How People Reason: A Grounded Theory Study of Scientific Reasoning about Global Climate Change

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For My Family

Abstract

Scientific reasoning is crucial in both scientific inquiry and everyday life. While the majority of researchers have studied "*how people reason*" by focusing on their cognitive processes, factors related to the underpinnings of scientific reasoning are still under-researched. The present study aimed to develop a grounded theory that captures not only the cognitive processes during reasoning but also their underpinnings. In particular, the grounded theory and phenomenographic methodologies were integrated to explore how undergraduate students reason about competing theories and evidence on global climate change.

Twenty-six undergraduate students were recruited through theoretical sampling. Constant comparative analysis of responses from interviews and written assessments revealed that participants were mostly drawn to the surface features when reasoning about evidence. While prior knowledge might not directly contribute to participants' performance on evidence evaluation, it affected their level of engagement when reading and evaluating competing arguments on climate issues. More importantly, even though all participants acknowledged the relative correctness of multiple perspectives, they predominantly favored arguments that supported their own beliefs with weak scientific reasoning about the opposing arguments. Additionally, factors such as personal interests, religious beliefs, and reading capacity were also found to have bearings on the way participants evaluated evidence and arguments.

In all, this work contributes to the current endeavors in exploring the nature of scientific reasoning. Taking a holistic perspective, it provides an in-depth discussion of

factors that may affect or relate to scientific reasoning processes. Furthermore, in comparison with traditional methods used in the literature, the methodological approach employed in this work brought an innovative insight into the investigation of scientific reasoning. Last but not least, this research may help initiate further discussion regarding how to bridge cognitive research with science education to promote student learning of complex scientific issues such as global climate change.

Table of Contents

List of Tables

List of Figures

CHAPTER I INTRODUCTION

Scientific reasoning is an essential element in science teaching and learning. Traditional science teaching mainly focuses on factual recall and confirmatory experiments (Driver, Newton, & Osborne, 2000; Layton, 1973; Weiss, Pasely, Smith, Banilower, & Heck, 2003), whereas in the recent decades, increasing emphasis has been given to enhancing scientific literacy by promoting scientific reasoning skills (e.g., American Association for the Advancement of Science, 1989, 2007; National Research Council, 1996, 2001, 2012). The newly released *Next Generation Science Standards* (2013) have particularly stressed scientific reasoning as a prominent component in science education. By Grade 12, students should be able to reason scientifically to link evidence to explanations as well as defending and critiquing claims and explanations. Through scientific reasoning, students should also be able to evaluate the merits of arguments critically in not only science classrooms but also everyday life.

To promote scientific reasoning, a majority of the previous research has looked into the development of cognitive processes such as hypothesis testing, experimental design, and evidence evaluation (Zimmerman, 2005). This line of work aims to answer the question "*how people reason*" by focusing on how prior knowledge affects the way students and scientists conduct experimental procedures, coordinate theory and evidence, test hypotheses, and so on (e.g., Dunbar, 2001; Lawson et al., 2000; Schauble, 1996; Watters & English, 1995; Zeinneddin & Abd-El-Khalick, 2010). In contrast, only a few studies have explored the underlying factors for the diverse approaches people take to reason (Kind, 2013). Individuals may reason in distinctive ways even when presented with the same information (e.g., Koslowski, 1996), but there is a lack of understanding about the underpinnings of such individual differences. Therefore, despite the ongoing research efforts, no consensus has been reached about what constitutes the essence of scientific reasoning, which has resulted in inconsistent construct definitions for scientific reasoning in the existing literature (Kind, 2013). To better inform science teaching and learning, there is an urgent call for a comprehensive and integrated understanding about scientific reasoning.

The majority of previous research focused on exploring scientific reasoning with well-structured problems that had clear-cut solutions and did not require sophisticated domain-specific knowledge. Figure 1 shows a task of this type developed by Chen and Klahr (1999). This task evaluated children's skills in systematically controlling variables as they attempted to identify what factors may affect the distance a ball rolls after leaving a downhill ramp. With two slopes, children could make comparisons to explore the effect of variables such as the angle of the slope, the structure of the ramp, the length of the ramp, and the type of the ball. To conduct unconfounded experiments, children did not necessarily need to hold rich knowledge about slopes as long as they could control all other variables while changing the variable of interest.

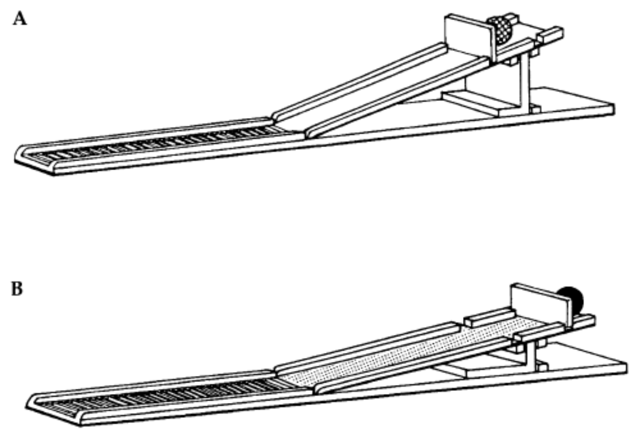

Figure 1 The slope task (Chen & Klahr, 1999). Materials for this task included two wooden ramps and two kinds of balls (golf balls and rubber squash balls). Children could easily adjust the ramps and make comparisons when conducting experiments. This figure shows an example of a confounded experiment one participant made.

Recently, researchers have started to explore scientific reasoning with socioscientific issues such as genetic engineering, local pollution issues, and global climate change (Acar, & Turkmen, & Roychoudhury, 2010; Kuhn, 1993; Sadler & Donnelly, 2006). Socioscientific issues are controversial in nature: they involve the social, technological, and environmental aspects of our daily lives that do not have straightforward, clear-cut solutions (Sadler, 2009). As evidence on socioscientific issues is usually implied and the criteria for evidence evaluation are not well defined, reasoning about these issues requires not only rigorous reasoning of the underlying science, but also competence in appreciating and understanding the uncertainty and complexity of science (Sadler, Barab, & Scott, 2007). Thus, investigating reasoning processes with socioscientific issues may add an authentic element to the current efforts in exploring the nature of scientific reasoning.

Issues related to *global climate change* constituted the topic of interest in this investigation. Global climate change has been widely discussed in the public media for the past decades. Faced with multitude perspectives and debates regarding global climate change, individuals need to be able to reason critically about the information they receive to reach a scientific understanding and communicate effectively to support or refute claims. Exploring scientific reasoning with the topic of global climate change can greatly enrich our understanding of how individuals process scientific information, as well as the underpinnings of their decision making. At the same time, it expands the scope of previous research on scientific reasoning and will contribute to an increasingly comprehensive perspective toward the nature of scientific reasoning.

The primary goal in the present study was to develop a grounded theory about scientific reasoning. The overarching research question was: *How do individuals reason scientifically about competing arguments on global climate change?* In particular, three research questions guided this work:

1. How do individuals reason when evaluating evidence?

2. How do individuals coordinate theories and evidence as they evaluate competing arguments?

3. How do factors such as epistemological understandings relate to scientific reasoning processes?

To investigate these questions, the present study adopted a qualitative approach that integrated two methodologies: *grounded theory* (Glaser & Strauss, 1967; Strauss &

Corbin, 1990) and *phenomenography* (Marton, 1981, 1992). Grounded theory studies feature an exploratory development of theory that is grounded in data from the field (Glaser & Strauss, 1967), whereas phenomenography mainly focuses on the study of how people experience, conceptualize, realize and understand various aspects of phenomena in the world around them (Marton, 1992). These two methodologies have complementary theoretical foundations and operational procedures, and together can lead to a "grounded" insight into the nature of scientific reasoning.

The grounded theory developed through this work holds both theoretical and methodological significance. By exploring the cognitive processes involved in scientific reasoning and their underlying factors, this work will add to the ongoing endeavors in developing an integrated framework that captures different aspects of scientific reasoning. Moreover, previous research on scientific reasoning mainly employed quantitative approaches where researchers tended to focus on their own presumptions that may lead them to overlook some hidden features of the way individuals reason. The combination of grounded theory and phenomenography in this study provides a more "naturalistic" perspective toward the nature of scientific reasoning and will open up more in-depth discussion about the underpinnings of scientific reasoning.

The remaining chapters are organized as follows. Chapter II presents a literature review focused on three main aspects. First, the construct definition for scientific reasoning is discussed with an emphasis on two main research approaches: domain-general and domain-specific. Second, three major theoretical frameworks on scientific reasoning are reviewed as well as their supporting research. Chapter II concludes with a discussion about the need for a grounded theory that captures the nature of scientific reasoning from a more comprehensive perspective.

Chapter III discusses the research methods employed in this investigation. The theoretical foundations and operational procedures of the methods are presented first. Next is a detailed discussion of the study design, sampling process, and data analysis. Additionally, Chapter III includes a brief overview of approaches that were taken to establish trustworthiness in this qualitative study.

Chapter IV presents the findings of this study. First, a brief summary is provided regarding the descriptive results about participants' reading capacity and the categories of their general epistemological understandings. The next section includes an in-depth discussion of the categories and themes that emerged in terms of different aspects of scientific reasoning and its related factors, followed by illustration of the theoretical framework developed through this work.

Chapter V discusses how the current findings relate to existing literature and their educational implications. Moreover, there is a brief review of the significance and limitations of the present study, along with a proposal for directions in future research.

CHAPTER II LITERATURE REVIEW

Research on scientific reasoning abounds in the literature of science education, educational psychology, and cognitive science. Despite the numerous studies exploring scientific reasoning, multiple issues are still under debate. In this chapter, I will focus on three main aspects of the scientific reasoning literature. First, the construct definition of scientific reasoning will be presented with a brief review of the two major research approaches: domain-general and domain-specific. Then, there will be a review of three theoretical frameworks on scientific reasoning in the existing literature. Finally, the chapter will conclude with a discussion about the need for a grounded theory that more comprehensively captures the nature of scientific reasoning.

What is Scientific Reasoning?

Definitions for scientific reasoning vary in the literature as researchers hold different understandings of science and reasoning. Broadly speaking, reasoning is a process of drawing conclusions from principles and evidence so as to infer new conclusions based on what is already known (Wason & Johnson-Laird, 1972). It consists of mental processes involved in generating and evaluating logical arguments (Anderson, 1990), and relates to skills such as clarification, inference, and evaluation (Ennis, 1987). As an important type of reasoning, scientific reasoning entails cognitive processes that are required in scientific activities.

Developmental psychologist Jean Piaget was one of the pioneers in the investigation of scientific reasoning. Together with colleagues, Piaget conducted a series of studies on children to investigate their performance on tasks that required minimal knowledge in the topic area, such as the one shown in Figure 2. In this task, children were asked to solve a problem about making a certain color through combining colorless chemicals. Four identical flasks were provided, containing colorless, odorless liquids: (1) diluted sulphuric acid, (2) water, (3) oxygenated water, and (4) thiosulphate. The smaller flask *g* contained potassium iodide. The experimenter presented two glasses to the subject, one with (1) + (3) and the other with (2). As the subject watched, several drops of *g* were added to each glass. The liquid in the glass containing (1) + (3) turned yellow. The subject was then asked to reproduce this color, using all or any of the five flasks. Successful completion of this task did not require any knowledge about the chemicals involved. Children who could make systematic combination with the chemicals were able to solve the problem.

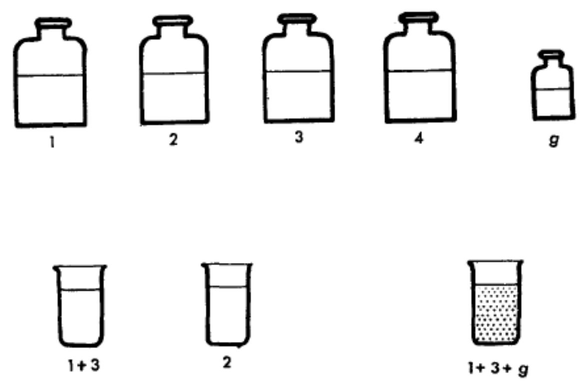

Figure 2 Diagram illustrating the problem of colored and colorless chemicals (Inhelder & Piaget, 1958, p.108).

Based on their extensive work with young children, Inhelder and Piaget (1954) proposed that scientific reasoning entails the ability to undertake a set of logico-mathematical operations such as logical reasoning, probabilistic thinking, and manipulating abstract variables. Closely aligned with the “stage theory” of cognitive development proposed by Piaget (1954), the Piagetian perspective of scientific reasoning identified reasoning processes children can or cannot undertake at different ages. This thus led to the suggestion that the development of general cognition improves the learning of science knowledge and contributes to the improvement of scientific reasoning (Kind, 2013; Lawson, Karplus, & Adi, 1978; Shayer & Adey, 1981).

The Piagetian approach to scientific reasoning has guided research in this area for several decades, endorsed by a great number of educational and psychological researchers. Followers of the Piagetian perspective attribute developmental differences in reasoning to factors such as information-processing capacity, problem-solving skills and logical competence while evaluating young children’s reasoning processes (e.g., Kail, 1991; Klahr & Robinson, 1981; Sodian, Zaitchik, & Carey, 1991). They argued that it is the insufficient cognitive development, rather than knowledge acquisition, that results in the various levels of reasoning among children.

While the Piagetian perspective was prevalent in scientific reasoning research, many researchers raised concerns that Piaget’s view of scientific reasoning as a system of “logic-driven” operations undermines the role of knowledge and contexts in reasoning. They considered that the learning of science requires both science knowledge and science process skills (Dunbar, 2001; Dunbar & Klahr, 1989; Kuhn, Amsel, & O’Loughlin, 1988). Students come to the classroom holding a variety of prior knowledge, and such knowledge will influence or even determine how they interpret new information and then make associations between what is new and what is already known (She & Liao, 2010).

Thus, the study of scientific reasoning should not be isolated from contexts or domain-specific knowledge (e.g., Dunbar, 2001). Indeed, scientific reasoning serves as a very important strategy for learners to "make associations among new mental sets with already-existed hierarchical structure-based memory" (She & Liao, 2010, p. 91). As Schauble (1996) stated, appropriate knowledge supports the selection of appropriate reasoning strategies, which in turn supports the development of more accurate and complete knowledge. Therefore, evaluating reasoning processes while minimizing the influence of their extant knowledge is of little help to inform science teaching and learning (Koslowski, 1996; Lawson et al., 2000).

With an increasing emphasis on facilitating scientific reasoning during inquiry in science education (American Association for the Advancement of Science, 1989, 2007; National Research Council, 1990, 1996, 2001), the domain-specific approach has become increasingly common in scientific reasoning research. Studies taking this approach are embedded in content-rich scenarios to investigate various aspects of reasoning that may be involved in scientific inquiry, such as hypothesis testing, experimental design, and evidence evaluation (e.g., Amsel & Brock, 1996). The rationale for such studies is that scientific reasoning is an explanatory mechanism individuals apply when trying to make sense of or coordinate the information they are exposed to (Schauble, 1996; Watters & English, 1995). In other words, scientific reasoning is a combination of procedural and conceptual knowledge: when reasoning scientifically, an individual may rely on established science content knowledge to conduct experimental procedures, and this process helps them acquire new information and adjust their prior understanding

(Osborne, 2010; Vosniadou, 2002; Zeineddin & Abd-El-Khalick, 2010; Zimmerman, 2005).

In general, no matter whether a researcher adopts the Piagetian perspective of domain-general scientific reasoning or endorses the domain-specific approach to scientific reasoning, most work in this field investigates "how people reason" by focusing on the cognitive processes involved (Bailin & Siegel, 2002). In the current literature, there are three major theoretical frameworks that account for the cognitive processes during scientific reasoning: *Scientific Discovery as Dual Space* (Klahr & Dunbar, 1988), *Hypothetico-deductive Reasoning* (Lawson, 2005, 2009), and *A Theoretical Framework for Evaluating Inquiry Tasks* (Chinn & Malhotra, 2002). In the next section, I will briefly review these frameworks and their supporting research.

Three Major Theoretical Frameworks for Scientific Reasoning

Scientific Discovery as Dual Search (SDDS).

Klahr and Dunbar (1988) proposed an integrated framework, *Scientific Discovery as Dual Search* (SDDS), to interpret human behaviors in any scientific reasoning tasks. SDDS is based on Simon's work in which problem solving is defined as a process of searching different spaces and states (Simon, 1977; Simon & Lea, 1974). The fundamental assumption of SDDS is that scientific reasoning is a search process conducted in two related problem spaces: a space of hypotheses (i.e., *hypothesis space*) and a space of experiments (i.e., *experiment space*). The *hypothesis space* consists of hypotheses generated during the scientific discovery process, whereas the *experiment space* consists of all possible experiments that can be conducted and yield interpretable outcomes. The search in these two spaces is mediated by the *evidence evaluation* process, which assesses the fit between theory and evidence, as well as guiding further search in both the hypothesis space and the experiment space. To conduct the search successfully, two essential skills are stressed in this framework: *experimental design skills* and *hypothesis formation skills.* In accordance with the two problem spaces, *hypothesis formation skills* involve the formation and evaluation of hypotheses, while *experimental design skills* involve the design of experimental and observational procedures. These two sets of skills together are crucial to the success of scientific endeavors.

The original descriptions of SDDS highlighted this “dual-search” coordination between the hypothesis and experiment spaces. It captured the discovery processes from the initial formulation of hypotheses, through experiment evaluation, to the decision that there is sufficient evidence to accept a hypothesis (Klahr, 2000). To depict scientific discovery processes in more depth, updated descriptions of SDDS further specified three components: *search hypothesis space, test hypothesis,* and *evidence evaluation* (Klahr, 1994, 2000, 2005; Klahr & Dunbar, 1988), and under each of these three main components, the framework also identified more specific subcomponents to further illustrate the reasoning during discovery (see Figure 3).

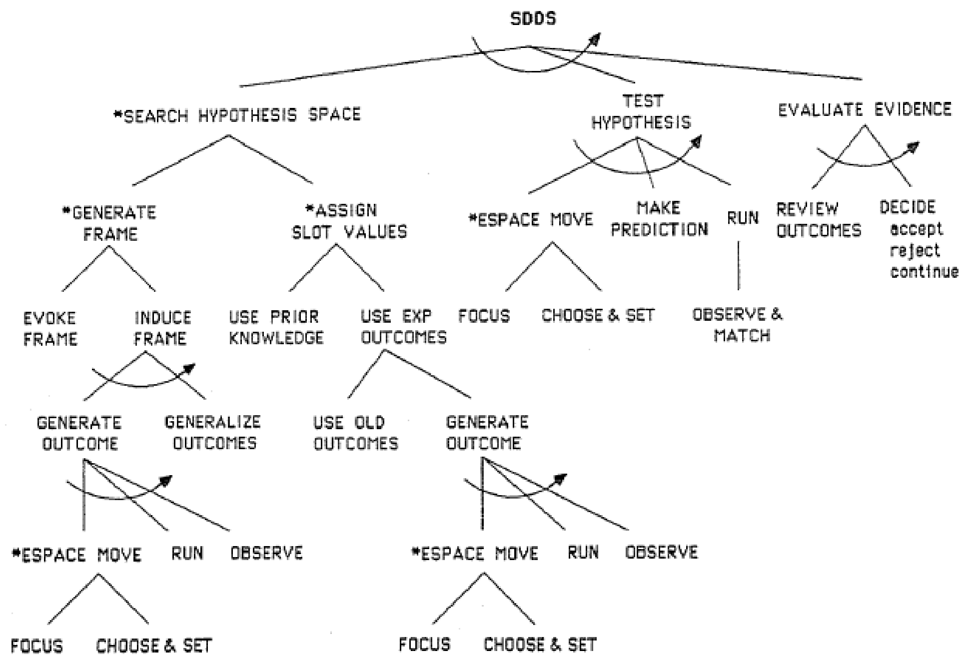

Figure 3 Process hierarchy for SDDS (Klahr & Dunbar, 1988, p. 34). All subprocesses connected by an arrow executed in a sequential conjunctive fashions. All process names are preceded by an asterisk including conditional tests for which subprocesses to execute.

Importantly, SDDS suggested that prior knowledge guides the formulation of hypotheses and leads individuals to adopt different experimental strategies to test plausible and implausible hypotheses. Klahr (2004) introduced the distinction between *weak methods* and *strong methods* (Simon, 1986) to further explain the role of prior knowledge in reasoning. Similar to the idea of domain-general approach, *weak methods* refer to problem solving processes that require relatively little knowledge of the problem structure. *Strong methods*, in contrast, require more expertise in the problem domain and may allow solutions to be found with little reasoning effort. For example, if asked to find the maximum of a function, someone who knows the calculus can use the *strong methods* to "apply a known algorithm (taking the derivative and setting it equal to zero) and find the answer without search" (Simon, 1986, p. 162). While *weak methods* would suffice to solve the tasks Klahr and colleagues developed (Klahr & Dunbar, 1988, Klahr, Fay, & Dunbar, 1993), SDDS acknowledged the influence of domain-specific knowledge on reasoning and called for more research that incorporates strong methods. After all, as Klahr (2004) stressed, individuals' domain-specific knowledge influences not only the initial search for hypotheses but also how the characteristics of evidence are attended to and encoded.

SDDS was derived from results of psychological experiments in which participants (university students and school children) solved simulated scientific inquiry tasks with a robotic machine called BigTrak (Dunbar & Klahr, 1989; Klahr & Dunbar, 1988). BigTrak was a self-contained and self-propelled "laser tank" that could be programmed to move around. Participants could press a series of buttons on BigTrak's keypad to control sequences of forward and backward movements. In the experiments, participants were first familiarized with the basic programming commands for BigTrak. Then, they were asked to figure out a new function, *RPT*, by writing a series of programs and observing BigTrak's behaviors. Analyses of participants' think-aloud protocols revealed how they formulated hypotheses and generated experiments to evaluate those hypotheses. It was found that many participants reached solutions by searching both the hypothesis and experiment spaces. As participants varied in their levels of prior knowledge in programming, the results indicated that those who knew more about programming were more likely to conduct appropriate search and complete the task correctly. Klahr and Dunbar (1988) thus suggested that differences in prior knowledge influence the hypothesis-formulation stage and lead to differences in experimental strategies.

