Climate Change Education, Learning Progressions, and Socioscientific Issues: A Literature Review

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Current literature emphasizes the need to teach about the climate change topic in a personally meaningful way. Not only can this approach motivate students to learn the science, but it also has the potential to encourage social activism with the purpose of ameliorating the situation (Cordero, Todd, & Abellera, 2008; Lester, Ma, Lee, & Lambert, 2006; Padretti, 1999). The socioscientific issues (SSI) initiative provides a framework for climate change education that is both personally and socially relevant.

Global climate change is a particularly challenging topic for students of all ages. Most students struggle to understand the topic because it involves complex systems (Svihla & Linn, 2009; Mohan, Chen, & Anderson, 2009). Additionally, many students have various misconceptions/alternative conceptions that hinder their abilities to understand this complexity. Learning progressions (LPs) provide a rich framework for understanding when and how students can learn about climate change at various levels (Mohan, Chen, & Anderson). Smith, Wiser, Anderson, Krajcik, and Coppola (2004) describe learning progressions pedagogy as where “big ideas can be understood in progressively more sophisticated ways as students gain in cognitive abilities and experiences with phenomena and representations” (p. 5).

Research on student conceptions of climate change also helps educators understand how students make sense of what they are learning. Together, the conceptual change and learning progressions areas of science education research inform instruction that will help students comprehend the complexities of climate change (an important socioscientific issue).

Review of Relevant Research

A deep understanding of carbon cycling is essential for developing an adequate conception of climate change (Shepardson, Niyogi, Choi, & Charusombat, 2009). Mohan, Chen, and Anderson (2009) used design-based research to develop a learning progression for understanding the carbon cycle beginning with upper elementary students and ending with high school students. The learning progression starts with a Lower Anchor (representing the understanding of a typical fourth grade school student) and ends with an Upper Anchor (representing the standards that society would want a high school student to meet upon graduation). The researchers stated, “Students at the Lower Anchor reason using models that invoke notions of natural tendency and vitalism. At the Upper Anchor, however, there is a focus on chemical processes that connect systems (generation, transformation, and oxidation of organic carbon)” (p. 684). Unfortunately, few students in the study were found to have reached the deep chemical understandings embodied by the Upper Anchor, which the authors argued was necessary to understand arguments and counterarguments about climate change. Rather, the more advanced high school students were mostly labeled level three, which the researchers characterized with the following statement: “students’ limited knowledge of chemical principles and of substances involved in processes prevented them from effectively applying atomic-molecular models" (p. 689). This statement prompts the question of how much chemistry does a learner need to know to understand climate change sufficiently? Related questions are when and how should chemical concepts be taught to learners? For example, are elementary students too young to learn about changes in matter in terms of chemical structure, caused by processes on the cellular level?

Smith, Wiser, Anderson, Krajcik, and Coppola (2004) presented a framework of "elaborated standards" for developing assessments tied to research about how children learn. They asserted that it is at the middle school level that students begin to develop an understanding of matter and its transformations at the atomic-molecular level. Additionally, "research has shown that students are more likely to understand the basic tenets of the atomic-molecular theory if they have a sound macroscopic theory of matter" (p. 31). Therefore, Smith and colleagues proposed that students spend the upper elementary years developing an understanding of the macroscopic properties of matter in order to build a strong foundation for later learning in middle school. Only in middle school should students be assessed on the transformations of invisible gases. The construct "invisible gases" (particularly gases such as carbon dioxide and methane that are known to produce the greenhouse effect) is a necessary construct for students to learn when beginning to explore the complex topic climate change.

Smith and colleagues (2004) used some guiding principles in developing their framework that distinguished their work from the majority of large-scale and classroom assessments currently in use. First, the assessments were specifically designed to elicit student thinking, recognizing that teachers can learn a great deal about student thinking from incorrect answers. Second, the assessments were designed to align closely with students' life experiences, as opposed to current large-scale assessments, which "encourage teachers to focus on memorization and recitation of isolated science facts and procedures" (p. 4). Finally, the assessments were created based on research about how children learn and develop conceptual frameworks at different phases of their lives. Thus, the authors placed an emphasis on designing assessments that helped teachers develop conceptual frameworks in a logical, developmentally appropriate sequence that avoids important misconceptions that hinder many students in understanding atomic-molecular theory.

