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Urban High School Students' Critical Science Agency: Conceptual Understandings and Environmental Actions Around Climate Change

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Abstract This study investigates how the enactment of a climate change curriculum supports students' development of critical science agency, which includes students developing deep understandings of science concepts and the ability to take action at the individual and community levels. We examined the impact of a four to six week urban ecology curriculum on students from three different urban high schools in the USA. Data collection included pre and posttest written assessments from all students (n=75) and pre and post interviews from focal students (n=22) to examine how students' conceptual understandings, beliefs and environmental actions changed. Our analyses showed that at the beginning of the curriculum, the majority of students believed that climate change was occurring; yet, they had limited conceptual understandings about climate change and were engaged in limited environmental actions. By the end of the curriculum, students had a significant increase in their understanding of climate change and the majority of students reported they were now engaged in actions to limit their personal impact on climate change. These findings suggest that believing a scientific theory (e.g. climate change) is not sufficient for critical science agency; rather, conceptual understandings and understandings of personal actions impact students' choices. We recommend that future climate change curriculum focus on supporting students' development of critical science agency by addressing common student misconceptions and by focusing on how students' actions can have significant impacts on the environment.

Keywords Climate change · Critical science agency · High school · Curriculum · Science education · Environmental action, environmental literacy

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As scientists and policymakers develop a deeper understanding of the nature of global climate change, an increasing call has emerged for supporting public understanding (Niepold et al. 2007). Recently, the Climate Change Science Program (CCSP) defined a climate literate person as someone who understands the Earth's climate system, is capable of assessing the credibility of new climate information and makes informed and responsible decisions with regard to actions that may affect climate (2009). Others have suggested that case based issues, such as climate change, may serve as strong entry points into science education, fostering critical thinking and socioscientific reasoning as well as ethical and moral development (Sadler et al. 2004; Zeidler et al. 2005). Specifically, socioscientific reasoning includes developing students' ability to recognize inherent complexity, examine issues from multiple perspectives, understand the ongoing nature of scientific and social research and exhibit healthy skepticism when presented with new information. In our work, we build on Basu and Calabrese Barton's views of "critical science agency", which includes students developing deep understandings of science concepts and scientific inquiry as well as developing agency or the ability and desire to take action at either the individual or community level (Basu et al. 2009; Calabrese Barton 2008). Hence, students with critical science agency align well with the CCSP's definition of a climate literate person that includes moving beyond just developing an understanding of the science concepts to engage in informed and responsible environmental action. Our study investigates how the enactment of a climate change curriculum supports students' development as climate literate citizens specifically in terms of the impact on both students' knowledge and personal environmental actions about climate change.

Theoretical Background

Critical science agency includes students developing both deep conceptual understandings and using knowledge to take action (Basu et al. 2009; Calabrese Barton 2008). In order to frame our study, we first discuss current research that examines students' conceptual understandings of climate change. This literature base on students' conceptual understandings includes three different foci: models of climate change, human causes of climate change, and environmental impacts of climate change. Since our goal is not only to change students' understanding of climate change, but also their related actions we then shift to discussing relevant research focused on students' environmental action. In the section on environmental action, we discuss how multiple factors, such as conceptual understandings, knowledge of the social, political and economic context, personal relevance and knowledge of appropriate environmental actions, can potentially impact students' choices. We discuss how these two bodies of research about students' conceptual understandings and environmental actions informed both our design of the curriculum and our research study examining the impact of the curriculum on urban high school students' understandings and actions around climate change.

Students' Conceptions of Climate Change

Climate change is the long-term change in the earth's climate, which includes changes in the earth's temperature, precipitation and other weather patterns due primarily to human-induced emissions of heat-trapping gases such as carbon dioxide (Karl et al. 2009). Climate change includes more than just global warming, or the increase of the earth's average surface temperature, to also encompass other changes in weather patterns such as an increase in severe storms. Previous research on students' understanding of either global warming or climate change suggests that they lack deep understandings of these concepts and frequently hold several alternative conceptions (Boyes and Stanisstreet 1997; Koulaidis and Christidou 1999).

Models of Climate Change Understanding climate change includes developing a model of how climate change occurs and the underlying science behind climate change. Students struggle to develop models and systems as well as to apply those models to understand global issues, like climate change (Mohan et al. 2009). The literature suggests that students often have two different groups of models, one focused on greenhouse gases and the other on the ozone layer, as well as variations of their understanding of those models.

The first group of models aligns with the scientifically accurate model that a defined layer of greenhouse gases somewhere in the atmosphere impacts climate change by holding or trapping in radiation or heat from the sun. Yet students often have inaccurate or incomplete ideas about this model. For example, some students incorrectly describe this barrier of gases as bouncing back heat from the earth (Andersson and Wallin 2000; Shepardson et al. 2009). In this instance, students believe climate change is caused by heat being produced by industry that is trapped and bounced back toward the surface of the earth. Students also have different levels of understanding about what are greenhouse gases. In one study, just over half of students in tenth grade knew CO_2 was a component of "unpolluted" air (Skamp et al. 2004), while in another, only 25% could identify CO_2 as a greenhouse gas (Shepardson et al. 2009). However, another study found 50% of students believed CO_2 was a cause of the greenhouse effect (Boyes and Stanisstreet 1997). Consequently, students can have a model that focuses on the role of greenhouse gases, but that model can be incomplete or inaccurate.

The second group of models inaccurately connects climate change to the ozone layer. For example, Boyes and Stanisstreet (1997) found 80% of the 500 high school students surveyed believed ozone layer depletion caused the greenhouse effect. The dominant model here is that CFCs, CO_2 or some other air pollutants cause holes in the ozone layer. These holes allow more heat and/or UV rays to reach the earth's surface and thus cause global warming (Andersson and Wallin 2000; Boyes and Stanisstreet 1997; Koulaidis and Christidou 1999; Osterlind 2005). One typical student describes this model as "CFCs go to the ozone layer and make holes in it... And so the sun hits the earth and... more ultraviolet rays come in and the climate gets hotter" (Koulaidis and Christidou 1999, p. 566). This group of models includes an inaccurate understanding of the causes of climate change in which students confuse the issues of the greenhouse effect and the depletion of the ozone layer.

The Role of Humans in Climate Change In general, studies found that students were often unclear as to the role of humans in climate change. Students can have difficulty distinguishing the earth's natural greenhouse effect compared to the increased effect caused by anthropogenic activity. Furthermore, students do not understand what human activities do impact climate change (e.g. driving a car) compared to those activities that do not impact climate change (e.g. littering). In discussing relevant human actions, pollution, generally, was the most common cause in the literature, though some studies also found students specifically mentioned CO_2 (Boyes and Stanisstreet 1997), air pollution (Andersson and Wallin 2000; Myers et al. 2000; Shepardson et al. 2009), and garbage (Boyes et al. 1993). In addition, a recent study found most students attributed climate change to pollution from vehicles and factories (Shepardson et al. 2009). Students appear to be unclear about which of their specific daily actions can potentially impact climate change.

Environmental Impacts of Climate Change Student ideas about the environmental impacts of climate change varied in terms of how a change in the climate could potentially impact the world around them. Several of the studies found students incorrectly believed that climate change would increase skin cancer rates (Boyes et. al. 1993; Boyes and Stanisstreet 1993, 1998). Shepardson and his colleagues (2009) found that nearly half of the students surveyed believed ocean levels would rise as a result of climate change while 16% believed they would fall. In addition, students also believed local temperatures would rise (Andersson and Wallin 2000; Shepardson et al. 2009). Furthermore, Shephardson and his colleagues (2009) found that 76% of students surveyed believed wild plants and animals would die off and 33% went further linking these deaths to hotter weather. However, student responses revealed no understanding of geographic description and they also failed to make links to the agricultural consequences, even though the students surveyed were from a mid-western agricultural community. Boyes and Stanisstreet's (1993) analysis revealed similar confusion over regional differences in the effects of climate change. Consequently, students had mixed views in terms of both accuracy and completeness of the consequences of climate change.

