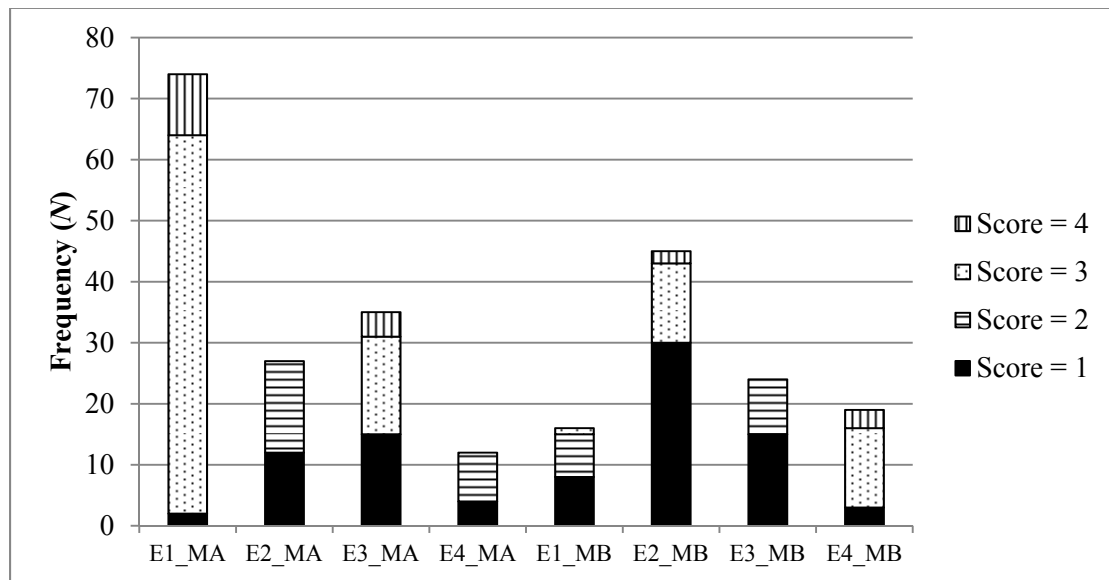


Figure 10. Frequency of scores for each evidence-to-model link. In the figure, evidence-to-model links are coded based on the evidence number (1, 2, 3, or 4) and model (A or B) at each end of the link (e.g., E1-MA therefore shows the link from Evidence #1 to Model A).

Participants wrote the second greatest number of evidence-to-model link explanations ($N = 45$; 17.9% of the total explanations) for Evidence #2 and Model B. Evidence #2 describes the association between energy output by the Sun and average global temperatures over the past 100 years (see Appendix F for details). Model B attributes current climate change to increasing amounts of energy released from the Sun. Interestingly, the predominant score for this link was 1 ($N = 30$), indicating that many participants incorrectly thought that Evidence #2 supported Model B. In fact, this evidence, contradicts Model B because it shows a decreasing amount of solar energy received by Earth over the past 30 years.

The fewest explanations ($N = 12$; 4.8% of the total explanations) were written for the link between Evidence #4 and Model A. Evidence #4 describes paleoclimatic associations between sunspots (one measure of the Sun's activity) and average global temperatures as measured by tree rings. Evidence #4 is the only evidence which supports Model B.

Nonparametric Associations

The content analysis and subsequent scoring of explanations show evidence of various levels of participants' ability to be critically evaluative. However, the following question arises that is of particular importance to this dissertation study: Are participants' levels of critical evaluation associated with reappraisal of their plausibility judgments? To examine this question, I conducted a nonparametric analysis using Kendall's τ -b. This ordinal-by-ordinal analysis is appropriate for looking at correlational relationships between ordered categories, such as the explanation scores generated using the rubric shown in Table 7. Model plausibility scores at postinstruction can also be considered as

ordered categories, where a score of 1 = greatly implausible (or impossible) and 10 = highly plausible. Unlike other correlational analyses, Kendall's τ -b is not based on covariance between two variables, but on two variables' relative ranking as they are examined for each case (Nussbaum, 2011b). If Case 1 and Case 2 both have the same relative ranking for a variable pair (e.g., both rank variable A greater than variable B), they are concordant. On the other hand if Case 1 and Case 2 have different relative rankings for a variable pair (e.g., Case 1 ranks variable A greater than variable B, but Case 2 does the opposite), they are discordant. A statistical predominance of either concordant or discordant pairs helps to gauge degree of association between ordinal variables. Like other tests of association, Kendall's τ -b values range from -1 (strong negative association or discordance) to 1 (strong positive association or concordance; Nussbaum, 2011b).

Table 8 shows Kendall's τ -b values for the evidence-to-model link scores and participants' perceptions of model plausibility postinstruction. The table shows associations between the eight possible evidence-to-model links (four evidences by two models) and three measures of model plausibility perceptions (plausibility of Model A and Model B at postinstruction, as well as overall model plausibility at postinstruction, calculated as Model A minus Model B).

Table 8

Kendall's τ -b Showing Associations between Evidence-to-model Links and Postinstruction Perceptions of Model Plausibility

| Variable | Aplaus-pst | Bplaus-pst | Mplaus-pst |
|------------|------------------|------------|------------|
| E1-MA (74) | .17 | .01 | .08 |
| E2-MA (27) | .10 | .01 | .08 |
| E3-MA (35) | -.16 | -.02 | -.07 |
| E4_MA (12) | .02 | -.02 | -.04 |
| E1-MB (16) | .00 | .22 | .01 |
| E2-MB (45) | .31 [*] | .10 | .09 |
| E3-MB (24) | .15 | -.12 | .18 |
| E4-MB (19) | .06 | .06 | -.04 |
| E_TOTAL | .17 | .06 | .06 |

^{*} $p < .05$.

Note. Number of explanations shown in parentheses. En - Mx = evidence-to model link for evidence n (1, 2, 3 or 4) and model x (A or B); Aplaus-pst = Model A plausibility, postinstruction; Bplaus-pst = Model B plausibility, postinstruction; Mplaus-pst = Model A – Model B plausibility, postinstruction. E_TOTAL is the sum of the three link scores.

As shown in Table 8, perceptions of model plausibility at preinstruction had nonsignificant correlations with scores relating to participants' evaluation of evidence-to-model links. Most of the associations between perceptions of model plausibility at postinstruction were also nonsignificant. Interestingly, however, there was one significant correlation between participants' evaluation of the link between Evidence #2 and Model B, with Kendall's τ -b = .31, $p = .018$. This link is the only one which shows evidence contradicting a model. This reveals an important finding that contradictory evidence had the only significant association with participants' postinstruction plausibility judgments, where a greater critical evaluation score was correlated with a greater plausibility of

Model A (i.e., the scientific model of human-induced climate change) and vice versa (i.e., low scores were correlated with lower plausibility). Whereas, the well-known principle that correlation does not imply causation certainly applies with this result, the significant association with contradictory evidence and plausibility appraisal is a promising finding, supporting continued investigation of the relationship between critical evaluation that can be facilitated by instruction, reappraisal of plausibility judgments, and an increased potential for conceptual change.

These associations do provide some evidence of a connection between various levels of critical evaluation promoted by instruction and participants' postinstruction plausibility judgments. Such a connection is of particular interest as we endeavor to understand the role of plausibility judgments in conceptual change and instruction that facilitates conceptual change.

Results Summary

The results showed that treatment group participants experienced significant change in their perceptions of model plausibility and correctness, as well as knowledge of human-induced climate change, after experiencing an activity that promoted critical evaluation (i.e., the model-evidence link diagram instructional scaffold, or MEL). These changes represented medium to large effect sizes and show that participants' moved toward greater plausibility perceptions and knowledge toward the scientific model of human-induced climate change. The comparison group, which experienced the regular curriculum, did not show any significant changes in these variables. However, both the treatment and comparison groups had significant change in the overall plausibility perceptions of climate change, with a small to medium effect size. These results address,

in large measure, research questions 1 and 2, and also support my hypothesis that the MEL activity would facilitate plausibility reappraisal of alternative climate change models, as well as knowledge reconstruction about human-induced climate change. Because scores of participants' beliefs about climate change evidence and understanding about weather and climate distinctions lacked reliability, this study could not address changes in these measures pre to postinstruction.

