

## Article

# Is the Earth Crying Wolf? Exploring Knowledge Source and Certainty in High School Students' Analysis of Global Warming News

Florian C. Feucht <sup>1,2,\*</sup> , Kate Michaelson <sup>2</sup> , Susan L. Hany <sup>3</sup> , Lauren N. Maziarz <sup>4</sup>  and Nathan E. Ziegler <sup>5</sup> <sup>1</sup> Department of Educational Studies, University of Toledo, Toledo, OH 43606, USA<sup>2</sup> Thinking Habitats, Detroit, MI 48201, USA; kate.michaelson@thinkinghabitats.com<sup>3</sup> The Arts Garage, Port Clinton, OH 43452, USA; dr.susanhany@gmail.com<sup>4</sup> Department of Public and Allied Health, Bowling Green State University, Bowling Green, OH 43403, USA; Lmaziar@bgsu.edu<sup>5</sup> CommonSpirit Health, Chicago, IL 60606, USA; nathan.ziegler@commonspirit.org

\* Correspondence: hello@thinkinghabitats.com

**Abstract:** The marked contrast between the scientific consensus on global warming and public beliefs indicates a need to research how high schoolers, as future citizens, engage with and make meaning from news articles on such topics. In the case of socioscientific issues (SSIs) such as global warming, students' acquisition of knowledge from the news is mediated by their epistemic understandings of the nature of science (NOS) and use of informal reasoning in evaluating claims, evidence, and sources. This exploratory qualitative study examined twelve U.S. high school students' understandings, opinions, and epistemic beliefs concerning global warming knowledge. Researchers examined microgenetic changes as students discussed global warming during semi-structured interviews and a close reading of global warming news texts. Although results showed that most students could articulate a working concept of global warming, in follow-up questions, a subset offered personal opinions that differed from or contradicted their previously stated understandings. Meanwhile, students who offered opinions consistent with the scientific consensus often argued that the dangers of global warming were exaggerated by politicians and scientists who wished to profit from the issue. This study suggests a need for more explicit focus on NOS and scientific news literacy in curricula, as well as further research into the interplay between epistemic beliefs and the informal reasoning students use to negotiate diverse sources of SSI knowledge—from the classroom to the news media and public life.

**Keywords:** critical thinking; epistemic beliefs; global warming; high school students; nature of science; news media literacy; socioscientific issues



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## 1. Introduction

Given the ubiquity of contradictory sources, the technical complexity of socioscientific issues (SSIs), and the advent of “fake news” in public discourse, it can be challenging for the voting public—let alone high schoolers—to know what sources are credible when it comes to socioscientific news and who is “crying wolf.” Medical breakthroughs are glossed over in headlines, technological advancements pour in from newsfeeds, and debates concerning public health issues, such as vaccinations, ignite on social media. Unfortunately, a profusion of scientific information does not necessarily equal a public understanding of it [1,2]. With scientific information comprising one of the top categories of fake news [3], calls for education to provide students with the capacity to evaluate claims resonates more than ever in science classrooms. Without the ability to apply reasoning to the scientific news that affects our everyday lives, “the links between rigorous thought and evidence on the one hand and democratic deliberation and informed policymaking on the other are

severely compromised" [4] (p. 29). Fittingly, research has begun to investigate how students intermingle scientific information gathered from everyday, out-of-school sources with their formal education [5,6]. Calls for epistemological considerations in science education [2,7] coincide with frameworks, standards, and assessments that promote definitions of scientific literacy that move beyond understanding concepts and toward more crosscutting skills and scientific practices such as posing questions about everyday phenomena, constructing explanations, and supporting arguments with evidence [8–10].

The need for scientific literacy in the context of the media is uniquely evident in students' understandings of SSIs. Woven into our national vocabulary, SSIs such as energy production, healthcare, genetic modification of foods, stem-cell research, and global warming play significant roles in the formation of sustainable public policy and the course of individual lives [11]. As such, students must be equipped with the ability to evaluate and integrate multiple texts into workable knowledge for their own decision-making [1,12,13]. However, in this complex media landscape, making sense of these competing scientific perspectives also requires that students acquire an understanding of the nature of science (NOS) and the ability to coordinate evidence with explanations [7,11,13–15]. Further, understanding when and why students apply their knowledge of the NOS to everyday situations calls for an examination of the contextual epistemic beliefs that drive these actions [2,7,16].

Accordingly, the purpose of this research study was to collect multi-faceted, fine-grained data to explore rural U.S. adolescents' understanding of global warming, their opinions on the subject, and their epistemic understandings concerning the sources and certainty of knowledge on the topic. This study examined students' understandings before, during, and after an analytical reading activity using the think-aloud method. Although observations occurred before, during, and after the reading activity, this study was not intended to function as an intervention; rather, the aim was to examine participants' cognitive processes and assess a moment-to-moment change of their explanations as they engaged with multiple news articles on the complex socioscientific topic of global warming. A better understanding of how students' epistemic understanding affects their reading of socioscientific texts will provide valuable insights for reading comprehension instruction for adolescent readers, particularly in the area of science news media. This will offer both practical and theoretical applications to the fields of science education [1,2,7] and personal epistemology [13,16]. For this study, the following research questions were addressed via semi-structured interviews to gain an understanding of students' understandings of global warming:

1. What are rural U.S. high school students' understandings of the scientific concept of global warming?
2. What are rural U.S. high school students' personal opinions about global warming?

A second set of questions examined rural U.S. students' epistemic understandings and were asked before, during, and after an analytical close reading of news articles on global warming:

1. What are high school students' epistemic understandings of the sources and certainty of global warming knowledge prior to an analytical close reading of news articles?
2. Can high school students identify their own understanding (agreement), rebuttals (disagreement), and better ways of thinking during an analytical close reading of news articles?
3. Have students' epistemic understandings of knowledge source and certainty changed after an analytical close reading of news articles?

This literature review explores models that explain the process of reading multiple texts and the role that informal reasoning and argumentation play in this process. This section continues with a framework for assessing students' personal epistemology and its significance in taking knowledge from news articles and applying knowledge of the nature of science (NOS). The section concludes by discussing the need for public socioscientific news media literacy and an explanation of the significance of global warming as a topic of study.

### 1.1. Scientific Literacy: Informal Reasoning and the Nature of Science

As scientific knowledge becomes increasingly available outside of traditional academic environments, science education standards—from the Program for International Student Assessment PISA to the Next Generation Science Standards (NGSS)—have expanded to include scientific literacy skills [17]. These skills include the ability to pose and evaluate arguments, consider information on the basis of source, reach valid conclusions, and apply conclusions appropriately [8,18]. PISA [10] further defines the scientifically literate student as one who can consider the political, economic, moral, and ethical aspects of science and technology as they relate to both personal and global issues; use evidence-based argumentation to engage in responsible civic actions after weighing the possible consequences; and distinguish between personal opinion and proven fact, as well as between reliable and unreliable information. Thus, scientific literacy is concerned not only with the results of formal science reasoning published in textbooks, but also with the informal reasoning that created them and the representations of science that students will encounter outside of the classroom [19].

In cases such as climate change and global warming, where readers likely encounter multiple texts on a topic, the intertext model [20,21] describes how readers must consider sources as they compare multiple texts, draw on prior knowledge, and use critical thinking to evaluate texts individually and as a whole [5,6]. For instance, if students were to read a sampling of news stories on the causes of global warming, as in this study, depending on the source, they might encounter a variety of explanations—ranging from a natural heating of the earth to a build-up of greenhouse gasses as a result of human activity. When asked to explain their thoughts, individuals must find a way to evaluate the relative validity of these differing views. In such situations, readers' epistemic beliefs on the nature of knowledge and processes of knowing converge with their comprehension. Do readers stick to their prior knowledge, allow for the possibility that the various opinions are equally valid, or critically evaluate the validity of the various claims? Such processes are largely influenced by context, informal reasoning, and personal epistemology [2,16].