The Impact of Curriculum While the studies described above examined common conceptions among middle and high school students, only a handful of studies have begun to examine how different curricular interventions might impact student learning over time. In general, these studies illuminate the complex nature of understanding climate change and difficulty in shifting students' preconceived notions. In one study, Rye and his colleagues (1997) interviewed 24 middle school students from four classrooms following the completion of a teacher-designed two-week global warming unit. These interviews revealed that the majority of students held misconceptions, particularly that CO_2 causes ozone layer depletion and ozone layer depletion is the cause of global warming. Based on their findings, Rye and his colleagues recommend that future curriculum on global climate change should include an explicit focus on students' common alternative conceptions to support them in developing richer understandings of the causes of climate change. In another study, Cordero and his colleagues (2008) also found similar and persistent misconceptions among the 400 non-science major undergraduates they surveyed. These misconceptions were similar to those that Rye and his colleagues (1997) found regarding CO_2, the ozone layer and global warming. However, after a semester long course in Meteorology, they found that the prevalence of these misconceptions decreased but still remained in approximately 10–20% of the students. Jakobsson and his colleagues (2009) conducted a study examining how fourteen and fifteen year-olds' conceptual understanding of climate change evolved over a six-week curricular unit. They found that after significant discursive work students were able to interactively develop a strong understanding of global climate change. While these studies suggests that an educational intervention can change students' understanding of climate change, they also highlight the importance of time and certain characteristics of the instruction (e.g. addressing alternative conceptions and engaging in scientific discourse) in order to shift students' understanding of a very complex and multifaceted socioscientific issue such as climate change.

Environmental Action

Environmental action refers to the decisions and behaviors that students engage in that have a positive impact on the health of the natural environment, such as conserving electricity or recycling. There are multiple factors that impact whether or not students decide to engage in environmental actions, such as their conceptual understandings of the scientific phenomenon, their understandings of the larger social, political and economic context, their views about personal relevance, and their knowledge of appropriate environmental actions. While research has examined students' conceptions of global climate change, the more challenging aspect is the link between knowledge and action. Research with fifth-grade students in a large urban district found that there was a relationship between stronger content knowledge (i.e. students' depth of understanding of the greenhouse effect and the possible consequences of a warmer climate) and environmental activism (Lester et al. 2006). Yet other research has found that while understanding the causes and consequences of climate change is a critical piece, there is not necessarily a causal link between knowledge and action and in fact promoting environmental action is a more socially and culturally complex process (Kollmuss and Agyeman 2002). Youth draw upon multiple funds of knowledge when making decisions in their everyday lives. At times, they are aware that scientific knowledge is relevant, but other competing knowledge can be more important in determining their actions. For example, Moje and her colleagues (2004) describe urban youth's decisions about wearing a bike helmet in the context of an eighth grade science curriculum focused on the physics of bike helmets. While a number of the students understood the physics behind why bike helmets are important, they still chose not to wear them citing reasons such as they look stupid, they are hot or they are uncomfortable. This example illustrates that content knowledge may not be sufficient to alter the actions of students.

Controversial issues, such as climate change, require an understanding of social, political and economic factors in addition to conceptual understandings (Oulton et al. 2004). These other factors impact individual's personal actions, yet it can be difficult for students to consider these other factors. Andersson and Wallin (2000) analysis of a study of 600 Swedish high school students who responded to open-ended items found that students do not understand the broader social and economic contexts of climate change. For example, students called for drastic reductions in CO_2 emissions without acknowledging or accounting for the economic consequences. The authors suggested this might be due to the disciplinary nature of these students' education whereby students are accustomed to only drawing upon "science" knowledge in science learning contexts, ignoring other potential sources of knowledge.

Students' environmental actions can also be impacted by whether they see problems as personally relevant. Skamp et al. (2004) surveyed more than 1000 middle and high school students and found students agreed to environmental statements regarding taxation and legislation when they were directed at other individuals or companies while disagreeing with the same statements when they involved themselves. Thus, students felt the responsibility for environmental action, this case reducing air pollution, fell more to others than on their own personal actions. Skamp et al. (2004) suggest that this data may also be explained by a lack of perceived personal responsibility. Students may feel that they do not contribute to air pollution so they do not bear the responsibility for reducing it. Students may also lack knowledge of what personal actions can positively or negatively impact the environment. For example, Jenkins and Pell (2006) found that the majority of fourteen and fifteen year-old students in their study did not feel that they could personally influence what happens to the environment. This is similar to the findings of Connell and her colleagues (1999) who found that the majority of sixteen and seventeen year olds in their study did not feel personal responsibility or feel that their choices or actions could have a significant impact on the environment. Sadler et al. (2004) in a study of high school students reading contradictory reports about global warming, found personal relevance and beliefs had the greatest influence on students' environmental actions.

These studies suggest that if we want to support critical science agency around climate change, we must understand how educational experiences impact both students' understanding of climate change, but also how these experiences influence their beliefs and actions. This also suggests that we need curriculum designed to support students in seeing the personal relevance of scientific issues and support environmental actions, going beyond presenting students with detailed information about the problem or solely focusing on content knowledge. Rather, science curriculum needs to include lessons specifically focused on environmental actions and their impact on the natural world. Therefore the curriculum enacted here and the data collected examine both the impacts on students' scientific understanding of climate change and their beliefs and actions.

To this end, in this study we examine how a high school curriculum designed to support both knowledge and action influence students' critical science agency around climate change. Specifically, we address the following questions:

1. How do high school students' understandings of climate change alter after a curricular unit focused on the topic?
2. How do high school students' beliefs about climate change alter after a curricular unit focused on the topic?
3. How do high school students' environmental actions about climate change alter after a curricular unit focused on the topic?

Furthermore, we examine the relationships between the changes in students' understandings, beliefs and environmental actions to consider how to better design curriculum to support students in developing critical science agency around climate change.

Methods

Instructional Context

This study took place during a high school urban ecology curriculum, *Urban Ecolab: How do we develop healthy and sustainable cities?* (Strauss et al. 2007). The curriculum was developed as a capstone course for high school students to engage students in environmental science and connect the science to their cities and their lives. The curriculum includes eight modules. Specifically, this study focuses on the second module, which examined energy and climate change. Table 1 provides an overview of the eleven lessons included within the climate change unit including the estimated number of periods and a description of the lesson.

Originally, the curriculum developers projected the module would take approximately 16–19 class periods, but the teachers' enactments took between 20–30 class periods with each period taking approximately forty-five minutes.

The curriculum focused on a number of key science ideas, such as the causes and consequences of global climate change. Furthermore, as Rye and his colleagues recommend (1997), we explicitly designed the lessons to address common student alternative conceptions. For example, many students think that the ozone layer depletion causes the greenhouse effect (Boyes and Stanisstreet 1997). Consequently, Lesson 2: The Greenhouse Effect included a discussion of the ozone layer depletion and how this is different than the greenhouse effect. In addition, we also specifically designed some lessons in the curriculum to focus on how human actions impact climate change to address the misconception that students often have that their personal actions do not impact the environment (Connell et al.