As one of the first general theoretical accounts for scientific reasoning, SDDS has served as a theoretical foundation for many later studies and a number of empirical studies have directly or indirectly supported it. For example, Klahr, Fay, and Dunbar (1993) studied how adults and school students conducted dual search in the hypothesis and experiment spaces with a computer miscroworld. Participants were asked to enter a sequence of commands to a “spaceship” to find out how a certain button on a keypad functions. They were asked to write at least three programs and observe the results, and also had the option to write additional experiments if they were still uncertain about their answers. The findings revealed a developmental trend in the overall systematicity and effectiveness with which participants searched the hypothesis and experiment spaces. While young students were able to search the two spaces appropriately, compared to adults, they were less able to constrain their search and were unsystematic in the way they designed experiments. Besides, they tended to avoid considering multiple hypotheses and performed much worse when coordinating the search of the two spaces. The cognitive demands imposed by the need to search the hypothesis space for a plausible hypothesis to oppose an implausible one and then to search the experiment space for a discriminating test may have exceeded the capacity of the young participants. Dunbar (1995) observed four biology laboratories to explore how scientists really think and reason. He compared and contrasted the scientists’ reasoning in three aspects: mental representations, experimental heuristics, and problem-solving heuristics and identified the characteristics of reasoning involved in science inquiry, which further supported the SDDS framework.

SDDS integrated scientific reasoning processes during scientific discovery and explained the cognitive processes involved in such reasoning from a broad sense so it captured a wide range of reasoning contexts. It described the complexity and the cyclical nature of the process of scientific discovery (Klahr, 2000). As one of the first integrated frameworks that attempted to capture scientific reasoning, SDDS addressed the ongoing debate regarding whether scientific reasoning is domain-general or domain-specific. Acknowledging the importance of domain-specific knowledge, this framework stressed that search in the hypothesis and experiment spaces are guided by both domain-general and domain-specific knowledge, which expanded the scope of research that follows the Piagetian perspective and elicited more focus on the relationship between prior knowledge and scientific reasoning in later work.

However, despite its prominent value in scientific reasoning literature, a few limitations exist in the application of SDDS. SDDS was proposed based on studies that explored scientific reasoning with simulated scientific inquiry tasks, and such tasks were rather artificial and cannot fully represent the authentic scientific inquiry conducted either by scientists or in everyday life. Although Dunbar (1995) investigated this issue in science laboratories, given the various ways scientists in different disciplines may conduct science, we cannot come to any conclusion that this framework captures scientific reasoning in all contexts. For one thing, the laboratories Dunbar observed in were biology laboratories, and the scientific inquiry processes employed may vary across disciplines and it is thus uncertain whether SDDS is applicable in fields such as astronomy and geology (Allchin, 2003; Lawson, 2003). For another, previous research supporting SDDS was mainly conducted in psychology laboratories, which leaves its practical implications for classroom science teaching and learning not well addressed.

Moreover, Klahr and Dunbar (1988) acknowledged that the role of prior knowledge in SDDS should be specified in terms of how it is “activated, searched and utilized by the discovery context” (p. 38). This is especially important considering that in their study some participants with more prior knowledge discovered the solution without searching the experiment space. Besides, the characterization of evidence evaluation in SDDS is rather general. There is not much discussion regarding what counts as evidence and how evidence evaluation should be carried out for communication and advancement of science. Since the process of evidence evaluation is a crucial element in the construction of argumentation, SDDS implies an opportunity for future research to investigate the link between scientific reasoning and argumentation.

Hypothetico-deductive reasoning.

Similar to Klahr and Dunbar, Lawson also emphasized the importance of generating and testing hypotheses in scientific reasoning. In his work, Lawson (2005, 2010) used the term *hypothetico-deductive reasoning* to capture the essence of scientific reasoning and depicted four types of inferences that may be involved, including abduction, retroduction, deduction and induction (Lawson, 2005, 2010). Table 1 presents the definitions for each of the inferences and aligns them with the example of Galileo's discovery of Jupiter's moons in the "*If… then… Therefore…*" format.

Table 1 Four basic inferences involved in scientific reasoning (Lawson, 2010, p. 343)

Inference	Question	Example
Abduction	What caused the puzzling observation (e.g., the three new points of light new Jupiter)?	*If* ... points of light seen in the night sky are caused by fixed stars embedded in the celestial sphere, *and* ... three new similar looking points of light are seen in the night sky, *then*... perhaps they also are fixed stars.
Retroduction	Does the proposed cause explain what we already know?	*If*... the points of light are fixed stars, *and* ... their positions are compared to each other, *then*…their positions should be random. *But*…they appear exactly in a straight line parallel to the ecliptic. *Therefore*… perhaps they are not fixed stars.
Deduction	What does the proposed cause lead us to predict about future observations?	*If*... the three points of light are moons orbiting Jupiter, *and*…I observe them over the next several nights, *then*…some nights they should appear to the east of Jupiter and some nights they should appear to the West. Further, they should appear along a straight line on either side of Jupiter.
Induction	How do the predictions and new observations compare?	*If* ... the new observations match the predictions based on the orbiting-moons hypothesis, as they do in this case (e.g., some nights the lights appeared to the east of Jupiter and some nights they appeared to the west), *then* ... the hypothesis is supported.

Generally, abduction is an inferential process and involves reasoning to mentally derive causal claims from premises. Once a hypothesis has been generated via abduction, it must pass retroduction, which is an inferential test for evaluating alternative explanations. Deduction is used to generate one or more predictions about future observations that should occur provided this hypothesis is correct, whereas induction is an inference process employed to draw a conclusion. Based on these four elements of hypothetico-deductive reasoning, Lawson specified six steps of reasoning in any given scientific inquiry contexts (see Figure 4):

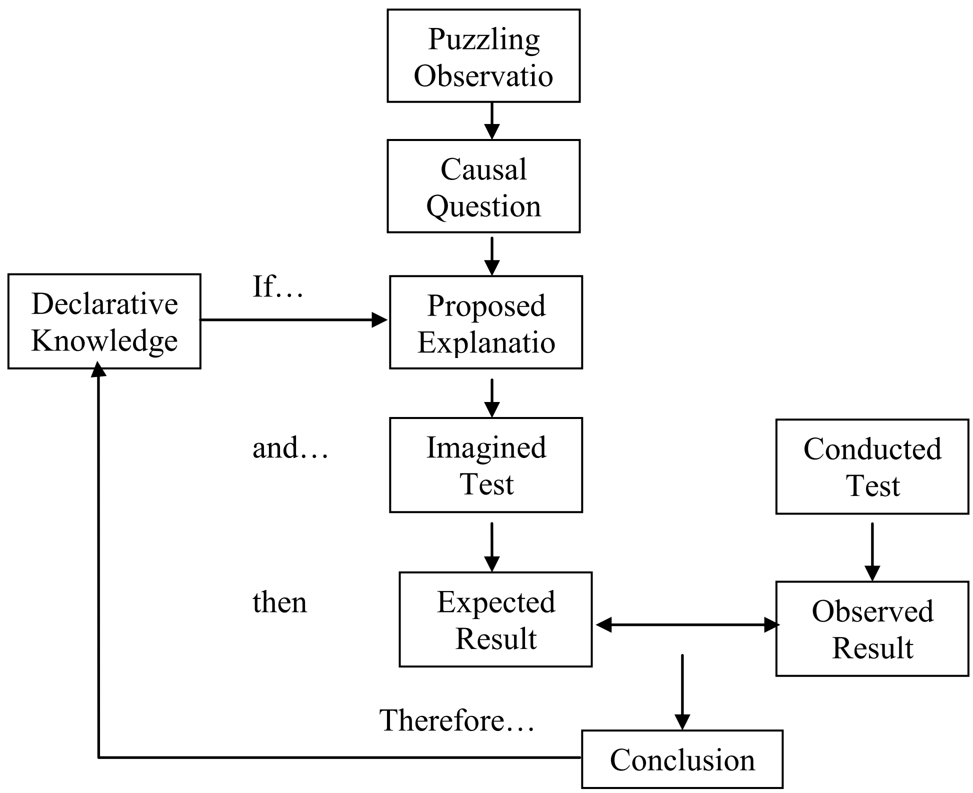

Figure 4 A model of the elements of *If/then/Therefore* reasoning and argumentation used during the generation and subsequent test of proposed explanations (Lawson, 2010, p. 342).

(1) *Making an initial puzzling observation*. In science, observations are puzzling when they contradict current predictions about how the world should work. Importantly,

current predictions are based on current mental models. Thus, puzzling observations lead to the possibility that current mental models may need to be modified or replaced.

(2) *Generating one or more hypotheses using analogical reasoning or abduction.* Here, Lawson differentiated hypothesis from prediction with the definition from Cothron, Giese, and Rezba (2006), considering that a hypothesis is “a prediction of the effect that changes in the independent variable will have on the dependent variable” (p. 45).

(3) *Designing imagined tests to test the hypotheses.* This will allow the deduction of predicted results.

(4) *Conducting the imagined test*. If the initial ideas are in fact tested, the test must be conducted so that its predicted result(s) can be compared with the observed result(s) of circumstantial, correlational, or experimental in nature.

(5) *Comparing predicted and observed results*. This comparison allows one to draw a conclusion. A good match means that the hypothesis is supported but not proven, whereas a poor match means that something is wrong with the hypothesis, the test, or both. A poor match does not disprove or falsify a hypothesis in any ultimate sense, because a poor match between predicted and observed results can arise from one of two sources-a faulty hypothesis or a faulty test.

(6) *Recycling the procedure until a hypothesis is generated, tested, and supported on one or more occasions and its competing alternatives have been tested and rejected.*

Lawson emphasized that these six steps may occur on a subconscious level or the process may stop somewhere along the way and mistakes may be made in this process.

To further support his proposition that hypothetico-deductive reasoning is at the core of reasoning, Lawson (2005) discussed the way our brains process when receiving new information and pointed out that new information activates our mental representations and leads us to assimilate input and deduce predictions that in turn allow our ideas to be tested. This path of information processing lends support to the claim that hypothetico-deductive reasoning underlies everyday inquiries.

Lawson (2005) investigated college students' reasoning with two sets of tasks (see Figure 4). The difference of these two sets is that the question on the left in Figure 4 requires enumerative induction to find the answer whereas the other one does not. Participants randomly received one set of the tasks and were asked to select one of the options as well as explaining their choices. Analysis of participants' explanations revealed that *hypothetico-deductive reasoning* was applied in tasks that required enumerative induction and participants reached the appropriate solutions by reasoning in an *If-then-Therefore* pattern. Lawson (2010) also illustrated the role of *hypothetico-deductive reasoning* with analysis of several historical cases in science, including Galileo's discovery of Jupiter's moons, Rosemary and Peter Grants' research on Darwin's finches, and Marshall Nirenberg's Nobel Prize-winning research on genetic encoding. He analyzed these cases in terms of the four inferences he proposed and concluded that hypothetico-deductive reasoning was crucial in leading to these achievements.

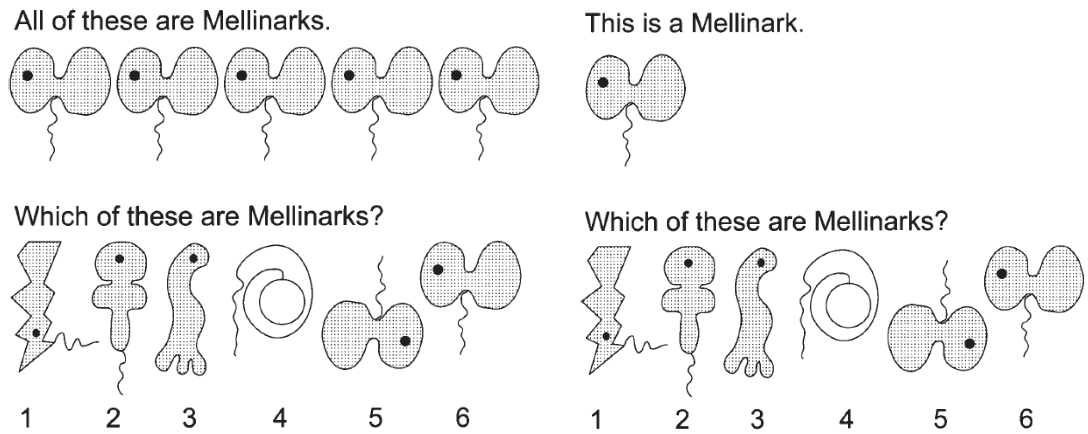

Figure 5 (Left) A Mellinark task that requires the use of enumerative induction because the first row includes several Mellinarks; (Right) A Mellinark task in which enumerative induction cannot be used because only one Mellinark is shown in the first row (Lawson, 2005, p. 721-722).

Compared to SDDS (Klahr & Dunbar, 1988), Lawson's framework for scientific reasoning focused more on how induction and deduction constitute and influence individuals' reasoning and inquiry. Additionally, as Lawson gave specific emphasis on the importance of observation during inquiry, his account made it possible to capture scientific reasoning in a broader range of disciplines in science. Lawson's account also implied the importance of domain-specific knowledge in scientific reasoning. Although the studies he conducted with enumerative induction was in a domain-general context with little prior knowledge required, his analysis of historical cases in different science disciplines connects the investigation of scientific reasoning with the development of scientific knowledge.

Lawson proposed that hypothetico-deductive reasoning accounts for scientific reasoning in most, if not all, contexts. However, some researchers debate this conclusion.

For example, Allchin (2003) argued that in many disciplines and contexts, scientific inquiry is conducted through blind search instead of logical reasoning. Allchin pointed out that Marcello Malpighi did not discover capillaries by strict hypothetico-deductive reasoning: Malpighi started the discovery without planning or expecting to observe small blood vessels connecting arteries and veins, so the discovery was not guided by hypothetico-deductive reasoning. Allchin also argued that Lawson's analysis of historical cases was mostly based on the scientists' personal narratives, which may not fully reveal their thinking processes during the discovery. Later, Lawson (2010) acknowledged that hypothesis testing does by no means always occur. Indeed, it is common practice for people to generate hypotheses and simply believe them to be true without making an attempt to test them. Although predicted results must be compared with observed results to test hypotheses, observed results can sometimes be obtained before one or more predictions have been deduced. Furthermore, although Lawson conducted follow-up studies that further revealed the importance of hypothetico-deductive reasoning, the tasks used in these studies were rather artificial: they required very little scientific knowledge in any specific domains and were rather different from problems one would usually encounter in everyday life. There is not enough evidence to show that the four inferences involved in hypothetico-deductive reasoning are applicable for authentic scientific inquiry that takes place in science laboratories or everyday contexts. Therefore, hypothetico-deductive reasoning may not always suffice to account for how people reason scientifically.

A theoretical framework for evaluating inquiry tasks.

While SDDS and hypothetico-deductive reasoning provide integrative accounts for scientific reasoning, it is unclear whether they fully capture individuals' reasoning in the classrooms and daily life. Chinn and Malhotra (2002) addressed this concern from a practical science teaching and learning perspective. They proposed a framework for scientific reasoning by contrasting authentic scientific inquiry with simple inquiry tasks. Authentic scientific inquiry was defined as "a complex activity, employing expensive equipment, elaborate procedures and theories, highly specialized expertise, and advanced techniques for data analysis and modeling (Dunbar, 1995; Galison, 1997; Giere, 1988)" (Chinn & Malhotra, 2002, p. 177). In contrast, simple inquiry tasks were referred to as tasks regularly used in science textbooks and educational software. Chinn and Malhotra further distinguished three types of simple inquiry tasks: *simple experiments, simple observations,* and *simple illustrations* (see Table 2 for definitions and examples).

Table 2 Definitions and examples for three types of simple inquiry tasks (Chinn & Malhotra, 2002)

Tasks	Definition	Example
Simple Experiments	Students conduct straightforward experiment, usually evaluating the effects of a single independent variable on a single dependent variable	*Meterstick experiment* (McFadden & Yager, 1993, p. 276): students investigated the effect of weight on how far the meter stick bends; they simply hang weights of various sizes to the end of the meter stick.
Simple Observations	Students carefully observe and describe objects	*Observing a starfish* (Warner et al., 1991, p. 272): students measured features such as a starfish's diameter and noticed the location of various structures such as the mouth and tube feet
Simple Illustrations	Students follow a specified procedure, usually without a control condition, and observe the outcome; no opportunities are provided for further exploring any new empirical phenomena	*Bleach task* (Thompson, McLaughlin, & Smith, 1995, p. 315): students followed steps in the textbook to ignite a match using the chemical reactions between bleach and cobalt chloride.

The foundation of this framework is the cognitive theory, *models-of-data*, proposed earlier by Chinn and Brewer (1996). The basic premise of the *models-of-data theory* is that an experiment or other forms of research can be represented as a model that integrates theoretical explanations with observations and details of the data gathering procedures. Such models incorporate four kinds of inferential connections - *causal*, *contrastive*, *inductive*, and *analogical connections* - to link events in a schematically semantic network (see Figure 6 for an example).

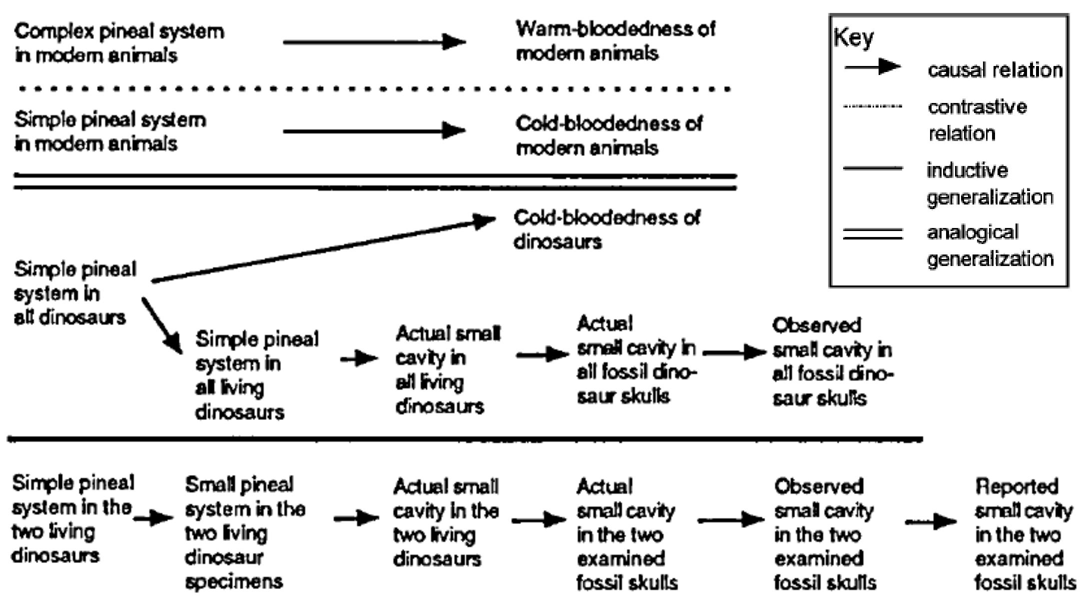

Figure 6 A model of the pineal system based on the *models-of-data theory* (Chinn & Brewer, 1996, p.216)

Based on the *models-of-data theory*, Chinn and Malhotra (2002) discussed two differences between authentic scientific inquiry and simple inquiry tasks. First, the *cognitive processes* needed to reason about simple inquiry tasks are often different from those required in authentic scientific inquiry. Chinn and Malhotra held that the teaching of scientific reasoning in K-12 science classrooms tends to focus on general categories of reasoning such as controlling variables and generating explanations (Bybee, 2000; Germann, Haskins, & Auls, 1996; Hafner & Stewart, 1995; Kuhn, Garcia-Milar, Zohar, & Anderson, 1995; Zimmerman, 2000), but these reasoning aspects may not be unique to authentic inquiry. They claimed that some textbook tasks, for example, simply require students to hold one variable constant while changing the other in order to answer a research question and such tasks may bear little resemblance to science. To illustrate this view in more depth, Chinn and Malhotra developed a taxonomy to compare and contrast the cognitive processes employed in authentic and simple inquiry tasks (see Table 3).

Table 3 Cognitive processes in authentic inquiry, simple experiments, simple observations, and simple illustrations (Chinn & Malhotra, 2002, p. 180)

Type of Reasoning Task				
Cognitive Process	Authentic Inquiry	Simple Experiments	Simple Observations	Simple Illustrations
Generating research questions	Scientists generate their own research questions	Research question is provided to students	Research question is provided to students	Research question is provided to students
Designing studies				
Selecting variables	Scientists select and even invent variables to investigate. There are many possible variables	Students investigate one or two provided variables	Students observe prescribed features	Students employ provided variables

Table 3-continued

	Type of Reasoning Task			
Cognitive Process	Authentic Inquiry	Simple Experiments	Simple Observations	Simple Illustrations
Planning procedures	Scientists invent complex procedures to address questions of interest. Scientists often devise analog models to address the research question	Students follow simple directions on how to implement a procedure. Analog models are sometimes used, but students do not reflect on whether the models are appropriate	Students follow simple directions on what to observe. Analog procedures are usually not used	Students follow simple directions on how to implement a procedure. Analog models are sometimes used, but students do not reflect on whether the models are appropriate.
Controlling variables	Scientists often employ multiple controls. It can be difficult to determine what the controls should be or how to set them up	There is a single control group. Students are usually told what variables to control for and/or how to set up a controlled experiment	Control of variables is not an issue. Not applicable	Control of variables is usually not an issue Not applicable
Planning measures	Scientists typically incorporate multiple measures of independent, intermediate, and dependent variables	Students are told what to measure, and it is usually a single outcome variable	Students are told what to observe	Students are told what to measure, and it is usually a single outcome variable

Table 3-continued

	Type of Reasoning Task			
Cognitive Process	Authentic Inquiry	Simple Experiments	Simple Observations	Simple Illustrations
Explaining results				
Transforming observations	Observations are often repeatedly transformed into other data formats	Observations are seldom transformed into other data formats, except perhaps straightforward graphs	Observations are seldom transformed into other data formats, except perhaps drawings	Observations are seldom transformed into other data formats, except perhaps straightforward graphs
Finding flaws	Scientists constantly question whether their own results and others' results are correct or artifacts of experimental flaws	Flaws in experiments are seldom salient	Flaws in experiments are seldom salient	If students do not get the expected outcome, they often assume that they did the experiment incorrectly
Indirect reasoning	Observations are related to research questions by complex chains of inference. Observed variables are not identical to the theoretical variables of interest	Observations are straightforwardly related to research questions. Observed variables are the variables of interest.	Observations are straightforwardly related to research questions. Observed variables are the variables of interest.	Observations are straightforwardly related to research questions. Observed variables differ from theoretical variables, but the text explains the link directly

Second, Chinn and Malhotra argued that the differences in cognitive processes imply that the epistemology underlying simple inquiry tasks is very different from the epistemology that guides authentic scientific reasoning. A second taxonomy was developed to analyze the differences between the epistemology of simple inquiry tasks and that of authentic science (see Table 4). In particular, regarding the nature of reasoning, they argued that simple inquiry tasks require the use of simple, often algorithmic strategies of reasoning, whereas reasoning in real science involves uncertain judgments and heuristics, and scientists may thus be unsure about every aspect of drawing inferences from experiments. Therefore, simple inquiry tasks may not only fail to help students learn to reason scientifically; they may also foster a nonscientific epistemology in which scientific reasoning is viewed as simple, certain, algorithmic, and focused at a surface level of observation.