Student conceptions

A significant body of research exists on student conceptions, particularly on their misconceptions/alternative conceptions about climate change science. Researchers have found that students commonly confuse ozone layer depletion and climate change (Boyes & Stanisstreet, 1993; 1998; Rye, Rubba, & Wiesenmayer, 1997; Andersson & Wallin, 2000; Rebich & Gautier, 2005; Fisher, 1998). Students also struggle to understand the mechanism of the greenhouse effect and the causes of climate change (Andersson & Wallin, 2000; Rebich & Gautier, 2005; Fisher, 1998; Boyes & Stanisstreet, 1993). Additionally, many students fail to understand the political and economic consequences of reducing greenhouse gas emissions (Andersson & Wallin, 2000). The research referenced involved a variety of data collection procedures, including surveys, student-created concept maps, open-ended questionnaires, interviews, and student drawings. Data analyses were both qualitative and quantitative, using both constructivist and objectivist epistemologies.

Shepardson and colleagues (2009) provided a recent investigation of student conceptions about climate change in the United States. The authors studied seventh grade students' conceptions of global warming and climate change in the rural Midwest. The sample comprised 91 students of varying abilities. They were approximately 95% White, and approximately 30% of them were on free and reduced meals. The researchers chose to study seventh grade students, because this is when the science curriculum in the USA has students begin learning about global climate, weather, and related phenomena. Shepardson and colleagues employed a constructivist epistemology, aiming to understand student meaning through both written responses and drawings. They used an inductive approach to data analysis, looking for patterns in meaning to emerge from student responses. After developing emergent categories, student responses were coded into a category representing their conceptions of global warming and climate change. Specifically, these conceptions were about carbon dioxide-temperature graph interpretation and the effects of climate change on oceans, weather, and plants and animals. The authors found that most students did not interpret the graphs about carbon dioxide and temperature appropriately. Also, many students believed that climate change would not have a significant impact on people or society. Students largely thought that climate change would cause changes in local weather events, but not an increase in the frequency, severity, and variation of severe weather events. Shepardson and his colleagues stated, "In essence these students hold a simple conception of an earth climate system" (p. 562). The authors concluded that, in general, student conceptions of climate change were narrow and lacked complexity.

Science-Technology-Society and Socioscientific Issues Instruction

Since the 1970s, science educators have used the term "Science-Technology-Society" (STS) to represent science education emphasizing the relationships between science and society (DeBoer, 1991). The STS framework essentially involves science instruction in a social context (Padretti, 1999). Recently, many science educators have shifted towards a related but distinctly different initiative called "Socioscientific Issues" (SSI). One major difference between these two initiatives is that SSI involves a greater emphasis on the moral and ethical development of students (Zeidler, Sadler, Simmons, and Howe, 2005).

Zeidler and colleagues (2005) were critical of the STS initiative, suggesting that it lacks a well-developed theoretical basis. They wrote, "STS education as typically practiced does not seem embedded in a coherent developmental or sociological framework that explicitly considers the psychological and epistemological growth of the child, nor the development of character or virtue" (p. 358). Additionally, earlier research by McGinnis and Simmons (1999) presented compelling evidence that science teachers educated in STS pedagogy avoided teaching controversial topics due to their concerns about job security. In contrast, the SSI initiative specifically focuses on the personal, moral, social, and physical worlds of students. The SSI framework provides a working model about psychological, sociological, and developmental factors that affect student reasoning about important socioscientific issues that include controversial topics.

According to Sadler, Chambers, and Zeidler (2004), exploring an SSI topic involves understanding content, processing information, attending to moral/ethical considerations, and adopting a position. Padretti (1999) provided an example of how younger students can explore an SSI topic. She studied how fifth and sixth-grade

Canadian students learned about the controversial SSI topic of zinc mining. In this study, the teacher worked together with a science center to provide students with both in-school and out-of-school experiences to help them learn the complexities of the controversy topic. Padretti argued that engaging young students in reasoning about a controversial and complex social issue was appropriate. She wrote that her research "supports the claim that constructing an atmosphere of natural inquiry, critical thinking and decision making about science and technology and the links to the world they encounter at an early age is important for young children" (p. 175). In one activity, students participated in role-playing, deciding whether or not to vote for a zinc mine to be created in a town. This activity allowed students to consider multiple perspectives on zinc mining, making explicit the needs and wants of various stakeholders.