Table 1 Description of climate change curriculum

#Periods	Lesson	Description of Lesson
1 period	Lesson 1: Is the earth's climate changing?	Teacher shows video clips on global climate change and leads a discussion about whether the climate is changing. Students analyze global climate change data.
1 period	Lesson 2: The Greenhouse Effect	Teacher shows students Flash presentation about the greenhouse effect. Students model the greenhouse effect using clear plastic bottles and they log the temperature changes.
1 period	Lesson 3: Why should we care about global warming?	The class brainstorms the effects of global warming. Teacher presents the consequences of global warming. Students use Google Earth to analyze surface temperature and hurricanes. Teacher presents historical weather data to connect surface temperatures to storm intensity.
1–2 periods	Lesson 4: Where's the carbon?	Teacher presents the carbon cycle. Students play a game about the carbon cycle.
1 period	Lesson 5: How do humans impact the production of greenhouse gases?	Teacher conducts a demonstration showing the differences in temperature between CFL and incandescent light bulbs. Students calculate carbon emissions of an incandescent and CFL light bulbs. Students model their carbon emissions for using software.
1 period	Lesson 6: Food Choices and Global Warming	Teacher presents energy pyramids and food chains in relation to climate change. Students complete an activity to determine how many miles the food in a typical lunch travels.
2–3 periods	Lesson 7: Urban Heat Islands	Teacher conducts a demonstration of the impact of color on temperature. Students collect data and evaluate the impact of surface material on temperature around their study site.
2–3 periods	Lesson 8: Urban Tree Field Study	The class brainstorms their ideas regarding the impact of trees in a city. Students identify and evaluate tree location, health and growing conditions in their field study site.
3 periods	Lesson 9: Impact of trees on a city	Students evaluate case studies of tree planting on a city's ecological and economic health. Students analyse their tree data to evaluate their study site's ecological health and how their trees impact energy savings of nearby buildings.
2 periods	Lesson 10: Exploring renewable energy sources	Students weigh environmental and economic factors in deciding how to power their city. Students use an online simulation to test the energy choices.
1 period	Lesson 11: Performing school-wide and personal energy audits	Students complete a personal energy audit and brainstorm ways to reduce their energy consumption. Students consider the energy usage of their school site and determine ways to reduce the school energy consumption.

1999; Jenkins and Pell 2006). For example, in Lesson 9 students evaluate how planting different amounts and types of trees impact carbon sequestration. Lesson 10 has students test different ways to power a city and how those choices impact the environmental health. Finally, lesson 11 has students conduct both a personal and school audit of energy consumption as well as brainstorm actions on how to reduce both their personal and school energy consumption. The goals of the curriculum included helping students develop a stronger scientific understanding of global climate change and a richer understanding of how their personal actions impact the environment. The design of the curriculum was informed by previous research on students' conceptual understandings and views about environmental action to specifically address their common misconceptions.

Participants

This study took place during the 2007–2008 school year with three teachers who piloted four of the eight modules in three different high schools in the same large urban school district in the USA. For the urban school district, approximately 36% of high school graduates enroll in and earn a college degree with the majority of students pursuing other pathways. Table 2 provides the demographic information for the three specific schools.

As Table 2 illustrates, the schools were racially, ethnically and linguistically diverse, and a majority of the students came from low-income households. The teachers used the curriculum as a capstone class for eleventh and twelfth grade students who were typically between sixteen and eighteen years old.

Study Design

We collected data both before and after students completed the climate change curricular unit. The data consisted of two different measures. Pre and posttests were collected from all of the students in the three teachers' classes to evaluate any changes in the students' understanding of the science content. Focal students from each teacher were also selected to be interviewed in order to further assess the students' understanding of the content as well as to evaluate how their beliefs and personal actions changed over the course of the curriculum.

Table 2 School demographics

		Mr. Dodson's School	Ms. Steven's School	Ms. Baker's School
Total enrollment[a]		261	305	289
Racial & ethnic diversity[a]	Hispanic	62%	61%	47%
	Black	33%	34%	34%
	White	3%	4%	16%
	Asian	2%	<1%	3%
	Native American	<1%	1%	<1%
Language[b]	English not First Language	18%	24%	30%
	LEP	1%	6%	4%
Income[b]	Low Income[c]	78%	64%	73%

[a] Data from district profiles

[b] Data from state website

[c] Low Income is the number of students on free and reduced lunch

Pre and Posttest Students completed identical pre and posttests before and after completing Modules 1 and 2 of the urban ecology curriculum. The test consisted of 16 multiple-choice items and 3 open-ended items. Six of the multiple-choice items and one of the open-ended items aligned with the global climate change content that is the focus of this study. These items can be found in Appendix A. The other items focused on Module 1, which was an introduction to urban ecology, and were not included in this analysis. The assessment items were designed by a team consisting of science education researchers, a teacher, and a scientist. The item development process was adapted from DeBoer and his colleagues (2008), which includes a focus on precise alignment of items to carefully defined learning goals, consideration of potential student misconceptions, comprehensibility of the item for linguistically and culturally diverse students, and consideration of the scientific accuracy of the items.

Student Interviews We also interviewed twenty-two students both before and after completing the climate change module. Eight of the students were in Mr. Dodson's class, seven of the students were in Ms. Stevens' class and seven of the students were in Ms. Baker's class. Students were selected to be interviewed based on whether they had returned their consent form and the teachers were asked to select students with a range of background knowledge.

The interview protocol was designed by an education researcher (i.e. the first author) and two student research assistants to address the specific research questions targeting students' beliefs and actions related to climate change. The goal was to design a protocol that encouraged a conversation with the high school student in which the participant's perspective was able to unfold and not be biased by the perspective of the interviewer (Marshall and Rossman 1999). After the initial design, the interview protocol was reviewed by the entire research team of educational researchers, a teacher and a scientist in terms of accessibility to the students, accuracy of the science content, and alignment with the research goals. The interview asked students about their understanding of global warming,[1] whether they thought global warming was occurring, if global warming concerned them, and if they are personally doing anything to limit their impact on global warming. The specific questions that were analyzed for this study are included in Appendix B. After initial questions were asked, follow up questions were asked if a student said something unclear such as—"You mentioned______. Can you tell me more about that?" Each interview lasted approximately ten to fifteen minutes, with the post interviews taking slightly longer than the pre interviews.

Data Analysis

In this section we describe our data analysis both for the students' pre and posttests as well as for the student interviews.

Pre and Post For the multiple-choice items, we scored and tallied all six items based on whether or not students selected the appropriate response for a possible total of six points. The one open-ended item asked students: '*What are three human behaviors that impact climate change? Why?*' We developed a rubric for the question, which consisted of two

[1] In the interview, we used the phrase "global warming" instead of "climate change". Climate change is accepted as the more appropriate term, because it encompasses all of the long term changes in weather patterns and does not just focus on the surface temperature increases. We initially used global warming on the pre interview, because it seemed more prevalent in the media and that students would be more familiar with the term. We then wanted to keep the language consistent on the post interview.

different codes. The first code focused on the human behaviors and was rated from zero to three depending on the number of appropriate behaviors the students provided. The second code examined the students' reasons for why the behaviors would impact climate change. This code included ratings from zero to four, with the highest score including an explanation of how human behaviors impact the amount of greenhouse gases and how those gases then impact the heat and energy in the atmosphere, which impacts long term weather patterns (see Appendix C for rubric). Twenty percent of the students' responses were randomly selected and scored by two independent raters. We then calculated interrater reliability by calculating percent agreement. The interrater reliability was 88% with all disagreements resolved through discussion.

Student Interviews All of the pre and post interviews for the twenty-two students were transcribed. We then developed the coding scheme for the transcripts from both our theoretical framework and an iterative analysis of the data (Miles & Huberman, 1994). We developed codes for four different themes: 1) understanding of the causes of climate change, 2) understanding the consequences of climate change, 3) beliefs about whether climate change is occurring, and 4) personal actions to limit their impact on climate change.