In the documents model, Bråten, et al. [6] integrate aspects of the intertext model, which examines how various texts agree, disagree, or tie into one another, with the situation model, in which readers work with a holistic evaluation of both single and multiple texts. By looking at the role of context and prior knowledge, as well as the influence of a variety of texts and source evaluation, Bråten and colleague's documents model most thoroughly addresses modern media consumption of SSIs, where news must be contextualized, and a variety of perspectives layered upon a framework of prior knowledge. Informal reasoning, specifically the ability to identify and coordinate claims with evidence, plays a significant role in these processes, particularly in the context of debatable issues in the news media [12]. Because socioscientific news plays a great role in how we understand scientific issues and make decisions, it is necessary to understand where informal reasoning, an understanding of NOS, and epistemic beliefs intersect with and shape these processes.

In the context of this study where participants engage with news articles on an SSI, they need both informal reasoning and an understanding of NOS to make sense of competing claims and the evolving nature of knowledge. Informal reasoning is the dynamic process of challenging premises, questioning claims, assumptions, sources, and evidence. According to Toulmin's [22] structure of an argument, a reader looking at explanations and rebuttals on global warming must identify the central claims of each piece and then evaluate how well the evidence provided supports the conclusions. Scientists, quite similarly, use informal reasoning when they consider, question, and build arguments or support claims, especially when the problem they are solving is open-ended, debatable, and complex [15].

The nature of science (NOS) closely relates to the epistemology of science and acknowledges that scientific inquiry is not an accumulation of information but rather a way of knowing [23]. With NOS, the use of reasoning to construct evidence-based explanations "goes beyond the notion that scientific knowledge is tentative and more accurately reflects an evaluative stance about the nature of science" [24]. Science education must prepare

students to process the competing claims found in scientific news and, thereby, make informed personal and civic decisions; to accomplish this, their educational experiences must foster an understanding of NOS and informal reasoning skills [6,11,25]. However, teaching these concepts in the classroom does not always translate to their everyday application; research in scientific education has recognized the importance of both individual and discipline-specific epistemology in furthering a public understanding of scientific claims and the nature of science [2,7,26,27].

### *1.2. Frameworks for Evaluating Epistemic Beliefs*

Students' capacities to understand NOS, address the complexity of global warming, and acquire science literacy skills are directly affected by their beliefs about scientific knowledge and knowing [2,11,13,14,26,28–31]. Of further significance, there is "amounting empirical evidence that beliefs concerning the nature of knowledge and knowing are linked to the comprehension of multiple texts" [6] (p. 57). Therefore, theories of epistemology were used as the framework to ground this research study. Epistemological research has been conducted using various terminologies such as, personal epistemology [32], epistemic beliefs [30], epistemic cognition [2,7], epistemological understandings [33] and reflective judgment [34]. Regardless of terminologies, research in personal epistemology is spurred by a belief that individuals' views on knowledge and knowing [35] influence their learning processes and outcomes [6,25,36].

Personal epistemology focuses on how individuals justify, interpret, evaluate, and construct their knowledge of the world. This includes the dimensions certainty of knowledge, simplicity of knowledge, sources of knowledge, and its justification [32,35]. Certainty of knowledge is the degree to which a person believes knowledge is fixed, absolute and unchanging or is dynamic, tentative and ever-evolving [32,35]. Certainty may pose a particularly difficult concept for students to grasp when it comes to NOS where knowledge may not be considered absolute or certain, yet it is grounded in methodical, systematic observation. These perceptions of knowledge certainty are particularly pertinent to complex SSIs such as global warming since disagreement among experts, lack of consensus, and ambiguity on a complex topic have been shown to pose problems for those who see knowledge as certain [37,38]. The simplicity of knowledge explores how individuals think knowledge is structured. In other words, do individuals think of knowledge as a simple accumulation of somewhat isolated facts and figures [39], or do they think of knowledge as complex, interconnected, and coherent [32,35]? Some epistemic beliefs are more conducive to navigating the complexity of SSIs; notably, students who believed knowledge to be complex, had greater success when asked to summarize a variety of texts containing conflicting information on the topic of climate change [40].

Finally, personal epistemological research also focuses on the source of knowledge, or where an individual believes knowledge resides [35] and originates, which shapes how individuals view and consume socioscientific news. Sources of knowledge are considered either external or internal. External sources are those that exist outside the self and are transmitted from an external authority. Conversely, a belief that knowledge is actively constructed by the self through interaction with the outside world is an internal source of knowledge. This internal evaluation situates knowing as a process that follows rules of inquiry, interpretation of information, and the evaluation of multiple sources of knowledge, rather than deference to outside authority [6]. For instance, an individual who perceives knowledge as residing externally would have a difficult time reconciling the two conflicting news articles on global warming, while those who view knowledge as internal would see a need to critically evaluate the credibility of each source [12]. This requires the ability to think critically, evaluate, interpret, and justify knowledge, as well as the belief that knowledge is context sensitive and subject to change [41].

As a whole, research in personal epistemology explores what we know, how we know what we know, and why we believe it [18]. It informs how individuals resolve competing knowledge claims, evaluate new information, and make fundamental decisions

that affect public policy [6,36]. Because SSIs require individuals to evaluate knowledge claims, construct knowledge, challenge existing knowledge, synthesize knowledge, and make decisions based on what they believe, they illustrate personal epistemology in action.

### 1.3. Socioscientific Media Literacy and Global Warming

Socioscientific issues (SSIs) are the ideal candidate for the application of informal reasoning [14,42] and NOS [7,11]. Defined as issues that are embedded in science, social, political, economic, and technological dimensions of knowledge [11], such dilemmas are often involve value judgments and become points of political contention [15,18]. Simply understanding SSIs requires the ability to balance and synthesize information from multiple sources [30]. However, education must prepare students to apply these understandings as they vote, make purchases, or protest based on their knowledge of SSIs such fracking, contaminated waste storage, water rights, and global warming.

As a sociopolitical dilemma intertwined with science, discussions of global warming call for logical, informal reasoning, and the evaluation of source and content knowledge [11]. Adding to the challenge of negotiating socioscientific information is a media landscape divided into ideological bubbles and fraught with both fake news and assertions that real news is fake [12,43]. Global warming has not escaped the fake news epidemic with stories that scientists have identified as misleading appearing in major newspapers [44]. In the midst of this discourse, only 58% of U.S citizens believe climate change is mostly caused by human activities [45] in contrast to the more than 98% of publishing climate scientists who assert that human activities play a role [46]. Although data on political ideology could not be collected as part of this study, it should also be noted that meta-analyses have shown political affiliation to be a significant determinant as to beliefs on this issue, with those who hold liberal views consistently more likely than conservatives to believe that human-induced climate change is real e.g., [47]. Without an adequate understanding of the processes that underlie climate change, citizens cannot make informed decisions on public policies aimed at combatting it. Because most adults receive the majority of their information about science through the news media [1], it is vital that students are prepared to step into this environment of competing explanations and disinformation, make reasoned judgments, and take the informed actions necessary to promote sustainable public policy and citizenship [12,30].

### 1.4. The Present Study

Aside from the socioscientific complexity that makes global warming suitable to studying students' epistemic understandings, it is a pervasive enough issue to be addressed on levels ranging from the global to the local. As part of the United Nations Sustainable Development Goals under the topics of clean energy and climate action [48], it is a topic of worldwide concern, but also local enough in nature that the concept inhabits students' daily lives. On the local level, political sorting between rural, urban, and suburban areas of the United States results in different regional sets of beliefs [47] and localized conceptualizations of environmental issues as a whole [49].