Sadler and colleagues (2004) pointed out that all SSI's are inherently controversial, as the presence of diverging perspectives is unavoidable. Similarly, Kolstø (2001) wrote, "Controversial socioscientific issues often include disagreements related to various actors' diverging evaluations of the validity or trustworthiness of the science-related claims involved" (p. 292). Additionally, Sadler and colleagues explained that SSI topics are controversial because people are asked to make decisions when outcomes are uncertain.

Kolstø (2001) presented a general framework for discussing the science dimension of controversial socioscientific issues like global climate change. Kolstø argued that "content-transcending knowledge" (similar to nature of science (NOS) knowledge) considerations should play a greater role in SSI instruction. He explained how epistemic stances affect student interpretations about factual claims. Specifically, students might learn to value scientific estimates or claims even when scientists disagree or when it is necessary to make decisions even though scientific knowledge remains inconclusive or uncertain. Moreover, teaching students to ask epistemic questions about evidence has the power to expand their decision base on a controversial SSI. Learning to question knowledge claims might also help students to discredit pseudoscientific or antiscientific assertions.

Kolstø (2001) argued that students should be respected as decision-makers when it comes to exploring controversial socioscientific issues. He wrote, "My conclusion is that guidelines for how to rank different knowledge claims ought to be omitted when designing teaching models for inclusion of science in social contexts in the science classroom" (p. 307). Instead, students should develop skills to evaluate knowledge claims and weigh evidence by exploring controversial SSIs and applying content-transcending knowledge. Kolstø (2001) identified a void in the literature on student views on science and scientists as they explore an SSI like global climate change in the classroom. The author felt that case study methodology was a particularly appropriate methodology for this research.

Sadler and colleagues (2004) addressed this void in the literature, investigating how students handle conflicting evidence about global warming as related to their conceptions of NOS. The authors used qualitative case study methodology, analyzing data from interviews and open-ended questionnaires. Sadler and colleagues explained their choice of data collection and analysis, writing, "In more recent years, the growing acceptance of qualitative methodologies has enabled science educators to look more closely at student and teacher ideas about NOS without the constraints of standardized instruments" (p. 389). One reason why qualitative methodologies are particularly important in NOS research on SSIs is that students and researchers often associate different meanings to words used on instruments like questionnaires and surveys. Qualitative methodologies are better able to create a more comprehensive account of student understanding and identify misinterpretations caused by different connotations of words. However, the authors did report frequency counts of student responses in taxonomic categories, which they identified as a controversial procedure in qualitative research. To address potential critics, Sadler and colleagues explained that these frequency counts were far less important than the taxonomic category itself.

Sadler and colleagues (2004) conducted their research on 84 high school students, using 30 of these students as a subsample for interviews. The authors identified two research questions that their study aimed to answer:

> 1. How do high school biology students conceptualize the following aspects of NOS in the context of a socioscientific issue: the meaning and interpretation of data; cultural embeddedness; and tentativeness as demonstrated by viable, opposing positions?
> 2. How do students interpret and evaluate conflicting information regarding a socioscientific issue? (p. 388)

The study did not involve an instructional intervention about global warming. Instead, students read two conflicting position statements on the SSI before responding to questionnaire and interview questions.

Sadler and colleagues (2004) found that "interpretation and evaluation of conflicting evidence in a socioscientific context is influenced by a variety of factors related to NOS such as data interpretation and social interactions including individuals' own articulation of personal beliefs and scientific knowledge" (p. 387). Additionally, the authors explained that many students did not consider scientific merit when making decisions about the global warming SSI. Rather, these students seemed to compartmentalize scientific knowledge and personal opinion.

Instructional interventions

Dutt-Donner, Wilmer, Stevens, and Hartmann (2000) employed a qualitative case-study approach to investigate student learning on an Internet web quest about global warming in two middle school science classrooms. In the web quest, students assumed the roles of groups testifying before the U.S. Senate about the Kyoto Protocol. Students were required to take a multidisciplinary approach to the assignment, weighing economic, environmental, societal, and scientific considerations related to the issue. Interestingly, the project pulled resources and time from language arts and social studies classes. Evidence of student learning included the following student reflection:

> I learned how global warming affects us and what can happen. Our group thought we should ratify the treaty. It doesn't matter to me if it's signed. I do want to try to stop global warming, but after watching other presentations I don't like the idea of prices going up and people losing jobs. (p. 161)

This student reflection is convincing evidence that the student was beginning to understand the complexities of the climate change issue.