The results also revealed an interesting relationship between student explanations and their perceptions of model plausibility. Specifically, the contradictory evidence to model link was significantly associated with perceptions of model plausibility. Unfortunately, it was not possible to directly determine if student explanations of evidence-to-model links were strictly psychological responses to anomalous data, as theorized by Chinn and Brewer (1993). This finding may indicate a connection between how participants weigh evidence (an indicator of critical evaluation) and plausibility reappraisal.

The results were inconclusive about students' understanding of weather and climate distinctions because of low score reliability. Similarly, score reliability of participants' beliefs about climate change was also low, which also led to inconclusive results regarding their beliefs.

I will discuss implications of these findings in the next chapter. Specifically, I will discuss how these results provide support of my model of plausibility in conceptual change, implications for instruction, and potential avenues for further study.

CHAPTER 5

DISCUSSION

This chapter discusses the results within the context of the model on the role of plausibility judgments in conceptual change situations initiated by cognitive dissonance (see Figure 2 and accompanying explanation) and suggests a modification to this model. The chapter then discusses the implications of the modified model on instruction and future research. Prior to discussing these implications, I briefly summarize the study's findings within the perspective of the three research questions and the associated hypotheses, as well as the study's limitations.

Summary of the Findings

In broad terms, research questions 1 and 2 asked about the effect of critical evaluation on reappraisal of students' initial plausibility judgment and subsequent conceptual change. As a reminder, I am using a working definition that plausibility is a judgment on the *relative potential* truthfulness of incoming information compared to our existing mental representations. Researchers have theoretically implicated plausibility as an important mechanism in conceptual change learning (i.e., where concepts may be cognitively reconstructed through instruction; see, for example, Chi, 2005; Dole & Sinatra, 1998; Posner et al., 1982). In this study, I specifically examined participants' plausibility judgments about two competing climate change theories (human-induced climate change, which is the scientifically accepted theory, and increasing energy received from the Sun, which is a popular theory used by skeptics), as well as participants' degree of transformation in their understanding about climate change.

The results of the analyses show that treatment group participants had statistically significant changes pre to postinstruction in their relative judgments about two models explaining climate change. The treatment group participants also had statistically significant change from pre to post instruction in which of the models they thought was correct. Similarly, treatment group participants had statistically greater scores at postinstruction on a questionnaire that probed their understanding of the fundamental principles underlying climate change, as well as demonstrating knowledge reconstruction about the causes of climate change. The effect sizes of all these changes were medium to large, indicating a practical significance that has increased bearing on instructional implications and future research. Furthermore, changes experienced by treatment group participants were toward the scientifically accepted model of human-induced climate change and away from a popular alternative model that current climate change is caused by increasing energy received from the Sun. Comparison group participants had no significant changes pre to postinstruction in their relative judgments and ideas about model correctness, or in the questionnaire scores.

The results suggest that the treatment group instructional activity, which promotes critical evaluation of these two climate change models and their connections to evidence, might potentially be a causal mechanism for these changes. Furthermore, the results suggest that participants' critical evaluation may have resulted in a plausibility reappraisal toward the scientifically accepted model of human-induced climate change, which in turn contributed to conceptual change (i.e., reconstructing their knowledge from misconceptions about the causes of climate change to conceptions that are consistent with climate scientists). These findings support my hypotheses that when students consider

competing climate change models, the one with the greater plausibility will correspond to the theory that students think is correct (H_{2A}), and also that students who use MEL diagrams (i.e., the instructional scaffold promoting critical evaluation) will give a greater plausibility ranking to the scientifically accepted model of human-induced climate change compared to the alternative model that Earth is receiving an increasing amount of energy from the Sun (H_{2B}). It is important to note that this hypothesis deals with plausibility perceptions about the alternative models of climate change and not the overall plausibility of scientific statements about climate change—these overall plausibility perceptions are part of my first set of hypotheses, which I discuss below.

The findings also partially support my hypothesis that increases in plausibility perceptions of human-induced climate change will result in reconstruction of students' knowledge about human-induced climate change, conceptual change about weather and climate distinctions, and beliefs about climate change evidence (H_{1B}). Whereas, the results reveal that participants reconstructed their knowledge about human-induced climate change, I could not reliably measure students' understanding about weather and climate distinctions or beliefs about climate change. Therefore, in terms of these two variables, the results are inconclusive.

The findings are also inconclusive toward my hypothesis that instruction promoting critical evaluation will increase students' overall plausibility perceptions of scientific statements about climate change (H_{1A}). Both treatment group participants, who experienced the model-evidence link diagram activity, and control group participants, who did not, expressed greater plausibility perceptions of climate change at postinstruction. This result may be due—in part—to the marginal reliability of

preinstructional scores. However, Lombardi and Sinatra (2012) showed that even limited instruction can result in significant changes in overall plausibility perceptions that Earth's climate is changing, and the results of this study support our earlier findings.

Research question 3 asked specifically about how participants' psychological responses to anomalous data were related to their plausibility judgments. Unfortunately, the nature of the explanatory tasks at the end of the model-evidence link diagram activity provided a barrier to directly answering this question. Because of the wording of the tasks, no participants provided any indication that the climate change evidences were anomalous to their pre-existing theories. However, qualitative examination of the explanations revealed participants engaged in various levels of critical evaluation. Furthermore, quantitative analysis showed that participants who expressed a greater level of critical evaluation about evidence contradicting a climate change model had significantly greater plausibility perceptions about the scientifically accepted model of human-induced climate change.

This finding does not directly test my hypothesis that there would be a discernible relationship between model plausibility ratings and psychological response to anomalous data (H_3); however, it does provide some tentative support of the connection between critical evaluation and plausibility reappraisal, as suggested by my model on the role of the plausibility judgment in conceptual change situations. These results also suggest a need to modify my model, which I discuss later in this chapter. Prior to that discussion, I provide a brief overview of some this study's limitations.

Limitations of the Study

Limitations are inherent within all forms of educational research and this study is no exception. One limitation relates to study participants and the degree to which the findings are generalizable. The participants are a representative sample of middle school students in many urban southwestern U.S school districts (i.e., predominantly Hispanic, with a relatively high proportion—just about half—in a low socioeconomic status). However, one should exercise caution generalizing these results beyond this population and this caution raises the need for future work on the relationships between critical evaluation, plausibility reappraisal, and conceptual change with various other populations and age levels.

Another limitation lies within the nature of the quasi-experimental research design. With this design, I could not truly control the experimental situation through random selection of participants. Participants were randomly assigned to either the treatment or comparison condition, but were randomly assigned at the class level (i.e., preexisting participant groups experienced the random assignments). The results revealed no significant classroom effects, however, indicating a much lower potential for unaccounted confounding variables and subsequently a greater level of internal validity. In other words with significant and practical differences among from pre to postinstruction in classes taught by different teachers, the instructional scaffold appears to be a plausible catalyst for promoting critical evaluation, plausibility reappraisal, and conceptual change under various classroom conditions.

The lack of true experimental conditions might weaken somewhat the causal claims linking critical evaluation to plausibility reappraisal to conceptual change.

However in addition to the results showing no significant classroom effects, this study was based on a pre/post design and results showed no significant differences in any either group prior to instruction. This result also creates increased confidence levels that significant and practical gains experienced by the treatment group are due to the instructional scaffold.

Finally, results relating to overall plausibility perceptions of climate change (PPM) show only a main effect pre to postinstruction. It is important to note that PPM scores should not be confused with the more specific scores of perceptions of model plausibility (i.e., scores that show statistically significant shifts in treatment group participants' plausibility perceptions toward the scientifically accepted model of human-induced climate change). The lack of interaction in overall plausibility may have been a result of the marginal reliability of preinstruction scores. An alternative explanation is that the PPM measured plausibility perceptions of scientific statements that extended beyond the instructional topic (i.e., the causes of current climate change).