Defined as the increase in the earth's near surface and sea temperatures due to a naturally occurring cycle brought on by a multitude of factors both human and environmental [50], global warming is an umbrella term that encompasses its companionate terms climate change and greenhouse gases. This varied terminology and the complex causal elements inherent to global warming have been found to interfere with students' abilities to articulate scientifically accepted conceptions of global warming. In a qualitative study of students in three Midwestern secondary schools, Shepardson et al. [51] found that students confused the concepts of greenhouse gas effect and its impact on global warming. Similarly, eleventh graders in southeastern Greece, after completing a closed-form questionnaire, were found to hold a narrow understanding of both greenhouse gases and the causes of global warming [52]. Turkish secondary students expressed similar misconceptions [53]. Overall, few secondary students, regardless of nationality, are able to differentiate between

global warming, greenhouse effect, and climate change, nor are they often able to link them together in a coherent explanation. Fundamentally, secondary students' understandings of global warming and climate change are simplistic, limited in scope, and lack rich conceptualization [51]. Even graduate students at two elite universities in the United States and a majority of adults surveyed for a public understanding of global warming were unable to effectively conceptualize a working definition [54].

In addition to extending research on students' understandings and opinions of global warming, the researchers in this study selected global warming as the content knowledge area for student readings because the field of personal epistemology research assumes that the epistemic understanding of a person is discipline-specific and, therefore, should be assessed within a specific content knowledge area [55]. Depending on their beliefs about knowledge, students will bring different critical thinking skills to a task, but at the same time, it is important to recognize that an individual's personal epistemology is not fixed and may vary significantly in the context of different knowledge domains and social situations [27,33,34]. Contextuality can likewise affect what epistemic approach is most useful [56]; as Sinatra and colleagues [2] note, "although it might be useful and sophisticated to believe in the tentative nature of science and the evolving nature of knowledge, it is also useful to know which aspects of science are grounded in a substantial body of evidence," offering climate change as one such example (p. 127). Such considerations make global warming an ideal topic for studying students' epistemologies of science [7]. Hence, the topic was conducive to developing an ill-structured reading task that would trigger demonstrations of personal epistemology and give students a context in which to apply more advanced epistemic understandings of SSIs [41,57–59].

## 2. Materials and Methods

### 2.1. Setting and Participants

Participants in this study were students from a public high school with an enrollment of approximately 700 in a rural area of Northwest Ohio in the United States of America. The participants were 11th and 12th grade students from lower to middle socioeconomic backgrounds [60]. Participants ranged in age from 16–19 years old, with a mean age of 17.75 years (SD = 0.72). Eight (67%) of the twelve participants identified as male and four (33%) as female. The study used a convenience sampling strategy, selecting participants from a population of junior and senior social studies students who were available during their study hall period. To be included, students had to provide their assent to participate in the study (which meant missing their study hall period), as well as documentation of parental consent. The selection of twelve students allowed for in-depth, microgenetic analysis of think alouds and interviews [61]. The study was reviewed and approved via an expedited review process by the Institutional Review Board; the collection of participants' political affiliation was not permitted because the majority of high school students were minors, and the data were collected within their school context.

### 2.2. Materials and Procedures

The purpose of this exploratory qualitative research design was to examine the understandings, opinions, and sources of knowledge high school students hold about global warming. These data were gathered with the overall goal of identifying similarities and differences within and among these constructs and to assess students' abilities to take meaning from news articles on an SSI. Interviews and close-reading tasks were used to gain a qualitative, microgenetic understanding of high school students' grasp of global warming and beliefs about the sources and certainty of global warming knowledge during a reading task. The microgenetic method is defined as an intensive collection of data over a period of time "to generate a very rich picture of moment-to-moment learning processes" [62] (p. 439). Although the microgenetic method is typically utilized for more extended time periods, it was used in this study to explore the fine-grained changes of students' mental models on a moment-by-moment basis before, during, and after the

reading task. As small-scale, internalized representations of an external reality, mental models help researchers and educators understand individuals' conceptions of particular knowledge domains, such as math or science, and can be useful in uncovering inaccurate, idiosyncratic, and inconsistent beliefs [63]. The materials used in this study were six news clippings that offered different perspectives on the topic of global warming. The reading activity of six conflicting news clippings was designed to challenge students to employ an epistemic understanding of global warming at a cognitively demanding level rather than eliciting lower levels of epistemic understanding that might suffice for less complex tasks [24,57]. Excerpts were taken from three national newspapers and modified for the activity. To minimize potential bias, the newspaper names were replaced with the generic name Daily News and the reporters' full names were initialized to control for reporter preference and gender bias. Each article was shortened by cutting material from the end to ensure an approximate reading time of two minutes and to match the eighth-grade reading level that is standard for U.S. newspapers, while still maintaining the original content and structure of the article, including its supporting graphs, charts, and/or pictures. News clippings could not be republished due to copyright issues.

The data collection process consisted of semi-structured thirty-minute interviews with the participants followed by an analytical close-reading task. The reading activity was not intended to function as an intervention to promote conceptual change but, rather, as an opportunity to examine moment-to-moment changes in participants' thinking as they engaged with multiple news articles on a complex socioscientific topic. The method of semi-structured interviews combines a structured interview protocol of fixed questions with the freedom to ask additional ad hoc questions to ensure a necessary depth and clarity of participants' responses [62]. Interview questions, provided in Appendix A, were created to answer the research questions concerning understandings and opinions of global warming, as well as knowledge certainty and source. Interviews were conducted in one-on-one sessions with participants. Sessions were recorded using web cameras focused on the participants' hands to capture the processes of the highlighting task and to capture the audio from the interviews.

Interviews were followed by a close reading and highlighting activity. At the beginning of the activity, each participant received an envelope with a randomized set of news clippings. While participants completed the highlighting task, they were asked to provide think-alouds of the thought processes behind their actions. In general, the method of thinking aloud permits researchers to study the cognitive processes a person is using during activities such as problem solving, reading, and other reasoning tasks; accordingly, the transcripts of think-alouds permit insights into the immediate cognitive criteria and steps a person attends to when accomplishing the actual activity in that moment [64]. The hands-on reading activity required participants to read (Task 1) and analyze six news clippings on the topic of global warming by highlighting text within them (Task 2).

In the highlighting task, participants were asked to differentiate between sections in the news clippings with which they agreed or disagreed, as well as those they perceived as better ways of thinking about global warming. "Better ways of thinking" were defined as additional pieces of information that added to rather than simply reinforced or agreed with the participant's previous explanation. While participants performed this task, they were prompted to provide think-alouds to explain their behavior.

### 2.3. Data Analysis

Following data collection, files were digitized in the form of transcripts and scans, in which personal identifiers were removed. The interviews were recorded, transcribed, and analyzed following Mayring's Qualitative Content Analysis [65,66] method using a combination of inductive and deductive coding schemes. In Mayring's version of QCA, coding occurrences are reported numerically; thus, this method of analysis allows for the quantification of explorative data in order to indicate the relative weight and meaning of coding results and code density [66,67].

Using the software Atlas.ti, two researchers coded the complete data set together, and using an iterative process, developed a comprehensive coding scheme. After all of the data were coded, 40% of the transcripts in Atlas.ti were then re-coded by an additional researcher with expertise in qualitative content analysis. The degree of interrater reliability was 96%, and differences in coding agreement were resolved by consensus. Codes are described and defined in Table 1, which also includes number of occurrences for each code. In the results section, codes are identified using italic fonts, and code occurrence among participants is noted with “*n*”.

**Table 1.** Global warming understandings and opinions with coding schemes.

	Understanding of Issue				Opinion on Issue			Understanding vs. Opinion									
	Effects of Global Warming		Cause of Global Warming		Truth of Scientific Consensus	Rationales for Rejection	Degree of Seriousness	Degree of Consistency									
	Heating of the earth	Melting of the arctic ice	Rising of water levels	Interrupting of water and air cycles	Man-made: Pollution	Man-made: Greenhouse gases	Man-made: Holes in ozone	Natural warming trend	Man-made problem	Natural warming trend	Politicians	Capitalists	Scientists	Degree of Seriousness	A: Opinions align with man-made and natural trend understanding.	B: Opinions align with natural trend understanding.	C: Opinions refute earlier statement.
P1	X				X!	X!	X	Not true !	True	X			Hoax/Joke				X!
P2	X	X				X!	X	Not true !	True					-			X!
P3	X						X	Not true	True	X				Hoax/Joke		X	
P4	X						X	Not true	True		X			Hoax/Joke		X	
P5	X	X	X	X	X	X		True	True					Serious	X		
P6	X	X	X	X	X			True	-					Serious	X		
P7	X	X	X	X	X		X	True	True					Serious	X		
P8	X	X				X		True	True	X	X			Blown out of proportion	X		
P9		X						-	-					Serious	-		
P10	X				X	X		True	-					Blown out of proportion	X		
P11	X						X	Not true	True					Serious		X	
P12	X	X	X				X	Not true	True					Blown out of proportion		X	

Legend: ! = This aspect of the understanding was later refuted by the participant’s opinion.