Table 4 Epistemology of authentic inquiry, simple experiments, simple observations, and simple illustrations (Chinn & Malhotra, 2002, p. 188)

	Type of Reasoning Task			
Dimension of Epistemology	Authentic Inquiry	Simple Experiments	Simple Observations	Simple Illustrations
Purpose of research	Scientists aim to build and revise theoretical models with unobservable mechanisms	Students aim to uncover a simple surface-level regularity	Students aim to observe structures of objects	Students aim to understand a provided theory
Theory-data coordination	Scientists coordinate theoretical models with multiple sets of complex, partially conflicting data. Scientists seek global consistency.	Students coordinate one set of observable results with conclusions about those observable results. Students seek at most local consistency	Students record what they see. Students seek at most local consistency	There is no theory-data coordination. There is no theory-data coordination

Table 4-continued

	Type of Reasoning Task			
Dimension of Epistemology	Authentic Inquiry	Simple Experiments	Simple Observations	Simple Illustrations
Theory-ladenness of methods	Methods are partially theory laden	Methods are not theory laden	Methods are not theory laden	Methods are not theory laden
Responses to anomalous data	Scientists rationally and regularly discount anomalous data	There is little scope for students to rationally discount data	There is little scope for students to rationally discount data	Data are rejected as erroneous results contradict expectations
Nature of reasoning	Scientists employ heuristic, nonalgorithmic reasoning. Scientists employ multiple acceptable argument forms. Reasoning is uncertain.	Students employ algorithmic reasoning to derive a conclusion from an experiment. Students employ simple contrastive arguments. Reasoning is certain.	Students may employ various modes of reasoning about visual structures. Students often make no arguments.	Students comprehend the provided explanation linking the theory to the data. Students make no arguments.
Social construction of knowledge	Scientists employ multiple acceptable argument forms. Reasoning is uncertain. Scientists construct knowledge in collaborative groups. Scientists build on previous research by many scientists. Institutional norms are established through expert review processes and exemplary models of research.	Students employ simple contrastive arguments. Reasoning is certain. Students construct knowledge in collaborative groups. Students seldom build on any previous research. There are no institutional norm-setting processes	Students often make no arguments. Reasoning is certain. Students construct knowledge in collaborative groups. Students seldom build on any previous research. There are no institutional norm-setting processes.	Students make no arguments. Reasoning is certain. Students construct knowledge in collaborative groups. Students seldom build on any previous research. There are no institutional norm-setting processes.

Chinn and Malhotra's framework provided a descriptive account to evaluate cognitive processes and epistemology involved in authentic inquiry tasks. It was used to analyze and compare the extent to which typical textbook inquiry tasks and inquiry tasks designed by researchers resemble authentic scientific inquiry. Chinn and Malhotra (2002) found that the research activities in the textbooks consistently failed to incorporate elements of authentic scientific reasoning. For example, none of the textbook activities they evaluated allowed students to generate their own research questions, and there were few opportunities for students to think about complex inquiry processes. In contrast, the tasks developed by researchers included more authentic features: for instance, some tasks involve complex control of variables and explaining competing claims with evidence.

Building on Chinn and Malhotra's (2002) framework, Dolan and Grady (2010) developed a matrix called *Complexity of Scientific Reasoning during Inquiry (CSRI)* matrix (see Table 3). They divided the cognitive processes of reasoning into four levels of complexity along a continuum: least, somewhat, more, and most complex, with most complex reflecting the depth of reasoning associated with the work of research scientists and least complex representing the limited reasoning involved when information is provided to students rather than gathered or reasoned by them.

Table 5 Matrix for evaluating complexity of reasoning during scientific inquiry (Dolan & Grady, 2010)

Cognitive process	Increasing complexity of scientific reasoning tasks			
	Least complex	Somewhat complex	More complex	Most complex
Generating questions				
	The over-arching research question is provided; students do not generate or explore other question during the inquiry	The over-arching research question is provided; students generate and/or explore other questions based on observations during the inquiry	The over-arching research question is provided; students generate and/or explore other questions based on observations and wider exploration of the research topic during the inquiry	Students generate their own research question: other questions are generated and explored based on observations and wider exploration of the research topic during the inquiry
Posing preliminary hypotheses				
	Students do not pose preliminary hypotheses or they pose non-testable or irrelevant hypotheses without conducting prior investigations into the research question	Students pose relevant and testable preliminary hypotheses without conducting prior investigations of the research question	Students pose relevant and testable preliminary hypotheses based on prior investigations of the research question	Students pose relevant, testable, and falsifiable preliminary hypotheses based on prior investigations of the research question
Designing and conducting the research study				
Selecting dependent and independent variables	Students do not have a rationale for their choice of variables	Students have a limited rationale for their choice of variables	Students have a thoughtful, non-technical rationale for their choice of variables	Students have a thoughtful, scientific rationale for their choice of variables

Table 5-continued

Cognitive process	Increasing complexity of scientific reasoning tasks			
	Least complex	Somewhat complex	More complex	Most complex
Considering experimental controls	Students give no attention to the design of controls	Students give minimal attention to the design of controls	Students give some attention to the design of controls	Students give purposeful, focused attention to the design of controls
Explaining results				
Considering the meaning of the representations of data	Students are provided with a formatted data table and do not consider meaningful representations of data	Students design their own data tables giving little consideration to the meaning of representations of data	Students represent data in multiple ways including tables, drawings, graphs, photographs, or statistical representations with little consideration of the meaning of representations	Students represent data in multiple ways including tables, drawings, graphs, photographs, or statistical representations, thoughtfully considering the meaning of representations
Considering the limitations or flaws of their experiments	Students do not consider or report limitations or flaws of their experiments	Students consider superficial limitations or flaws of their experiments at the end of the inquiry and report these limitations or flaws orally or in writing	Students thoughtfully consider limitations or flaws of their experiments during the inquiry but do not make adjustments in inquiries. Students report these limitations orally or in writing	Students thoughtfully consider limitations or flaws of their experiments during the inquiry and adjust inquiries accordingly.

Table 5-continued

Cognitive process	Increasing complexity of scientific reasoning tasks			
	Least complex	Somewhat complex	More complex	Most complex
Connecting data to the research question	Students do not connect data to research questions	Students use their data to answer questions other than the primary research question	Students use different forms of reasoning (e.g., contrastive, deductive, inductive) to connect data to the primary research question. Reasoning may require inferences involving several layers of connections	Students use results from different studies, as well as different forms of reasoning (e.g., contrastive, deductive, inductive) to connect their data to the primary research question. The reasoning may require inferences involving several layers of connections
Providing suggestions for future research	Students do not pose suggestions for future research and do not suggest additional hypotheses	Students pose superficial suggestions for future experiments or suggest unrelated hypotheses	Sudents pose relevant suggestions for future experiments or suggest additional, pertinent testable hypotheses	Students pose relevant suggestions for future experiments, including pertinent testable hypotheses
Communicating and defending findings	Students do not communicate or defend their findings either orally or in writing	Students give limited attention to communicating and defending their findings orally or in writing	Students communicate their findings orally or in writing with some emphasis on defending their findings	Students communicate their findings orally or in writing. Students use logical arguments to defend their findings.

The framework proposed by Chinn and Malhotra (2002) compared and contrasted the cognitive processes and epistemology involved in authentic and simple inquiry tasks. While the accounts Klahr and Dunbar (1988) and Lawson (2005) proposed both attempted to capture scientific reasoning during scientific inquiry, the framework Chinn and Malhotra (2002) developed made a clear distinction between authentic and classroom inquiry. Klahr and Dunbar defined scientific inquiry/discovery as the search between two spaces, which according to Chinn and Malhotra's framework can either be authentic or simple inquiry depending on how the inquiry is planned and conducted. Lawson analyzed historical cases to explain hypothetico-deductive reasoning in the context of scientists' inquiry processes, but his empirical work on reasoning mainly focused on inquiry with domain-general topics such as enumerative induction. Therefore, although both SDDS and Lawson's framework emphasized scientific inquiry in the study of scientific reasoning, Chinn and Malhotra's framework enriched the discussion of how to better facilitate scientific inquiry in the classrooms. In comparison to previous research that focused primarily on the cognitive processes during scientific reasoning, this framework brought an innovative perspective into the study of scientific reasoning and expanded its scope.

However, since there was no further empirical research to validate this analytical framework, how it can be effectively applied in classroom teaching and learning was not well addressed. Additionally, although this framework emphasized the importance of engaging students in authentic inquiry, the discussion was focused on reasoning with rather well-defined scientific topics where there is one correct answer to questions. Little emphasis was placed on how individuals reason outside the classrooms when no one absolute answer can solve a problem.

Summary.

The frameworks above capture important features of scientific reasoning. In general, they explore the question “how do people reason scientifically” by investigating the cognitive processes and skills involved in scientific reasoning. However, the scientific reasoning they have characterized may not fully represent how people really reason in various scientific contexts. In particular, while SDDS entails rigorous analysis of scientific discovery processes, the research it derived from was conducted in the context of simulated inquiry tasks and Klahr (2004) acknowledged that “weak methods” were employed in these tasks as little knowledge in the problem domain was required. Hence, although SDDS highlighted the importance of prior knowledge in scientific reasoning, it did not fully reveal scientific reasoning in science classrooms and everyday settings. Lawson proposed hypothetico-deductive reasoning to account for the essence of scientific reasoning and his framework was generated with an assumption that individuals reason logically during scientific inquiry. Yet, it has not been fully demonstrated whether all students and scientists reason in such a logical way across all disciplines and contexts. Last but not least, even though Chinn and Malhotra (2002) emphasized the differences between authentic and simple inquiry tasks and attempted to enhance the quality of scientific inquiry in the classrooms, their framework stays at an analytical level and has not yet been validated by further empirical studies. It is thus uncertain whether the cognitive processes they discussed about authentic inquiry are all applicable in K-12 science teaching and learning.

Therefore, while these three main frameworks contributed in-depth analysis of the essence of scientific reasoning, they are relatively limited in characterizing scientific reasoning in a practical sense. Research that follows these frameworks mostly focused on exploring scientific reasoning in psychology laboratories with participants performing domain-general tasks that required very limited content knowledge (e.g., Chen & Klahr, 1999). Even when more prior knowledge was required, the tasks are usually limited to well-defined scientific problems to which there is one correct solution (e.g., Zimmerman & Glaser, 2001; Kuhn & Dean, 2004). There is thus a great need for more research that explores the authentic nature of scientific reasoning.

How Do People Really Reason?

A large portion of the scientific reasoning in our everyday life is with ill-structured scientific problems to which there is no one definite solution. In recent years, increased attention has been given to expanding scientific reasoning research with a focus on individuals' reasoning about *socioscientific issues* (e.g., Acar, & Turkmen, & Roychoudhury, 2010; Kuhn, 1993; Sadler & Donnelly, 2006). Unlike topics that are traditionally used in studies on scientific reasoning, socioscientific issues are controversial in nature. As arguments can be constructed from multiple perspectives in response to the dilemmas of socioscientific issues, to reach a scientific understanding, individuals need to move beyond mere formal, logical thinking and incorporate reasoning that will allow them to consider the inherent complexity of science and think critically when presented with potentially biased information (Sadler, 2004; Sadler, Barab, & Scott, 2007). Exploring scientific reasoning using socioscientific issues provides a fresh insight into how people really reason. Zeidler, Sadler, Simmons, and Howes (2005) held that, faced with socioscientific issues, individuals need to understand science as a "way of knowing" rather than absolute truth. Compared to the reasoning captured in the three frameworks above, reasoning about socioscientific issues requires not only advanced cognitive processes but also sophisticated epistemological understandings.

Kind (2013) pointed out that investigating scientific reasoning with an emphasis on epistemological understandings reflects a philosophical perspective in research on scientific reasoning. When assessing scientific reasoning, psychologists tend to focus on the cognitive processes and abilities that may be involved during reasoning, and they usually take a descriptive perspective to investigate how individuals reason (Bailin & Siegel, 2002). In comparison, researchers taking the philosophical perspective explore the underlying factors for the ways individuals reason and mainly focus on aspects such as the role of epistemological understandings in reasoning (e.g., Kuhn, 1993, 2004). Unlike research taking the psychological perspective, empirical work that explores scientific reasoning from a philosophical perspective is relatively sparse (Zeineddin & Abd-El-Khalick, 2010). To obtain a comprehensive understanding of scientific reasoning, more research should be done to explore how people reason by integrating both the psychological and philosophical perspectives. The present study aims to contribute to such integration by using a socioscientific topic, *global climate change*, to explore the cognitive processes during reasoning and their underpinnings. Before further discussing the rationale of this work, the following section will present a brief review of research that investigates epistemological understandings and their relationship with scientific reasoning.

Epistemological Understanding and Scientific Reasoning

What is epistemological understanding?

Research on epistemological understanding abounds. Similar to scientific reasoning, definitions for epistemological understanding vary as well as the terminology itself. In the literature, several terms have been used, such as epistemological understandings (Kuhn, Iordanou, Pease, & Wirkala, 2008), epistemological theories (Hofer & Pintrich, 1997), epistemological beliefs (Perry, 1970; Schommer, 1994), epistemological reflections (Baxter Magolda, 1992), epistemological assumptions (King & Kitchener, 1994) and so on. The various terms being used align with different propositions researchers hold.

William Perry pioneered research on epistemological beliefs by studying how college students make meaning of their educational experiences (Perry, 1970). Based on his findings from two longitudinal studies, Perry proposed nine schemes of intellectual and ethical development students perceive in college, which are usually clustered into four categories: *dualism, multiplicity, relativism,* and *commitment within relativism*. Specifically, dualism refers to a right-and-wrong view of the world, whereas multiplicity characterizes people who recognize the diversity and uncertainty of knowledge and believe that truth is knowable even when authorities disagree. On the other hand, relativism describes those who perceive knowledge as relative and contextual, and consider their own active role in knowing. Last but not least, commitment within relativism reflects firmer commitments to values and careers, as well as personal identity. Perry's conceptualization of how epistemological beliefs develop was later further explored and developed by King and Kitchener (1994) and Hofer and Pintrich (1997).

King and Kitchener (1994) proposed a reflective judgment model to capture how individuals perceive and reason about ill-structured problems, with a focus on their conception of the nature of knowledge and the nature of justification for knowledge. Building on Perry's model, King and Kitchener described seven levels of reflective thinking college students demonstrated when reasoning with uncertainty and abstractions. In their review, Hofer and Pintrich (1997) revisited Perry's model and King and Kitchener's work together with some other previous research, such as Baxter Malgoda (1992) and Belenky, Clinchy, Goldberger, and Tarule (1986), and claimed that there are two general areas represent the core structure of individuals' epistemological theories: *nature of knowledge* and *nature of knowing*. In particular, *nature of knowledge* refers to what one believes knowledge is, whereas *nature of knowing* is beliefs about the process by which one comes to know.

Hofer and Pintrich further identified two dimensions within each of these two general areas. In particular, *certainty of knowledge* and *simplicity of knowledge* constitute two dimensions under *nature of knowledge*. *Certainty of knowledge* is the degree to which one sees knowledge as fixed or more fluid throughout research, whereas *simplicity of knowledge* means that knowledge is viewed on a continuum as an accumulation of facts or as highly interrelated concepts. In particular, a lower-level view of knowledge sees it as discrete, concrete, knowable facts, with individuals at higher levels viewing knowledge as relative, contingent, and contextual. The two dimensions within the area of *nature of knowing* are *source of knowledge* and *justification for knowing*. *Source of knowledge* refers to whether individuals view knowledge as residing in external authorities or view themselves as an active constructor of meaning. The *justification for knowing* dimension, on the other hand, includes how individuals evaluate evidence to substantiate and justify their claims as well as their beliefs in authority and expertise.

Similarly, Kuhn (1991) identified three main types of epistemological understandings - *absolutists*, *multiplists*, and *evaluativists* - in her work on the public's argumentation skills with ill-structured social issues. *Absolutists* believe that experts' knowledge is certain and absolute. They either *do* or *can* know with certainty about the causes of the phenomenon in question. In contrast, *multiplists* and *evaluativists* deny the possibility of expert certainty. *Multiplists* recognize that knowledge does not consist of facts and accept the coexistence of multiple viewpoints that can be equally correct. Similar to *multiplists*, *evaluativists* also acknowledge that viewpoints can be compared with one another and evaluated with respect to their relative adequacy or merit. They consider that although absolute certainty is impossible, experts may come closer to achieving such certainty than non-experts with close observation, examination, and analysis. Of note, the difference between *multiplists* and *evaluativists* is that, while the former accept the coexistence of multiple viewpoints, they are still likely to believe in a single certain truth, whereas the latter attempt to reconcile alternative theories.

Kuhn’s categories of epistemological understandings were embedded in the context of argumentation, which aligns well with the rationale of the present study. Therefore, the term *epistemological understanding* is employed in this work to capture participants’ perception about the nature of science and the process of scientific knowing (Kuhn, 1991; Kuhn et al., 2008). Of note, many researchers have used the terms “epistemological understandings” and “nature of science (NOS) understandings” interchangeably. However, NOS involves only one aspect of epistemological understandings by covering “the nature and construction of knowledge” (Khishfe, 2012, p.493). Therefore, in the current study, the term *epistemological understanding* is used to capture a wider range of perspectives toward nature of knowledge and knowing than NOS.

Relationship between epistemological understanding and scientific reasoning.

Epistemological understanding may greatly influence the way individuals think in science (Driver, Leach, Millar, & Scott, 1996; Tytler & Peterson, 2003). While the definitions and conceptual models presented above vary in their characterization of epistemological understandings, researchers have come to consensus that limited epistemological understandings may lead people to appreciate science in a very limited way and thus unlikely to see its relevance to their own lives (Hofer & Pintrich, 1997; Mason & Scirica, 2006; Tsai, 2000; Yang, Chang, & Hsu, 2008).

An increasing number of researchers have attempted to explore the relationship between epistemological understandings and scientific reasoning. For example, Driver, Leach, Millar, and Scott (1996) conducted a longitudinal study with young elementary students on how their scientific reasoning developed overtime. Based on students' views about the nature of scientific explanations and the relationship between explanations and descriptions, Driver and colleagues identified three qualitatively distinctive epistemological reasoning patterns: *phenomenon-based reasoning, relation-based reasoning,* and *model-based reasoning*. Students holding *phenomenon-based reasoning* representation do not distinguish between *descriptions* and *explanations* of phenomena. They consider scientific inquiry as either direct observation of phenomena or a re-description of the phenomenon. In *relation-based reasoning,* descriptions and explanations are considered separately. Explanations take the form of relations between observable features, which can be either a chain of cause-and-effect relationships or linear causal reasoning. However, students who apply *relation-based reasoning* tend to assume explanations correspond with the material world without any reference to underlying mechanisms. In contrast, explanations are expressed in terms of a theoretical system instead of being grounded in the language of observation in *model-based reasoning*. Individuals with this representation view scientific inquiry as the evaluation of conjectured models in the light of evidence. They recognize that empirical evidence can never "prove" the truth of a conjectured model, although it can eliminate competing conjectures. Also, they make clear distinctions between descriptions and explanations with descriptions relating to the observed phenomena and explanations describing the behavior of the conjectured model.

Driver and colleagues' characterization of epistemological reasoning indicated that epistemological understandings have significant bearing on scientific reasoning processes and outcomes (Driver et al., 1996; Driver, Newton, & Osborne, 2000). Later research following this path has revealed reciprocal influences between epistemological understandings and scientific reasoning (Khishfe, 2012). On the one hand, people with limited reasoning abilities may find it difficult to process information from multiple perspectives, which in turn discouraged them from endorsing more sophisticated epistemological understandings that acknowledge the tentative and complex nature of knowledge (Zeidler, Walker, Ackett, & Simmons, 2002).

On the other hand, individuals who hold epistemological understandings shared in the science community recognize argumentation as a central process in which science advances, and engaging in argumentation in turn facilitates the development of such epistemological understandings (Kuhn, Iordanou, Pease, & Wirkala, 2008). Naïve epistemological understandings were found to be associated with the tendency to decline scientific explanation (Sinatra, Southerland, McConaughy, & Demastes, 2003). Absolutists tend to overlook the need to engage in scientific reasoning and are more likely to treat information that does not support their existing beliefs in a biased manner (Chan, Ho, & Ku, 2011; Hofer & Pintrich, 1997; Kuhn, 1999, 2001; Weinstock & Cronin, 2003). Absolutists use fewer cognitive strategies when comprehending dual-position texts, reflecting a tendency to ignore certain information, draw oversimplified or absolute conclusions from opposing arguments, and distort contradictory information in order to make it consistent with preexisting beliefs during free recall of text information (Kardash & Howell, 2000; Schommer, 1990; Kardash & Scholes, 1996; Schommer-

Aikins & Hutter, 2002). This heavily limits their practice and development of higher level reasoning skills (Chan, Ho, & Ku, 2011).