A Modified Model of Plausibility in Conceptual Change

The results show that treatment group participants reappraised their plausibility judgments and experienced change toward conceptions consistent with scientific understanding. However, the explanatory tasks revealed only one significant association between scores relating to participants' evaluation of evidence-to-model links and their perceptions of model plausibility at postinstruction. Interestingly, this suggests that critical evaluation of individual evidence to model links are not as powerful in reappraising plausibility judgments as the synergistic effect of considering multiple evidence to model links, as was the case with the model-evidence link diagram activity

(i.e., where participants simultaneously consider eight evidence to model links). Indeed, such consciously controlled coordination of different types of evidence with theories serves as a foundation for development of scientific thinking (Kuhn & Pearsall, 2000) and may contribute to more robust critical evaluation. In the case of the model-evidence link diagram, the process of considering several links between evidences and models may have had a greater impact on participants' plausibility reappraisal than the consideration of single evidence-to-model links in isolation.

One component of the model that I presented in Chapter 2 (see Figure 2)—the *response* to the plausibility judgment—may not properly account for the process of considering multiple alternatives. Earlier, I proposed that Chinn and Brewer's (1993) seven responses to anomalous data aligned with plausibility judgments. Chinn and Brewer's responses are based on the connection between an incoming piece of anomalous data and individuals' preexisting theories. In my model, I theorized that plausibility judgments acted as mediators between incoming anomalous information and a psychological response. However, the results were inconclusive about whether the participants' explanations reflected psychological responses to anomalous data. Furthermore, I found only one significant association between participants' evaluation of evidence to model links (i.e., Evidence #2—recent decreases in solar energy—was contradictory to Model B—climate change is caused by increasing energy from the Sun) and their plausibility perceptions of a single model (i.e., Model A—climate change is caused by human activities). Participants' change in relative model plausibility perceptions (Model A – Model B) may have been related more to their consideration of

multiple lines of evidence (i.e., the four evidences presented in the model-evidence link diagram) than to a single psychological response about Evidence #2.

The study results do, however, reveal that the degree of critical evaluation may be important to plausibility reappraisal. Participants who engaged in critical evaluation changed both their relative plausibility perceptions between the two competing climate change theories and the model they thought was correct. Furthermore, these participants also experienced a greater degree of conceptual change about the causes of climate change. Relative plausibility perceptions between two (or more) competing theories appear to be necessary for conceptual change. Other factors may also contribute to conceptual change (e.g., message comprehensibility, personal relevance, need for cognition; Dole & Sinatra 1998) and it is still feasible that psychological responses in single evidence to model links are involved in this process. However, the results of this study support the following idea: if the plausibility of a scientifically accurate conception is not greater than that of an alternative, it is unlikely that conceptual change will result—even if other factors are conducive for change. This study specifically showed that participants who engaged in an activity promoting critical evaluation shifted their relative plausibility perceptions towards the scientifically accepted model of human-induced climate change. This plausibility reappraisal also accompanied a shift in perceptions about which model the participants thought was correct—again toward the scientifically accepted model—as well as knowledge reconstruction about the causes climate change. Because the earlier model did not reflect the relative plausibility judgment and the findings of this dissertation study, I have revised my model on the role of plausibility in conceptual change (as shown Figure 11 and discussed in more detail below).

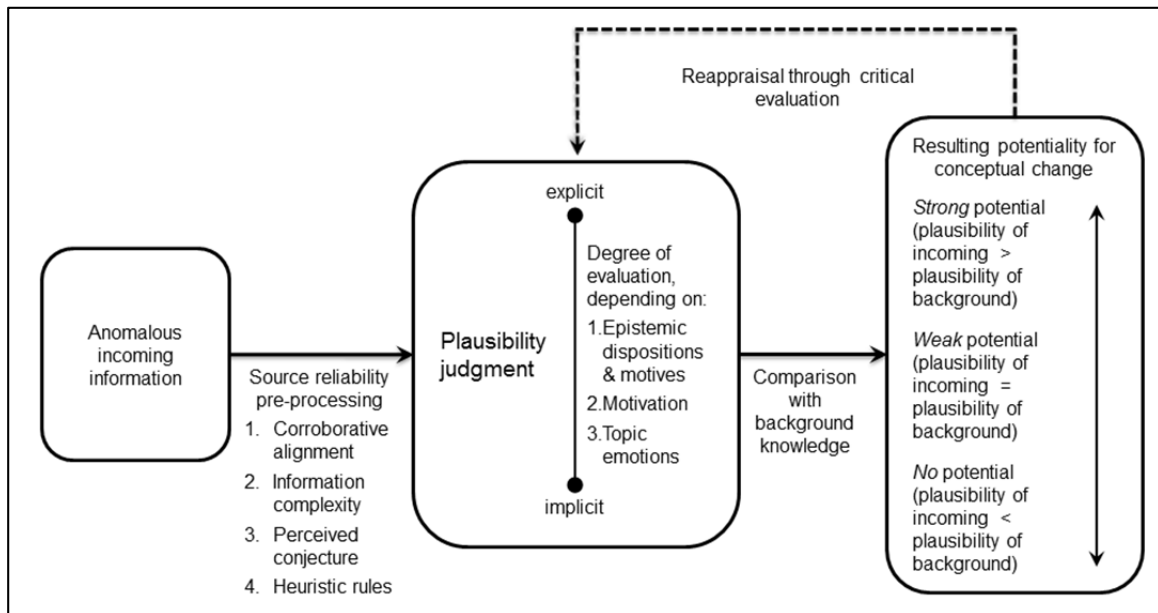


Figure 11. A modified model of the role of plausibility judgment in a conceptual change situation initiated by cognitive dissonance.

This modified model contains most of elements that I discuss in detail in Chapter 2. For example, the plausibility judgment is initiated by anomalous incoming information and pre-processing based on source reliability. The plausibility judgment is made in relationship with potential interacting factors (e.g., epistemic motives and dispositions, motivation, and topic emotions). The judgment is made along various degrees of evaluation that follows a continuum of cognitive processing from completely implicit to completely explicit. Furthermore, the study results reinforce the notion of plausibility reappraisal through explicit, critical evaluation can be facilitated instruction.

The major difference in this modified model is that I have replaced the last node, which was titled “response,” with “resulting potentiality for conceptual change.” This *potentiality for conceptual change* is based on the relative strength of the incoming (or reappraised) information to background knowledge. When the plausibility of the incoming information is much less than an individual’s background, there is virtually no

potential for conceptual change. A somewhat greater potential exists when the plausibility perceptions are about equal, but the potential is only weak. In this situation, an individual may be uncertain and rate plausibility of both conceptions as moderate, or may rate both with high (or low) plausibility (note that plausibility of both as either very high or very low is an example of how these judgments differ from probabilistic reasoning). Finally, a strong potential for conceptual change only occurs when the plausibility of the incoming information is much greater than that of the alternative.

I see this potential for conceptual change as a continuum, as represented by the arrow in Figure 11, and not as three distinct categories. This potential for conceptual change is analogous to Dole and Sinatra's (1998) engagement continuum, where there may be a gradual variation of "information processing, strategy use, and reflectivity" (p. 121) that individuals employ in a conceptual change learning environment. However, this continuum relates specifically to the relative plausibility of the incoming information to the individual's existing conception. Whereas cognitive, affective, and metacognitive processes are involved in making plausibility judgments and reappraisals, it is simply the relative strength of two competing conceptions that may determine the potential for conceptual change (i.e., as indicated by participants' changes in both relative model plausibility perceptions toward the scientifically accepted model and knowledge of human-induced climate change). Of course as I have discussed earlier, other factors may also be required for an individual to experience conceptual change. Be that as it may, these findings support the suggestion that a necessary condition for knowledge reconstruction is that the plausibility of incoming information supersedes the plausibility of any competing alternatives.

The other change to the modified model (Figure 11) is that I relabeled the path from the judgment node to the result node from “judgment implementation” to “comparison with background knowledge.” This study suggests that is not a simple matter of psychologically responding to incoming data relative to your preexisting theory (Chinn & Brewer, 1993), but rather a more elaborative coordination of multiple lines of evidence with alternative models, and in the case of conceptual change learning, at least some of these alternatives are mental representations in individuals’ background knowledge. Complex and metacognitive coordination of theories and evidence is a thinking skill used by scientists (Kuhn & Pearsall, 2000). Furthermore, such a scientific habit of mind may be required to gain greater understanding and knowledge reconstruction of complex topics, such as global climate change.