Table 3 describes the coding scheme for students' understanding of the causes of climate change. In developing this coding scheme, we took into consideration the codes for the open-ended assessment item about climate change (see Appendix C), because we wanted alignment across the two coding schemes so we could compare students' written and

Table 3 Coding scheme for students' understanding of the causes of climate change

Level	Description
5	Explains 5 of the 5 elements
	1. Weather Patterns- Explains that these processes cause long-term weather patterns to change such as increasing the surface temperature of the earth.
	2. Greenhouse Effect- Explains that heat or energy is being trapped in the atmosphere.
	3. Example Greenhouse Gases- Names examples of specific greenhouse gases in explanation such as carbon dioxide, methane, and nitrous oxide.
	4. Source- Describes sources of the greenhouse gases such as emissions from cars, buses, and factories or that trees being cut down are no longer able to sequester carbon.
	5. Amount of Greenhouse gas- explains that the amount of greenhouse gases is increasing in the atmosphere.
4	Explains 4 of the 5 elements
	Weather patterns, Greenhouse effect, Example of greenhouse gas, Source or Amount of greenhouse gases.
3	Explains 3 of the 5 elements
	Weather patterns, Greenhouse effect, Example of greenhouse gas, Source or Amount of greenhouse gases.
2	Explains 2 of the 5 elements
	Weather patterns, Greenhouse effect, Example of greenhouse gas, Source or Amount of greenhouse gases.
1	Explains 1 of the 5 elements
	Weather patterns, Greenhouse effect, Example of greenhouse gas, Source or Amount of greenhouse gases.
0	No idea.
	Says they do not know what causes climate change or describes an inaccurate explanation.

Table 4 Coding scheme for students' understanding of the consequences of climate change

Code	Description
Scientifically accurate	Number of the following six accurate consequences: 1) Long term climate change, 2) Changes in storm patterns (e.g. stronger hurricanes), 3) Melting ice caps or glaciers, 4) Rising ocean levels, 5) Habitat destruction or wildlife displacement, and 6) Facilitate the spread of disease.
Misconception: short-term weather	Discusses short-term weather patterns or the current weather patterns (e.g. This October was really hot).
Misconception: other	Includes any of the following misconceptions: 1) Increase in respiratory issues such as asthma and 2) Ozone layer depletion.
Death and destruction	Talks in general about death and destruction (e.g. We're all going to die. It is going to cause the end of the world).
Don't know	States that they do not know any consequences of climate change.

spoken explanations. Level 5 is the highest score that a student could receive and included an explanation of five different elements. In order to receive a Level 5, in the student's interview he or she needed to explain that the amount of greenhouse gases is increasing in the atmosphere, describe a source of greenhouse gases, provide a specific example of a greenhouse gas, explain that the greenhouse gases are trapping heat or energy in the atmosphere, and describe how the greenhouse effect can alter long-term weather patterns. The interview included one extra level compared to the coding scheme for the written assessment in that we coded separately students mentioning "greenhouse gases" compared to naming a separate greenhouse gas such as "carbon dioxide" or "methane". On the written assessment we gave students credit for either naming a specific greenhouse gas or discussing greenhouse gases in general.

Table 4 provides the coding scheme for assessing students' understanding of the consequences of climate change. When students described the potential consequences of global climate change, we coded their responses in terms of the number of scientifically accurate consequences, discussing short-term weather patterns, including common misconceptions, focusing on death and destruction and stating that they did not know. In terms of providing scientifically accurate consequences, we also coded for how many

Table 5 Coding scheme for students' reasoning for the occurrence of climate change

Code	Description
Scientifically accurate	Discusses scientifically accurate evidence or reasoning such as long term climate change, changes in storm patterns, melting ice caps or glaciers, rising ocean levels, habitat destruction and wildlife displacement.
Short term weather	Discusses their personal experiences with short-term weather patterns or the current weather patterns (e.g. This October was really hot).
Human impact	Based on knowing that humans have a large impact on the environment or describes specific human impacts such as driving too much or producing pollution.
Other people or media	Based on hearing about climate change from someone else such as a friend, family member or through the media (e.g. TV.).
Don't know	States that they do not know anything to provide a strong reason.

Table 6 Coding scheme for students' personal environmental actions

Code	Description
Limit transportation energy use	Discusses limiting transportation energy use such as using public transportation, carpooling, using a hybrid car, walking more or using bicycles more.
CFL light bulbs	Discusses switching to CFL light bulbs in their house.
Conserve electricity	Discusses turning off lights, unplugging appliances or otherwise to reduce personal electricity use.
Conserve water	Discusses turning off water, using less water or taking shorter showers.
Recycle	Discusses recycling or reusing paper and other products.
Don't litter	Says that they do not litter or throw trash on the ground.
Wants to reduce	Says they want to reduce their impact, but does not provide specific actions or states that they do not know specific actions to reduce their impact.
Not interested in personal action	States that they are not interested in changing their actions to reduce their impact on climate change.

different accurate consequences students provided with the highest possible score of 6. For the consequences of climate change coding scheme, students' responses could receive more than one possible code. For example, a student's response could be coded as including both scientifically accurate consequences as well as including misconceptions if they discussed in their response both the melting of glaciers (accurate) and causing an increase in asthma (misconception).

The third theme focused on whether or not students believed climate change was occurring. Students' initial responses were coded for four responses: 1) yes, 2) maybe, 3) no, and 4) I don't know. The interviewer then followed up by asking why students held that belief. Students' reasoning was then coded based on the five categories in Table 5. If a student mentioned multiple reasons, their responses received multiple codes.

The last theme focused on students' personal environmental actions. Their responses were first coded either yes or no. We also coded students' responses for a variety of different actions. Those codes are summarized in Table 6. If students discussed multiple actions, they received multiple codes in terms of their personal actions that impact climate change.

Two independent raters coded the pre and post interviews. The four themes were coded across the interviews since the participants' ideas unfolded during the discussion and they often revisited ideas that they previously mentioned. This differed from the student written assessment where students had only one opportunity to convey their ideas. Twenty-five percent (6 pre and 6 post) were randomly selected across the teachers to be coded by both raters. The interrater reliability, which was calculated by percent agreement, was 81%. All disagreements were resolved through discussion.

Results

The results section is structured based on our three research questions: 1) How do high school students' understandings of climate change alter after a curricular unit focused on the topic? 2) How do high school students' beliefs about climate change alter after a curricular unit focused on the topic? and 3) How do high school students' environmental actions about climate change alter after a curricular unit focused on the topic? In the

Table 7 Climate change items (n=75)

Pretest M (SD)[a]	Posttest M (SD)	t-Value[b]	Effect Size[c]
3.45 (1.69)	6.57 (2.24)	10.42***	1.85

[a] Maximum score=13

[b] One-tailed paired t-test

[c] Effect Size: Calculated by dividing the difference between posttest and pretest mean scores by the pretest standard deviation

***p<.001

discussion section, we then consider the possible relationships between students' conceptual understandings, beliefs and personal environmental actions.

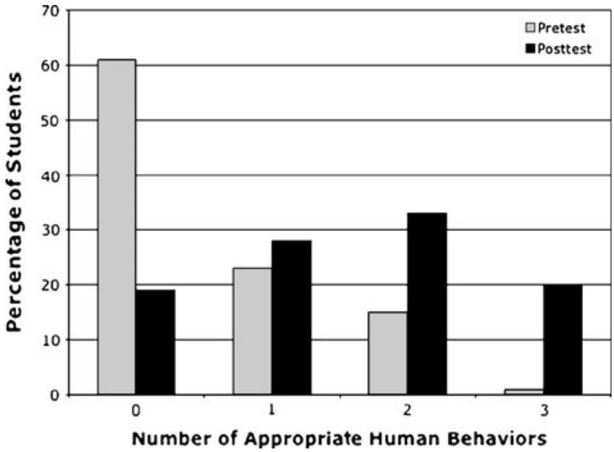
Understanding of Climate Change

General Understanding of Climate Change In order to assess any change in students' understanding of climate change, we examined their pre and posttest results as well as their responses on the student interviews. Table 7 provides the results from the entire student assessment and illustrates that the students achieved significant learning gains in terms of their increased understanding of the science content with a large effect size of 1.85.

Students understood significantly more about what global climate change is, the causes of global climate change and the effects of global climate change after the curriculum unit compared to before the unit.