### 3. Results

This section presents the findings from the research questions in the order the questions were posed to the students before, during, and after their close-reading analysis of news articles. The first two subsections present participants’ understandings and opinions of global warming prior to the reading task. This is followed by participants’ epistemic understandings of knowledge sources and certainty prior to the reading task. The next

section details the results of the analytical close-reading task in which participants were asked to find areas of news articles that agreed with their own opinions, rebutted them, or expressed better ways of thinking about global warming. The results conclude by reporting how students' epistemic understandings changed after the reading activity and by summarizing changes and inconsistencies between understandings and opinions uncovered throughout the interview process.

### 3.1. Understandings of and Opinions about Global Warming

#### 3.1.1. Understandings of the Concept of Global Warming

All participants were able to articulate an understanding of the scientific concept of global warming. The understanding encompassed different causes and effects of what constitutes global warming with varying degrees of elaboration and complexity. The majority of students began their responses by focusing on the effects of global warming and later addressing causes of global warming. Eleven students initially offered generic understandings of global warming by rewording the term as the Heating of the earth and then provided more specific effects that were coded as the Melting of the arctic ice ( $n = 7$ ), the Raising of the water levels ( $n = 3$ ), and the Interruptions of the air and water cycles ( $n = 3$ ). Some participants combined these different effects in their responses. Subsequently, participants also explained different causes that contribute to global warming and referred to them as Man-made causes and Natural warming trends. Participants differentiated man-made causes as Pollution ( $n = 5$ ), Greenhouse gases ( $n = 3$ ), and Holes in the ozone layers ( $n = 3$ ), while the cause of Natural warming trends ( $n = 7$ ) was not further differentiated. Some participants combined different causes within their global warming understandings. When the researchers compared participants' understandings with their opinions, some p ( $n = 2$ ) contradicted themselves explicitly by refuting the man-made explanation they provided minutes earlier. Table 1 provides a synopsis of the different codes.

#### 3.1.2. Opinions on the Concept of Global Warming

When participants were explicitly asked to express their opinions about global warming, they had permission to express their own perspectives in a way that may differ from the scientific concept they were expected to learn and repeat in school. While participants' opinions on global warming aligned with their previously provided understandings that temperature change as the defining characteristic of the phenomenon, they differed notably in their explanations of the causes and truth value of these changes. With respect to a man-made causation, five participants believed this explanation to be True, six believed it to be Not true, and one had no opinion on global warming other than "it's bad" (P9). With respect to a natural warming trend, nine participants believed this explanation to be true and three did not comment on this cause in their response (see Table 1).

The interviews of participants who disagreed with the man-made explanations demonstrated an interesting pattern: Some participants ( $n = 4$ ) started with a complete rejection of the existence of global warming as a problem but would subsequently provide a differentiated explanation specifying that they disagreed with the man-made explanation (Not true) and considered the natural warming trend as a valid explanation (True). The following interview excerpt demonstrates this identified reasoning pattern (underlined) and includes the codes (italicized) for his understanding of and opinion about global warming.

Interviewer (I): How would you explain the concept of global warming?

Participant (P): It's we're causing pollutions to heat up the earth [Heating of earth], and it's causing a hole in the ozone layer [Holes in ozone layer].

I: All right.

P: It's supposed to melt the polar icecaps [Melting of arctic ice] and then alter the temperature of the earth [Heating of earth]. [Man-made explanation]

I: All right. And what's your opinion on global warming?

P: I really don't believe in it. [Initial, rejection of global warming] I think it's just a cycle the earth takes every so many years. [Subsequent specification: Natural explanation: True; Man-made explanation: Not true] It's going to happen, oh well. (P2)

This reasoning pattern of first rejecting global warming overall but then following up with a more differentiated explanation was identified in four other participants (P1, P3, P4).

### 3.1.3. Reasons for Rejecting the Man-Made Explanation

Six participants rejected the explanation of human activity as a cause of global warming. While two participants did not elaborate on their reasoning, four expressed thoughts that this explanation was biased and driven by different people who had a financial and/or political interests in promoting the man-made explanation. Two participants believed that scientists promoted research in favor of the man-made explanation based on scientific and financial self-interest. One participant stated that scientists "started researching [global warming] and realizing that maybe this isn't actually happening . . . . They didn't want to like say anything because they were getting money for it...and their jobs all depended on it pretty much" (P4). Another participant implied that researchers are biased because "probably studies by universities...are funded by like companies that try to make green products that kind of stuff, so they can say this is happening and promote their product" (P8).

Two participants offered the opinion that Capitalists focused on the promotion of the man-made explanation for financial benefit and not for its truth value. One participant explained "I think it's a joke. I think it's the earth naturally warming and cooling itself, and people are just trying to make money from it by scaring people" (P3). Similarly, another participant mentioned the misuse of research to market green products for financial interest. Finally, one participant opined that Politicians invented the man-made explanation for fundraising and campaigning. He stated "I don't think it's real . . . . I think it was made up to make money for campaigns . . . . Political people use it." He concluded later "Yeah, politicians, I don't really trust them. [Laughter]... Well, they finally found something that they can promote and make money off of, and they are taking advantage of it" (P1). The theme of financial interest was identified across all three subcodes as it was assigned to scientists, capitalists, and politicians alike. These opinions on scientists, capitalists, and politicians resurfaced in later responses to subsequent interview questions that asked about the source and certainty of global warming knowledge.

### 3.1.4. Perceived Seriousness of Global Warming

The majority of the participants ( $n = 11$ ) did not hesitate to express their opinions about the importance of global warming as a socioscientific problem. Three levels of degrees were identified ranging from Serious to Blown out of proportion to Hoax/Joke. Five participants had Serious concerns about global warming as an advanced problem that required some level of societal attention to be addressed. One such participant discussed the "need to take care of the earth" and "take into consideration generations from us" (P11). This level of seriousness was most often expressed by participants who agreed with the man-made explanation of global warming and, thus, hoped to reduce the human impact on global warming. In contrast, three participants held opinions that the problem of global warming existed, but its seriousness was Blown out of proportion. Participant responses ranged from simply stating "I think it's happening, but it's blown out of proportion" (P8) to more elaborate explanations, such as "I don't think that it's really a big deal cause we've been doing it for so many years, and I don't think that we should really have to change much because it's not really harming many people" (P11). Finally, three participants believed that man-made explanation was a Hoax or Joke and that it was either invented or based on false evidence. Participants concluded "I think it was made up to make money for campaigns" (P1), "I think it's a joke" (P3), and "I think that it's like a hoax pretty much" (P4). These participants attributed global warming to a natural warming trend and expressed little concern toward its significance as a societal problem.

### 3.2. Epistemic Understandings Prior to the Reading Task

#### 3.2.1. Sources of Global Warming Knowledge

In the framework, source of knowledge was defined as one aspect of the epistemic understanding that a person holds about the processes of knowing. When asked where knowledge about global warming comes from, participants named a variety of different knowledge sources: Scientists ( $n = 9$ ), News media ( $n = 7$ ), Politicians ( $n = 2$ ), and People ( $n = 3$ ). Participants named an average of about two sources, indicating an epistemic understanding that global warming knowledge originates from multiple sources. All participants perceived these sources as external; that is, knowledge about global warming resided outside of the participant in the external world. However, one participant (P1) discussed that Politicians were fabricating knowledge about global warming and, therefore, indicated that knowledge could be a human construct and, thus, could come from an internal source.