For example, Yang and Tsai (2010) interviewed elementary school students and asked about their perspectives regarding contradictory or uncertain information included in science-related news reports. They found that performance on scientific reasoning in informal contexts among children is influenced by their epistemological understandings, and the mastery of scientific reasoning might in turn help advance epistemological understandings. In particular, participants who were identified as multiplists coordinated contradicting theory and evidence better than those who were absolutists. Interestingly however, the difference in reasoning performance among absolutists and multiplists was more distinguishable for some topics than others. Overall, most children in the study had the absolutist understanding about the source of knowledge, which at some level explained their poor performance of evidence-based reflective reasoning.

Broadly, epistemological understandings have also been observed to produce impacts on argumentation skills and argument analysis (Halpern, 1998). Those with naïve epistemological understandings tend to avoid argumentative situations (Nussbaum & Bendixen, 2003) and perform poorly in ill-defined tasks with multiple, non-guaranteed solutions (Schraw, Dunkle, & Bendixen, 1995). Nussbaum and Bendixen (2003) claimed that epistemological understandings relate directly to students' willingness to engage in argumentation. Students who believe that knowledge is simple, certain, and unchanging reported that arguments were anxiety-promoting, and thus they tended to avoid them. Likewise, Linn and colleagues (Bell & Linn, 2000; Songer & Linn, 1992) found that students who viewed science as dynamic and constantly changing-that is, those who had more "constructivist epistemic beliefs" regarding scientific knowledge (Stathopoulou & Vosniadou, 2007)-tended to create more complex and integrated arguments. Kuhn (1991) found that students with more constructivist epistemological perspectives were more likely to consider alternative theories and disconfirming evidence. Compared to absolutists, multiplists were also more apt to use reasons and evidence to address the claims of others (Weinstock & Cronin, 2003).

Across previous studies, when researchers argue for a relationship between epistemological understandings and scientific reasoning, most of them examine this relationship in contexts that involve the evaluation of two-sided scientific arguments or multiple solutions in relation to controversial or ambiguous issues (Chan, Ho, & Ku, 2011). A scientific argument consists of a claim supported by evidence and a rationale, and argumentation is the process of generating arguments (Walker & Sampson, 2013). Argumentation is a social and verbal means of trying to resolve, or at least to contend with, a conflict or difference that has arisen or exists between two or more parties. It involves processes in which individuals "create artifacts to articulate and justify claims or explanations" (Sampson & Clark, 2008, p. 448). Kuhn (1993) claimed that the forms of thinking and reasoning "can be rigorously defined within the framework provided by the structure of argument" (p. 333). In other words, argumentation is a "verbal activity" to probe into the internal scientific reasoning processes (Bricker & Bell, 2008; Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002), and eventually a key feature of scientific reasoning (Yang & Tsai, 2010).

Moreover, socioscientific issues are the most commonly used topic in the study of the role epistemological understanding plays in scientific reasoning. The level of sophistication of an individual's epistemological understanding is particularly associated with performance on open-ended and ill-structured thinking tasks, which involve comparing alternative viewpoints, the strength of evidence, and the adequacy of arguments in order to arrive at a judgment. It is in these situations that an absolutist tendency appears to produce the greatest impact on thinking and information processing (Chan, Ho, & Ku, 2011). Therefore, studying the relationship between epistemological understanding and scientific reasoning in the context of argumentation about socioscientific issues not only enriches the discussion about how scientific reasoning relates to argumentation, but also proposes an enriched perspective about scientific reasoning.

The Need for A Grounded Theory of Scientific Reasoning

Despite increasing efforts to explore the bearing epistemological understanding has on scientific reasoning, there is still a lack of work that investigates their relationship in depth. Instead, current research in this regard mostly focuses on how epistemological understanding may affect students' engagement in argumentation. Existing findings have shown that the relationship between argumentation and epistemological understanding is complicated and non-linear, and a variety of factors may mediate this relationship (Bromme, Kienhues, & Stahl, 2008). For example, Sandoval and Millwood (2005) suggested that a number of factors such as content knowledge one holds, besides epistemological understandings, may influence argumentation. Whether an individual has sufficient knowledge about the topic of interest can greatly affect the quality of argumentation regardless the level of sophistication of their epistemological understandings (Driver et al., 2000; Lehrer & Schauble, 2006; Yang & Anderson, 2003; Zimmerman, 2000).

Nonetheless, while many studies suggested that the performance of scientific reasoning and argumentation has much to do with the acquisition of domain-specific knowledge, there are studies showing that the effect of domain-specific knowledge was not clear when the problems in discussion were ill-structured by nature (Mason & Scirica, 2006; Perkins, 1985). More importantly, researchers have found that gaining more knowledge sometimes results in less sophisticated epistemological understandings. For example, Köller, Baumert, and Neubrand (2000) investigated high school students' physics-specific epistemological understandings and found that the longer and more intensive students learnt about physics, the more they thought that absolute "truth" could be reached in physics. With such epistemological understandings, when asked to generate arguments and counterarguments, students may find themselves more likely to be confined to one side and limited in constructing arguments from different angles.

Despite the growing attention to exploring how scientific reasoning relates to epistemological understandings, this critical aspect of scientific reasoning is still under-researched and several challenges exist in this line of research. On the one hand, since discrepancies exist in the definitions for both scientific reasoning and epistemological understanding, it is difficult to generalize the findings from previous studies, as researchers often adopt different construct definitions. On the other hand, instead of directly investigating how epistemological understanding impacts scientific reasoning, some research explores their relationship in the contexts of argumentation. As scientific reasoning and argumentation are sometimes used without specific distinctions, to better inform future research on scientific reasoning, a discussion of the relationship between scientific reasoning and argumentation is critical.

It has been shown that epistemological understanding plays a role in mediating reasoning, argumentation, teaching and learning approaches (Hofer & Pintrinch, 1997; King & Kitchener, 1994; Kitchener, 1983; Kuhn, 1991, 1999; Mason & Scirica, 2006; Schommer-Aikins, 1993; Tsai, 1998, 1999, 2000; Yang, Chang, & Hsu, 2008). However, although research has shown an "intimate" relationship between epistemological understanding and scientific reasoning as well as between epistemological understanding and scientific argumentation, the nature of the relationship is still vague. Moreover, the varied results on the relationship between epistemological understanding and argumentation in previous studies may have been, to some degree, due to methodological differences across studies such as the use of different instruments (Bromme, Kienhues, & Stahl, 2008). There is a great need of further work that explores this relationship in more depth to obtain a comprehensive understanding of how scientific reasoning and argumentation abilities may interact with epistemological understanding.

The study of scientific reasoning in the present work was in an argumentative context where participants evaluated competing arguments on global climate change. Scientific argumentation requires individuals to analyze and evaluate data and then rationalize its use as evidence for a claim (Sampson & Clark, 2008). Previous research has shown that rigorous reasoning contributes to the effectiveness and reliability of arguments one generates and enables quality evaluation of other people's arguments (e.g., Bricker & Bell, 2008; Duschl & Osborne, 2002; Mercier & Sperber, 2011). Therefore, analyzing arguments can help reveal individuals' reasoning processes as well as exploring and identifying their reasoning skills that need improving.

This chapter presented a review of existing literature on scientific reasoning. Three major theoretical frameworks for scientific reasoning were first reviewed and an evaluation of their empirical support and significance was presented. As these frameworks mostly captured scientific reasoning in contexts of well-defined science problems, more research is needed to explore how people reason in scenarios such as ill-defined socioscientific issues. Investigating scientific reasoning with socioscientific issues provides an opportunity to look into not only the cognitive processes involved in reasoning but also their epistemological underpinnings. Thus, later in this chapter, there was a brief review of research on epistemological understandings to help illustrate the need for a grounded theory of scientific reasoning in order to obtain a comprehensive perspective of how people really reason with issues such as global climate change. The next chapter will introduce the methodology used in this study.

CHAPTER III METHODOLOGY

This study employed a qualitative approach to explore the nature of scientific reasoning. In particular, it integrated two main methodologies: *grounded theory* (Glaser & Strauss, 1967; Strauss & Corbin, 1998) and *phenomenography* (Marton, 1981, 1992). In this chapter, I will first briefly discuss the theoretical foundations and operational procedures of both methodologies. Then, I will explain the methodological details of this work regarding the sampling, study design, and data analysis.

The Two Methodologies

Grounded theory.

Grounded theory methodology was introduced to the social sciences in the 1960s (Glaser & Strauss, 1967), when traditional research approaches in this field most heavily relied on quantitative investigation. In their early work, Glaser and Strauss proposed that grounded theory features an exploratory development of theory that is grounded in data from the field. To conduct grounded theory studies, researchers should be theoretically sensitive to a wide range of possibilities as they gather and analyze data, allowing the analytic, substantive theory to emerge themselves from the phenomenon of interest (Glaser, 1978; Glaser & Strauss, 1967). With an objectivist and positivist perspective, Glaser and Strauss emphasized that researchers should take a passive approach and separate themselves from the theory as it emerges (Charmaz, 2006). Later, diverging from Glaser's propositions, Strauss and Corbin (1990) maintained that researchers should interact with the data more actively when allowing the theory to be discovered. Thus, depending on their backgrounds and beliefs, different researchers may place focus on very different aspects of the collected data.

In contrast, Charmaz (2000, 2006) objected that grounded theories are discovered. Holding a constructivist perspective, Charmaz believed that grounded theories should be constructed. Different from traditional grounded theory methods, the constructivist grounded theory Charmaz proposed characterizes grounded theory methods as a way to learn about the world we study and a method for developing theories to understand it. More importantly, Charmaz suggested that grounded theories should be constructed by both the interviewee and researcher in an interpretive way. In other words, the development of grounded theories should be a journey that involves not only the researcher but those whose perspectives about the world are being studied.

In terms of operational procedures, Glaser and Strauss (1967) proposed in their initial work that data analysis in grounded theory studies should combine two processes. In the first process, the researcher codes all data and systematically analyzes these codes to generate categories. Next, the researcher should focus more on inspecting the categories, using memos to track the analysis, and developing theoretical ideas. Glaser and Strauss claimed that neither process is sufficient to accomplish the task of theory development; it is their integration that leads to a grounded theory and the processes leading to this integration is also referred to as *constant comparative analysis*. Through constant comparative analysis, data are taken apart and examined at a conceptual level to reassemble pieces of information for emerging themes. Strauss and Corbin (1990) furthered the initial work of Glaser and Strauss by proposing three levels of data coding that grounded theory research should entail: *open coding*, *selective coding*, and *axial coding*.

In a grounded theory study, data coding starts with ***open coding***, which is line-by-line analysis of data where incidents are compared with each other to identify participants' experiences, understandings, and insights. In this process, patterns in the data are named "with a label that simultaneously categorizes, summarizes, and accounts for each piece of data" (Charmaz, 2006, p.43). As open coding allows categories to develop naturally, it helps researchers to explore data with less influence from their predispositions or biases. Another important aspect of open coding is that it requires exploring and delineating the properties and dimensions of categories. Properties are the specific characteristics of a category, and dimensions are the variations that exist within the properties. Strauss and Corbin (1998) stressed that examining categories by identifying properties and dimensions is critical as it not only helps to clearly differentiate categories from each other but also clarify ideas more precisely for forming further abstract concepts.

The second level of analysis is ***axial coding***. Strauss and Corbin explained that "when analysts code axially, they look for answers to questions such as why or how come, where, when, how, and with what results, and in doing so uncover relationships among categories" (Strauss & Corbin, 1998, p. 127). During axial coding, categories are compared with each other according to their properties and dimensions in order to identify relationships, discover patterns, and establish connections. Axial coding is the process through which categories generated during open coding are systematically connected into a coherent whole (Charmaz, 2006; Strauss & Corbin, 1998). Additionally, the core category, or axis of the conceptual model, will begin to emerge and take shape.

Selective coding is the process of integrating and refining categories (Strauss & Corbin, 1998). It brings the entire theory or conceptual model together through the recognition of relationships among categories. The conceptual model must be presented as a set of interrelated concepts, not as just a list of themes. Researchers should work very closely with the data to derive the relationships and identify core categories to be included in the conceptual model as they decide saturation is being reached. To identify the core category, Strauss and Corbin (1998) offer three strategies: writing the storyline, using diagrams, and reviewing and sorting memos. The final stage of selective coding requires refinement of the conceptual model.

Overall, these three levels of data coding do not take place in order: constant comparative analysis requires an iterative process. Data collection, coding, memo-writing, and theoretical sampling can occur concurrently and in a cyclical manner until saturation is reached, which can be decided when new data yields no new insights (Charmaz, 2006; Glaser & Strauss, 1967; Jones, Torres, & Arminio, 2006).

The exploratory feature of grounded theory makes it an appropriate methodology for this work. Previous research has mainly relied on traditional, quantitative approaches when investigating issues related to scientific reasoning. Researchers tend to evaluate the various aspects of scientific reasoning with presumptions of their own, which may have led them to overlook some hidden features of the way individuals reason. Using a grounded theory approach can provide a more “grounded” insight into the nature of scientific reasoning. More importantly, employing the grounded theory techniques will help to open up more discussions regarding the potential underpinnings or related factors of scientific reasoning.

Phenomenography.

Phenomenography was first proposed by Marton (1981) as an approach to obtain empirical understandings of the different ways in which people think of the world. With an aim of exploring the relations between human beings and the world around them, phenomenography mainly focuses on the study of how people experience, conceptualize, realize and understand various aspects of phenomena in the world around them (Marton, 1992).

Marton (1981, 1992) stressed that phenomenographic research features description, analysis, and understanding of experiences with specific phenomena. To better illustrate his statements, Marton distinguished between first-order and second-order perspectives. With first-order perspective we orient ourselves towards the world to draw conclusions about it, whereas with second-order perspective, we draw on people's ideas and experience about the world to make inferences. Although these two perspectives are complementary, phenomenography mostly favors the second-order perspective. Marton (1981) stated the pedagogical significance of using second-order perspective to explore different ways people perceive and conceptualize various aspects of phenomena. More often than not, students bring various perspectives about the topics of interest into the classroom and may likely leave with understandings rather different from what the textbook presents or the teachers have in mind. A more in-depth knowledge of "what is learned" and "what should be learned" is thus critical in informing classroom teaching strategies.

In phenomenographic studies, it is essential to investigate learning with a focus on both its process and content (Marton, 1981, 1992). In contrast with the Piagetian perspectives about domain-general thinking and reasoning, Marton (1981) claimed that learning should be described in terms of its content and "no experiment on learning can be undertaken without some content" (p. 184). Specifically, Marton and Booth (1997) developed a structured model for the analysis and description of learning. The experience of learning is investigated from two aspects: *how people learn* and *what people learn*. When investigating the *what* aspect, the focus is the content of the phenomenon learned, whereas the *how* aspect looks into the approaches learners take to learn. To obtain a phenomenographic understanding of learning, researchers should "bracket" preconceived ideas" and "instead of judging to what extent the responses reflect an understanding of the phenomenon in question which is similar to their own, he or she is supposed to focus on similarities and differences between the ways in which the phenomenon appears to the participants" (Marton, 1994, p. 4428). In addition to bracketing, Ashworth and Lucas (2000) pointed out that researchers should also have empathy as it will allow "a detachment from the researcher's life world and an opening up to the life world of the student" (p. 300).

The significance of employing the phenomenography methodology in this work is twofold. On one hand, the fundamental assumption about learning in phenomenographic research closely aligns with the rationale of this work. The investigation of scientific reasoning in the present study is embedded in the context of global climate change. By exploring participants' perspectives about this socioscientific issue, this work takes a domain-specific approach in the discussion of scientific reasoning. This focus on both the process and content of participants' learning will provide a more comprehensive perspective toward the nature of scientific reasoning. Moreover, the use of phenomenography emphasizes participants' perception about their relationship with the world, which will contribute to the discussion of the epistemological underpinnings of scientific reasoning and facilitate the integration of the psychological and philosophical perspectives about scientific reasoning.

Grounded theory and phenomenography methodologies are complementary to each other, and together contribute to a "grounded" perspective about scientific reasoning. Specifically, phenomenographic research requires "bracketing" researchers' own predispositions. This corresponds to the foundations for grounded theory research, which is to obtain a naturalistic understanding of a given phenomenon. The combination of these methodologies in the present study aligns well with the research purposes and brings innovations to scientific reasoning research.

The Study

Participants.

A total of 26 undergraduate students (20 females and 6 males, mean age=20.00) at the University of Minnesota participated in this study. They were from a very wide range of majors, including communications, child psychology, kinesiology, pre-nursing, family social science, elementary education, art, nutrition, speech and hearing, political science, linguistics, business, and anthropology.

Data collection started with convenience sampling (Richards & Morse, 2007), which allows locating participants who were available, interested in the study, and comfortable with the research process (Bryant & Charmaz, 2007). Five undergraduate students interested in the issue of global climate change, two enrolled in an introductory psychology course and three in an introductory biology course, volunteered to participate in this study. At the same time, an advertisement was handed out in several other undergraduate courses and students who expressed interest were contacted for participation.

After the interviews for the first five participants were complete, theoretical sampling started based on the data collected from these interviews. First, interview transcripts from the first five participants were analyzed and the interview protocol was revised to better investigate the research questions. Next, more participants were recruited for interviews. As the main principle of theoretical sampling is to let emerging categories and the researcher's increasing understanding of the developing theory direct the sampling (Glaser, 1978), participants were selectively chosen at this stage. For example, I purposefully recruited from environmental education courses and science courses for participants with a relatively stronger conceptual background about climate science. Also, to maximize the diversity of the sample, the study was advertised across campus through classroom visits and bulletin board announcement. Undergraduate students who responded to the call for participants were then selected based on their personal interests in climate issues and according to other factors such as their personal backgrounds and level of content knowledge. Of note, for theoretical sampling, the sample size is uncertain until the researcher decides that the saturation of theoretical categories is reached (Glaser & Strauss, 1967). Thus, data collection and analysis took place iteratively until saturation was reached. The decision of ending data collection was made after 26 participants were interviewed.

Materials.

Assessment of reading capacities.

To evaluate participants' reading capacity and detect its potential impact on argument evaluation, a reading task, *the reading maze* (Deno, 1985; Fuchs & Fuchs, 1992), was given to participants at the beginning of the study. Reading maze is a multiple-choice cloze task that participants complete while reading silently. The first sentence of a 150-400 word passage is left intact. Thereafter, every 7^{th} word is replaced with three words inside parenthesis. While one of the words is the exact one from the original passage, the two others are distracters. These distracters are not haphazard. One of the distracters is a near distracter, a word of the same "type" (e.g., noun, verb, adverb), that does not make sense or preserve meaning. The other distracter is a far distracter, a word not of the same type but a word that is selected randomly from the story that does not make sense. The original reading maze assessments were curriculum-based measurement (CBM), designed for monitoring student reading progress in specific curricula (Deno, 1985). Research has shown that maze yields reliable and valid scores that are sensitive to growth and differentiates poor readers from typical readers (Brown-Chidsey, Davis, & Maya, 2003; Deno et al., 2002).

The maze assessment used in this work was developed by the Florida Center for Reading Research (http://www.fcrr.org/forf_mazes/forf10-11.shtml) to evaluate 12th-Grade students' reading capacities. The assessment included three passages, each of which depicted some aspects of the life of American Indians (See Appendix 1). The order of the passages was randomized. Participants had one minute for each passage and were prompted to choose the correct words to complete the sentences as fast as they could. Before they started, participants were provided with two practice sentences.

Interview protocol.

An interview protocol was developed for in-depth investigation of participants' scientific reasoning. The interview protocol included a 606-word reading document and 13 open-ended questions. The reading document consisted of two opposing perspectives: global climate change is human caused versus global climate change is due to natural changes. Koslowski (1996) stated that initiating arguments requires a resource or data to enable the construction of argument. Hence, commonly, competing theories have been accompanied by evidence that students need to evaluate and decide whether the evidence presented supports either, neither, or both the theories (Osborne, Erduran, & Simon, 2004). This reading document involved three most commonly discussed subjects that relate to global climate change: Earth's temperature change, rising sea level, and extreme weather events. The three topics were presented on separate pages with arguments from both sides (See Appendix 2).

The interview questions were designed to assess the following three aspects.

1. Prior knowledge about global climate change.

Three open-ended questions were included in the interview to assess participants' prior knowledge about the topic of global climate change. Specifically, participants were asked:

- What is your definition for greenhouse gases? What are some greenhouse gases that you know?
- How would you explain the greenhouse effect? *and*
- How much would you say that you know about global climate change, compared to the average person?

2. Evaluation of evidence and arguments.

Two perspectives regarding global climate change were presented in the 606-word reading document. One side of the argument claimed that global climate change is human caused, whereas the other side held that global climate change is natural changes. As each of the three topics was presented on a separate page, participants were asked the following questions when they finished reading each page:

- Which evidence seems more plausible? Why?
- What are the strengths of each evidence?
- What are the weaknesses of each evidence?
- How well do you think the evidence supports the claim?

- Do you think the evidence is explained sufficiently? If not, how would you explain it differently?
- Is there any other information you may use as evidence? If so, what is it? How does it support one or both of the arguments?

3. Epistemological Understandings.

Four open-ended questions were included in the interview to investigate participants' epistemological understandings in depth. In particular, the participants were asked the following questions after they finished reading all three topics:

- In general, which argument about the cause for global climate change do you think is stronger? Why?
- Do you think only one side of the argument is correct or is it possible that both are correct? Why?
- How are these arguments possible if people have access to the same set of data and use them to derive their conclusions?
- Do you think people who advocate either argument may change their views on global climate change? Please explain your answer.

Written assessment of general epistemological understandings.