Implications for Instruction

The study findings provide evidence that instruction promoting critical evaluation and plausibility reappraisal can facilitate conceptual change. The instructional scaffold used in this study was the model-evidence link (MEL) diagram, where participants weighed the links between scientific evidences and two alternative models of climate change. As I discussed in the previous section, the MEL helped students to coordinate evidence with theories in a mode of critical evaluation. Recently, the National Research Council (NRC) of the National Academies of Science, Engineering, and Medicine published a report providing a framework for the next generation of science education standards (NRC, 2012). The report authors state that coordination of evidence and theory through critical evaluation supports the learning of epistemic practices of scientists and engineers (NRC, 2012). With the framework calling for changing students’ conceptual

understanding of such epistemic practices (i.e., epistemic conceptual change; Chinn & Sinatra, 2011), the MEL is an instructional scaffold appropriate for meeting this challenge.

The new framework for science education standards (NRC, 2012) also places evaluation at the intersection of “two spheres of activity” (p. 45) common to science and engineering: (a) investigating and (b) developing explanations and solutions. The framework also states that evaluation requires critical thinking, “whether in developing and refining an idea...or in conducting an investigation. The dominant activities in [evaluation] are argumentation and critique, which often lead to further experiments and observations or to changes in proposed models, explanations, or designs” (NRC, 2012, p. 46). Employing critical evaluation in the classroom may then lead to plausibility reappraisal—as suggested by this study—and cognitively reconstructing misconceptions into conceptions consistent with scientific understanding.

Engaging students explicitly in considering and reappraising their plausibility judgments may also increase students’ understanding of the nature of science. A key component to understanding the nature of science is the idea that scientific knowledge is tentative (Lederman, 1999). But of equal importance to knowing that scientific knowledge is tentative, students should also “be able to step back from evidence or an explanation and consider whether another interpretation of a particular finding is *plausible* with respect to existing scientific evidence and other knowledge that they hold with confidence” (NRC, 2007, p. 39, emphasis mine). This explicit and conscious reappraisal of plausibility judgments is essential for understanding the nature of scientific knowledge and how scientific knowledge develops over time. Whereas individual

scientists may not actively engage in plausibility reappraisal of the theoretical frameworks critical to their research agenda, the larger scientific community will evaluate major scientific theories and eventually dispel of those that are deemed less plausible than competing theories (Lakatos, 1970). Instruction using explicit plausibility reappraisal could then facilitate understanding of the development of scientific knowledge. In fact, the new framework for science education standards specifically calls for instruction where, students “come to appreciate that alternative interpretations of scientific evidence can occur, that such interpretations must be carefully scrutinized, and that the plausibility of the supporting evidence must be considered,” and ultimately understand “that predictions or explanations can be revised on the basis of seeing new evidence or of developing a new model that accounts for the existing evidence better than previous models did” (NRC, 2012, p. 251).

The 7th grade study participants in this study revealed a capability to learn how to use critical evaluation and reappraise their plausibility judgments. This is congruent with the suggestion that students can begin to comprehend the meaning of plausibility in middle school (Snow, 2010). The participants specifically showed a significant relationship between weighing of contradictory evidence (i.e., evidence opposed to the alternative model) and their plausibility judgments (i.e., the only significant association revealed in their explanations). Thus, contradictory evidence had greater bearing on the participants’ plausibility judgments than evidence that strongly supported, supported, or had nothing to do with the models. In this way, participants engaged in a practice that was similar to the overall scientific community (i.e., looking for evidence contrary to a

theory), and by doing so may have also gained a greater understanding of how scientific knowledge is constructed.

The treatment activity occurred in just two class meetings, constituting about 90 minutes of total instruction. Treatment group participants quickly learned how to critically evaluate evidence and reappraise their plausibility judgments when scaffolded by the MEL diagram. In other words, these participants experienced a powerful effect in a relatively short amount of time. With Chinn and Buckland (2012) using the model-evidence link diagrams over the course of a semester—and also showing appreciable benefits to learning—the effects of sustained instruction using this instructional scaffold may have a greater effect on students’ ability to engage in plausibility reappraisal. This also suggests that middle school students can engage in explicit and conscious plausibility reappraisal of alternative theories to increase their knowledge about the nature of science. This last statement about plausibility reappraisal is speculative, but provides a hopeful prospect that instruction can promote epistemic conceptual change, a process that is critical for promoting greater understanding of science and abilities to be engaged in scientific reasoning (Sinatra & Chinn, 2011). Along with this potential for epistemic conceptual change, this study provides evidence that instruction promoting critical evaluation and plausibility reappraisal leads to conceptual change about the relatively complex topic of climate change. A summary of these implications that I developed for educators is included in Appendix H.

Implications for Future Research and Concluding Thoughts

A number of studies (Connell & Keane, 2004, 2006; Lombardi & Sinatra, 2012) together provide a growing body of evidence supporting the importance of cognitive

plausibility judgments. This study provides further empirical evidence that critical evaluation can lead to plausibility reappraisal, which in turn helps support the modified model of plausibility judgments in conceptual change (see the discussion earlier in this chapter). However, the model is in need of further testing, where one possible investigative avenue might be in examining the factors that lead to cognitive preprocessing of the incoming information's source reliability. As a reminder, source reliability may depend on the complexity of the information, the corroborative alignment of the information with background knowledge, and the perceptions about the degree of conjecture inherent in the incoming information (Connell & Keane, 2004, 2006), as well as other cognitive processes (e.g., heuristics and biases). More needs to be understood about these during conceptual change learning, and specifically, how these factors influence the initial plausibility judgment about incoming anomalous information.

An area for future examination of source reliability may be misconceptions about what scientists mean by uncertainty. Lombardi and Sinatra (2012) speculate that individuals' judgments may be influenced by "insufficient understanding about scientific uncertainties as they gauge the plausibility of human-induced climate change" (p. 213). Individuals who confront scientific information that is parameterized by a range of uncertainty (e.g., climate models that predict a range of future global temperatures) may deem that information to be of lower plausibility because they perceive scientific uncertainty as a high degree of conjecture. Similarly, the factor of corroborative alignment may be related to the perceived trustworthiness of the information. A study by Bråten, Strømsø, and Britt (2009) showed that individuals' trustworthiness perceptions of different information sources on climate change related strongly to their comprehension.

Trustworthiness as a measure of source reliability may therefore influence the initial plausibility judgment, and ultimately the possibility for greater cognitive engagement with the incoming information. Researchers are currently examining many facets of the interaction between differing source texts and epistemic cognition (see for example, Ferguson, Bråten, & Strømsø, 2012), and my model may present an opportunity to examine the plausibility judgment as an important mediator in this interaction.

Another possible avenue for future research is to look at how motivational factors may be related to the degree of evaluation that occurs in both the initial plausibility judgment and potential plausibility reappraisal. For example, Sinatra and Taasoobshirazi (2011) describe the process of intentional conception change, where “motivation drives the cognition and metacognition needed for conceptual change” (p. 209). With intentional conceptual change, individuals have the goal of examining incoming information in comparison to their background knowledge and evaluating the need for knowledge reconstruction. Research into whether explicit use of plausibility judgments may facilitate such a goal-directed comparison could provide greater understanding of the self-regulatory skills that promote conceptual change. In turn, this could help us better understand the interaction of learner and message characteristic as postulated by Dole and Sinatra’s (1998) Cognitive Reconstruction of Knowledge Model (CRKM).

A third avenue for future research would extend our understanding of how instruction promoting critical evaluation leads to plausibility reappraisal and conceptual change. This study provided initial evidence that the model-evidence link diagram can lead to both plausibility reappraisal and conceptual change, but the potential exists that other instructional strategies may also lead to these cognitive processes. For example,

Nussbaum and Edwards (2011) have shown that critical questions can be used to increase students' abilities to successfully evaluate arguments. Critical questions—such as “What is the likelihood?” and “How do scientists know?”—may enable students to evaluate connections between evidence and scientific models, although more research in this area is warranted. Furthermore, incorporating collaborative argumentation into instruction may allow for greater elaboration and evaluation when explicitly considering both judgments based on plausibilistic reasoning, as well as more precise probabilistic reasoning (Nussbaum, 2011a).