Researchers have also taken quantitative approaches to studying the climate change SSI. Using a pretest-intervention-posttest design, Lester, Ma, Lee, and Lambert (2006) studied the effects of an instructional intervention on the climate change content knowledge and social activism of a diverse sample of fifth grade students. The intervention was developed within the STS framework and was specifically designed to be relevant to the lives of students. The authors found that students were more likely to suggest ways that people can help mitigate the effects of climate change after this intervention. Additionally, the authors suggested that students who demonstrated greater climate change content knowledge also demonstrated greater social activism. However, the authors were cautious in presenting their conclusions, suggesting that students may have expressed social activism ideas in response to teacher enthusiasm, the writing prompt, or a desire to please the teacher. Moreover, it is possible that students expressed more social activism when they had better content understanding because they were more successful students, having learned to give teachers the desired responses.

Lee, Lester, Ma, Lambert, and Jean-Baptiste (2007) wrote about the same large-scale intervention, though this work focused on student conceptions about the greenhouse effect and global warming. The authors felt that they were filling a gap in the literature on climate change instructional interventions because their work looked at specific subgroups of students in the United States. The intervention involved numerous writing activities, videos about climate change, hands-on activities, and graphing exercises.

Lee and colleagues (2007) analyzed student responses to writing prompts in order to evaluate the effectiveness of the intervention. Consequently, some student responses introduced ambiguity into the data analysis. Lee and colleagues wrote, “The ambiguity of coding student responses raised questions about reliability. Thus, quantitative analysis was conducted only with regard to scientific conceptions” (p. 120). The quantitative analysis showed that student conceptions of global warming improved significantly in several categories, except for the category labeled “Explanations of an Intensified Greenhouse Effect.” Qualitative analysis of alternative conceptions emerging from the written responses showed that students incorrectly equated the greenhouse effect with the definition of greenhouse gases and with the ozone layer. Students often discussed inadequate supplies of oxygen, the need to stop building greenhouse gases, and the harmful gases in aerosol sprays and air conditioners when explaining global warming.

Interestingly, Lee and colleagues (2007) explained that their quantitative analysis showed that the intervention did not have a statistically significant effect on either the African-American or Haitian subgroups. It should be noted, however, that the majority of students in these subgroups came from a single elementary school. As the authors explained, “The third school served predominately Haitian and African-American students (90%), with 22% of students designated as LEP and most from low-SES homes (99% free or reduced price lunch)” (p. 119). Alternatively, the majority of the other subgroups came from the other four elementary schools.

Also using a pretest-intervention-posttest design, Rule and Meyer (2009) found that a group of urban, high-poverty U.S. high school students exhibited increased motivation to learn about climate change and improved graph interpretation skills after engaging in a climate change module of a high school biology course. The authors partially described the module,

> Mathematics (mostly as graph interpretation), literacy (a movie presenting the book, *The Lorax*, by Dr. Seuss) and student discussions of political issues were integrated into lessons that used hands-on materials to capture attention and portray concepts at a concrete level. (p. 337)

Rule and Meyer argued that their study has implications for science courses besides biology at a range of developmental levels. For instance, the use of data focusing on changes in biological organisms can easily be substituted with data more closely related to earth science courses, such as ice core or climate data. The authors suggested that more advanced high school students can focus on graphical interpretation of more complex data sets, while upper elementary and middle school students can focus more on concrete manipulative materials used during the "hands-on" components of the module.

Rule and Meyer (2009) described their findings as important because they contradicted earlier work by Lee and colleagues (2007). Rule and Meyer wrote, "Our positive results are significant, as another study reporting the results of a large-scale intervention on global climate change concepts that included diverse groups of fifth-grade students (Lee et al., 2007) showed no gains for African-American students" (p. 344). However, as Rule and Meyer noted, comparisons between these two studies are limited because of differences among content, methods, and student populations.

Klosterman and Sadler (2010) also used a quantitative pretest-intervention-posttest approach to study student learning during a climate change SSI unit. The authors measured student learning of content knowledge through both curriculum-aligned (proximal) and standards-aligned (distal) assessments. Klosterman and Sadler employed this type of multi-level assessment because it provides more complete understandings about the effects of innovative curricula. In many cases, such assessments have revealed that innovative curricula produce significant gains on curriculum-aligned assessments, but not standards-aligned assessments. However, Klosterman and Sadler found that the students in their study showed significant gains in content knowledge on both the curriculum-aligned and standards-aligned assessments.