In addition to the interview questions, a four-item assessment was used to categorize individuals' epistemological understandings (see Appendix 3). First, to identify the types of overall epistemological understandings participants hold, the assessment developed by Kuhn, Cheney, and Weinstock (2000) was adapted for use in this study. The original assessment included 15 items, covering five domains: judgments of personal taste, aesthetic judgments, value judgments, judgments of truth about the social world, and judgments of truth about the physical world. Kuhn et al. (2000) pointed out that this instrument may not capture the richness and range of epistemological thinking that a more extended interview reveals. However, a major practical advantage is that the assessment becomes short and simple enough to undertake across multiple domains. In this work, aligned with the present research purpose, only the three items that evaluate how participants make judgments about the physical world were included in this assessment. A participant is categorized as conforming to the absolutist, multiplist, or evaluativist level for a particular judgment type if responses to two of the three items assessing that judgment type conformed to the pattern characterizing that level. The order of the items was randomized when presented to participants.

The fourth item was adapted from Kuhn et al. (2008). In this item, a scenario about why dinosaurs became extinct is presented. The purpose of this item is to facilitate willingness to loosen the absolutist's commitment to knowledge as objective fact (and thereby foster developmental advance), to a degree that would equal or exceed that observed in the social domain. Because the Dinosaur phenomena are situated in a pre-human era, the possibility of the direct observation by humans that an absolutist conception requires is precluded. Moreover, because direct observation is impossible, the potential negative influence of human subjectivity (the “biased” observation that is a dominant concern in the social domain) is minimized. In the Dinosaur problem, the only way in which knowledge can advance is by means of the positive, constructive role of human theorizing and its coordination with various forms of indirect evidence. Kuhn and colleagues predicted that the Dinosaur problem would facilitate epistemological understanding beyond an absolutist level, to a level at least equal to and perhaps beyond that observed in the non-scientific problem. All participants were asked to respond in writing to the problems.

Procedure.

Participants were interviewed individually in an office. Before the interview, each participant was given the consent form and received brief instructions about the tasks they would do during the interview.

After the participants consented to proceed in the study, they were given the reading maze. The following instruction was used:

> *In this reading task, you will read three passages. Some of the words in the passages are replaced with a group of three words. You will circle the correct one that completes the sentence. You have one minute to read each passage. Let's practice on two examples first.*
>
> (*When they finished the practice*)
>
> *When I say "Begin", turn to the first passage and start reading silently. When you come to a group of three words, circle the 1 word that makes the most sense. Work as quickly as you can without making mistakes. If you finish a page, turn to the next one and keep working until I say "Stop" or you finish the whole passage.*

After they completed the reading maze, participants proceeded to the interview session. They were first asked the topic knowledge questions. Then, participants were provided with the reading document and asked to read aloud and think aloud. The think-aloud technique is employed in the interviews to reveal participants' reasoning processes when comprehending the reading materials. In the reading document, there was a red dot at the end of each sentence to remind participants to pause and report their thoughts at the moment. After participants finished reading each of the three topics, they were asked to answer the argument evaluation questions. By the end of the reading document, participants were asked the four questions that tap into their epistemological understandings. On average, each interview lasted for approximately 45 minutes.

Finally, participants were asked to complete the written measure of epistemological understandings.

Data analysis.

Reading maze.

The numbers of correct maze choices (CMC) and incorrect maze choices (IMC) participants made in each reading passage were counted and recorded. Then the average numbers of CMC and IMC made across the three passages were calculated. Participants' reading comprehension capacities were represented by finally subtracting IMC from CMC (Brown-Chidsey, Davis, & Maya, 2003).

Written assessment of general epistemological understandings.

Participants' responses to the written assessment of general epistemological understandings were entered into a spreadsheet. According to Kuhn et al.'s criteria (2008), participants were identified as one of the three categories - absolutist, multiplist, or evaluativist – using their responses to the first three items. Specifically, when participants responded at least twice that *only one can be right*, they would be categorized as absolutists; when they selected *no one is more right than the other* for at least two items, they would be counted as multiplists; or when they claimed that *one can be more correct than the other* for at least twice, they would be considered as evaluativists. This categorization was then aligned with participants' responses to the dinosaur item, and based on the criteria used by Kuhn et al. (2000), conclusions were made about the categories of participants' general epistemological understandings.

Interview transcripts.

The interviews were audio-recorded and later transcribed verbatim. The transcripts were entered into NVivo 8 for data coding. NVivo is a tool that assisted with data management tasks and was used to store and retrieve codes as identified in the data; store, link, and retrieve memos and diagrams; and assist in diagramming the final conceptual model. The constant comparative method (Glaser & Strauss, 1967) was used for systematic coding in the data analysis.

First, *open coding* started after the first interview was conducted and went on throughout data collection. In the process of open coding, potential *axial codes* were considered and generated for further analysis in *selective coding*. Aligned with the theoretical sampling process, data collection and coding in this study underwent a recursive process to saturate theoretical categories (Charmaz, 2006; Fassinger, 2005; Jones et al., 2006). Specifically, as new interviews were conducted and analyzed, previous transcripts were constantly revisited, so that categories could be compared with one another in terms of whether they interacted with and/or subsumed each other. Techniques such as memoing and diagramming were employed throughout the coding processes. Data collection was complete after twenty-six participants were interviewed. The final decision of saturation being reached was made after interviewing three additional participants. As no new theoretical categories emerged from these interviews, the results reported in this paper only include data from twenty-six participants.

Establishing trustworthiness.

Establishing trustworthiness refers to the ways in which a researcher provides evidence that the study findings are worthy of attention. It is a way of showing the rigor of the study (Guba & Lincoln, 1988). This process is akin to determining reliability, validity, and objectivity in quantitative studies. Lincoln and Guba (1985) offer four criteria to help researchers establish trustworthiness: (a) credibility, (b) transferability, (c) dependability, and (d) confirmability.

In the present study, efforts were made to establish trustworthiness. First, the researcher spent sufficient time reading through the collected data repeatedly to familiarize with the styles of participants' responses. Second, data coding in this work underwent a rigorous process. Following Strauss and Corbin's (1997) coding system, I carefully cross checked the codes within and between participants. Codes and categories that were similar in their definitions were further analyzed to decide their final categorization. Moreover, to improve the quality of the grounded theory, I made thorough memos and generated several diagrams during theory development. These efforts, together with others such as communications with researchers familiar with the two methodologies, have greatly contributed to the establishment of trustworthiness in this work. The next chapter will present the main findings from this study.

CHAPTER IV RESULTS

The purpose of this study was to develop a grounded theory of undergraduate students' scientific reasoning as they evaluated competing arguments on global climate change. This chapter presents the findings on how participants evaluated and coordinated competing theories and evidence on climate issues. First, descriptive analysis of participants' overall reading capacity and their general epistemological understandings will be presented. The next section will discuss in depth about the theoretical categories emerged and conclude with the final theoretical model for scientific reasoning that captured the relationships among its related factors.

Overall Reading Capacities

The total correct answers participants made on the reading maze task ranged from 5 to 28 per passage across the three passages. Participants' average CMC (correct maze choices) was 15.88 for Passage 1 (SD=5.41), 15.88 for Passage 2 (SD=3.92), and 11.96 for Passage 3 (SD=3.83). Overall, participants made 14.58 CMC per passage (SD=3.88) and 0.87 IMC per passage (SD=1.24). The average CMC-IMC was 13.71 (SD=4.22), with a maximum of 24.67 and a minimum of 8 (see Table 6 for scores by individual participants). Compared to the suggested reading level by the Florida Center for Reading Research that developed the reading passages used in this study (http://www.fcrr.org/forf_mazes/forf10-11.shtml), participants' overall reading capacity was slightly below the average12th Grade level.

Table 6 Participants' performance on the reading maze task and categorization of their general epistemological understandings

Participant No.	Reading Maze Scores*			General Epistemological Understandings
	CMC	IMC	CMC-IMC	
1	14.67	2.33	12.33	Absolutist
2	11.67	6.33	5.34	Multiplist
3	16.33	0	16.33	Multiplist
4	14.67	0.33	14.33	Evaluativist
5	15.00	0.67	14.33	Evaluativist
6	17.33	0	17.33	Multiplist
7	9.67	0.33	9.34	Evaluativist
8	18.00	1.00	17.00	Absolutist
9	9.00	1.00	8.00	Absolutist
10	13.33	0.33	13.00	Evaluativist
11	14.33	0.67	13.66	Multiplist
12	25	0.33	24.67	Evaluativist
13	11.67	0	11.67	Absolutist
14	19.33	1.00	18.33	Evaluativist
15	9.67	1.00	8.67	Multiplist
16	14.33	0.33	14.00	Evaluativist
17	15.67	0	15.67	Evaluativist
18	8.67	0.67	8.00	Absolutist
19	14.00	1.00	13.00	Multiplist
20	13.33	0.67	12.66	Absolutist
21	12.00	0.33	11.67	Evaluativist
22	19.67	1.00	18.67	Evaluativist
23	14.33	0.33	14.00	Multiplist
24	21.33	1.00	20.33	Evaluativist
25	11.67	0.33	11.34	Evaluativist
26	14.33	1.67	12.66	Multiplist

*Scores are averaged across all three passages.

Categories of Epistemological Understandings

The general epistemological understandings held by participants were revealed from their responses to the written assessment according to the criteria proposed by Kuhn, Cheney, and Weinstock (2000) and Kuhn et al. (2008). Six participants were categorized as absolutists, with eight being multiplists and twelve evaluativists (see Table

6 for categorization by individual participants). As the written assessment could only capture a general view of participants' epistemological understandings, this result will be combined with findings from the interviews for more in-depth discussion regarding epistemological understandings later in this chapter.

Findings from Interviews

A total of 185 codes were generated through open coding of interview transcripts. Axial codes were then developed to capture participants' prior scientific knowledge about global climate change, their personal beliefs and interests, reasoning processes about competing evidence and arguments, and epistemological understandings about climate science. In the following section, I will first present participants' content knowledge, as well as their personal interests and beliefs about climate issues. This will provide baseline information about the participants in this study and help readers understand their cognitive processes during scientific reasoning as well as the epistemological understandings they held. Quotes from participants will be specified with their assigned participant number (such as P1, P2, and so on) as listed in Table 6.

Content knowledge about global climate change.

During the interview, participants' content knowledge was assessed based on their understanding of the basics about greenhouse gases and the greenhouse effect. In addition, analyses of participants' think-aloud protocols also revealed their prior knowledge about issues related to global climate change. In general, the levels of participants' scientific understandings varied greatly.

On one hand, eighteen out of the twenty-six participants were not able to give detailed definitions for greenhouse gases and/or name an example greenhouse gas. They either did not understand the metaphorical use of "greenhouse" in these two terms, or demonstrated very little knowledge of what the two terms were about. For instance, when asked to explain greenhouse gases, P22 answered "Greenhouse gases? Um, is that, oh gosh, I don't even remember. Do those come from greenhouses?" Similarly, P20, instead of answering the question, asked "Is it like, greenhouse like a factory here?"

Some inaccurate understandings were identified in the ways participants explained about greenhouse gases. For example, participants tended to perceive a causal relationship between CO_2 emissions and ozone depletion. Although ozone depletion, mainly caused by the emission of fluoride-based compounds, is not directly related to temperature increase, eleven participants identified the increase of greenhouse gases/CO_2 as the cause for ozone depletion as they were the main player in temperature change. When defining greenhouse gasses, P16 mentioned:

> I know that they (greenhouse gases) are causing a big hole in the ozone over the North Pole, um, they, I'm pretty sure they're mostly from like giant cow farms, and giant urban cities that have 50,000 cars on the road. Um, and, greenhouse gases I think just are also that we cut all the forests and now we don't have as much oxygen and the CO_2 isn't really going anywhere.

P1 offered a similar explanation by relating to her understanding of greenhouse effect:

> Um, that greenhouse gases, like, whatever that includes, cause the ozone layer to thin, which causes the planet to heat up and more precipitation. The greenhouse effect… maybe just all the greenhouse gases and their effect on the planet, but it's a negative thing, the greenhouse effect, like it's not something, I feel like it's not a term that was used, so it's something about how they are negatively impacting.

Given the close connections between greenhouse gases and greenhouse effect, those who were unable to explain greenhouse gases provided few or no explanations about the scientific processes of the greenhouse effect. They either simply stated that "I don't know what that is", or briefly described greenhouse effect. P6, for example, said:

> Um, isn't it like, I don't know, isn't it like, um, the, don't the gases like, block something so like the heat is like trapped in the atmosphere or something. I don't know, I sound dumb.

On the other hand, eight participants were able to provide more detailed scientific explanations about greenhouse gases and greenhouse effect. They were also very much aware of humans' impact on the Earth's temperature. P11, for instance, illustrated his understanding of greenhouse gases and greenhouse effect with a focus on human activities:

> We can take them (greenhouse gases) and they (the atmosphere and oceans) can hold them for a certain amount of time, and then release them to something that is good for everyone. Um, but we're putting so much out there that they can't contain it at all. We're also cutting down

> the trees or hurting the oceans, so there's issues like being able to contain it, so we're having all this excessive heat that we're generating, producing right into the world and because this is no way to convert it and keep the cycle going, it's staying in the environment, staying in the atmosphere.

The levels of participants' knowledge of greenhouse gases were further identified through the example greenhouse gases they named. A majority of the participants were not able to provide any examples, or they could only name CO_2 when prompted. Four participants (P1, P3, P11, and P25) were able to name more than one greenhouse gases, such as methane and water vapor. For example, P11 said:

> Um, the two (greenhouse gases) that come to my mind first are CO_2 and methane. Um, methane especially, because methane is so bad and no one ever talks about methane, and it's like, release methane and methane stays in the atmosphere way longer than CO_2 does, so it does a lot more harm. But we only ever talk about CO_2 because there is so much of it, so it's a lot easier to point to like, oh yeah, CO_2 obviously is bad because we're pumping tons. So those are the two that come to mind.

Furthermore, participants were reflective on how sufficient their knowledge was about climate issues. Throughout the interviews, participants often expressed lack of confidence in how much they knew about climate science. P25 mentioned:

> I know very little about climate change. I don't know hardly anything. Um, yeah, like we said, I don't know, just taking care of recycling, taking care of, yeah, I don't know hardly anything.

Participants tended to give few or very brief answers to questions that assessed their content knowledge and mentioned that they did not know much and thus could not provide any further answers. When defining greenhouse gases, P5 explained:

> I think those (greenhouse gases) are… I'm so bad with this type of stuff, but I feel like that, those are the gases that are ruining like our ozone layer, but they're ruining it, right? Not helping it? Oh, gosh! I'm so bad with this stuff. But I feel like they're messing up our ozone layer and our atmosphere just in general.

Interestingly, even though participants displayed lack of confidence in their level of knowledge about global climate change, they perceived themselves as holding average, if not higher, level of content understanding compared to average people. The same participant, P5, although acknowledging lack of knowledge about global climate change, considered herself as holding reasonably average understanding compared to the general public:

> I think I'm kind of like an average, I mean probably not with the greenhouse gas part, but like with the rest of it, I feel like a lot of people are not knowledgeable about it, like they should be, so probably average.

In addition, participants sometimes mentioned the sources of their scientific knowledge about global climate change. The main sources that came up included science classes and extra-curriculum activities, social media, and significant others such as parents and teachers. Of note, influence of news and documentaries was the most commonly mentioned source of knowledge, followed by science classes and projects before or during college. For instance, one of the participants, P16, mentioned:

> I know just a little (about global climate change). What I've seen in 60 Minutes and on the news, like occasionally, um, I saw the Inconvenient Truth… the Ugly Truth? It was Al Gore, right? I did see that, but it was a while ago, I think we watched in high school, during biology class or something. So I feel like, I haven't done any like "research" research on it, so I feel like I've just seen what the public sees.

Personal interests and beliefs related to climate issues.

In spite of their various levels of content knowledge, most participants were aware of the seriousness of global climate change and agreed that human activities play a major role in it. However, even though participants attributed global climate change to human activities, very few of them explicitly expressed interests in climate issues or concerns about their relevance to everyday life. Two participants, P7and P11, particularly discussed their personal interests in climate issues. P11, for example, explained his perspectives about why climate change should raise more concerns:

> I feel like it (climate change) is not a topic that like is brought up a lot, which is really surprising because it's very important, you know? It's like, it's one of the things like, every person matters. It may not seem like you could do something, but like you deciding to not go and smoke cigarette, or you deciding to not go and do something drastically affects someone else. Kind of like the butterfly effect, you know, if, like, all

> because something happened all on the other side of the road, it doesn't mean that it doesn't affect everyone, and obviously like it's really hard to believe, everyone has like a role in this, so I feel like I am a little more intrigued than most people, like most people either don't believe it or choose to not care.

In contrast, four participants (P4, P10, P16, and P21) showed doubts about the urgency of climate issues. They either considered that global climate change was not personally relevant to them, or held that there was not a great need for personal action as it was still uncertain whether the ongoing climate change was anthropogenic. P10, for example, explained the reason for her doubts by claiming that "I feel like, my view is- The Earth is going to go on for a long, long, long time. Why do I need to really care about that?"

Of note, one participant among all, P25, particularly reported that her religious beliefs had influenced her perspectives about global climate change and its scientific evidence. When discussing her beliefs in the anthropogenic nature of climate change, P25 said:

> Personally, I believe in Jesus Christ, and I believe that God created the Earth… and he wants us to take care of it, because it was a gift, um, but he also wants us to use what we have been given, just not take advantage of it.

Cognitive processes of scientific reasoning.

Scientific reasoning processes were revealed not only when participants evaluated evidence and arguments but also when they were thinking aloud with them. Integrating both aspects, three levels of scientific reasoning were identified based on the complexity of cognitive processes involved. Of note, a participant's reasoning was not limited to only one level: depending on the content they were discussing about, participants demonstrated change of reasoning levels throughout their individual interviews. Thus, the results below illustrate different levels of cognitive processes participants demonstrated in general rather than identifying the level of reasoning each participant performed at.

Level 1: No reasoning or very little reasoning.

When reading the arguments, participants often responded in very simple ways, revealing none or rather limited reasoning as they were thinking aloud. Five main types were identified in this respect.

First, participants tended to repeat the sentences as they read. When the sentences were longer, they were prone to repeating quietly to themselves and only reading aloud the section that they were not able to follow. The second type was to simply agree or disagree with what was being read. Participants either only said "yeah""okay" or stated "I agree/disagree" after reading information presented in a given sentence. Third, sometimes participants expressed that they liked or disliked the information they were reading, but did not give any further reasons. Fourth, some participants requested specification or clarification after reading information that they were not familiar with or uncertain about. For example, after reading the title "Temperature Change and CO_2 Emissions", P15 asked

"CO_2, that's carbon dioxide, isn't it?" Last, participants might recognize and briefly identify the consistence or conflict of information in the reading with what they already knew. For example, after reading about the composition of the atmosphere and the percentage of CO_2 in it, P14 responded "OK, I guess I didn't know that CO_2 only constitutes less than 1% of the trace gases."

Moreover, as they evaluated evidence and made judgments about a given argument, participants often simply conformed to or refuted it without providing their reasoning in details. For example, P23 explained her reasons for agreeing with the argument about "Temperature change is due to human-induced CO_2 emissions":

> It seems strong. Yeah, there's no, like, unnecessary information, it's all strong, and, I don't know, it seems credible.

Level 2: Reasoning at surface level.

Compared to Level 1, reasoning processes identified at Level 2 involved more cognitive efforts and included more details about how participants processed any given information. To start with, rather than only agreeing or disagreeing with the text when thinking aloud, participants revealed their reflection on aspects such as how their background knowledge may have influenced their perception of evidence. For instance, after reading the sentence "The increase in extreme weather events is human-caused", P23 reflected on her confusion and pointed out that it might have been due to lack of knowledge:

> I don't see how like a temperature increase would really result in like a more intense tropical cyclone. Ok, I just don't know that much about weather.

More importantly, Level 2 reasoning demonstrated how participants emphasized the surface features of evidence as well as the arguments it supported. When reading the arguments, participants made comments on their writing features such as tone of writing. After reading the sentence "Changes in the frequency and intensity of extreme weather events are due to human-caused Earth's temperature increase", P22 commented:

> This, um, even though I believe this, this sentence came off a little biased. Even though I do believe that it is human caused, but I don't know, it seems to, it came off a little strong. So I don't know.

When making further, in-depth evaluation of arguments, participants brought up concerns about the writing techniques in each element of the arguments (the claim, evidence, and justification) in terms of their coherence, straightforwardness, and choice of wording in the writing. P4, for instance, critiqued on the wording used in the argument for "The increase in extreme weather events is not human-caused", saying "the word like 'appears to have decreased', it's like not concrete". Similarly, P18, made the following comments on the argument that supported "Rising sea level is not human caused":

> I would definitely first change the wording of these numbers and eliminate the prentices, so these are actually a part of the sentence, and then I might write at the end a summary sentence saying this suggests that

> um the rising sea level is not human caused. And then that would kind of sum it up in a nice way.

Furthermore, when asked to evaluate evidence in depth, participants expressed concerns about whether the evidence was described sufficiently. Presented with the information “Compared to pre-industrial values, there has been a 50% increase of CO_2 concentration in the air as of 2011”, which was used to argue that “Temperature change is due to human-induced CO_2 emissions”, P25 commented:

> I think they’re (evidence in both arguments about temperature change and CO_2 emissions) very vague. Because the first one is saying that “there has been a 50% increase of CO_2 concentration in the air as of 2011”, but they’re not really showing that as compared to what? Like what they’re comparing that increase to?

Another important aspect of evidence evaluation at Level 2 reasoning was participants’ preference for more numerical values in the arguments. A common critique participants provided was that more factual information should be used to strengthen the arguments. When commenting on the arguments about “Temperature Change and Extreme Weather Events”, P19 considered that the major weakness of the argument that supported “The increase in extreme weather events is not human-caused” was “they didn’t give me as many dates (as the opposing argument) and saying specifically like there was a decrease during this time and the increase during this time”. As for its opposing argument, P19 pointed out that “I wish they have put more numbers in there”. However, such preference for more factual information was not clearly justified.

In other words, Level 2 reasoning revealed that when participants evaluated evidence, they were prone to relying on the availability of numbers rather than more in-depth reasoning of their meanings and values. For example, P3 commented:

> The argument (for "The increase in extreme weather events is human-caused changes") could have added some numbers, maybe to say like during these years, there is how many hurricanes and tropical storms that have happened and how it's doubled since 1970 and 1974.

Even though in this comment P3 proposed an alternative way to structure the evidence, she still did not give further reasons for why this change should be made.