In addition to the use of critical questions and collaborative argumentation, the effectiveness of various text forms on plausibility reappraisal may be a fourth avenue for future study. Sinatra and Broughton (2011) have called for more research about refutation texts—a particularly effective medium for promoting conceptual change. Specifically, these researchers wonder about “how best to increase the value-added benefit of refutation text for promoting science learning” and how the text “can be augmented to increase the refutation text advantage” to facilitate conceptual change (Sinatra & Broughton, 2011, p. 389). Research about the incorporation of critical evaluation of evidence to model connections and plausibility reappraisal into refutation text may be one way to increase this advantage. In the broader scheme of progressing our understanding about the role of plausibility judgments in conceptual change, studies using other instructional methods to promote critical evaluation along with various text sources could provide additional empirical tests to my model, and specifically, a more thorough inspection of the reappraisal mechanism.

A fifth avenue for future research may be examining how instruction influences the development of scientific thinking. This study showed that middle school student can engage in critical evaluation and plausibility reappraisal of competing climate change theories by coordinating multiple lines of evidence and such coordination is characteristic of scientific thinking (Kuhn & Pearsall, 2000). Previous research has been mixed on when individuals naturally develop the ability to think scientifically, with most pointing toward late adolescence and adulthood (Kuhn & Pearsall, 2000). However, instruction can promote critical evaluation and plausibility reappraisal in adolescents (as shown by my findings) and research could examine if such abilities could be facilitated at an earlier age (e.g., upper elementary grades 4 and 5). Whereas, using the term “plausibility” with elementary students may prove to be difficult, elementary students may be able to learn how to weigh connections between evidences and alternative theories (e.g., by using a model-evidence link diagram) and relate these connection to how scientists make judgments. It would also add to our understanding of basic cognitive processes to investigate how elementary students can coordinate multiple lines of evidence. Such studies help us better understand how and when an instructional foundation can be developed that facilitates students’ use of explicit critical evaluation and understanding about how scientists construct and reconstruct knowledge.

A sixth avenue for future research may be in the investigation of the relationship between an individual’s metacognitive abilities and his or her ability to reappraise plausibility judgments. The present study examined the connections between critical evaluation that occurs in scientific modes of thought (i.e., analyzing how evidentiary data support a hypothesis and its alternatives) and the plausibility reappraisal. Consequently,

with metacognitive processing usually involving evaluating of science learning (Schraw, Crippen, & Hartley, 2006), an interesting relationship may exist between metacognition and plausibility reappraisal. Instruction that makes the plausibility judgment explicit may help facilitate evaluation of what an individual knows, along with increasing understanding about how they know. Therefore, research into associations with metacognitive ability may potentially extend the importance of plausibility judgments beyond conceptual change learning to more general situations of self-regulated learning.

Finally, it is important to consider the implications of this study for future educational research around the scientific topic of this study: global climate change. This study expands our understanding of fundamental mechanisms involved in conceptual change, and specifically helps substantiate the idea that reconstructing knowledge about human-induced climate change is neither a simple matter of debunking nonscientific positions nor learning about the several lines of evidence that support the scientific model. Rather, moving toward the scientifically accepted conception that humans are altering Earth's climate may well require connecting evidences to alternative models and evaluating the strength of these connections with respect to each alternative. Doing so in an instructional setting may seem counterintuitive to those that are involved in the climate change debate on a daily basis, but individuals who are committed to developing a citizenry that is climate-literate (i.e., understanding of humans' influence on climate and climate's influence on society; U.S. Global Change Research Program, 2009) must be open to the notion that discussing alternative explanations may lead to greater awareness and understanding of the science. The community of scholars examining climate change education is growing and additional research on the role of the

plausibility judgment in altering conceptions about climate change may provide a fruitful contribution to this community by helping develop climate-literate individuals. Such literacy is critical to developing a society that characteristically exhibits scientific habits of mind and is equipped to deal with future challenges in a way that is beneficial to our nation.

APPENDICES

Appendix A: Plausibility Perceptions Measure (PPM)

Grade 7 Reading Level Version

Read the following statements. Rate the plausibility on a scale from 1 to 10: 1 being greatly implausible (or even impossible) and 10 being highly plausible. Try to use the full range of numbers in your responses.

1. The Earth is warming. Rising air and ocean temperatures, melting glaciers, and rising sea levels are evidence of this warming.

| | | | | | | | | | | |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Greatly implausible (or even impossible) | | | | | | | | | | Highly Plausible |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

2. Evidence from around the world shows climate is changing in many regions.

| | | | | | | | | | | |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Greatly implausible (or even impossible) | | | | | | | | | | Highly Plausible |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

3. Greenhouse gas levels are increasing in Earth's atmosphere. Human industry has caused these gases to increase.

| | | | | | | | | | | |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Greatly implausible (or even impossible) | | | | | | | | | | Highly Plausible |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

4. Human activities that release greenhouse gases are causing global warming.

| | | | | | | | | | | |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Greatly implausible (or even impossible) | | | | | | | | | | Highly Plausible |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

5. Human influences on climate include rising sea levels and melting of snow and ice.

| Greatly implausible (or even impossible) | | | | | | | | | | Highly Plausible |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

6. Human releases of greenhouse gases will increase. This will cause much greater warming in the future.

| Greatly implausible (or even impossible) | | | | | | | | | | Highly Plausible |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

7. Releases of greenhouse gases by human activities could remain at the same level. But climate change will still occur for centuries because of these releases.

| Greatly implausible (or even impossible) | | | | | | | | | | Highly Plausible |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

8. Human caused global warming will lead to some impacts that are sudden, such as massive polar ice melt.

| Greatly implausible (or even impossible) | | | | | | | | | | Highly Plausible |
|---|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> | <input type="checkbox"/> |

Appendix B: Human-induced Climate Change (HICCK) Instrument

Below are statements about climate change. Rate the degree to which you think that *climate scientists* agree with these statements.

(Note that items with an asterisk directly relate to misconceptions tabulated by Choi et al., 2009. These asterisks will not be included on the version used by participants.)

| | Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|-------------------|----------|----------------------------|-------|----------------|
| 1. The Sun is the main source of energy for Earth's climate. | 1 | 2 | 3 | 4 | 5 |
| 2. Human have very little effect on Earth's climate. | 1 | 2 | 3 | 4 | 5 |
| 3. We cannot know about ancient climate change. | 1 | 2 | 3 | 4 | 5 |
| 4. Earth's climate has probably changed little in the past. | 1 | 2 | 3 | 4 | 5 |
| 5. Earth has recently been receiving increasing amounts of the Sun's energy.* | 1 | 2 | 3 | 4 | 5 |
| 6. The Sun's brightness is one way to measure solar activity. | 1 | 2 | 3 | 4 | 5 |
| 7. Sunspot number is related to solar activity. | 1 | 2 | 3 | 4 | 5 |
| 8. The Earth receives the Sun's energy mostly from ultraviolet light.* | 1 | 2 | 3 | 4 | 5 |
| 9. Earth's atmosphere reflects away almost all of the Sun's energy. | 1 | 2 | 3 | 4 | 5 |
| 10. The greenhouse effect refers to Earth's protective ozone layer.* | 1 | 2 | 3 | 4 | 5 |
| 11. Greenhouse gases make up less than 1% of Earth's atmosphere. | 1 | 2 | 3 | 4 | 5 |
| 12. Burning of fossil fuels produces greenhouse gases. | 1 | 2 | 3 | 4 | 5 |
| 13. Humans produce billions of tons of greenhouse gases each year. | 1 | 2 | 3 | 4 | 5 |
| 14. Humans are reducing the amount of fossil fuels they burn. | 1 | 2 | 3 | 4 | 5 |
| 15. Greenhouse gas levels are increasing in the atmosphere. | 1 | 2 | 3 | 4 | 5 |

| | Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|--|-------------------|----------|----------------------------|-------|----------------|
| 16. Greenhouse gases absorb some of the energy emitted by Earth's surface. | 1 | 2 | 3 | 4 | 5 |
| 17. Earth's climate is currently changing. | 1 | 2 | 3 | 4 | 5 |
| 18. Humans are behind the cause of Earth's current climate change. | 1 | 2 | 3 | 4 | 5 |
| 19. Earth's climate is not currently changing. | 1 | 2 | 3 | 4 | 5 |
| 20. Current climate change is caused by human activities. | 1 | 2 | 3 | 4 | 5 |
| 21. Current climate change is caused by an increase in the Sun's energy.* | 1 | 2 | 3 | 4 | 5 |
| 22. Current climate change is caused by the ozone hole.* | 1 | 2 | 3 | 4 | 5 |
| 23. Current climate change is caused by changes in Earth's orbit around the Sun.* | 1 | 2 | 3 | 4 | 5 |
| 24. Current climate change is caused by volcanic eruptions. | 1 | 2 | 3 | 4 | 5 |
| 25. Current climate change is caused by increasing dust in the atmosphere.* | 1 | 2 | 3 | 4 | 5 |
| 26. Earth's climate is warmer now than it has ever been. | 1 | 2 | 3 | 4 | 5 |
| 27. Future climate change may be slowed by reducing greenhouse gas emissions. | 1 | 2 | 3 | 4 | 5 |
| 28. Humans cannot reduce future climate change. | 1 | 2 | 3 | 4 | 5 |
| 29. The Earth is warming faster at night compared to daytime. This is evidence that humans are causing climate change. | 1 | 2 | 3 | 4 | 5 |
| 30. Satellites do not provide evidence that humans are changing Earth's climate. | 1 | 2 | 3 | 4 | 5 |

| | Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|--|-------------------|----------|----------------------------|-------|----------------|
| 31. Earth's average temperature has increased over the past 100 years. This is evidence of climate change. | 1 | 2 | 3 | 4 | 5 |
| 32. Average sea level is increasing. This is evidence of climate change. | 1 | 2 | 3 | 4 | 5 |
| 33. Less energy has been stored in Earth's oceans recently. This is evidence of climate change. | 1 | 2 | 3 | 4 | 5 |
| 34. Most of the world's glaciers are decreasing in size. This is evidence of climate change. | 1 | 2 | 3 | 4 | 5 |

Appendix C: Distinctions between Weather and Climate Measure (DWCM)

Read the following statements. Decide if the statement best fits into the category of weather or climate and check the appropriate box.

| | |
|---|--|
| 1. There was a heat wave last summer. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 2. It rarely snows in Southern Alabama. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 3. It is colder than normal outside. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 4. By mid-May, it is usually warm enough to go to the beach. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 5. The monsoon rains will probably begin in June. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 6. Clouds cover about 40% of the sky. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 7. For the last 4 years, the least rainfall occurred during October. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 8. There was considerable fogginess on the drive from Los Angeles to Santa Barbara. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 9. The average annual temperature in Reno is 51°F. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 10. Miami's record low temperature is 30°F. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 11. We are predicting that temperatures will be greater than normal this autumn. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 12. Over the last 7 years, a drought has caused lake levels to drop about 13 feet. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 13. Tree rings reveal that the region received greater rainfall 700 years ago. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 14. It often rains on the windward coasts of the Hawaiian Islands. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 15. Snowpack at the ski resort has been below average for the last ten years. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 16. Skies have been partly cloudy for the last three days. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 17. The record annual rainfall in Atlanta is 71 inches. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 18. The tomato growing season in northern Minnesota is from mid-June to August. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 19. The 7-day forecast indicates a rainy week ahead. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |

| | |
|--|--|
| 20. It snowed a total of 42 inches in Chicago last winter. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 21. The average temperature in Greenland was about 2°F greater between 1950 and 2000 than between 1900 and 1950. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 22. Computer models predict that 5 hurricanes will make landfall next year. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 23. We do not expect any tornadoes to occur in Nebraska during the month of February. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 24. The city experienced three blizzards last winter. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 25. It has rained twice as often on the mountain compared to the nearby valley for the last 40 years. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 26. The North Pacific Current lowers temperatures near the coast. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 27. Strong and dry winds have contributed to an active fire season this summer. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 28. The airport runway direction was determined by the average wind conditions. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 29. An area of high pressure usually forms over Bermuda during the summer. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 30. The wind blows from west to east in the jet streams. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 31. The number of glaciers in the Canadian Rockies has decreased over the last 100 years. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 32. The sound of thunder means that storms may be nearby. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 33. A low pressure system has been moving across the United States slowly. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 34. Strong thunderstorms occurred when a frontal system passed our city. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |
| 35. Rome, Italy usually has hot, dry summers and cool, wet winters. | <input type="checkbox"/> Climate <input type="checkbox"/> Weather |

Appendix D: Beliefs about Climate Change Evidence (BCCE)

Below are several statements about global climate change. Decide how much you agree or disagree with each statement.

| | Strongly disagree | Disagree | Neither agree or disagree | Agree | Strongly agree |
|--|-------------------|----------|---------------------------|-------|----------------|
| 1. Global temperatures have increased over the past 100 years. | 1 | 2 | 3 | 4 | 5 |
| 2. Average sea levels have increased over the past 50 years. | 1 | 2 | 3 | 4 | 5 |
| 3. Atmospheric greenhouse gas concentrations have been rising for the past 50 years. Human activities have led to greater releases of greenhouse gases. Temperatures have also been rising during these past 50 years. | 1 | 2 | 3 | 4 | 5 |
| 4. Solar activity has decreased since 1970. Lower activity means that Earth has received less of the Sun's energy. But, Earth's temperature has continued to rise. | 1 | 2 | 3 | 4 | 5 |
| 5. Satellites are measuring more of Earth's energy being absorbed by greenhouse gases. | 1 | 2 | 3 | 4 | 5 |
| 6. Increases and decreases in global temperatures closely matched increases and decreases in solar activity before the industrial revolution. | 1 | 2 | 3 | 4 | 5 |

Appendix E: Model Plausibility and Correctness

Read the following information carefully.

Humans create *models* to help explain things.

Below are two models. These provide different explanations for why global temperatures have increased over the past 100 years and average sea levels have increased over the past 50 years.

Model A: Climate change is caused by humans who are releasing gases into the atmosphere.

A person who supports this model makes the following argument:

A few gases in Earth's atmosphere prevent some of energy Earth's energy from escaping out into space. Human activities are increasing the amount of these gases in the atmosphere. Therefore, humans are causing climate change.

Model B: Climate change is caused by increasing amounts of energy released from the Sun.

A person who supports this model makes the following argument:

The Sun is the main source of energy for planet Earth. Scientists have shown that for thousands of years Earth's average temperature increases when the Sun releases more energy. Therefore, the Sun is causing climate change.

Circle the plausibility of each model. [Make two circles. One for each model.]

| | Greatly implausible (or even impossible) | | | | | | | | | Highly Plausible |
|----------------|---|---|---|---|---|---|---|---|---|------------------|
| Model A | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Model B | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

Circle the model which you think is correct. [Only circle one choice below.]

| | | | | |
|--|---|--|---|--|
| Very certain that Model A is correct | Somewhat certain that Model A is correct | Uncertain if Model A or B is correct | Somewhat certain that Model B is correct | Very certain that Model B is correct |
|--|---|--|---|--|

Appendix F: Instructional Scaffold: Human-Induced Climate Change Model-Evidence Link (MEL) Diagram

MEL Part A: How do scientists change their plausibility judgments?

Scientists may change their plausibility judgments about scientific ideas. They do this by looking at the connections between evidence and the idea. Evidence may:

- *Support* an idea
- *Strongly* support an idea
- *Contradict* (oppose) an idea
- Have *nothing to do* with the idea

| Which type of evidence do you think is most important to a scientist's plausibility judgment? Use numbers 1 to 4 to <i>rank</i> each evidence. (1 = most important and 4 = least important) | |
|---|--------------|
| Type of evidence | Your ranking |
| Evidence supports the idea | |
| Evidence strongly supports the idea | |
| Evidence contradicts (opposes) the idea | |
| Evidence has nothing to do with the idea | |

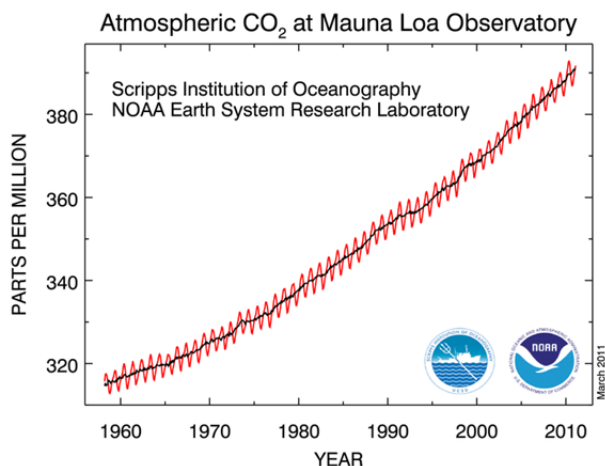
Carefully read the following paragraph.