#### 3.2.2. Certainty of Knowledge about Global Warming

Certainty of knowledge was defined as one aspect of the epistemic understanding that a person holds about the nature of knowledge. It was conceptually divided into two aspects: the certainty of knowledge in the here and now (i.e., the certainty of knowledge pertaining to what is known at this moment and in this context) and certainty of knowledge from a future time perspective (i.e., a point in time when more knowledge may be available).

All students stated that knowledge about global warming changes in the here and now and indicated an understanding that the nature of knowledge is uncertain. They explained that this uncertainty was caused by Quantitative changes and Qualitative changes in the body of knowledge within the scientific and public arena. On one hand, participants ( $n = 9$ ) who believed in Quantitative changes described knowledge as a constantly increasing and accumulating body of information about global warming. They explained that scientists did not know much about the concept of global warming at the beginning but gained more and more insight about it and its causes. One participant explained that as “[scientists] continue to study stuff, I think they find different things . . . [and] more and more information about it” (P8). Within the public arena, participants believed that the amount of knowledge changes based on individuals’ increasing knowledge of global warming over time. Participants stated, for example, “I think we’re learning more about it. So, it’s going to change a little bit with everything we’re learning” (P12) and “I think that knowledge about a lot of things changes. I think people learn more, new information about it” (P4).

On the other hand, participants who believed in Qualitative changes of knowledge ( $n = 5$ ) described the nature of a body of knowledge as being revised over time and, thereby, changing the content of the existing body of knowledge about global warming. Within the scientific arena, participants described the uncertainty of global warming based on changes in how the scientific concept was entitled, explained, and viewed by scientists. One participant simply stated that “the world’s changing and the scientists’ viewpoints all change” (P6). Another participant elaborated on how title changes represent qualitative changes in what is known about the concept of global warming, giving the example that “first there was global warming, then they [scientists] changed it to global cooling, now it’s global climate change” (P2). Within the public arena, participants ( $n = 2$ ) also described qualitative changes in how people understood and responded to global warming. One participant explained, for example, “because before, like, global warming was just global warming—like now the big thing is they’re talking about going green to help with global warming and help keep the air clean and pollution going down” (P10).

When asked whether everything about global warming could be known at a future point in time, one participant ( $n = 1$ ) thought such knowledge could be known with certainty. This participant thought that certainty would be achieved “in the future when we can actually see a correlation [between man-made and natural explanations]. Currently, no; it’s just—it’s like guessing what the weather’s going to be” (P7). The vast majority of participants ( $n = 11$ ), however, responded that no one could ever know everything

about global warming with certainty due to the amount of Unknown knowledge and Unstable knowledge. On one hand, four participants believed that knowledge about global warming is Unknown and cannot be known in the future with certainty. Participants often referred to examples, such as the human brain and the oceans, to illustrate (a) how little the scope of knowledge is in comparison to what is unknown and (b) how much time it takes to get to know new information. One participant explained how the scope of knowledge contributes to its uncertain nature by referencing the vastness of entities such as the oceans and outer space: “They say it’s forever long, and they say they know more about the—more about outer space than they do about the ocean. I find that hard to believe. But like it’s just everything is so vast, you can’t cover everything.” On the other hand, six participants believed that knowledge about global warming is Unstable and would be changing because the phenomenon itself was subject to constant change. Rationales for its changing nature ranged from simple statements such as “there’s always some factor that is unpredictable” (P11), to more cause-and-effect explanations such as “if something big happens, that’s going to change our knowledge about it, because we’re going to find out more why that happened and what we can do to prevent it again” (P6). One participant offered an anthropomorphic understanding of global warming as having a life of its own: “it’d be kind of hard to know everything about one thing, especially global warming, when global warming could be doing anything it wants to do. And it would be kind of hard to predict that kind of stuff and know [it].” (P9).

Finally, the three participants who believed that global warming was a Hoax or Joke reiterated their doubts about the existence of global warming under this future oriented question, again. While they had stated uncertain understandings about the here and now, here, they pointed out that researchers might discover at a future point in time that global warming did not exist (or at least it is man-made cause). Two participants stated that one would not be able to know everything about global warming with certainty at a future point in time “unless they [scientists] like figure out that it doesn’t actually exist” (P4) and “if they [scientists] found out that there’s no such thing” (P1). The third participant added that future uncertainty about the topic was also driven by fear in the scientific and public arena that global warming “is true and they don’t want the world to end” (P3).

### 3.3. Reading Task: Identifying Explanations, Rebuttals, and Better Ways of Thinking

After giving their explanations of global warming, participants were asked to read six articles on global warming and, in steps, to verbally explain and highlight statements in the news clippings that: (1) agreed with their own explanation of global warming; (2) disagreed with their own explanation; and, (3) they considered better ways of thinking about global warming. The better ways of thinking were more than simply a restatement or reiteration of their previously green highlighted explanation.

The analysis demonstrated that ten participants were able to identify statements they agreed with and eight participants were able to identify statements they disagreed with. For example, one participant (P6) agreed with and highlighted a statement in an article that discussed how a Chinese farmer was planting and selling sand willows as an alternative fuel to produce electricity, which produces fewer greenhouse gases than other energy sources such as coal. In support of his green underlined opinion, participant P6 stated, “This farmer, even though he didn’t know that it was going—he was going green. He was still helping the environment, and him helping the environment kind of reflects upon me because that’s what I’m trying to do” (P6).

Three students highlighted statements and verbalized better ways of thinking about global warming. Two participants focused on aspects of uncertainty and explained that not enough is yet known about global warming. For example, one participant stated that “They [scientists] should do a couple of more studies on it before they like...came out and told everyone about global warming and got a bunch of people kind of afraid . . . . We really don’t know. We don’t have enough information yet” (P1). The third participant was more concerned about the health of the environment. She summed up that “Some of the

[articles] that are more focused on keeping the environment cleaner” provide a better way of thinking about global warming as a global issue (P4).

Essentially, the number of students who highlighted statements based on agreement ( $n = 10$ ) was greater than the number of students who highlighted based on either disagreement ( $n = 8$ ) or a better way of thinking ( $n = 2$ ). Additionally, the number of statements highlighted based on agreement was considerably more ( $n = 32$ ) than either disagreement ( $n = 12$ ) or better ways of thinking ( $n = 2$ ). This density distribution of codes indicated that participants were more likely or able to identify statements they agreed with than statements they disagreed with, despite different viewpoints on global warming being addressed within the text of the news clippings

### 3.4. Epistemic Understandings Post-Reading Task

Few participants changed their epistemic understanding of knowledge sources by adding on more sources to their initial list from before the reading activity. Because participants did not “replace” knowledge sources, both lists were compiled to get their full understanding of knowledge sources after the reading activity. The compiled list was used to assess the source aspect of participants’ epistemic understanding of global warming.

When asked a second time about knowledge source for global warming, three participants ( $n = 3$ ) mentioned new sources of knowledge while the remaining participants explained that they didn’t change their understanding of knowledge sources. Hence, changes in the source of knowledge were considered quantitative additions of new sources rather than qualitative replacements of sources. P2 added sources that were coded as People and News media and P9 added Government. P10 mentioned Knowledge Sources in China which referred to a news text in the reading activity that reported on a Chinese strategy to produce green energy. A fourth participant, P3, explained that news media should not be counted as a knowledge source as it cannot be trusted in reporting scientific evidence. This exclusion aligned with the participant’s earlier point of view about the lack of the news media to produce credible reports about global warming and, thereby, increased her list of invalid sources: “Not friend” and “Not news media.” In summation, after working through the reading activity, one of the participants (P2) added News media as knowledge source, while a second participant (P3) explicitly stressed its exclusion.

None of the twelve participants changed their epistemic understanding about the certainty of knowledge in the here and now. However, two participants stated that their epistemic understanding about certainty of knowledge from a future perspective differed after the reading activity. P7 changed from certain to uncertain because “there will never be a point where we can know everything about the weather . . . just like with global warming. It’s nature.” P9 changed from uncertain to certain “cause people keep on studying global warming, they’re going to find out stuff—more stuff about it.”