Additionally, whether the given evidence was from recent years or a rather long time ago was also emphasized when participants evaluated the quality of evidence. They tended to relate better to evidence that discussed climate changes in recent years and perceive evidence as stronger when it specifically included years very close to the present. In contrast, evidence that presented events from the ancient years or focused on larger timescale was usually considered as insufficient or irrelevant, even when such events supported the claim scientifically. For example, when comparing the overall quality of competing arguments in the whole reading document, P26 considered arguments with evidence from recent years as appearing stronger, but did not follow up with any further explanation for how evidence from different points of time may strengthen its link with the claims:

> I feel like it (the side that climate change is human induced) uses like more recent data to support its claims, because it cites you know

> 2012, which is like 2 years ago, and it really does it for all three pages. It was like it goes back to 2000s, so it's really recent. And in claim 2 (the side that climate change is due to natural changes), I feel like it's not strong because the first page, extreme events, it talks about recent years, but in the second claim, rising sea levels, it just goes back thousands of years, and in the third claim, it doesn't even really address like a recent time change.

Level 3: Complex reasoning.

Reasoning at Level 3 probed into the deep structure and content of evidence and arguments. Three aspects were identified to capture this level of reasoning.

First, Level 3 reasoning revealed participants' distinction between correlation and causation. All of the arguments participants read during the interview were centered on whether human activities are the cause of global climate change. A prerequisite for evaluating these arguments was to be able to understand the nature of correlation and causation, identify factors that differentiate correlation from causation, and evaluate the sufficiency of evidence used to support the causal relationship. Thus, to elicit participants' reasoning in these aspects, the evidence in the written arguments was purposefully designed with insufficient evidence for causation to elicit discussions in this regard.

During the interviews, participants who were clearly aware of the distinction between correlation and causation adopted this distinction as their main criterion for evidence evaluation. For example, when he was evaluating the evidence used to prove

“Temperature change is due to human-induced CO_2 emissions”, P17 briefly commented that “I found that they’re showing a correlation between high CO_2 emissions and climate change, but they’re not showing causation.” Participants also expressed that there was a need for more examples and scientific explanations to prove any causal relationship. For example, P6 identified that coexistence of events does not suffice for causation if no further information was presented:

> Just because these things (human activities and extreme weather events) happen at the same time doesn’t mean they’re like, connected. And like, if they’re saying that, like, human activities have resulted in temperature increase and there has been an increase in cyclone activities, they are trying to connect those things just because they are putting them in the same sentence, but there is no proof that says they correlate at all.

The request for more information was sometimes further specified as participants discussed the potential impact of other related factors. For example, P14 explained such concern when evaluating the argument for “The increase of extreme weather events is human-caused”:

> I think we learned that you cannot always assume things, I mean even if they have a correlation, they’re not always, that doesn’t mean causation. So there might be another factor that could have been like, I don’t know what that’s called, but there might be another factor that could be instead, um, affecting this. So for example, if they did have the improvement of technology, it could also mean why there has been an

> increase in these activities, because they have been able to track them. So I think that this argument doesn't account for other variables as well.

Additionally, participants revealed their awareness of the complexity involved in proving causation. P11 illustrated his openness to the uncertainty that might be involved in exploring causal relationships:

> It (causation) is obviously something hard to prove, I feel like the more you get closer to like, like it's a theory where it's like hard for you to prove that it's true, but I feel like the more you get toward it, the harder it is to buy that argument of these aren't related. Like I mean, we're never going to know, if x causes y, but more proof we have of x most likely is the cause of y, then it's like come on we've tracked it like that, the more we use this product, the more the environment changes, so we should start doing something about this.

One thing to note is that participants expressed preference for different representational tools, such as visual aids like graphs and charts, when attempting to make sense of the relationships among related factors. P26, for instance, mentioned that displaying information through a visual aid might help support the claim of "Rising sea level is not human-caused":

> I mean they're going to put this on chart, it will be like it's good that they show this like visual right there, look it's rising, and it goes up and it goes down, and that's what the Earth does. It's like humans have nothing to do with it.

Second, Level 3 reasoning showed that participants were engaging in critical thinking rather than simply taking in information as presented. They were aware of evaluating alternatives before making judgments about a given argument. For instance, P23 expressed her concerns about how much the findings from one region may be generalized to other places or in a larger geographical scale:

> I think the fact that they only mentioned one place, they're just saying the Australian region, it would be, probably be more reliable if they said, or probably be strengthened, if they included more areas, not just the Australian region.

Similarly, P26 revealed her critical thinking as she tried to not make conclusive judgment about global climate change simply based on regional information that was most available to her:

> Because sometimes I tend to say "Oh my god! This is so cold! What happened to global warming?" Like, I hear that too. But this is like one side of it, like you don't really know overall how climate has changed in all the parts of the world. So it might just be experiencing bad luck right now. So I mean because it's global warming, it's not just Minnesota, USA.

Moreover, participants demonstrated reasoning about the statistical meanings of numerical values. When presented with numbers such as the percentage of CO_2 in the Earth's atmosphere, concerns were raised that these numerical values alone might not be telling the whole story and participants requested clarification for the scientific meanings of these numbers. For example, P25 explained her concerns about the need for more information regarding the statistical significance of evidence:

> Like if the increase of CO_2 went from like 0.5 to 1%, like I mean I don't know how significant that would be. Um, they're also showing that the increase in the Earth average surface temperature but it also looks like a very small amount too. I don't know how big an impact that would have.

However, while participants often mentioned the word "statistics" when explaining the need for more explanations or backing to support a claim, it was sometimes unclear whether they simply meant more numbers should be provided or preferred any specific statistical procedures and results as well. Only one participant, P26, explicitly suggested the use of statistics such as *p-value* as evidence to examine whether the rates of increasing sea levels were significantly different over the years.

Third, when Level 3 reasoning was involved, evidence evaluation was in more depth as participants attempted to coordination between claims and evidence. When reasoning at Level 3, participants identified the advantages and disadvantages of evidence and evaluated the strength of the connections between evidence and claims. Rather than simply conforming to or refuting an argument, they evaluated both sides of the competing arguments on their strengths and weaknesses with great efforts of reducing potential biases resulted from their personal beliefs. Often times, they proposed viable solutions to improve the quality of arguments, without unreasoned preference for either side of the arguments. For example, when commenting on the argument that there may not be a direct connection between human-caused temperature change and extreme weather events, P14 said:

> I think if they actually show facts or information saying, instead of saying it's unreliable, if they showed like for example here... If they show that the number was really unreliable, instead of just saying that, I think that would help back their argument, and it would help with the second part, with the improvement (of technique), if they could show maybe there was just an increase in technology or if they explained like in this, during this time period, we only had this kind of techniques to detect them and now in this time period we have this kind of techniques. If they explained further how there have been improvements or the number, or the reliability, I think that would make more sense to back it.

Epistemological understandings.

Compared to the written assessment which identified participants' general epistemological understandings, the interview questions investigated the specific aspects of participants' epistemological understandings regarding global climate change. Three categories emerged, including participants' views toward the relativity of knowledge, perceptions about credibility, reflection on their own and others' epistemological understandings about global climate change.

The relativity of knowledge.

The relativity of knowledge refers to participants' views towards the relative correctness of multiple perspectives. According to their responses to the written assessment, six participants were identified as absolutists, claiming there is one absolute truth and thus only one perspective is correct. However, during the interview, all participants claimed that more than one perspective could be correct about global climate change and there was no absolute truth about it. Several participants further suggested, explicitly or implicitly, that some perspectives or views may yield more solid arguments and there were several reasons for this. In particular, P17 mentioned that the framing of an argument may influence its relative correctness as he commented on the two sides of arguments in the reading:

> Both arguments may be right in the fact like what data they're providing, but it's just the way that, it's not even, it's not only the data is what I'm trying to say; it's the way the arguments are phrased too, that just makes them more persuasive.

Perceptions about credibility.

Credibility refers to the trustworthiness of the source of evidence, the reliability of the source, and the scientific foundations. During the interviews, participants mentioned their concerns and uncertainty about whether the evidence could be relied on as its source and scientific grounds were unknown. For example, P6 critiqued the reliability of the source for evidence used in the argument for "Temperature change is due to human-induced CO_2 emissions":

> Um, well, like I noticed, um, it says that the average surface temperature, like, they measured it in 1880, and like, I don't know how they do that now, but I just assume that it's, I don't know, I just wonder if it's accurate.

Interestingly, while they were concerned about the issue of credibility, participants appeared to be convinced that the evidence they were provided with was credible even when there was no specific information to prove it. Thus, the written arguments were perceived as plausible as they were all "presenting a case, so have like some credible information". P17, for instance, mentioned that "obviously we are not all going to go out and measure sea level ourselves… I mean it (the evidence) just gives you like, I mean like the impact is just a lot more, because it's more relevant data".

Moreover, participants believed that scientists did not know about causes and consequences of climate change with much certainty. They either claimed that scientists were just as uncertain about climate science as the general public, or further discussed that scientists' stances about climate change are based more on their personal beliefs. For example, P26 stated:

> I don't know if they (scientists) know for sure, I mean they do try to use graphs to plot things, what I think is experts, they can't be in the middle. If they're in the middle, that doesn't make them as legitimate as being on one side, just opinionated. And it's so easy to just like pick a certain aspect, certain data, and to support your arguments, and I think that's what I expect to kind of do too, I think there's certain aspect of it,

> but then they try to like cover up the other aspects to just make their claim. And scientists really just, they just tell a story. So to tell an engaging story, using like just the facts that support the arguments, then people want to listen to them, versus someone just saying that "oh yeah, it could be this, it could be this." Then the odds would be like so what did he say? That feels kind of muddled up.

Reflection on one's own and others' epistemological understandings.

Participants were reflective about their perception of climate issues. They claimed being flexible with their beliefs regarding global climate change and willing to change their stances if presented with more solid arguments and credible evidence. For instance, P14 discussed how she considered debates about global climate change:

> I think it kind of just comes down to what kind of evidence they show for it. But I don't really have a specific claim that I'm tied to right now. I don't think that will change unless they come up with something, but if they come up with more information that supports the other side, I might switch back and forth (among different perspectives about global climate change).

At the same time, participants were also aware of various possibilities of how average people may perceive climate issues. When discussing how she thought about other people's stance on climate issues, P14 said:

> I think some people are already determined that maybe not "their way is the high way" kind of thing, but they already know they won't change their belief about something.

P14 continued to explain her understanding by discussing the influence of factors such as religious beliefs on people's perspectives about global climate change:

> I don't, this is kind of off the topic, but like evolution, like there are some people whose religious beliefs impact that, so I think that it's really hard for some people to change their opinions or they have already thought that it was this way and now some people are telling that's wrong. I think sometimes people have a hard time believing that, especially when you can't see it.

In the meantime, P14 also illustrated how the uncertainty and complexity of climate issues may influence one's perception:

> I mean, for example, you can't see the increase in the air; when we walk around, we can't see that. And I think that for an average human, you can't, it's hard to like see all the stuff they're saying, it's hard to see the actual changes. I mean our temperature, if it's really raised by just like one or two degrees, it's not, I mean we swing back and forth in Minnesota 70 degrees sometimes it will go from negatives to positives, so I think that's, it's something that we, people would have a hard time believing, unless they can actually see it happen right in front of them. So I think, and I think science is kind of like a complicated thing, for people who aren't

interested in it, I think it can be very confusing and hard to know what to believe, because there are so many different claims, so I think people end up taking a side, sometimes they don't know, like know if, they kind of just get stuck there. They aren't open to any of this.

Main Themes that Emerged

Constant comparative analysis in this study identified four main themes that emerged.

1. Prior knowledge was not a direct indicator of performance in evidence evaluation: participants mainly centered their evaluation on the surface features of evidence. In this study, the assessment of participants' content knowledge about global climate change entailed interview questions regarding their knowledge about greenhouse gases and greenhouse effect. Overall, participants' prior knowledge varied greatly: while a few participants were able to provide detailed and accurate explanations, the majority either responded very vaguely or could not answer at all. Many participants mentioned that they had heard of the two terms, but did not have clear clues what they were. In addition, participants tended to confuse greenhouse effect with other problems such as ozone depletion.

Broadly, regardless of their level of understanding about climate science, participants primarily focused on surface features when commenting on evidence provided in the arguments. The most common concern participants raised was that more numbers should be presented in the evidence to make it a stronger support for the argument, without discussing the importance of the statistical meanings these numbers might hold. Similarly, participants demonstrated overwhelming preference for evidence that involves more examples or "facts". If such examples entailed scenarios close to their own lives, participants would most likely be in favor of such evidence. In particular, participants were mostly swayed by examples that were closer to present times or more relevant to their geographical locations. Moreover, when asked to evaluate the quality of evidence, many participants were not able to distinguish correlation from causation and were prone to claiming causal relationships with insufficient evidence.

Sometimes those who held very little prior knowledge about the basic science of global climate change may perform well in employing higher level reasoning. P6, for example, only explained greenhouse gases as "gases caused by, I'm going to say human sources, um, that are, like, released to the atmosphere that harm the atmosphere" and greenhouse effect as "block something so, like, the heat is like trapped in the atmosphere or something". Nonetheless, limited understanding of these terms did not reveal to directly influence how P6 evaluated evidence. She was able to reason at Level 3 and provided in-depth critique on the insufficiency of evidence in supporting a given claim, such as identifying information needed to prove causation.

However, even though more prior knowledge might not necessarily lead to more complex scientific reasoning during evidence evaluation, participants who considered themselves as holding more knowledge about climate science tended to be more engaged when critiquing the strengths and weaknesses of evidence. On the contrary, those who could not answer the content knowledge questions in the interview tended to shy away from providing detailed critiques as they may "sound dumb". In other words, perception of their level of content knowledge may have influenced how participants approached evidence evaluation. Therefore, even though P6 was able to reason in depth when discussing how to strengthen the link between evidence and the claim it supported, during her interview, she often expressed concerns that because she only knew very little about the topic, she did not want to comment on the evidence too critically.

2. Reading capacity may affect the features of evidence participants were drawn to during reasoning. Three participants (P23, P25, and P26), among all, misread some sentences of the written arguments. Although they were able to realize their confusions and understand the text eventually, such confusions influenced how they viewed the evidence. For example, P23 first commented on the wording of the argument for “the increase in extreme weather events is not human-caused”:

> I guess it starts off the claim badly, because if you, usually if somebody says something is unreliable, then they might think that, well the rest of this is not, might not be reliable.

Then, she realized “I think I’ve been like just reading it wrong. Like, not reading the full thing. Because, OK, so yeah, I didn’t really understand what they were saying at first, but it’s making sense now.”

3. Scientific reasoning during evidence evaluation was closely related to the sophistication of participants’ epistemological understandings. Three aspects were revealed regarding the relationship between scientific reasoning and epistemological understandings. On one hand, participants who held more sophisticated epistemological understandings about climate science were also more likely to demonstrate complex reasoning during evidence evaluation. P17, for instance, expressed concerns such as the credibility of data sources and relative correctness of multiple perspectives, which were both identified as important aspects of epistemological understandings about climate science. At the same time, Level 3 reasoning was the primary level of reasoning revealed throughout data from the interview with P17. On the other hand, no linear relationship was implied between scientific reasoning and epistemological understandings. Even though P17 performed well in both aspects, he also held relatively more sophisticated scientific understandings about global climate change. Thus, within the limit of this study, it cannot be concluded how prior knowledge may play into this relationship.

More importantly, there was inconsistency between findings from the written assessments and interviews. Analysis of interview transcripts revealed that all participants claimed to accept the relative correctness of various perspectives about climate science. However, based on analysis of data from the written assessment for general epistemological understandings, participants were spread over all three categories (absolutists, multiplists, and evaluativists). Yet, such inconsistency did not occur for all participants. For instance, P17 was identified as an evaluativist by the written assessment, which aligned with his responses during the interview, whereas other participants, such as P18, were categorized as an absolutist but showed flexible epistemological understandings during the interview.

4. Several factors may affect the evaluation of competing arguments, such as participants' personal beliefs and opinions as well as the framing of the arguments. While in the present study only one participant, P25, explicitly discussed her religious beliefs and reflected on how that may have affected her perspective about climate change, analysis of her evidence evaluation revealed that one's religious beliefs might place great influence on the way they reason with scientific findings and assess the credibility of evidence. For instance, when evaluating the evidence that was used to support "Rising sea level is not human-caused", P25 stated that "I would have tried to find sources that were like based on the Creation (God's creation of the world) rather than the Theory of Evolution". Similarly, after reading "In particular, the number of hurricanes and tropical storms during 1995 and 2004 doubled that during 1970 and 1994 in North Atlantic", P25 reported the following as she was thinking aloud:

> The Bible warns in the book of revelation when Christ returns his coming, that there will be more like catastrophic events like that, like as his return years. So, like, as a Christian, as a follower of Jesus, like it's kind of exciting, like because you will wait for him to come back a second time, so I mean because God's words warn about that, so that makes me think of, I mean like, it's just like, just from that perspective.

Moreover, personal opinions about global climate change heavily influenced the way participants evaluated evidence. With or without being aware of it, participants were prone to strongly agreeing with arguments aligning with their own perspectives, even when they lacked sufficient knowledge to justify the scientific credibility of the evidence. P10, for example, believed that "The Earth is going to go on for a long, long time, why do I need to really care about that". When she was asked to evaluate evidence in both sides of the arguments, she considered all the evidence supporting her belief "just seems more plausible" but could not provide any specific scientific explanations. Additionally, the framing of the arguments may enlarge the influence of prior beliefs. Depending on the tone and wording of the arguments, participants, especially those who were strongly opinionated about climate issues, may be more open or resistant to opposing arguments.

The Grounded Theory

In this study, the nature of scientific reasoning was investigated in the context of global climate change, with a focus on exploring the approaches participants took to evaluate competing arguments on this topic. In particular, participants were asked to evaluate the quality of evidence, as well as its relationships with the corresponding claims. Grounded in iterative data analysis, a theoretical framework was developed to illustrate the cognitive processes during scientific reasoning and their underpinnings.
Figure 7 illustrates the relationships among key factors identified in the main theoretical themes emerged. This framework entails five main elements that were identified in participants' reasoning about competing arguments and the arrows connecting them revealed the relationships that emerged from the current findings. Of note, given the scope of the present study, the direction of the arrows in this framework proposes, rather than confirming, a causal relationship that invites further investigation.

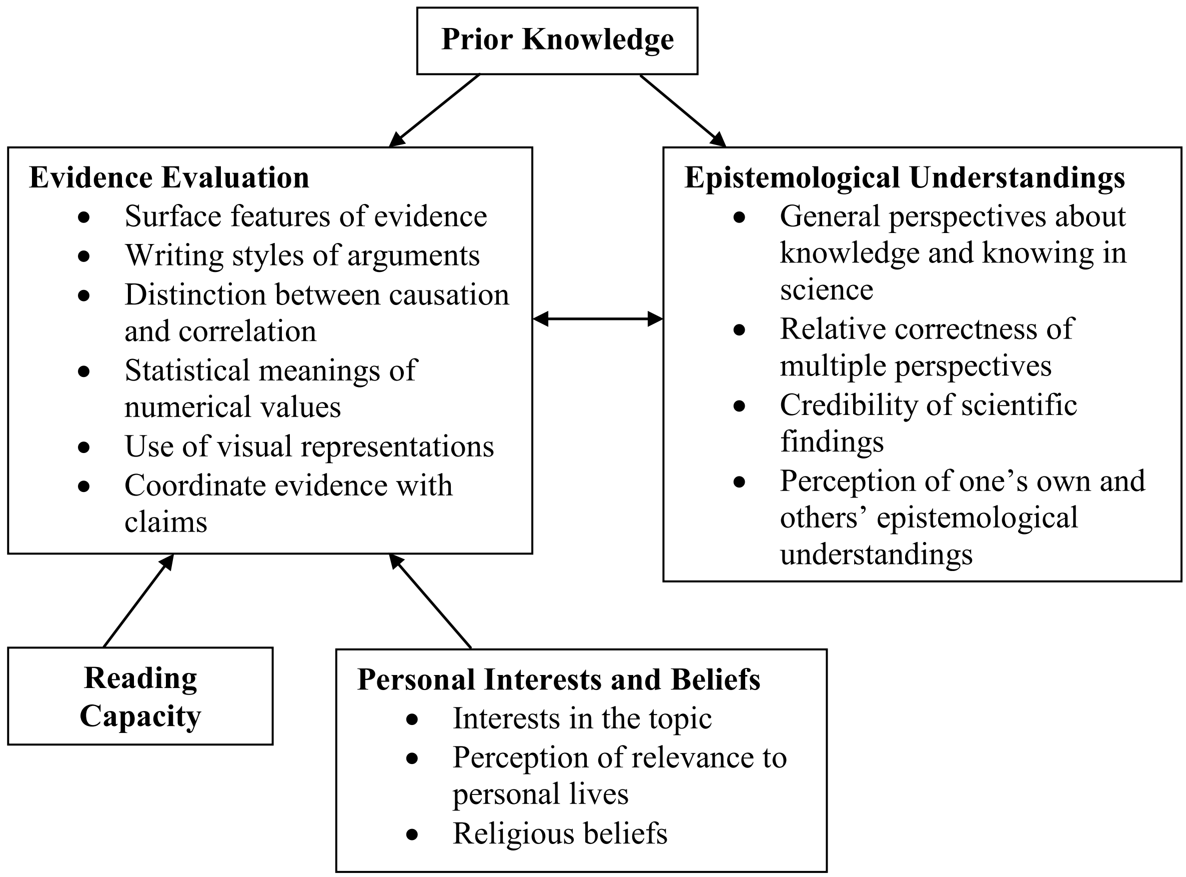

Figure 7 A theoretical framework for scientific reasoning about global climate change.

CHAPTER V DISCUSSION

The present study explored undergraduate students' scientific reasoning when faced with competing arguments about global climate change. A theoretical model was developed to capture the cognitive processes during scientific reasoning and their underpinning factors. This chapter will first present how current findings relate to existing literature and their educational implications. Next, the significance and limitations of this work will be discussed, with a proposal for directions in future research.