Scientific ideas must be *falsifiable*. In other words, scientific ideas can never be proven. But, ideas can be disproven by opposing evidence. When this happens, scientists must revise the idea or come up with another explanation. Falsifiability is a very important principle when evaluating scientific knowledge.

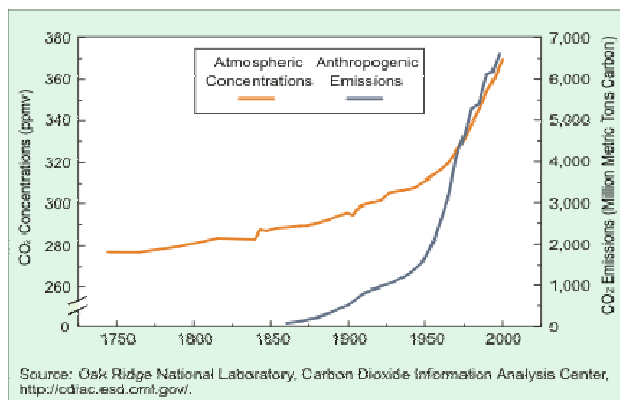
| With falsifiability in mind, <i>re-rank</i> each evidence from 1 to 4. (1 = most important and 4 = least important) | |
|---|--------------|
| Type of evidence | Your ranking |
| Evidence supports the idea | |
| Evidence strongly supports the idea | |
| Evidence contradicts (opposes) the idea | |
| Evidence has nothing to do with the idea | |

MEL Part B: Evidence Text

Evidence #1: Atmospheric greenhouse gas concentrations have been rising for the past 50 years. Human activities have led to greater releases of greenhouse gases. Temperatures have also been rising during these past 50 years.

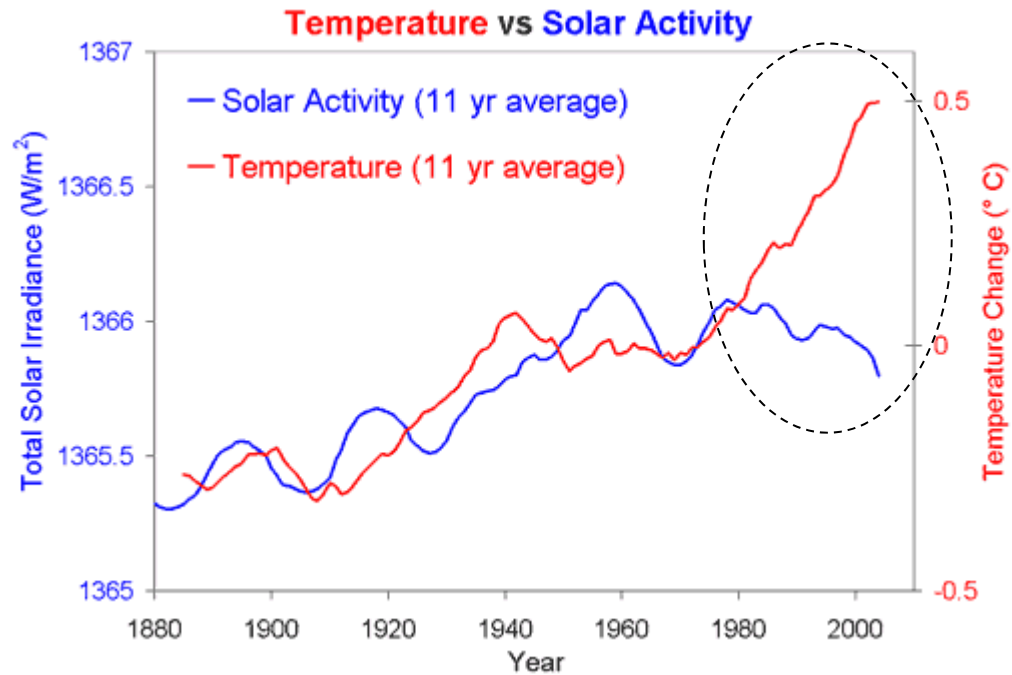


This graph shows carbon dioxide levels in the atmosphere. The symbol for carbon dioxide is CO₂. These levels have been increasing. CO₂ in the atmosphere absorbs energy emitted by the Earth. The atmosphere reradiates some of this absorbed energy back to Earth. People call CO₂ a greenhouse gas because it keeps some of Earth's energy from escaping to space.



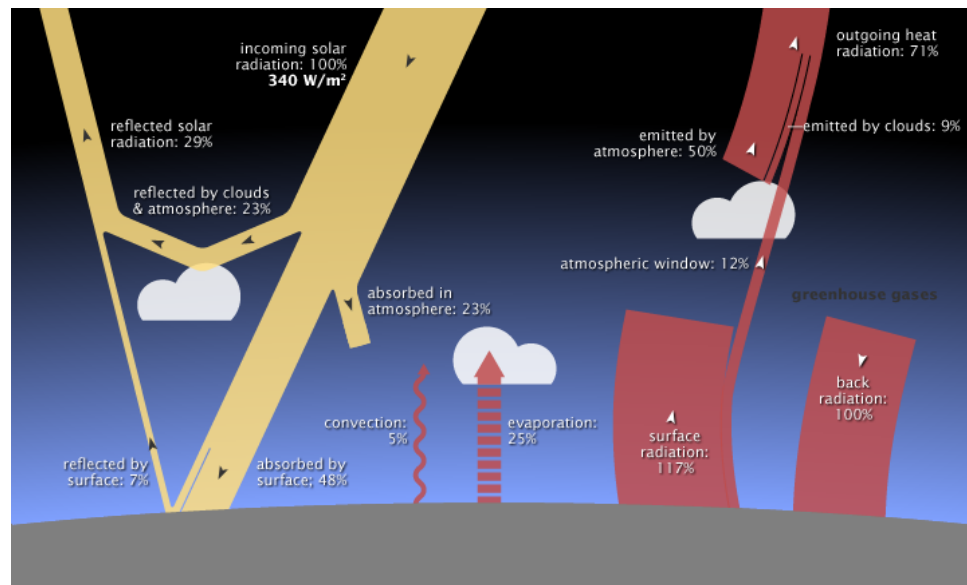
This blue line shows increasing releases of CO₂ by human activities. Burning coal, gasoline, natural gas, and wood releases CO₂ into the atmosphere. The yellow line shows increasing carbon dioxide in the atmosphere. Both the yellow and blue lines have been increasing with time.

Evidence #2: Solar activity has decreased since 1970. Lower activity means that Earth has received less of the Sun's energy. But, Earth's temperature has continued to rise.

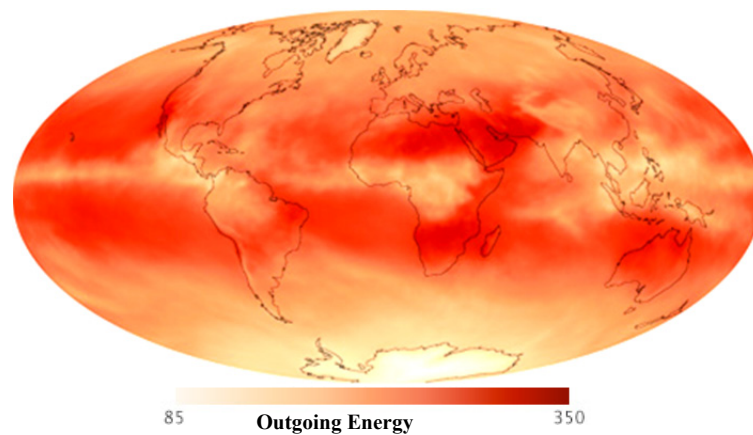


This graph shows solar activity levels. The Sun's brightness is one way to measure solar activity. The blue line shows the Sun's brightness. Since 1970, the Sun's brightness has been decreasing. The red line on the graph shows Earth's temperature. The graph shows that temperatures are increasing while solar activity is decreasing. The region outlined by the dashed circle show where solar activity is increasing and temperature is decreasing.