Causes of Climate Change The open-ended item on the written assessment specifically asked students about three human behaviors that impact climate change and why those behaviors impact climate change. Figure 1 illustrates the percentage of students who received levels 0–3 in terms of identifying appropriate human behaviors that impact climate change on both the pre and posttest. On the pretest, 61% of the students received a zero, because they were unable to identify any appropriate behaviors and only 1% of students received a level 3. On the posttest, there is a clear shift in the percentage of students able to provide appropriate behaviors with only 19% of students

Fig. 1 Human behaviors on open-ended written assessment (n=75)



receiving a zero and 20% of students receiving a level 3. This suggests that students were able to identify more human behaviors after the curriculum compared to before, yet there is still room for improvement.

Figure 2 shows that the students struggled on both the pretest and posttest in justifying why the various human behaviors impact climate change (see Appendix C for codes). On the pretest, 95% of the students received a level 0. This percentage decreased to 67% on the posttest, yet the majority of students still received a zero. Furthermore, no students received a level 3 or a level 4. This suggests that students struggled in providing an explanation for why these human behaviors caused climate change in their writing.

Although students struggled on the written posttest in terms of explaining the causes of climate change, we observed considerable improvements during students' interviews. There was a significant increase in students' ability to explain the causes of climate change from the pre-interview (m=1.10, SD=0.94) to the post-interview (m=3.05, SD=1.02), $t\ (20)=8.010$, $p<.001$. As we described previously (see Table 3), we coded the interviews to assess the students' understanding of the causes of climate change. Levels 1–5 captured the number of the following elements that were accurately described by the students: Greenhouse gas, Example of greenhouse gas, Greenhouse effect, Weather patterns or Sources. This included one more level than the rubric for students' written responses in that we split greenhouse gas and example of a greenhouse gas. Yet overall we were looking for students to articulate similar causes of climate change. Figure 3 shows the percentage of students who received each level on both the pre-interview and post-interview. On the pre-interview, students' scores ranged from zero to three with 29% of students receiving a zero and 43% of students receiving a one. On the post-interview, none of the students received a level 0. This is very different than the written posttest where 67% of the students received a zero for their explanations of the causes of climate change. Furthermore, on the written posttest only 8% of students received a level 2 with no students receiving higher than a level 2. This level is equivalent to a level 3 on the post-interview, which 43% of the students received. Furthermore, 33% of the students received a level 4 or a level 5 on the post-interview, which is a more complex explanation than any student provided on the written assessment.

Given students were better able to explain the causes of climate change as part of the interview compared to the written assessment, we compared individual student's responses

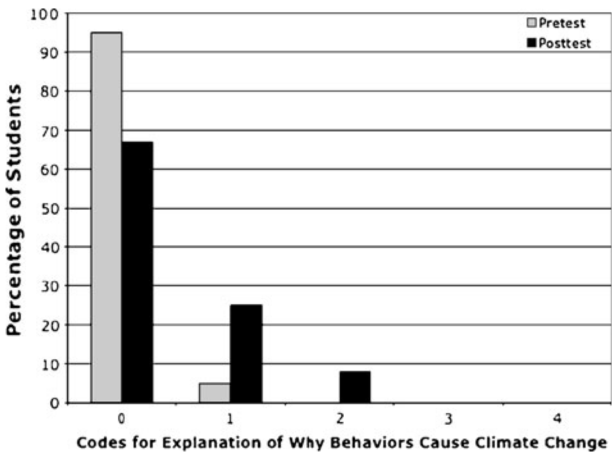
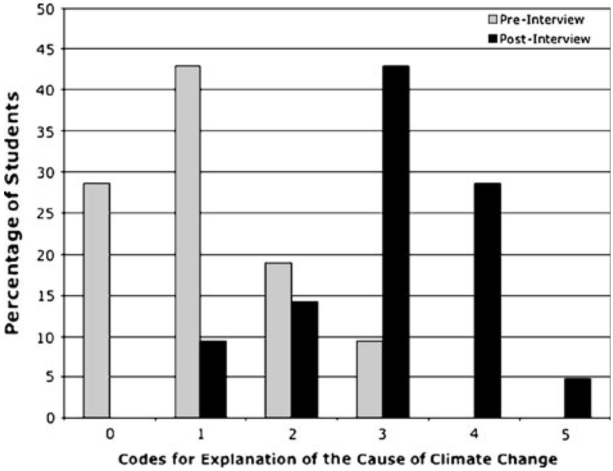


Fig. 2 Causes of climate change on open-ended written assessment (n=75)

Fig. 3 Causes of climate change from interviews (n=22)



on the tests and interview to further investigate the differences between these two forms of communication. We focused on students who completed both the written assessment and interview to ensure that the differences were because of the mode of communication and not because of a different understanding of the science content. Table 8 provides the written posttest response and the student interview response from three students, one from each teacher, to illustrate the differences that we observed.

Each student on the post-interview was able to provide a thorough explanation receiving a level 4 code. In terms of their writing, Olivia only received a 1 for her explanation of how human behaviors cause climate change. In her writing she mentions CO_2, but does not explain why or how CO_2 impacts climate change, while her interview provides a more in depth explanation of the role of greenhouse gases. Joe's responses are very similar to Olivia's response in that he also received a 4 on the interview, but only a level 1 on his writing, because he did not explain the role of CO_2. Pedro's explanation on the interview also received a higher score than his writing. He received a level 4 for his interview, but his writing was scored a level 0, because he did not explain how human behaviors impact climate change. In both Olivia and Pedro's writing, they provide three human behaviors that impact climate change, but they do not provide detailed explanations of how those behaviors impact climate change. In their interviews, both students provide much more detail about the role of greenhouse gases and specifically carbon dioxide in causing climate change. This difference may be because of the different wording of the written versus interview question. Another possibility is that certain characteristics of the interview setting, such as the act of talk versus writing or having an individual sitting there who is the audience, could support students in providing more detail. We discuss these possibilities in more detail in the discussion.

Consequences of Climate Change In terms of the consequences of climate change, many students were able to articulate at least one accurate consequence at the beginning of the science unit. Figure 4 provides the results from this analysis. On the pre-interview 77% of students were able to come up with at least one accurate consequence, which increased to 82% on the post-interview. We may have not observed a larger increase because it started so high to

Table 8 Examples of student writing and talk

Student	Posttest—written assessment	Post-interview
Olivia (Ms. Baker's class)	'When we drive cars we are putting out CO_2 into the air. The more CO_2 the thicker the greenhouse gasses get. Another reason is buying a lot of meat. Cows give off gasses and need a lot of room to grase including cutting down trees. The last is we give off gasses sometimes too using a lot of energy is bad too. So if we use foloresent lights would help'. (Coded 1)	'I think of the atmosphere heating up and how the greenhouse gases affect ... The sun beats down on the land, and it's already so hot that the carbon dioxide kind of makes a shield and it bounces off and goes into the atmosphere. But there's so much CO_2 that it kind of traps the gases in making heat hotter. And what happens is when the sun beats also on the ice, which is happening, it bounces off more and when that melts down you can see ground level and that makes it even hotter. So it's melting faster and faster. It's mostly like carbon dioxide in the air and how they're getting trapped and heating it up even more'. (Coded 4)
Joe (Mr. Dodson's class)	'One human behavior is the energy choices we make. Meaning if we choose to use something that runs on oil then we approve of combustion. Another behavior that impacts the climate change is the process of deforestation. This process is releasing more CO_2 in the air and increasing greenhouse gases. Lastly another behavior that impacts climate change is the excess use of nitrates and phosphates in agricultural lands. This leads to artificial eutrophication which damages the atmosphere'. (Coded 1)	'All the greenhouse gases in the atmosphere is pretty much heating up the earth and causing a lot of issues... I know that all the factories, and burning fossil fuels produce an excess amount of I guess carbon and greenhouse gases in the air, and that is trapping the air because of the amount that leaves it is not what it is supposed to be, it is over the limit I guess. So that creates the excess heat, and that ends up melting the ice polar caps which in turn creates higher sea levels and changes the water currents'. (Coded 4)
Pedro (Ms. Steven's class)	'Ignorance is one because if people don't care then it doesn't matter what anyone says to them. Carelessness, because if u are in a rush you might just do what ever to finish up something they may cause to hurt the environment or you just don't notice. And the last one which I'm alleriged to is stupidity because if your just plain stupid than you don't know what your doing or anything so your ignorant and careless at the same time'. (Coded 0)	'I learned about the greenhouse gases and the greenhouse gas effect, and how it traps infrared heat and it comes back to the earth and that's why the climate's getting hotter. The glaciers are melting and the polar bears are drowning. All the CO_2 emissions being produced, we're number 1'. (Coded 4)

begin with. In terms of the number of accurate consequences, we do see students provided more accurate consequences on the post-interview. On the pre-interview, on average students were able to provide 1.55 accurate consequences while on the posttest they provided 2.09 accurate consequences. Students with misconceptions, such as that climate change causes asthma or decreases the ozone layer, decreased with no students mentioning those misconceptions during the post-interview. Furthermore, the percentage of students that talked about death and destruction decreased on the post-interview. Unfortunately, the number of students describing short-term or current weather as a consequence of climate change increased from pre to post. One goal of the curriculum was to help students understand that climate change is not a short-