Current Findings

Evidence evaluation.

Evidence evaluation is an essential aspect of scientific reasoning (Kuhn, 2002). Koslowski (1996) stated that to engage in scientific reasoning and argumentation, an accurate understanding of what constitutes evidence is first and foremost important. Walker and Sampson (2013) stressed that evidence can be considered as data that is collected and used to prove or support a certain claim. While data can be in the format of traditional measurements or observations, evidence entails analysis and interpretation of data to show their potential relationships. To reason scientifically with evidence, individuals should be able to not only distinguish evidence from data, but also evaluate the conceptual and structural qualities of evidence.

Participants in the present study demonstrated various levels of reasoning in their evidence evaluation. First, the current findings showed that participants primarily focused on the surface features of evidence when reasoning about its strengths and weaknesses. The most common concern they raised was the frequency of numerical values provided in the arguments. Participants expressed overwhelming preference for "more" and "bigger" numbers, but did not pay much attention to the statistical meaning or practical indications of the numbers. On the other hand, participants who evaluated the quality of evidence in details revealed several challenges they encountered. For one thing, many participants confused correlation with causation. When arguing about the main causes for global climate change, very few participants recognized the insufficiency in the evidence for claiming causation. They tended to rely on co-occurrence of events to conclude the strength of causal relationships between human activities and temperature changes. For another, participants tended to overlook the importance of evaluating evidence on its epistemological characteristics. For instance, only a few participants mentioned concerns such as the trustworthiness of data sources.

Consistent with existing literature, the present study suggests urgent needs to enhance students' competence in data interpretation and evidence evaluation. Many studies have reported that students have difficulties engaging in evidence evaluation (e.g., Amsel & Brock, 1996; Koslowski, Marasia, Chelenza, & Dublin, 2008; Sandoval & Millwood, 2005; Yang, 2004). Driver et al. (2000) stated that the credibility of different sources of information concerns factors such as the theoretical mechanisms underlying the construction of the evidence, the origin of the evidence, and the authority of such origin. Previous research found that students at all levels experience challenges when evaluating credibility of evidence (e.g., Chinn, Duschl, Duncan, Buckland, & Pluta, 2008; Sandoval & Millwood, 2005; Zembak-Saul, Munsford, Crawford, Friedrichsen, & Land, 2002). For example, Pluta et al. (2008) documented that students typically found it difficult to make judgments about the relative strength of evidence, and tended to treat all evidence as equally strong. They mostly just mentioned the evidence that was potentially supportive of a claim and revealed limited understanding of the need to provide more elaborated justifications for the connection between the evidence and the claim. Similarly, Sanchez, Wiley, and Goldman (2006) reported that college students had difficulties in justifying their evaluations of evidence credibility. They identified four key areas in which college students needed support: evaluating the source of the information, interpreting the evidence that was presented, thinking about how the evidence fit into an explanation of the phenomena, and integrating the information with prior knowledge.

An important reason that may account for participants' lack of rigorous reasoning with evidence may be that they did not hold sufficient understanding of the criteria to evaluate the reliability and validity of evidence (Wu & Hsieh, 2006). Driver et al. (2000) noted that insufficient time is typically given in class to evaluative tasks beyond simple interpretation of data; for instance, questions such as "What trust can we place in data?" or "Are there different possible interpretations of this data?" are not frequently addressed. Existing inquiry curricula usually have explicit or implicit expectations that students treat data as non-biased and do not raise concerns over the credibility of the evidence (Nicolaidou, Kyza, Terzian, Hadjichambis, & Kafouris, 2011). Thus, more instructional efforts should be made to help students examine the source of the evidence and think about questions such as "What was the source for producing the evidence?" and "Was the finding replicable?" Evaluation of evidence constitutes a critical component of science teaching and learning: it bridges between understandings of the nature of science and scientific reasoning processes. Enhancing students' understandings of evidence and its credibility may lead to more advanced reasoning skills and sophisticated epistemological understandings.

In addition, when evaluating evidence, participants mentioned their preferences for making sense of scientific information through multiple representational tools. For example, they proposed to replace or complement the written information with graphical data as the latter can strengthen the evidence and its connection to the claims. Such concerns, while not explained thoroughly, demonstrated participants' awareness of their own cognitive processes and preferences for reasoning tools, which in other words, showed their metacognitive processes (Brown, 1987; Flavell, 1979; Kuhn, 1999; Olson & Astington, 1993; Perkins, Farady, & Bushey, 1991). Participants in this study not only reflected on the tools for thinking but also constantly monitored their cognition when reading and thinking aloud. Such efforts may have greatly contributed to the approaches they took to coordinate theory and evidence (Yang & Tsai, 2010). Some researchers referred to such metacognitive activities during scientific reasoning as reflective reasoning (Kitchener, 1983; Kuhn, 1999; Perkins et al., 1991; Talaska, 1992). Kuhn (1993) pointed out that reflective reasoning lays the foundation for individuals to evaluate arguments toward their own theories as well as viewpoints from others in order to connect supporting or refuting evidence with assertions so that argument can be moved to resolution. However, although the importance of reflective reasoning has long been established, very few studies have tentatively looked into it. The present study opened up more discussions in this regard and may constitute a first step for future research that investigates the influence of reflective activities on scientific reasoning.

Theory-evidence coordination.

In this study, evidence evaluation was investigated in argumentative scenarios. Argumentation is a context in which data is used as evidence to support singular or networks of claims (Walker & Sampson, 2013). As a major constitutive element of science, argumentation not only engages learners in the coordination of conceptual and epistemological perspectives but makes their reasoning more visible to teachers, which greatly promotes instructional design and assessment development (Osborne, Erduran, & Simon, 2004; Sandoval & Millwood, 2005). The core of reasoning processes involved in argumentation is the coordination of evidence and theory to support or refute an explanatory conclusion, model, or prediction (Suppe, 1998). Evaluation of evidence in competing arguments reveals not only participants' understanding of criteria for quality evidence but also their knowledge and skills in argumentation.

Findings from the present work revealed that many participants have difficulties evaluating arguments that opposed their own perspectives. Rather than coordinating the competing theories and evaluating the strengths and weaknesses of evidence, participants were prone to drawing conclusions solely based on the stance an argument supports. If the claim agreed with their own beliefs, participants tended to forgo its opposing argument without reasoning about the evidence or seeking coordination between perspectives. Nonetheless, some participants were more aware of their potential biases and thus more actively evaluated evidence from both sides of the arguments and proposed ways to improve the quality of evidence. Rather than unanimously agreeing or refuting arguments, their critique on the evidence was more reflective and scientific, even though more in-depth discussions about the connections between theory and evidence were still sparse. Moreover, many participants provided critiques on the writing techniques of the arguments, but their focus was mainly on the tone or wording used in the writing rather than how to strengthen the different elements of the arguments on a content level.

This study, closely aligned with existing work, revealed potential limitations students may have in argumentation. A large body of research has demonstrated that students have difficulties engaging in productive scientific argumentation to propose and justify an explanation (Acar et al., 2010; Sampson & Clark, 2008). Duschl and Osborne (2002) held that instruction on argumentation has not typically been a part of traditional science instruction and teachers should devote more time to engage students in argumentative discourse in class. Many curricula have adopted Toulmin's argumentation pattern as a model and foundation for teaching argumentation on socio-scientific issues like global climate change. According to Toulmin (1958), the statements that make up an argument have different functions, including claims, data, warrants, backings, qualifiers, and rebuttals. The strength of an argument is based on the presence or absence of specific combinations of these structural components (Sampson & Clark, 2008). To improve the quality of argumentation, explicit instruction is needed to teach students how to generate each of these components and incorporate them into their arguments (Bell & Linn, 2000).

More importantly, the way participants coordinated theory and evidence when evaluating arguments may be heavily influenced by their epistemological understandings. The following discussion will focus on discussing the relationship between epistemological understandings and scientific reasoning.

Epistemological understanding and scientific reasoning.

Epistemological understanding is fundamental in science learning (Driver, Leach, Millar, & Scott, 1996; Tytler & Peterson, 2003). A growing body of research has revealed that limited epistemological understandings may restrict the way individuals appreciate and engage in science (Hofer & Pintrich, 1997; Mason & Scirica, 2006; Tsai, 2000; Yang, Chang, & Hsu, 2008). Researchers have proposed several models to capture the nature of epistemological understandings (e.g., Hofer & Pintrich; 1997; King & Kitchener, 1994; Perry, 1970). In recent years, there are an increasing number of studies that attempt to further investigate the role epistemological understandings play in knowledge acquisition (e.g., Bendixen & Schraw, 2001; Tsai, 2000; Weinstock et al., 2006; Yang & Tsai, 2010). This line of research is usually embedded in argumentative contexts to explore how individuals' understandings of the nature of knowledge and process of knowing may affect their argumentation (Chan et al., 2011). Such approach not only reveals a complex relationship between epistemological understandings and scientific reasoning, but also provides a fresh insight into the relationship between scientific reasoning and argumentation.

Broadly, three major findings can be summarized from existing literature. First, epistemological understandings are a key factor involved in reasoning processes. Those who hold the epistemological understandings shared in the science community are more likely to evaluate evidence in depth and actively coordinate between theory and evidence (e.g., Nussbaum, Sinatra, & Poliquin, 2008; Sandoval & Millwood, 2007). Second, there is a reciprocal influence between epistemological understandings and abilities in reasoning and argumentation. Naïve epistemological understandings may lead individuals to overlook the necessity for argumentation and avoid argumentative situations (e.g., Kuhn, 1991; Nussbaum & Bendixen, 2003), which in return may cause difficulties in appreciating multiple perspectives and yield absolutist perspectives about the tentative and complex nature of knowledge (Chan, Ho, & Ku, 2011; Hofer & Pintrich, 1997; Kuhn, 1999, 2001; Schraw, Dunkle, & Bendixen, 1995; Stromso, Braten, & Britt, 2010; Weinstock & Cronin, 2003). Last but not least, several factors may mediate the relationship between epistemological understandings and scientific reasoning. Individuals' content knowledge and personal beliefs about the topic of interest, for instance, may influence the way they reason with given information and make inferences from it (Bromme, Kienhues, & Stahl, 2008; Köller, Baumert, & Neubrand, 2000; Lehrer & Schauble, 2006; Sandoval & Millwood, 2007; Yang & Anderson, 2003).

Consistent with previous research, the present study also revealed an "intimate" yet complex relationship between epistemological understandings and scientific reasoning. Participants with more sophisticated epistemological understandings tended to provide more in-depth critique on evidence and were better at evaluating the credibility of evidence. However, while participants demonstrated various levels of reasoning in evidence evaluation, they all acknowledged the relative correctness of multiple perspectives about global climate change. Most participants claimed to appreciate the coexistence of more than one viewpoint: they considered themselves as “in the middle” rather than strongly agreeing or disagreeing with any singular claim.

Of note, inconsistency was found among participants either between their responses to the written assessment and interview questions, or within their individual interviews. Some participants were identified as absolutists by the written assessment, but then demonstrated appreciation of multiple perspectives about climate issues during the interview. Others may claim a relativist perspective during the interview about climate science but at the same time tended to refute or accept an argument on global climate change as though it was the only correct perspective. Given such inconsistency, no simple, clear-cut conclusions can yet been drawn about the relationship between epistemological understandings and scientific reasoning.

One reason that may account for this inconsistency is the differences between individuals’ domain-general and domain-specific epistemological understandings. Debates exist regarding whether certain aspects of epistemological understandings are domain specific whereas others may generally apply across domains (Bromme, Kienhues, & Stahl, 2008; Tabak & Weinstock, 2005). As differentiating epistemological understandings was not within the initial scope of the present study, further research is needed to look into this issue. Additionally, the methodological differences may also have contributed to the inconsistency. In this work, a written assessment was used to tap into participants’ general epistemological understandings, whereas the interview questions targeted specifically at their epistemological understandings about climate science. Greene and Yu (2014) suggested that survey-type items may not suffice to reveal the essence of one's epistemological understandings, and measures such as interviews and self-report should be employed to provide a more comprehensive view. At the same time, they also raised the concerns that issues such as wording of interview questions and the overall quality of instrument may result in heterogeneous findings of epistemological understandings. Thus, before making any conclusive inferences about the current results, future research should be done to evaluate the quality of the instrument used in this work and investigate the methodological underpinnings that may have contributed to the inconsistency discussed above.

Nonetheless, the current finding indicated that more attention should be given to promote students' appreciation of the complex nature of science and encourage them to engage in argumentative activities (Duschl & Osborne, 2002). Lack of instruction on argumentation or epistemological understandings in the classroom may hinder students' perception of the complexity of science (Nussbaum, Sinatra, & Poliquin, 2008). We need to educate our students about how we know and why we believe in the scientific worldview, which requires developing their understanding of the criteria used in science to evaluate evidence and construct explanations (Driver, Leach, Millar, & Scott, 1996; Millar & Osborne, 1998). In particular, students should be encouraged to engage in argumentative activities, which will help them better understand the nature of scientific inquiry and enhance their abilities of making scientifically informed decisions in everyday life (Norris & Phillips, 2003; Osborne, Erduran, & Simon, 2004).

The role of content knowledge.

One of the debates in the study of scientific reasoning and argumentation is the role of content knowledge individuals hold about the topic of interests. While many studies suggested that performance on scientific reasoning has much to do with the acquisition of domain-specific knowledge (Driver et al., 2000; Lehrer & Schauble, 2006; Yang & Anderson, 2003; Zimmerman, 2000), there are studies showing that the effect of domain-specific knowledge was not clear when the problems in discussion were ill-structured by nature (Mason & Scirica, 2006; Perkins, 1985). In the present study, many participants demonstrated limited content knowledge about the topic of interest, *global climate change.* Although such limitation did not always lead to weak evaluation of evidence and arguments, the lack of sufficient knowledge was related to lack of confidence in evidence evaluation. Participants would also tend to shy away from engaging in detailed discussion about the arguments, claiming that they were not familiar about the information presented and thus could not make firm conclusions.

This research corresponds to studies that have suggested a close relationship between content knowledge and scientific reasoning (Osborne, 2010). For example, Sandoval and Millwood (2005) discussed that one of the reasons that students often fail to evaluate anomalous data or distort it to match already held ideas is students lack the depth of conceptual understanding that scientists can bring to bear on specific topics, and they have little practice designing and conducting systematic investigations. They claimed that students should acquire sufficient knowledge to help them better engage in reasoning and argumentative discourse activities. However, such a proposition is somewhat countered by a study Bao et al. (2011) conducted with Chinese physics undergraduates and their comparable American counterparts. All participants in the study were evaluated on their content knowledge and domain-general scientific reasoning skills. It was found that while the Chinese participants outperformed their American counterparts on content knowledge, there was no significant difference between their scientific reasoning performance. Osborne, Erduran, and Simon (2004) pointed out that the nature of this relationship depends on the topic of interests. Compared to scientific contexts that require very specific knowledge, topics that can be easily related to everyday life experience will reveal very different connections between content knowledge and scientific reasoning.

Whether the difficulty of reasoning about the ill-structured problems is a matter of developmental constraint or lack of relevant knowledge is in debate (e.g., Kuhn, 1991; Zimmerman, 2000). Some researchers suggest that other factors may have confounded the relationship between scientific reasoning and content knowledge, one of which is the epistemological understandings individuals hold. For example, Mason and Boscolo (2004) found that students with more advanced epistemological understanding demonstrated better reflection and evaluation of arguments on transgenic food. Bromme, Kienhues, and Stahl (2008) also stated that some amount of topic-related knowledge is necessary in order to judge about the viability of evidence and evaluate the methodological credibility of the construction of evidence. However, some existing studies challenge the idea of a linear relationship between the quality of epistemological understandings, scientific reasoning, and knowledge acquisition, as gaining more knowledge sometimes results in less sophisticated epistemological beliefs and scientific reasoning (e.g., Koller et al., 2000).

The present study suggested a close relationship between content knowledge, scientific reasoning, and epistemological understandings. To start with, participants who held more detailed understandings about the basic science of global climate change also demonstrated more complex reasoning about evidence and more sophisticated epistemological understandings about climate issues. However, content knowledge was not a direct indicator of reasoning levels: participants who revealed moderate or minimum knowledge about climate change may still be able to reason with evidence at an advanced level. Yet, the perception of their level of prior knowledge affected how participants engaged in evaluating competing arguments. Often, participants would avoid directly commenting on any given evidence or arguments, for knowing little about the topic and not wanting to "seem dumb". Within the limit of the present study, no conclusive remarks can be made to characterize how these three aspects relate to each other. Yet, this study adds to the current endeavors in educational psychology and science education that investigate how epistemological understandings relate to science learning. Sinatra, Kienhues, and Hofer (2014) recently proposed that more research should be done to help address the obstacles in public's understanding of complex science topics with a focus on three aspects: reasoning about knowledge and the processes of knowing, biases in such reasoning, and overcoming misconceptions. This work corresponds to their call for research by exploring the complexity and uncertainty of the relationships between content knowledge, scientific reasoning, and epistemological understandings.

Additionally, other factors may also contribute to the complexity of this relationship, such as participants' personal beliefs, interests in science or climate science in particular, as well as their reading capacity. For example, even when having similar amount of content knowledge and epistemological understandings, those who are religious may evaluate evidence very different from those who are not. Based on the current findings, science teachers should consider incorporating multiple dimensions in their teaching of science topics or scientific reasoning. More opportunities should be provided for students to reflect on their own understandings of the nature of science and personal beliefs as they make sense of complex scientific information and reach conclusive judgments (Mason & Scirica, 2006; Nussbaum, Sinatra, & Poliquin, 2008; Zeineddin & Abd-El-Khalick, 2010).

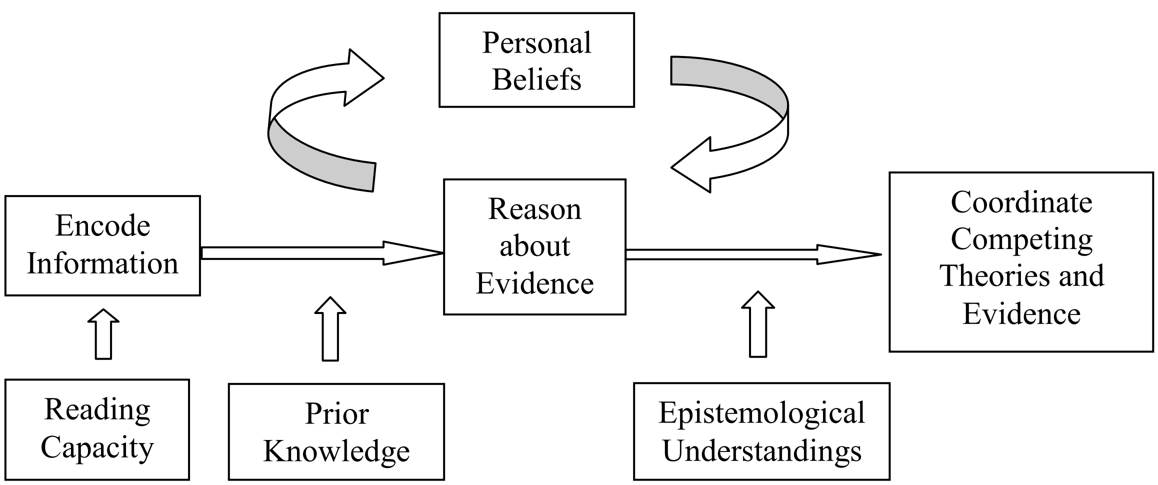

Figure 8 A hypothetical process of how people reason about global climate change

In all, the theoretical framework developed through this work implies a hypothetical process of how individuals reason about competing arguments on global climate change. As one encodes information in the arguments, their level of reading capacity may have bearings on what aspects of the evidence their attention is drawn to. Those who have a lower level of reading capacity may end up focusing more on surface features such as the wording rather than their more in-depth structural and conceptual characteristics. When they start to reason more specifically about evidence, what individuals already know about the topic and their personal beliefs play a big role: the majority would strongly prefer the evidence supporting their own point of view with little evaluation of the opposing evidence, even when they do not hold sufficient knowledge to back up such preference. More importantly, the relationship between personal beliefs and reasoning is reciprocal: while the former affects how one approaches evidence evaluation, the preference of evidence supporting their own perspective can further strengthen their beliefs and even biases. After assimilating the information into their own knowledge and belief systems, individuals make the decision of how to coordinate the competing theories and evidence. With diverse epistemological understandings about factors such as the relative correctness of perspectives and scientists' expertise, individuals arrive at different conclusions on whether to only agree with one side of the arguments or critically view arguments from all sides.

As a hypothetical illustration of how the components in the framework may connect to each other, this process demonstrates what individuals may potentially do when reasoning about competing arguments on global climate change. While further empirical investigation is needed to further investigate this hypothetical process, the present theoretical framework adds a new lens to the study of scientific reasoning and opens up further discussion on the essence of how people reason.

Scholarly Significance

A central goal of science education is to enhance students' skills in effective communication of scientific issues. National science education standards have emphasized that students should be able to reason scientifically in order to engage in scientific argumentation and thus communicate about issues that impact their daily lives (Achieve, 2013; NRC, 2012). Researchers have argued that participating in such decision making requires various cognitive processes which include, but are not limited to, making sense of complex data and writing the relevance and credibility of scientific evidence (Nicolaidou, Kyza, Terzian, Hadjichambis, & Kafouris, 2011). Despite the numerous studies in the field of scientific reasoning, no consensus is reached about what instructional support should be provided to facilitate student reasoning (Osborne, 2010). One of the reasons for this is a lack of comprehensive theoretical understanding about the nature of scientific reasoning.

The present study explored the nature of scientific reasoning by investigating how individuals coordinate theory and evidence in argumentative contexts regarding a socioscientific issue, *global climate change.* With a primary goal of investigating potential factors that may relate to the cognitive processes during scientific reasoning, the present study has led to a grounded theory of how undergraduate students reason about climate issues. The significance of this work is threefold.