### 3.5. Changes and Inconsistencies

After the analytical close reading, two students elaborated on their opinions of global warming. P9, who previously offered no opinion on the truth of global warming yet considered global warming to be a serious problem, seemed to be more hopeful after reading the news texts: “It is still bad, but people are finding ways to help fight against it.” This addition did not conflict with his point of view he initially expressed about global warming. P1 expressed a feeling of “guilt, we don’t do enough.” His second opinion aligned with his initial understanding of pollution and natural warming trends causing global warming; however, it contradicted his first explanation in which he vigorously claimed that global warming is not a man-made phenomenon. Throughout the interview process, P1 explained global warming using both man-made and natural warming trend explanations (initial conception), then he refuted the man-made aspect of the causal explanation as false and invented by politicians (first solicitation of explanation), and, after the reading activity, supported the man-made explanation again (second solicitation of explanation) by stating that society should take more measures to prevent global warming.

Finally, when comparing and contrasting the understandings and opinions that participants expressed during the interview sequence, three different groups of participants could be identified (Figure 1). These groups emerged due to their differing level of consistency of understandings and opinions concerning global warming. Two groups (A, B) were consistent in their concept of global warming and explanations of it while the third group (C) explicitly rejected aspects of their understandings as false when voicing their opinions.

	Man-made problem	Natural warming trend
<b>Group A</b>		
Understanding	True	True
Opinion	True	True
<b>Group B</b>		
Understanding		True
Opinion	Not true	True
<b>Group C</b>		
Understanding	True	True
Opinion	Not true	True

**Figure 1.** Groupings based on understandings of and opinions on global warming causes.

Participants in Group A ( $n = 5$ ) were consistent in their understandings and opinions; they concurred with the man-made explanation (True) and/or natural warming trend explanation (True). Because they agreed with the explanations, there was no internal conflict or contradiction in their mental model about global warming. Participants in Group B ( $n = 4$ ) were also consistent in their mental models. They believed in the natural warming trend (True) which was expressed in both their understandings and opinions. However, they differed from Group A, because they rejected the man-made cause (Not true) in their explanations. This was not perceived as an internal conflict or contradiction because they did not mention the man-made explanation as part of their understanding in the first place.

Participants in Group C ( $n = 2$ ) differed from Groups A and B because they were not consistent in across their understandings and opinions of global warming. They first agreed with the man-made explanation (True) alongside the natural warming trend explanation (True), but refuted the man-made explanation (Not true) in their explanation, leaving the natural warming trend (True) as the only valid explanation for global warming in the end. Based on this explicit inconsistency, it seems that the two participants had been willing to censor the disbelief they later expressed in their opinions when they initially referenced human activity as a component of global warming in their conceptions. Based on this explicit inconsistency (depicted by the 'not equal' sign in Figure 1), it appears that the two participants censored the disbelief they later expressed in their opinions when they initially referenced human activity as a component of global warming.

### 3.6. Summary

The high school students in this study could articulate a working definition of global warming and understood knowledge about global warming to be complex rather than a series of isolated events. From the beginning of the interview students' allusions to the interplay between humans, social movements, and the media demonstrated their understanding of global warming as a socioscientific concept by connecting science, social, political, economic, and technological dimensions of knowledge. For a majority of the participants, this contextuality seemed to add to or, at the very least, not interfere with their abilities to express consistent explanations of global warming; however, for four students,

particular socioscientific elements planted seeds of distrust that they expressed in their personal opinions.

While participants routinely discussed global warming in a socioscientific context, four participants verbalized issues that indicated doubt or uncertainty about the topic that stemmed from socioscientific elements of the problem. Two participants believed the science about global warming but expressed concern about the reliability of the news media to portray the scientific information reliably. Three of these participants either believed that the man-made explanation for global warming was a hoax or a joke. P1, for instance, believed that the man-made explanation of global warming was invented by politicians to make money for their campaigns, and throughout the interview he referred to politicians as people who cannot be trusted in what they say about global warming. With respect to the thinning of the ozone layers, he expressed epistemic doubts about the certainty of knowledge:

I don't know. I think that—I think that—I mean, maybe the ozone layer is getting thinner. It could happen. I don't know. How do you measure it? How do you know what it was? I don't know. It's a hard, fine line on who's right and who's wrong, I guess. (P1)

When addressing the difficulty of finding reliable knowledge sources and accurately justifying knowledge about global warming, P1 seemed to find the prospect overwhelming, stating three times that he simply didn't know. While the information P1 provided alludes to a distrust of knowledge sources (politicians), it also points to a lack of understanding or unwillingness to engage with the complexities of NOS.

Similarly, P3 believed that the man-made explanation of global warming was a hoax, describing it as “just a little crock . . . ” which was followed by laughter. This participant also expressed distrust toward institutions, specifically toward the news media and those whom she believed try to make money off of global warming concerns by selling green products to the citizens. While this participant referred to the news media as a major influence on what people “believe is right and wrong,” she specifically excluded it as a knowledge source in her own decision-making. In all, her statements indicated a belief that the media had mislead or manipulated others on the topic of global warming while she had discerned the hoax. Despite their understandings of global warming as a socioscientific problem, these participants expressed epistemic doubt about the nature of knowledge, knowledge sources, and processes of knowing.

As a whole, the data demonstrated that while most participants could articulate an appropriate scientific understanding of global warming, epistemological aspects, such as knowledge source and certainty, influenced the personal opinions of some participants and the seriousness with which they regarded the problem of global warming. Additionally, while students articulated epistemic understandings of knowledge as complex and constructed on an abstract level, they had more difficulty applying these understandings to the real-life topic of global warming.

#### 4. Discussion

In this exploratory qualitative study, we explored the understandings, opinions, and epistemological understandings rural U.S. high school students have about global warming to find out what high schoolers know, what they think, and how they know what they know about the topic [28,31]. Unlike other current research [50–52], the results showed that students in this study could state a working understanding of global warming that mirrored current scientific definitions. Further, they tethered their understandings to politics, economic, and environmental concerns, which indicated an awareness of global warming as a socioscientific issue; however, a subset of students displayed a disconnect between their professed scientific understandings and their personal opinions in which they seemed to reveal their true thoughts on the topic. In some cases, this resulted in contradictory explanations, while for other participants their opinions merely differed from their academic understandings. We will discuss these findings in terms of the impact the socioscientific context exerted on students' abilities to make meaning, how their personal

epistemologies and understandings of the nature of science intersected on the issue, and how efforts to teach socioscientific news literacy can promote the informal reasoning skills necessary for both media and scientific literacy.

#### 4.1. *Global Warming as a Socioscientific Problem*

For most participants, their responses throughout the interview process seemed to form coherent understandings of global warming. Based on their explanations, students in our study had knowledge of global warming as a complex environmental event influenced by and linked to other complex events, including air pollution, air and water cycle interruptions, political and economic incentives. Responses, such as those alluding to “unstabilized gases in the air because of human impact” and how “going green” could help alleviate the problem, demonstrated that the high schoolers in this study understood global warming to be a socioscientific issue.

Even the students who labeled global warming a hoax were able to provide textbook descriptions of global warming and companionate complex events. This contrasts with research that found that the public’s conceptual understanding of global warming and linked events to be imprecise [50,51,54]. However, based on the sometimes-contradictory personal opinions students articulated and the justifications given to support them, it is probable that the understandings that these particular students professed were reiterations of classroom materials [11] rather than deeply held scientific conceptions connected to their everyday lives. In fact, after linking pollution and air current patterns to produce scientifically accepted explanations of global warming, it was surprising for a subset of students to state that, in their opinion, global warming was “not true,” “a hoax,” or “not a big deal.” Even the remaining students who believed the scientific consensus on global warming to be true qualified their concern with statements such as “I mean, nothing is going to happen in our lifetime . . . ” In many cases, these high school students seemed to isolate school-based knowledge of science from their everyday decision-making [11,15]. Though they understood the content, they did not necessarily draw upon it when forming their opinions or relating it to their lives.