Evidence #3: Satellites are measuring more of Earth's energy being absorbed by greenhouse gases.

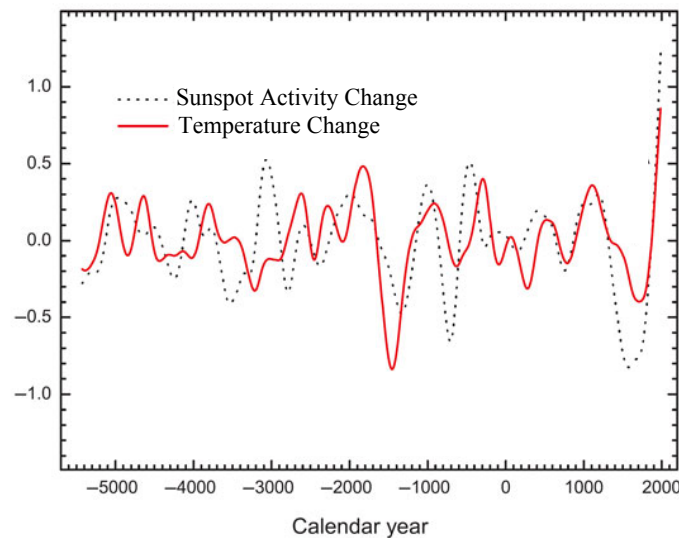


This figure above shows Earth's energy budget. Earth absorbs about half of the Sun's energy. Most of the Sun's energy comes to Earth as visible light. Earth reradiates this absorbed energy as invisible light called infrared. Some of this infrared energy is absorbed by the atmosphere and sent back to Earth. Some escapes into space.



NASA made the map above using satellite data. The map shows how much energy is escaping Earth's atmosphere. Over time, NASA has recorded less infrared energy leaving Earth's atmosphere.

Evidence #4: Increases and decreases in global temperatures closely matched increases and decreases in solar activity before the industrial revolution.



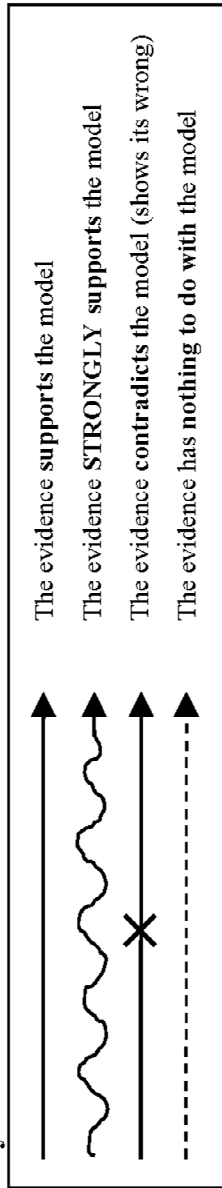
This graph shows sunspot activity and temperature. Sunspot activity is the dashed line. Solar activity increases when the Sun has more sunspots. The red line shows temperature. The shapes of the sunspot and temperature curves match closely. Peaks in the temperature are near peaks in sunspot activity. Dips in temperature are near dips in sunspot activity.

These data show sunspot activity and temperature for the past 9000 years. These data are based on evidence collected from tree rings. Some of the tree rings are from trees that are still living. Some of the trees rings are from ancient trees that have died.

MEL Part C: Diagram and Explanatory Tasks

Directions: draw two arrows from each evidence box. One to each model. You will draw a total of 8 arrows.

Key:



Evidence #1

Atmospheric greenhouse gas concentrations have been rising for the past 50 years. Human activities have led to greater releases of greenhouse gases. Temperatures have also been rising during these past 50 years.

Model A

Our current climate change is caused by increasing amounts of gases released by human activities.

Evidence #3

Satellites are measuring more of Earth's energy being absorbed by greenhouse gases.

Evidence #2

Solar activity has decreased since 1970. Lower activity means that Earth has received less of the Sun's energy. But, Earth's temperature has continued to rise.

Model B

Our current climate change is caused by increasing amounts of energy released from the Sun.

Evidence #4

Increases and decreases in global temperatures closely matched increases and decreases in solar activity before the industrial revolution.

Provide a reason for three of the arrows you have drawn. Write your reasons for the three most interesting or important arrows.

- A. Write the number of the evidence you are writing about.
- B. Circle the appropriate word (strongly supports | supports | contradicts | has nothing to do with).
- C. Write which model you are writing about.
- D. Then write your reason.

1. Evidence # ____ strongly supports | supports | contradicts | has nothing to do with Model ____ because:
2. Evidence # ____ strongly supports | supports | contradicts | has nothing to do with Model ____ because:
3. Evidence # ____ strongly supports | supports | contradicts | has nothing to do with Model ____ because:

4. Circle the plausibility of each model. [Make two circles. One for each model.]

| Greatly implausible or even impossible | | | | | | | | | | | | Highly Plausible | |
|---|---|---|---|---|---|---|---|---|---|----|--|---------------------|--|
| Model A | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | | |
| Model B | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | | | |

5. Circle the model which you think is correct. [Only circle one choice below.]

| Very certain that Model A is correct | Somewhat certain that Model A is correct | Uncertain if Model A or B is correct | Somewhat certain that Model B is correct | Very certain that Model B is correct |
|---|---|---|---|---|
|---|---|---|---|---|

Appendix G: Comparison Activity

Name _____ **Teacher** _____ **Period** _____

How is Global Climate Changing?

Do you think the world's climate is changing? If so, what will happen in the future? What will the climate be like for you, your children, and your grandchildren?

Scientists have been collecting evidence about climate change. Four main evidences are discussed on separate sheets.

1. Read each of the four evidences and answer the following questions:
 - a. What trends, if any, do you notice in the data over time?
 - b. Do global temperatures appear to be increasing, decreasing or staying about the same? Explain how you can tell.
 - c. How could you explain what you observe from the evidence?

2. Now think about what future climate change might be like.
 - a. Will it be much warmer or much cooler than it is now? If so, how much warmer or cooler? Or will climate be about the same as now?
 - b. Write down your prediction for what you think the climate will be like 100 years from now. Also include the reasons for your predictions. Hint: you should use information from the four evidences in your reasons.
 - c. Discuss your predictions with your group. List the predictions and reasons the other group members have.
 - d. In your group, develop a final prediction, with reasons, that all group members agree on. List that final prediction here. (a) What parts of the four evidences support your final prediction? (b) What parts of the four evidences do not support your final prediction?

Appendix H: Summary for Educators

Engage students in explicit critical evaluation of alternative explanations and plausibility reappraisal to promote conceptual change.

- Students should simultaneously consider the strength of connections between evidence and alternative scientific explanations (e.g., hypotheses and theories), as well as explanations promoted by science skeptics, particularly for controversial issues such as climate change.
- Such simultaneous consideration not only facilitates understanding of scientifically accurate conceptions, but helps students understand scientific and engineering practices.
- Students should understand that scientific knowledge is tentative, but students should also understand that scientists and engineers evaluate connections between evidence and explanations to construct their knowledge and solve problems.
- Through the process of critical evaluation, students should understand that certain hypotheses and theories have greater explanatory power than other alternative ideas.
- Instruction about critical evaluation and plausibility appraisal should be explicitly taught to students in order to help them develop their abilities to reason about scientific topics.
- Teaching about socio-scientific topics of great relevance (e.g., climate change) provides opportunities for students to engage in the authentic scientific practice of critical evaluation and plausibility reappraisal. In turn, socio-scientific topics can increase students' understanding of fundamental scientific principles. Therefore, instructors should not avoid controversial topics, but rather use such topics as vehicles to deepen knowledge.

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