First, the grounded theory developed through this work extends previous endeavors in the field of research on scientific reasoning. For a number of years, researchers have conducted studies about scientific reasoning using well-structured tasks

(Zimmerman, 2005). It is only in recent years that more attention has been given to assessing scientific reasoning with more authentic, real-life topics. Scientific reasoning is critical in daily experience as it makes it possible for one to make rational and sound judgments about controversial issues such as global climate change. Thus, the investigation of scientific reasoning within socioscientific issues like global climate change promote efforts in bridging scientific reasoning research with everyday reasoning (Yang & Tsai, 2010). Moreover, the study of scientific reasoning with the topic of global climate change expands the scope of previous research on scientific reasoning. The proposed theoretical framework integrates both the cognitive processes involved in reasoning and different factors that may affect these processes. In particular, the findings in this work enriched our understanding of the complex relationship between epistemological understandings and scientific reasoning by exploring the potential role of content knowledge, reading capacity, as well as personal interests and beliefs in this relationship. The results indicated that reading capacity and personal beliefs affect how individuals process the evidence presented and thus impact the approach they take to coordinate theory and evidence. Thus, even though one may have sophisticated understandings, with limited reading capacity, lack of sufficient content knowledge, or biased beliefs, the level of reasoning they demonstrate may end up very limited. This discussion proposed an alternative explanation for the existing heterogeneous findings mentioned in the literature review of Chapter 2 about how epistemological understandings may relate to the way people reason and will initiate more investigation in this aspect.

Second, the methodological approach employed in this study brought a new lens to research on scientific reasoning. The uniqueness of grounded theory and phenomenography makes the exploration of individuals' reasoning processes more naturalistic. Osborne (2010) suggested that there are several aspects of scientific reasoning skills that science education might seek to develop such as identifying patterns in data and resolve uncertainty of scientific inquiry. However, there have not been many empirical studies that provide empirical support for this proposal. Rooted in empirical data, the grounded theory from this work is consistent with the proposal Osborne made, but extended its scope in the context of a socioscientific issue. The use of phenomenography complements the grounded theory methodology. There can be no "art of teaching all things to all men" (Marton, 1992, p. 266). Yet, by studying how learners deal with various specific phenomena, we will be better equipped to teach them about those phenomena. The most fundamental aspect of learners' ways of dealing with specific phenomena is the different ways in which those phenomena are seen or understood. By revealing participants' perspectives and thinking processes about climate issues, this study provided critical information for teachers to consider as they develop their curriculum.

Furthermore, findings from this work add to the ongoing debates in climate change education about how to enhance climate literacy. One of the most critical educational objectives is for students to learn about how socioscientific issues are handled and evaluated within society so as to be able to act as responsible citizens in the future (e.g., Höttecke, Baumert, Neubrand, 2010). Educational and policy documents have suggested that students should develop reasoning skills that can help them evaluate the causes and effects of global climate change (NRC, 2001, 2012). Students should be more actively engaged in evidence-based reasoning about human impacts on the earth climate system to propose, test and modify possible solutions to current climate issues. Incorporating scientific reasoning into climate change education will help fulfill this goal. It is essential that the general public come to appreciate the relevance of scientific reasoning and its impact on climate literacy. However, although the importance of scientific reasoning in climate change education has been established, there have not been many detailed discussions on effective approaches to promote scientific reasoning and climate literacy. As the grounded theory in this work looked into the complex relationship between scientific reasoning and content knowledge as well as identifying multiple factors that may have affected students reasoning about climate issues, it may serve to initiate conversations between scientists and educators for potential collaborations in their efforts of enhancing the public's climate literacy.

Limitations and Future Directions

In spite of its potential contributions, there are a few limitations in this work that should be addressed in future research.

First, this study adopted a qualitative research approach to investigate scientific reasoning processes. While integrating the grounded theory and phenomenography approaches has yielded in-depth discussions about how undergraduate students reason about climate issues, like all qualitative studies, concerns may arise regarding the trustworthiness and credibility of this work. Thus, great efforts were made throughout data collection and analysis to avoid biases and minimize preconceptions for grounded theory development. However, given the nature of qualitative studies, it is open for further investigation whether the theoretical framework can be generalized across subject domains for different populations.

Moreover, the topic used in this investigation of scientific reasoning was global climate change, whereas scientific reasoning processes may differ as the topic in discussion varies. Follow-up studies will continue to explore how this theoretical framework may apply to reasoning with other socioscientific issues, such as genetic engineering and water pollution. At the same time, as the task involved in this study was critiquing arguments that were already generated, it is beyond the scope of the present work to cover all potential processes that may be involved in authentic scientific inquiry, such as reasoning during hands-on experiments and interpreting anomalous data. To obtain a holistic view of scientific reasoning across contexts, future work should be more grounded in authentic contexts, such as scientific laboratories, to capture a wider scope of scientific reasoning processes. Additionally, the assessment of content knowledge in this work was brief. Future research should place more emphasis on improving the assessment of content knowledge for a more accurate understanding of its relationship with scientific reasoning.

Last but not least, within the scope of the present study, the theoretical framework proposed did not exhaust all aspects of scientific reasoning or epistemological understandings. Categories and themes that emerged from this work revealed the reasoning of the participating students. Even though saturation was reached by the end of data collection, as participants were sampled from the same institution, it is possible that a more heterogeneous sample may demonstrate more dimensions about scientific reasoning. For example, only one participant was explicitly reflective about how her religious beliefs may have influenced her judgment on the multiple perspectives about global climate change. To obtain a more comprehensive understanding about the contributing factors of scientific reasoning, later researchers may find it helpful to expand the scope of investigation and consider aspects that have not been discussed very much in scientific reasoning research such as social and religious factors.

Conclusions

Scientific reasoning is at the core of scientific inquiry. However, it is not a vehicle that only scientists are entitled to. Reasoning scientifically affects how one understands and evaluates scientific findings from professional publications and public media (Giere, 2006). Thus, scientific reasoning has an essential role in our everyday lives. To promote scientific reasoning, researchers have conducted numerous studies that explored the cognitive processes during reasoning (Zimmerman, 2005). Yet, while previous research has indicated an "intimate" relationship between scientific reasoning and factors such as epistemological understandings and content knowledge (e.g., Yang & Tsai, 2010; Mason & Scirica, 2006), the nature of such relationship is still left uncertain. The grounded theory developed through the present study greatly contributes to the ongoing endeavors in constructing an integrated framework for scientific reasoning. It not only captured the cognitive processes individuals engaged in when faced with complex, competing scientific evidence, but also provided an in-depth understanding of how one's epistemological understanding, as well as other characteristics such as personal beliefs, may affect their reasoning. With a holistic perspective, this study may open up more discussion about how people reason in various contexts. Future work based on the current findings may lead to more reflection on potential ways to bridge cognitive studies with science education to enhance effective science teaching and learning.

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Appendix 1 The Reading Maze Task

Read each sentence. When you come to three words that are underlined and in dark print, you will circle the word that belongs in the sentence.

1. The snow was falling and the air was crisp. He put on his **trees/boots/houses** and walked to school.

2. He was late, so he **map/see/ran** to catch the bus.

Do not turn this page until you are instructed to do so.

Impressions of an Indian Childhood

A wigwam of weather-stained canvas stood at the base of some irregularly ascending hills. A footpath wound its way gently **down / ajar / skip** the sloping land till it reached **bin / the / map** broad river bottom; creeping through the **boss / long / knit** swamp grasses that bent over it **on / at / he** either side, it came out on **ode / the / tab** edge of the Missouri.

Here, morning, **chop / lore / noon**, and evening, my mother came to **draw / kite / lone** water from the muddy stream for **new / our / tan** household use. Always, when my mother **arrayed / incline / started** for the river, I stopped my **play / also / skin** to run along with her. She **red / zoo / was** only of medium height. Often she **oil / was / buy** sad and silent, at which times **ale / egg / her** full arched lips were compressed into **hard / bend / dine** and bitter lines, and shadows fell **gulch / hoist / under** her black eyes. Then I clung **is / he / to** her hand and begged to know **what / fort/ knob** made the tears fall.

"Hush; my **little / queue / organ** daughter must never talk about my **close / movie / tears**." Smiling through them, she patted my **oath / head / such** and said, "Now let me see **how / mad / out** fast you can run today." Whereupon I **colt / tore /knob** away at my highest possible speed, **mane / pawn / with** my long black hair blowing in **the / fur / net** breeze.

I was a wild little **girl / back / coal** of seven. Loosely clad in a **paid / slip / limp** of brown buckskin, and light-footed **rift / jeer / with** a pair of soft moccasins on **my / he / it** feet, I was as free as **ivy / the / aid** wind that blew my hair, and **it / no / as** less spirited than a bounding deer. **These / Badge / Meant** were my mother's pride – my wild **insists / freedom / snowmen** and overflowing spirits. She taught me **at / if / no** fear save that of intruding myself **upon / boot / rush** others.

Having gone many paces ahead I **asking / stopped / noises**, panting for breath, and laughing with **cage / jury / glee** as my mother watched my every **movement / skulking / workload**. I was not wholly conscious of **bleach / garage / myself**, but was more keenly alive to **gig / the / rim** fire within. It was as if I **were / hair / move** the activity, and my hands and **self / tomb / feet** were only experiments for my spirit **by / to / or** work upon.

Returning from the river, I **tugged / stream / double** beside my mother, with my hand **farm / upon / nose** the bucket I believed I was **animated / organism / carrying**. One time, on such a return, I **remember / outdoors / flamingo** a bit of conversation we had. **If / My / On** grown-up cousin, Warca-Ziwin (Sunflower), **box / lob / who** was then seventeen, always went to **the / paw / wet** river alone for water for her **armory / mother / ironic**. Their wigwam was not far from **ours / ajar / lady**; and I saw her daily going **at / to / in** and from the river. I admired **in / as / my** cousin greatly. So I said: "Mother, **when / meek / oven** I am tall as my **hoarse / cousin / reject** Warca-Ziwin, you shall not have **by / or / to** come for water. I will do **as / it /my** for you."

With a strange tremor **in / we / of** her voice which I could not **abandoning / newsletter / understand**, she answered, " If the paleface does **top / not / nod** take away from us the river **we / on / my** drink."

"Mother, who is this bad **function / workshop / paleface**?" I asked.

"My little daughter, he **is / at / or** a sham, -- a sickly sham! The **bronzed / aerobic /mortify** Dakota is the only real man."

Home is in Your Head

If you had the opportunity, would you pack your bags and leave for a foreign country at a moment's notice?

As the son of military personnel, **I / at / me** qualified as a "military kid," or **child / glove / tank** of an active-duty military employee. My **happy / family / paint** moved across the globe every two **at / we / or** three years, which meant that we **had / met / at** to adapt to different climates, new **groups / shirts / forks** of friends, and foreign cultures. When **you're / close / thank** a military kid, home is where **and / we / the** navy sends you, and for every **touchdown / lighthouse / fireplace**, a liftoff awaits around the corner.

European Vacation

My **touch / holds / family** moved to Gaeta, Italy, in 1983, **when / pool / glad** I was six years old, just **one / log / top** month before I began first grade. Gaeta **is / at / to** located between Rome and Naples in **and / why / the** southern region of Italy.

I **listened / attended / thanked** Joshua Barney Elementary, which was a Department **of / we / low** Defense school for the children of military **employees / catching / distance**. My friends consisted of Italian neighbors **and / it / who** spoke little or no English and **the / we / my** American classmates who spoke little or **no / yes / at** Italian. Still, we had a lot of **fun / week / play** together. We attended field trips to Rome **to / of / and** Pisa, where we could **inspect / borrow / little** Michelangelo's Sistine Chapel ceiling up close, **or / be / at** scale the Leaning Tower's floors, all **in / the / we** the name of education.

Although my **trust / school / basic** was basically the same as any American **basements / elementary / lifeguard school**, I had different after-school activities **than / pour / stand** my friends in America. We liked **be / at / to** hang out in the ruins **of / a / we** a 200-year old abbey. Bombs had **taken / burnt / nearly** destroyed the abbey during

World War II. My **friends / throwing / lights** and I uncovered frescoes and **rust / tear / wall** paintings that had lain burled beneath **the / put / our** rubble for dozens of years. I **hand / cold / felt** like I was digging into history **even / tent / went** when I was wasting time with **my / at / so** friends!

Next Stop: Florida!

After four **years / plate / slope** in Italy, my father was assigned **if / or / to** a base in Jacksonville, Florida. Returning **to / at / me** America sent me into culture **trunk / shock / chant**. In America, I could understand **close / every / heard** conversation I heard in the supermarket, **learn / every / patch** store accepted American dollars, and **all / our / she** television was in English! Also, many **at / in / of** my new friends in Florida were military **hard / kids / lean** themselves, so we already had **a lot / mat / tan** in common. They were familiar with **garage / living / oceans** a life "on the move" and **many / hold / lean** of them had recently moved to Florida, **just / kind / note** like me.

My family lived in Florida **clean / shout / until** 1990. I can still remember the day **my / at / on** father came home from work, called a **should / family / nickle** meeting, and announced that we would **at / or / be** moving to an island smack-dab in **the / him / our** middle of the Bering Strait.

He **paused / sleeps / framed** a moment before explaining that **the / and / pro** Bering Strait is located in the westernmost **region / blanket / writer** of Alaska. Another move across **the / far / act** world!

Good Indian

It was somewhere in the seventies when old Peaceful Hart woke to a realization that gold-hunting and a bad back do not take kindly to one another. The fact that his pipe **and / ton / sun** dim-eyed meditation appealed to him **acid / zeal / more** keenly than did his prospector's pick, **shovel / analog / orient** and pan seemed to imply that **he / on / is** was growing old. He was a **goblet / silent / proven** man, by occupation and by nature, **in / or / so** he said nothing about it; but, **brew / like / kick** the wild things of prairie and **wood / fuzz / iris**, instinctively began preparing for the winter **as / of / he** his life. Where he had lately **poll / rare / been** washing tentatively the sand along Snake River, **he / or / is** built a ranch. His prospector's tools **at / he / in** used in digging ditches to irrigate **ate / his / jog** new-made meadows. His mining days **he / at / or** lived over again only in halting **recital / abysmal / measure** to his sons when they clamored **how / for / and** details of the old days when Indians **band / were / dime** not mere untidy neighbors to be **abruptly / stoicism / gossiped** with and fed, but enemies to **be / is / or** fought, upon occasion.

They felt that **area / lava / fate** had cheated them -- did those five **kite / sons / lull**; for they had been born a **few / did / map** years too late for the fun. **War / Not / Pun** one of them would ever have **earned / abused / mosaic** the title of "Peaceful," as had **bug / his / low** father. Nature had played a joke **curb / upon / auto** old Peaceful Hart; for he, **day / odd / the** mildest-mannered man who ever helped **to / of / is** tame the West when it really **needed / absorb / outwit** taming, had somehow fathered five riotous **baker / tarry / young** males to whom fight meant fun—**van / and / oat** the fiercer, the funnier.

He used **to / at / in** suck at his old, straight-stemmed **pipe / chip / gang** and regard them with a bewildered **abduction / curiosity / motivated** sometimes; but he never tried to **sow / ivy / put** his puzzlement into speech. The nearest **he / in / as** ever came to acknowledgement, perhaps, was **book / deny / when** he turned from them and let **aim / his / pow** pale-blue eyes dwell speculatively upon **the / rag / duo** face of his wife, Phoebe. Clearly **if / he / of** considered that she was responsible for **altar / decay / their** dispositions.

The house stood cuddled against a **rocky / flash / joust** bluff so high it dwarfed the **level / melee / whole** ranch to pygmy size when one **niche / gazed / pupil** down from the rim, and so **steep / rebel / table** that one wondered how the huge, **gray / move / tarp** boulders managed to perch upon its **tame / raid / side** instead of rolling down and crushing **era / the / kin** buildings to dust and fragments. Strangers **bean / cake / used** to keep a wary eye upon **that / blur / mode** bluff, as if they never felt **abbey / quite / cited** safe from its menace. Coyotes skulked **climb / fancy / there**, and tarantulas and “bobcats” and snakes. **Once / Gulf / Keep** an outlaw hid there for days, **accept / mascot / within** sight and hearing of the house, **cat / and / fix** stole bread from Phoebe’s pantry at **night / album / press**--but that is a story in **admire / itself / salmon**.

A great spring gurgled out from **basin / under / clock** a huge boulder just behind the **house / cello / koala**, and over it Peaceful had **mural / built / overt** a stone milk house, where Phoebe **pause / radar / spent** long hours in cool retirement on **churning / admiring / paranoid** day, and where one went to **paw / beg / oil** good things to eat and to **birth / cheap / drink**. There was fruit cake always hidden **away / debt / garb** in stone jars, and cheese, and buttermilk, **shy / and / fin** cream.

Appendix 2 Reading Document for the Interview

Global Climate Change: Human Induced or Natural Changes?

There have been heated debates about what causes global climate change. Many people argue that climate change is mainly human induced as the change has become especially significant since industrial revolution. They consider the rising temperature is due to human activities, and so are other aspects such as rising sea level and extreme weather events.

However, others consider the current climate change as mainly natural since climate has changed in similar patterns throughout Earth's history. They hold that the Earth's temperature change is natural fluctuation and so are other aspects such as the changes in sea level and number of extreme weather events.

The following paragraphs include the evidence-based arguments from both sides.

Temperature Change and CO_2 Emissions

Claim 1: Temperature Change is Due to Human-Induced CO_2 Emissions

The Earth's temperature change is mainly due to the increasing human-caused CO_2 emissions since industrial revolution. Compared to pre-industrial values, there has been a 50% increase of CO_2 concentration in the air as of 2011. At the same time, the Earth's average surface temperature has increased by 0.85 °C (1.53 °F) from 1880 to 2012.

Claim 2: Temperature Change is NOT Due to Human-Induced CO_2 Emissions

Although there has been a human-caused CO_2 increase in the atmosphere, it is not the main cause for the Earth's temperature change. Earth's atmosphere is composed of 78% of nitrogen gas, 21% of oxygen, and 1% of other trace gases. CO_2 constitutes less than 1% of the trace gases. Thus, human-caused CO_2 emissions only influence a tiny fraction of Earth's atmosphere.

Temperature Change and Rising Sea Level

Claim 1: Rising Sea Level is Human-Caused

The average sea level has been rising in recent years due to human-induced temperature increase on Earth. Records show that global average sea level rose at an average rate of 1.7 mm per year between 1901 and 2010, 2.0 mm per year between 1971 and 2010, and 3.2 mm per year between 1993 and 2010. It is projected that the sea level rising rate will be even higher by the end of the 21st century.

Claim 2: Rising Sea Level is NOT Human-Caused

The average sea level has been rising in recent years at the same time that the Earth is warming up, but it is uncertain whether this change reflects a long-term trend. Over the last thousands of years, average sea level has been changing at various rates. For example, the global average sea level was at least 5m higher than present during the interglacial period (129,000 to 116,000 years ago), but it decreased in the following hundreds of years.

Temperature Change and Extreme Weather Events

Claim 1: The Increase in Extreme Weather Events is Human-Caused

Changes in the frequency and intensity of extreme weather events are due to human-caused Earth's temperature increase. In the past 50 years, human activities have resulted in temperature increase, and at the same time, there has been an increase in intense tropical cyclone activities, especially in the North Atlantic. In particular, the number of hurricanes and tropical storms during 1995 and 2004 doubled that during 1970 and 1994 in North Atlantic.

Claim 2: The Increase in Extreme Weather Events is NOT Human-Caused

The number of tropical cyclone activities has increased in recent years, but the number is unreliable. Improvements in radio detection techniques have artificially resulted in more intense tropical cyclones being recorded. Besides, the trends of tropical cyclone activities vary across areas. Records show that the total number of cyclones in the Australian region appears to have decreased during the mid 1980s compared to preceding years and remained nearly stable since then.

Appendix 3 Written Assessment for Epistemological Understandings

Instruction

Please answer the following questions by checking the option that fits with your view the most.

Example

Robin says warm summer days are nicest.

Chris says cool autumn days are nicest.

Can only one of their views be right, or could both have some rightness?

____Only one right

____Both could have some rightness

(*Skip if chose "Only one right"*)

Could one view be better or more right than the other?

_____One could be more right

_____ One could not be more right than the other

1. Robin believes one book's explanation of what atoms are made up of.

Chris believes another book's explanation of what atoms are made up of.

Can only one of their views be right, or could both have some rightness?

____Only one right

____Both could have some rightness

(*Skip if chose "Only one right"*)

Could one view be better or more right than the other?

_____One could be more right

_____One could not be more right than the other

2. Robin believes one book's explanation of how the brain works.

Chris believes another book's explanation of how the brain works.

Can only one of their views be right, or could both have some rightness?

____Only one right

____Both could have some rightness

(*Skip if chose "Only one right"*)

Could one view be better or more right than the other?

_____One could be more right

_____One could not be more right than the other

3. Robin believes one mathematician's proof of the math formula is right.

Chris believes another mathematician's proof of the math formula is right.

Can only one of their views be right, or could both have some rightness?

____Only one right

____Both could have some rightness

(*Skip if chose "Only one right"*)

Could one view be better or more right than the other?

_____One could be more right

_____One could not be more right than the other

4. Dinosaurs dominated the Earth for nearly 150 million years. Dinosaurs disappeared at the end of the Cretaceous Period, about 65 million years ago. There are different views about why dinosaurs disappeared. Recently a new finding was reported-a layer rich in Iridium near the geological layers of the Cretaceous Period.

According to Scientist Luis Alvarez, this finding supports his view that dinosaurs died out when the Earth was hit by a meteorite. (Meteorites contain a lot of Iridium.) The collision left enormous amounts of dust in the air that blocked the sunlight, resulting in a long dark winter that caused plants to die. Dinosaurs died from starvation and the very cold climate.

According to scientist Norman MacLeod, this finding supports his view that dinosaurs died out because of the difficult climate conditions caused by a series of giant volcanic eruptions from deep in the Earth. (Large quantities of Iridium are found at the Earth's core.) The volcanic eruptions filled the air with poison gas. This caused a Greenhouse effect, which raised the Earth's temperatures. Dinosaurs died from the poison gas and very hot temperatures.

Could both of the scientists' accounts of dinosaurs' extinction be right? Yes No

Could one be any more right than the other? Yes No

Could anyone ever be certain about why dinosaurs became extinct? Yes No

What would help us become more certain?