Additionally, contradictions in reasoning patterns indicated these same students had difficulty integrating information into a meaningful, working framework, perhaps due to the variety of perspectives presented across school, the media, and political discourse. Coupled with students’ formal, school-based curriculum, this onslaught of information was shown to interfere with some students’ abilities to form reasoned opinions or to consider personal engagement with the issue. Adding to potential confusion, some students expressed a sense of distrust toward institutions that distribute news of global warming, such as the government (politicians), the media, and scientists. Essentially, the “socio” aspects of global warming seemed to override the “scientific” in some cases as students described global warming as an issue up for bid in the public sphere. This subset of students, despite being able to articulate an accurate understanding of global warming, demonstrated personal opinions that drew more on public discourse than on academic or scientific discourse.

Not only did students demonstrate a distrust of the media, science, and politics—when students’ school-based definitions of global warming sharply contrast with their own personal perspectives, it is evident that they view what they learn in school with some skepticism as well. This duality is demonstrated in the disconnect between students’ textbook articulations of global warming and their opinions that it is a hoax or not anything serious; thus, in these cases, it seemed less an issue that these participants failed to understand the science and more that they did not believe the science they had been taught. These patterns mirror an overall shift toward distrust in the United States with reports of unprecedented declines in citizens’ trust in the media, government, and businesses [68]—the very institutions deemed untrustworthy by the students who considered global warming a hoax. These similarities suggest that public discourse on SSIs played a significant role in students’ personal opinions, particularly when students do not view other sources of

knowledge as trustworthy. For instance, some participants' prior knowledge from public discourse steered them toward the belief that global was invented by politicians [69]. This dichotomy between some participants' academic understandings versus their true opinions draws to mind Lederman and colleagues' [26] advice that science curriculum must take into account "the value judgments, beliefs, perceptions and experiences" that students bring to the process of understanding scientific knowledge (p. 145).

From an epistemological standpoint, one explanation for this disconnect between students' school-based understandings and their personal opinions could be because students at this age are immersed in a "poisoned well of doubt" [70]. As what Kuhn [71] would label multiplists, for these participants knowledge need not be reasoned, weighed, warranted, and justified because it is merely personal opinion and everyone is equally right. The discovery that experts disagree only substantiates this subjective aspect of knowing [36,47]. If students are only exposed to the scientifically accepted explanation of global warming in their classrooms, they may excel at memorizing it for a test, but how well are they equipped to reconcile that knowledge amidst the debates they encounter outside of the classroom? Without an understanding of the constructivist nature of science knowledge [7,24,28], news media literacy, or a developed epistemology of science [7] students see disagreement between experts as a signal that the science information and knowledge itself is untrustworthy or unattainable [29].

Another factor contributing to students' difficulties make meaning of a complex issue may be that all participants attributed their sources of knowledge to external delivery systems. For instance, one participant noted that her knowledge of global warming came "from scientists that, like, study that kind of stuff. They give it to us, to the news and whatever, and we can find out about it." According to this explanation, knowledge is simply received without evaluation. In cases where sources were critiqued, such as with politicians, the media, and scientists, the critique most often led to uniform distrust of that source, such as distrusting all politicians or the news in general rather than addressing specific claims or issues. As the next section discusses, addressing the epistemic understandings and informal reasoning skills essential to NOS, students may be more well equipped to confront global warming as a justified knowledge claim that could include some aspects of uncertainty alongside tested knowledge of the phenomenon.

#### *4.2. Nature of Science and Epistemology in the Public Arena*

In addition to sowing a distrust of knowledge sources, the need for absolute certainty fostered a passivity in students' evaluations of knowledge. By indicating that certainty on global warming may be unattainable, for instance, P1 eliminated the need for his own active engagement in the knowledge construction process. Two other doubters of the scientific consensus asserted difficulties with the uncertainty of knowledge on the issue. While P4 believed in a natural warming explanation, she considered the man-made explanation a joke and did not trust scientists in their capacity to produce valid research on the topic She referred to an exchange between scientists that had been discussed in the public arena as a source of uncertainty: "Those [emails] between the scientists that were like all over the news . . . I don't think they said like it was a hoax, but like how their studies were like not showing like anything really." Though this participant understood the role of the media in sharing scientific information with the public, the uncertainty portrayed in this event undermined her trust in scientists and in the credibility of their scientific findings on global warming. Based on the event she described, she concluded that she doesn't know anymore what to believe about global warming. This uncertainty supports findings that students do not know how to think about disagreements between scientists and lack an epistemology of science [7,26].

In contrast, while P7 acknowledged both the man-made and natural explanations of global warming and perceived it as a real and serious problem, he articulated the dilemma that science, at this point in time, was not able to identify if there were correlations between both explanations. However, unlike other participants, he trusted in the capacity of

scientists to produce credible results and argued that more time is needed to learn more about the causes for global warming from a long-term perspective. While P7 viewed knowledge as constructed by the scientific community, he later stated that he did not know what to believe about global warming due to the unreliability of the news media. He explained that he did not view the news media as a knowledge source because global warming was covered as a divisive sociopolitical issue rather than a scientific phenomenon, noting that on the news, reporters talk about “right and wrong, not the actual facts of like the currents and like what stuff is . . . It’s just about opinions in the news. So, I don’t know” (P7).

In this way, though P7 articulated what could be called a sophisticated epistemic understanding of scientific knowledge construction, he seemed confounded by issues of uncertainty concerning the media’s presentation of information. Such difficulties point to the necessity of emphasizing not only the ongoing pursuit of understanding in the scientific realm, but also teaching students about the presentation of this information in public discourse. Someone unfamiliar with the media norms of editorializing and presenting divisive issues with equal time for the two most oppositional camps [2] can easily become confused when two so-called experts on a topic disagree. Although students articulated epistemic understandings of knowledge as complex and tentative on an abstract level during interviews, the identified subset had difficulty applying this understanding to the real-life topic of global warming. This indicates a need for further in-class practice, including modeling of reading and critical thinking strategies, that could prepare students to evaluate the evidence behind competing claims [72]. If educators are to prepare students to transfer their school-based, scientific understanding of global warming to a “real life” context, they need to expose students to the contradictions and doubts they will encounter in the public sphere [12,25]. Such controversies can be framed in a context relevant to students if educators use local news to introduce SSIs to students, such as energy initiatives or other environmental debates [50,72].

#### *4.3. Implications: Scientific Knowledge Construction and Evaluation in Context*

While all of the students in this study believed knowledge about global warming was uncertain and ever changing, these students did not see themselves as participants in creating or constructing this knowledge. These results reinforce the call for science educators to engage students in scientific argumentation [31] and informal reasoning [42], particularly through the use of socioscientific news media [1,73]. The experience of generating and evaluating positions in response to the complex issues SSIs depicted in the news would provide students with practice and a framework by which evaluate claims, sources, and evidence and to tie explanation to a process of reasoning [42]. Scientific argumentation could refine and enhance students’ understanding of the constructivist, evaluative nature of scientific knowledge [7,9,29]. Research points to the value of an explicit reflective approach that involves consistently highlighting inherent aspects of NOS as students engage in scientific activities in the classroom [26]. From an epistemological perspective, informed reflexivity refers to the “disposition and capability to reason about one’s own knowledge-related actions (thinking and behaving) in a specific kind of context and for a specific epistemic aim” [16] (p. 286). In the context of science, this means students understand the process of knowledge construction and, thus, can make informed decisions. There are opportunities to introduce students to this mindset early in their educational process, particularly with an emphasis on how science connects to their lives and communities. This means that science should be introduced to young learners as a process of inquiry that demonstrates that science is a tool to answer authentic questions about phenomena in their lives, not merely a set of facts or series of steps in an experiment.