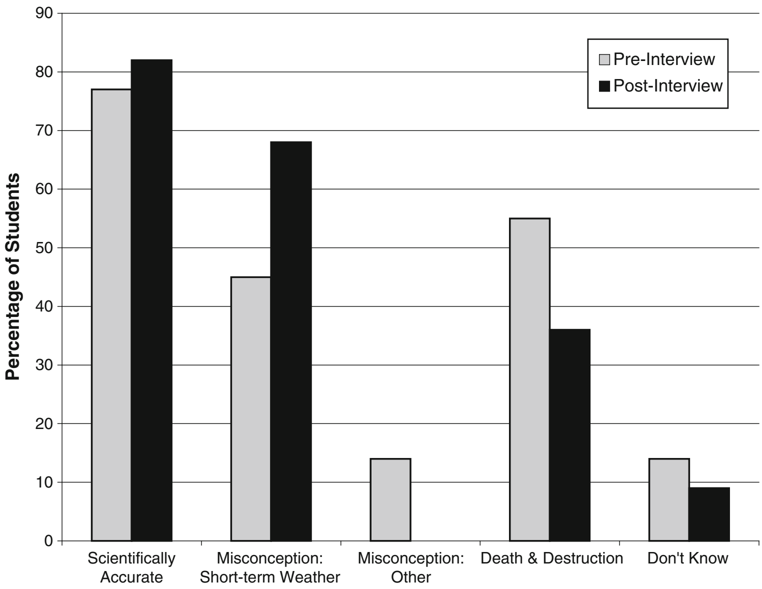


Fig. 4 Consequences of global climate change from interviews (n=22)

term process responsible for daily fluctuations, but rather a long-term process that has been occurring over the last one hundred years. A number of students cited the warm weather they experienced in the autumn and winter to be a result of climate change. For example, one student, Darren, said on his post-interview:

> it's getting hotter, and like it's not as bad as it was like a few years ago, or like it was last year, and it was like a whole lot warmer in the winter

When talking about the consequences of climate change, Darren discusses the warm weather that occurred in his city that winter. On the post-interview, 68% of the students brought up their local weather. This suggests that the students had difficulty distinguishing between short-term weather patterns and long-term climate change.

Beliefs about Climate Change

At the beginning of the curriculum, the majority of the students interviewed believed that the climate was changing. Before the curriculum 86% of the students said it is occurring with 14% of the students responding that maybe it was occurring. After the curriculum 90% of the students said it was occurring, with 5% responding maybe and 5% responding that it was not occurring. This suggests that overall students began and ended the unit believing that climate change was occurring. Although their overarching beliefs did not change, students' reasons for their beliefs did change. Figure 5 represents the students' reasoning. Only 15 students responded to this question on the pre-interview and on the post-interview so they are the only individuals included in the figure. On the post interview, students were more likely to provide scientifically accurate reasons for why they believed climate change was occurring either providing an explanation of the causes or consequences.

Considering that we observed an increase in their understanding of the causes (e.g. Fig. 3) and consequences (e.g. Fig. 4), it is not surprising that they utilized this information

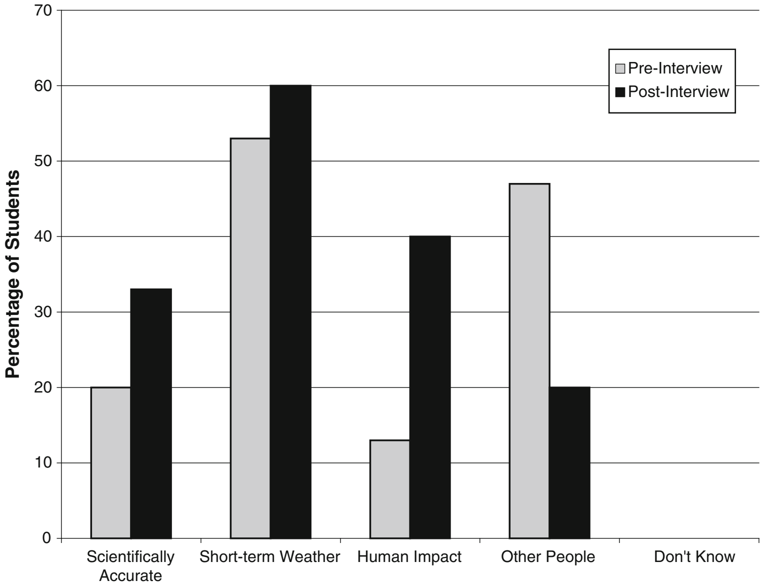


Fig. 5 Reasons for student beliefs about climate change from interviews (n=15)

in their discussion on the post-interview about whether or not they believed the climate was changing. Students were also more likely to talk about the role of humans and how their actions are impacting the environment suggesting they developed a greater understanding of how personal actions impact climate change. On both the pre and post-interview the most common response was to talk about short-term weather patterns. This is similar to what we observed when students discussed the consequences of climate change (e.g. Fig. 4). Students were coded for more than one category. For example, one student, Jamar, on the post-interview was coded for scientifically accurate, short-term weather and human impact for his reasons why he believed the climate is changing:

> Because of all the facts that were giving and um if you just look at how many trees are being cut down, the weather patterns—like that are occurring now, the whole thing with the glaciers um, your whole environment is changing so, yeah.

In his response, Jamar brought up glaciers melting, local weather patterns and humans cutting down trees. Jamar discussed multiple reasons why he believed the climate is changing. The one response that decreased on the post-interview was that other people or the media say climate is changing. On the pre-interview, students were more likely to give responses such as ‘because that’s what everyone is talking about right now’ and ‘The way people were talking about it in the movie, I think it is, yes.’ This suggests that while students’ beliefs that global climate change is occurring did not really change they were more likely to provide their own reason for their belief rather than just basing it on what they have heard other people say.

Environmental Actions around Climate Change

The last question we were interested in was whether or not students’ environmental actions changed at all over the course of the climate change curriculum. On the pre-interview, 50%

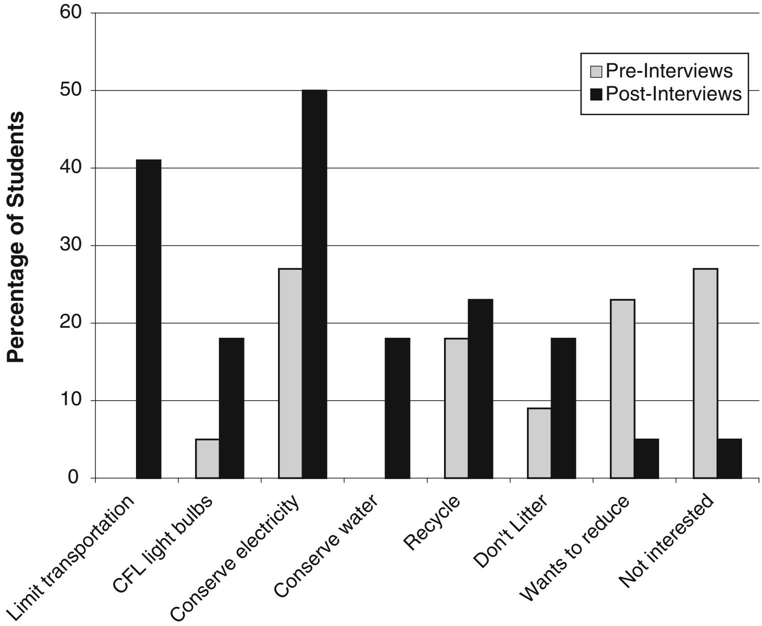


Fig. 6 Personal environmental actions from interviews (n=22)

of the students said they were currently doing something to limit their impact on global climate change (n=22). On the post-interview, 86% of the students said they were personally doing something to limit their impact on climate change (n=22). Only 3 of the 22 students on the post-interview said they were not doing anything to limit their impact. Besides the number of students increasing, the number and appropriateness of their actions also increased. Figure 6 illustrates the changes in their actions.