Fruitful Areas of Additional Inquiry in Climate Change Education

Mohan, Chen, and Anderson (2009) described the learning progressions for students in "status-quo teaching" about the carbon cycle. Consequently, the authors did not study instructional interventions intended to aid students' development in terms of this learning progression. Therefore, a fruitful area of research in climate change education would be to investigate how learners are able to understand about the underlying chemical processes of climate change when teachers use various instructional strategies. Also, the role of the nature of science (NOS) in learners' as they explore conflicting evidence about climate change would be fruitful to investigate. This type of research would involve collecting written responses and interviews from students in different grades of middle and high school (Mohan et al.).

Sadler and colleagues (2004) explained that research on encouraging students to integrate scientific knowledge into their decision making process is sparse. Sadler and colleagues stated, "Science education needs the development of a research program to investigate the many factors that influence socioscientific decision-making and their implications for education" (p. 404). Research on the socioscientific decision-making processes of middle school students is especially lacking. Therefore, another potential area for inquiry would be to investigate how teachers can encourage middle school students in the science classroom to integrate scientific knowledge in their decision making. Padretti's (1999) work could be used as a model to study similar instruction on global climate change for upper elementary or middle school students. Though Padretti worked with fifth and sixth grade Canadian students on the zinc mining SSI, similar work can be done with American middle school students on the climate change SSI, focusing on how students are able to negotiate and evaluate conflicting knowledge claims (Sadler et al.). Such research would lend itself well to qualitative case study methodology.

Zeidler and colleagues (2005) discussed informal reasoning as an important area for inquiry in SSI research. The authors posited, “opportunity to engage in informal reasoning through argumentation allows for the evaluation of evidence as well as thought, but finding appropriate pedagogical strategies to seamlessly integrate such dynamic social interaction in the science classroom remains a high priority,” (p. 366). A variety of qualitative approaches would be appropriate for this inquiry, including discourse analysis.

Quantitative research is also needed to assess the impact of instructional interventions based on the climate change SSI. A rich researchable area of investigation question would be to determine the impact on middle school students of various instructional interventions on climate change. Klosterman and Sadler (2010) provided a model for such research, using multi-level assessment and a pretest-intervention-posttest design. This research design is particularly suited to measure content knowledge gains during climate change instruction. However, this design could also be used to measure other kinds of learning, such as gains in NOS knowledge.

Cordero, Todd, and Abellera (2008) studied the effects of college students participating in an ecological footprint learning activity. The authors found that students who had participated in this activity were better able to connect personal actions and consumption with global warming. One potential area of inquiry would be to develop an ecological footprint learning activity adapted for middle and high school students and study its effect on teachers’ and students’ learning. This research lends itself well to a mixed methodology including a quantitative pretest-intervention-posttest approach and a qualitative data collection strategy.

Important to the inquiry described above is the critical question, “Will classroom teachers embrace climate change instruction?” Teachers may avoid teaching about controversial issues, especially when they believe that teaching such topics may put their jobs in jeopardy (McGinnis & Simmons, 1999). Additionally, teachers may avoid teaching about an SSI in today’s assessment-driven atmosphere, especially if teachers believe SSI instruction will hurt student performance on high-stakes tests (Klosterman & Sadler, 2010). Research is needed to investigate, “Are teachers willing to teach about the climate change SSI in their classrooms, and the reasons why teachers form their judgments in this decision?” This type of research lends itself well to qualitative case study methodology, including classroom observations, participant journals, and interviews of school personnel and students.

Finally, a body of research exists about student conceptions about global warming and climate change. However, much of this research investigated the conceptions of students in countries outside the United States. More research is needed on USA middle school students’ conceptions of global warming and climate change. Shepardson and colleagues (2009) suggested ways that students’ geographic locations may influence their conceptions of the impacts of climate change. An important area for inquiry is to determine how geographic location might affect these conceptions. Similar research can investigate differences in conceptions of students in different subgroups or socioeconomic statuses. As Shepardson and colleagues wrote, “Students from a different population might convey different conceptions as they may have different social-cultural experiences and access to different learning experiences and sources of information" (p. 565). Student conceptions about the impacts of climate change will likely affect student decision-making about the climate change SSI, and research is needed to investigate this relationship.

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