At older ages, students can be asked to explicitly engage with complex and contradictory socioscientific claims, evaluate explanations, and examine plausibility based on evidence and knowledge of the nature of science [74]. This would enable students to learn how to structure claims, justify evidence, evaluate sources, and critically evaluate

conflicting explanations. Feinstein [75] distinguishes between students who may become either “marginal insiders” or “competent outsiders” as a result of their scientific experiences; in one case, students may “do science” by performing experiments, recording results, and presenting their findings, resulting in marginal insiders who have gone through the motions and perhaps “mimed” science but not reflected on the purpose behind the process. Competent outsiders, in contrast, are taught to understand the knowledge construction process and find the relevance in scientific principles to their everyday lives and decisions, essentially, enacting informed reflexivity. In the context of issues such as global warming, students must be immersed in the public discourse surrounding the science. Current events present the perfect canvas for explorations of the epistemology of science. Because some students find doubt so confounding in their everyday understanding of global warming, confronting the sources of such doubt in climate change denial (versus the consensus in the scientific community) could prove very useful. Rather than opting out of complex socioscientific debates, with practice in argumentation, alongside the examination of science news media, students might feel more equipped to integrate science knowledge into the economic and sociopolitical policy decisions they will be making in their lives [50,72]. For example, Thinking Habitats [72], developed an online curriculum—The Front Porch Experience—that empowers high students with thinking tools to identify, analyze, and evaluate socio-scientific facts, opinions, and explanations about local issues reported in the news media of their own communities.

Finally, because the news is the greatest source of scientific information for adults [1], this study furthers calls to equip students with the skills to take their understanding of NOS into the public arena. SSIs are often presented through an ideological or value-laden perspective, and while students in this study often identified explanations with which they agreed in their readings, they demonstrated more limited abilities in identifying refutations of their own ideas. Interestingly, this pattern of noting points of agreement with one’s own ideology fits with what is known about confirmation bias and susceptibility to fake news [3,12,72]. Because socioscientific news is inherently loaded with political and social controversies, it is crucial that students are taught the epistemic virtue of setting aside biases so that they may draw on accurate information to make decisions [12,19,72]. Additionally, students would benefit from a foundational understanding of news terminology (such as editorials) and norms, such as the propensity for articles and broadcasts to present both sides with little to no commentary on the truth of claims. These very practices were shown to bewilder students in our study. Although the reading activity in the current study was not intended to function as an intervention to promote conceptual change, using news texts in the classroom can be helpful in activating critical evaluation of an explanation. Although refutational news texts are not widely used in scientific classrooms [24,76] studies have demonstrated how activities using refutation texts on the topic of global warming spurred students to critically evaluate the plausibility of explanations in a way that expository texts did not.

The call for teaching scientific news literacy is not novel, but methods of implementing it into already crowded curricula are less established [73]. Again, with class time at a premium, exploring where NGSS, Common Core Math, and English Language Arts (ELA) practices connect [77] can offer opportunities to use the news to not only to teach informal reasoning skills, but for students to see how these skills transfer across disciplines and into real-world issues. Appropriate curricular interventions can align with NGSS Standards, as well as those in social studies and ELA, and should provide modeling for students on how to apply informal reasoning skills to news articles, particularly in contexts that are relevant to students’ everyday lives, such as with local news [72]. Furthermore, projects that tie global concerns, such as those highlighted in UN Sustainable Development Goals, to issues in learners’ local communities can encourage young people to apply socioscientific reasoning to contexts that are meaningful and of consequence to them [72,78]. Such pedagogical approaches communicate to students that science is not merely a set of facts to be memorized but, rather, a set of tools that can help them understand the world

around them and address problems in their immediate environment. Concerns over global warming have spawned ethically driven economic policies and texts. Because underlying epistemic beliefs and understandings of NOS lay a foundation for engaging with these materials, it is also necessary to invest in teaching students how to evaluate what they know and how they know it when it comes to SSIs [15,28,35].

#### 4.4. Limitations and Further Research

This study's sample size of twelve rural Midwestern U.S. high school students limits the generalizability of our findings. Results for other countries and other areas of the United States would likely differ due to regional political sorting and localized sets of beliefs surrounding climate change and environmental policy [47,49]. Additionally, because we could not collect information on political affiliation from participants in our study, we cannot speak to the degree to which their responses were influenced by regional political discourse and ideology. However, with Climate Action as a United Nations Sustainable Development Goal [48], similar studies of different demographics around the world would offer interesting data for comparison.

Finally, because this study relied upon news articles, it is important to consider how these findings relate to students' engagement with other science news formats, from web-based news to stories shared via social media. Further research on the consumption of news shared over social media could be particularly illuminating in terms of exploring the ways in which public discourse and group identification may exacerbate disconnects between scientific understandings and personal opinions on SSIs [5].

## 5. Conclusions

The majority of students who pass through our schools may not go on to be scientists, but the science that they learn and their understandings of the nature of science will go on to affect their decision making long after they have left school. When a student's science education centers on a set body of facts, they may successfully navigate the educational system, but how well prepared will they be to navigate the complexities of public policies, elections, and healthcare choices? Their votes will decide water, energy, and clean air policies. To make sound decisions, they must understand these issues, not only because it is good for science but also because it is crucial for responsible citizenship and public policy.

When science is introduced as a process of inquiry and a way of building knowledge rather than a set of facts to be memorized or a rote series of steps, students develop, according to Dewey [79], epistemic understandings more suited to a world in which science does not "lie on the surface" but rather is "hidden and must be wrested from nature by an active and elaborate technique of inquiry" (p. 32). By practicing this process of inquiry and systematic evaluation in the context of science news media, students will further understand SSIs as complex phenomena that often intertwine with their local communities and daily lives. It is understandable to feel intimidated by this complexity, not to mention confused or disillusioned by the discord of ideologically based claims coming from a variety of media. Students living in this flexible information format require the ability to integrate and evaluate ideas from a variety of sources [6,80] as well as an understanding of the scientific process and informal reasoning skills. With experience in evaluating and critiquing explanations, students will have opportunities to develop the informal reasoning skills they will need to draw upon in situations where science intersects with their lives and they are called upon to make informed decisions. In advocating for the importance of education in preparing an informed citizenry, Dewey [81] noted that if educators were to "realize that the quality of mental process, not the production of correct answers, is the measure of educative growth, something hardly less than a revolution in teaching would be worked" (p. 207). In classrooms where students learn to engage with socioscientific news, evaluate explanations, engage in critical inquiry, and support arguments, this revolution is underway.

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## Appendix A

**Table A1.** Interview protocol.

Pre-reading activity questions
<ol style="list-style-type: none"> <li>1. What is your understanding of global warming. Please explain.</li> <li>2. What is your opinion of global warming. Please explain.</li> <li>3. Where do you think knowledge about global warming comes from? Please explain.</li> <li>4. Do you think knowledge about global warming changes? Please explain. If it changes, why does it change and how does it change?</li> <li>5. Do you think there will be a point when we know everything about global warming for sure? Please explain why and how?</li> </ol>
During-reading activity questions
<ol style="list-style-type: none"> <li>1. Please read these article clippings. They are about global warming. After you have read the clippings, I will ask you to sort them and to compare and to contrast them. [Reading time]. Pick two articles that are similar and one article that is different to the two similar articles. Explain your thinking behind your decision. [Repeat 3–4 times sorting the newspaper clippings differently].</li> <li>2. Did you change your explanation of global warming? Please explain.</li> <li>3. Is your opinion reflected in the article clippings? Please explain why? If yes, please highlight the sections in green.</li> <li>4. Are there sections in the article clippings with which you disagree? Please explain why. If yes, please highlight these sections in red.</li> <li>5. Do you think there is a better way of thinking about global warming? Please explain why? If there are sections in the text, please highlight them in blue.</li> </ol>
Post-reading activity questions
<ol style="list-style-type: none"> <li>1. After reading these news clippings, where do you think knowledge about global warming comes from? Please explain.</li> <li>2. After reading the news clipping, do you think knowledge about global warming changes? Please explain. If it changes, why does it change and how does it change?</li> <li>3. After reading these clippings, do you think there will be a point when we know everything about global warming? Please explain why and how.</li> </ol>

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