The percentage of students that discussed engaging in all of the different personal environmental actions increased. A larger percentage of students after the global climate change curriculum are limiting their energy consumption in terms of transportation (e.g. public transportation and carpooling), using more CFL light bulbs, conserving more electricity (e.g. turning off lights), conserving more water, recycling more and littering less. The only responses that decreased on the post interview were the percentage of students who said they would like to know ways to reduce their impact and students who said they were not interested in reducing their impact.

Discussion

Understanding of Climate Change

Overall, we found that students did have a significant increase in their scientific understandings of climate change after completing a four to six week unit specifically focused on this topic. By the end of the unit students had a stronger conceptual understanding of climate change including both the causes and consequences of climate change. Furthermore, although the majority of students believed the climate was changing during both the pre and post interviews, students were more likely to provide scientifically accurate rationales for their beliefs during the post interview. Students' interviews exhibited a stronger understanding of the causes of climate change with students articulating more complex explanations of the mechanism of climate change including a description of the sources of greenhouse gases, examples of gases and the greenhouse effect. In terms of consequences, students were able to describe more consequences by the end of the unit; furthermore, students did not mention any misconceptions about the consequences of global climate change at the end of the unit, such as increasing asthma or decreasing the ozone layer. This is in contrast to other research that has found that students still held misconceptions about the role of the ozone layer after instruction about global climate change (Rye et al. 1997). Yet as Rye and his colleagues recommended (1997), we explicitly incorporated instruction that clarified the role of the ozone layer during the climate change curriculum. Targeting these types of alternative conceptions in curriculum may be important in supporting students in developing a stronger understanding of climate change. By discussing and engaging in activities that address students' prior conceptions, students are able to reflect on and refine their previous ideas in order to develop richer and more scientifically accurate understandings.

Furthermore, as Jakobsson and his colleagues (2009) argue, the acquisition and use of appropriate scientific language, particularly when focusing on complex socioscientific issues, is a long and gradual process. Over the course of this four to six week curricular unit on global climate change, students had multiple opportunities to actively construct and reform their ideas about climate change. Students engaged in classroom activities as well as field investigations that supported them in refining their ideas. Altering students' conceptual understandings of climate change takes time and cannot be expected to occur over one or two lessons. Future research should investigate whether an even longer and more in depth curricular unit would support students in being able to articulate even more complex understandings of this socioscientific issue.

Climate Change as a Long Term Process

One area that students did still seem to struggle with was distinguishing between short-term versus long-term consequences. On the post-interview, the majority of the students cited the uncharacteristically warm weather that autumn as one consequence of global climate change. Students did not appear to fully grasp that climate change is a long-term process occurring slowly over tens of hundreds of years. Rather they seemed to focus more on whether the temperature was warmer than what they viewed as typical in their specific city.

Previous research focused on students' concepts of time suggests that they struggle to differentiate the time scale of different natural events (Trend 1998). Individuals tend to categorize events into general categories, such as extremely ancient, moderately ancient and less ancient, with little distinction within each of those categories (Trend 2001). In terms of climate change, students may view this event as occurring "less ancient" or even a different category such as "more recent" and struggle with differentiating between a trend over the last one hundred and twenty years compared to a trend over one year. Previous research examining students' conceptualization of scale shows similar struggles compared to those with geologic time. Students have difficulty estimating the size of objects outside of the visible realm with their accuracy decreasing at very small and very large scales (Tretter et al. 2006).

In the case of climate change, students struggled to conceptualize changes in weather patterns outside their own lived experience. Instead, they associated what they were learning about global climate change with the exceptionally warm autumn the students had experienced. One weakness of the climate change curriculum investigated was that it did not take into account students' previous conceptions about the role of short-term weather patterns nor did it provide sufficient support to help students develop an understanding of the distinction between short-term weather patterns and long-term climate change. Consequently, future climate change curriculum may need to include a specific focus on supporting students in developing a richer understanding of time and scale. Furthermore, students need to understand that a single event, such as one uncharacteristically warm or cold season, is not sufficient evidence to validate or invalidate a scientific process such as climate change. Individuals evaluate data based on their prior conceptions and theories (Chinn and Brewer 2001). If students believe that a single event is sufficient, this can significantly impact their interpretation of climate change data. In investigating controversial issues in science, students need support in distinguishing between strong and weak scientific evidence (Oulton et al. 2004). Consequently, in addition to supporting students in developing an understanding of time and scale, it is important for climate change curriculum to support students in understanding the importance of using multiple data points and trends in data to evaluate long-term scientific processes. These student misconceptions are important to address in the future design of climate change curriculum. Furthermore, future research should investigate how addressing students' initial conceptions through the use of climate change curriculum impacts their development of content knowledge.

Written Test vs. Interview

In terms of the causes of climate change we found that students provided stronger explanations during the interview compared to the written assessment. There are multiple possible causes of this difference. One possible cause is the wording of the questions and how the two measures were administered and analyzed. For the written assessment, we evaluated students' understanding of the causes of climate change by analyzing their responses to one-open ended item that asked students: What are three human behaviors that impact climate change? Why? Students only had one opportunity to articulate their understanding of the causes of climate change and it was specifically asked in relation to the role of humans. This is in contrast with the student interview in which we analyzed students' responses across multiple questions of the interview in order to assess their understanding of the causes of climate change. We decided to assess students' understandings of climate change across the interview, because we found that students often revisited and clarified an idea they had brought up in an earlier question. The format of the interview provided them with more opportunities to express their understanding of the causes.

Another possibility for this difference in students' explanations is that the form of communication, written versus oral, influences students' ability to express their level of understanding. This aligns with Jakobsson and his colleagues (2009) recent critique of climate change research in which they argue that students' written work presents a negative bias of students' understanding of climate change. Other educational researchers in literacy have found that students' written work typically lags behind the quality of their ability to communicate orally (Kantor and Rubin 1981). This suggests that focusing solely on students' written work about global climate change may underestimate students' scientific knowledge. Furthermore, the role of audience can be important in terms of how students communicate (Wollman-Bonilla 2001). During an interview, there is clearly a specific audience with whom the student is communicating with and trying to explain their ideas. As Roth (2005) argues, language is always bound up in the purpose for which that language is used. Often language use in schools is not a purposeful activity, but rather is just seen by students as part of the game of school. Engaging in an interview where the students were trying to explain their ideas to a person sitting in front of them may have been a more purposeful activity, because of the audience. This suggests that a more purposeful writing activity, such as a flyer or letter to convince others of the importance of climate change, may have encouraged more elaborate explanations of what is causing climate change compared to a decontextualized written assessment. Designing a different type of written assessment than a traditional test may also provide opportunities to engage in more holistic coding, like we used in the interview, where ideas can be revisited in the artifact. When evaluating students' understanding of science concepts, it is important to consider both oral and written assessments as well as the perceived purpose of the assessment by students. Future research needs to compare different assessment measures and their ability to evaluate students' conceptual understandings and environmental actions.

Critical Science Agency and Environmental Action

Critical science agency should be an essential outcome of science education, which includes students not only developing deep conceptual understandings, but also using science knowledge to take action at either an individual or community level (Basu et al. 2009; Calabrese Barton 2008). One of our explicit goals of the global climate change curriculum was to support students in engaging in environmental actions. After the curriculum, the majority of students reported they were now currently engaged in some action to limit their impact on climate change. Consequently, we observed that students' reported environmental actions did increase. Furthermore, the number and appropriateness of the environmental actions they discussed increased to include more ways of limiting their energy consumption such as in terms of transportation (e.g. public transportation and carpooling), using more CFL light bulbs, and conserving more electricity. This is particularly interesting when considered in conjunction with the fact that their beliefs about whether the climate was changing did not alter—most students thought the climate was changing on both the pre and post interview. This suggests that just believing the climate is changing is not enough to motivate students to engage in environmental action. Students can feel that the responsibility for environmental action falls more to others than to their own personal actions (Skamp et al. 2004). The fact that the majority of students felt the climate was changing at the beginning of the unit, but they were not engaged in personal environmental action to prevent this suggests that the students may have felt they were not responsible for the problem or did not know how to engage in action at the beginning of the curriculum. This leads us to ask the question—What occurred during the curriculum to promote their greater environmental action?

One possibility is that the students' greater understanding of the science behind global climate change encouraged the students to engage in more environmental actions. On the pre-interview 27% of the students responded that they were not interested in engaging in environmental actions that would limit their impact on global climate change. Perhaps developing a stronger understanding of climate change helped encourage these students to want to engage in action. This aligns with previous research that found that fifth-grade students with science knowledge tended to express environmental activism more frequently than students without content knowledge; furthermore, students' activism increased as they gained better science knowledge (Lester et al. 2006). Yet other research suggests that there is not necessarily a causal link between knowledge and action (Kollmuss and Agyeman 2002). Conceptual knowledge is important for students to leverage in order to use that science knowledge to take action and impact their lives and their worlds, but it is not sufficient to support students in developing agency (Basu et al. 2009). Consequently, although the students' greater scientific understanding may have impacted their environmental actions, we do not feel that it was the sole cause of the changes in students' environmental actions.

Another characteristic of the curriculum that may have impacted the change in students' environmental actions is the specific focus on how humans in general impact climate change as well as how the students' individual choices impact climate change. Previous research with college students found that those students enrolled in a two-month course with a specific focus on environmental action and responsible environmental behavior had greater gains in students' environmental responsibility, intention to act, perceived knowledge of and skills in using environmental action strategies and responsible environmental behavior, compared to college students in a control group (Hsu 2004). Students require not only knowledge about environmental problems, such as climate change, but also specific skills and strategies that empower them to change their own environmental behaviors as well as those behaviors of others, such as knowledge about how energy choices impact the environment. Students may feel that their choices and actions do not impact the health of the natural environment and need support to realize that their actions do make a difference.

Critical science agency (Basu et al. 2009; Calabrese Barton 2008) is essential for scientific literacy that not only supports students in understanding the world around them, but also promotes responsible scientific behaviors for environmental topics, but also other socioscientific issues. In today's science and technology infused world, individuals need to make informed and responsible decisions and engage in actions that impact not only themselves, but also their community and their environment. In order to support critical science agency, future science curriculum should include not only a focus on scientific knowledge and scientific inquiry practices, but also a focus on action at the individual and community levels.

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Appendix A: Pre and Post Test Questions

<u>Multiple-Choice Items</u>

3. Climate change

    a. is only caused by human activities
    b. explains a previous summer's heat wave
    c. is a change in long-term weather patterns
    d. explains the decrease in available fossil fuels

9. Greenhouse gases in the Earth's atmosphere trap:

    a. heat, but not visible and ultraviolet light
    b. visible light, but not heat and ultraviolet light
    c. ultraviolet light, but not heat and visible light
    d. heat, visible and ultraviolet light

10. Carbon sequestration is

    a. The production of carbon dioxide by cars
    b. The amount of carbon that is produced by burning one tree
    c. The amount of carbon dioxide that is in the Earth's atmosphere
    d. The removal and storage of carbon from the Earth's atmosphere

12. If the earth had no greenhouse effect, the average surface temperature would be:

    a. lower than present
    b. higher than present
    c. the same as it is now
    d. scientists just aren't sure

14. Which of the following is **NOT** the result of global climate change

    a. storms become more intense
    b. ocean levels decrease
    c. timing of season changes
    d. tropical diseases spread north

15. The primary cause for the Earth's greenhouse effect is:

    a. Water vapor in the atmosphere
    b. An increasingly hot sun
    c. Increasing carbon dioxide in the atmosphere
    d. Decreasing ozone levels in the atmosphere

Open-ended Item

2. What are three human behaviors that impact climate change? Why?

Appendix B: Interview Questions

Question 2 was altered on the post interview to acknowledge that students had just completed a curriculum unit focused on global climate change.

1. What comes to mind when you hear the phrase global warming? What do you think it means?
2. PRE—Where have you heard about or gotten information about global warming? What did you learn from that source?
2. POST—What have you learned specifically about global warming from this class? Can you explain the scientific process of global warming?
3. Do you think global warming is occurring? Why or why not?
4. Is it an issue that concerns you? Why or why not?

    a. *If consequences do not come up*—What do you think are the consequences of global warming?

5. Are you currently doing anything personally to limit your impact on global warming?

Appendix C: Rubric for Open-Ended Assessment

Open Ended Question: 'What are three human behaviors that impact climate change? Why?'

Code	Level 0	1	2	3	4
Three Human Behaviors	Provides no appropriate behaviors.	Provides 1 appropriate behavior.	Provides 2 appropriate behaviors.	Provides 3 appropriate behaviors.	N/A
	May include inappropriate behaviors such as: throwing trash, spitting, using hair spray, and cigarette smoking.	May include appropriate behaviors such as: driving cars, burning fossil fuels, running factories that create pollution, creating green spaces, cutting down trees, and buying local (or non-local) food.	May include appropriate behaviors such as: driving cars, burning fossil fuels, cars or factories producing greenhouse gases, creating green spaces, cutting down trees, and buying local (or non-local) food.	May include appropriate behaviors such as: driving cars, burning fossil fuels, cars or factories producing greenhouse gases, creating green spaces, cutting down trees, and buying local (or non-local) food.*	
Explanation for why the behaviors cause global warming	No explanation or an inappropriate explanation.	1 of any of the following: Greenhouse gases OR Heat OR Energy OR Weather patterns	2 of any of the following: Greenhouse gases OR Heat OR Energy OR Weather patterns	Greenhouse gases + Heat OR Energy + Weather pattern	Greenhouse gases + Heat + Energy + Weather pattern
	May include an inappropriate explanation such as—Using coal to burn is dangerous because people inhale that and get asthma.	Describes how the behaviors either increase or decrease greenhouse gases. OR Greenhouse gases trap heat in the atmosphere OR Greenhouse gases increase the amount of energy in the atmosphere. OR This energy/heat causes long-term weather patterns to change.	Describes how the behaviors either increase or decrease greenhouse gases. OR Greenhouse gases trap heat in the atmosphere OR Greenhouse gases increase the amount of energy in the atmosphere. OR This energy/heat causes long-term weather patterns to change.	Describes how the behaviors either increase or decrease greenhouse gases. Greenhouse gases trap heat in the atmosphere OR Greenhouse gases increase the amount of energy in the atmosphere. This energy/heat causes long-term weather patterns to change.	Describes how the behaviors either increase or decrease greenhouse gases. Greenhouse gases trap heat which increases the amount of energy in the atmosphere. This energy causes long-term weather patterns to change.

*Points were not taken off for mentioning inappropriate behaviors. The levels were only based on the number of appropriate behaviors mentioned.

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