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Investigating Weather, Climate, and Climate Change Understanding of Appalachian Middle-Level Students

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ABSTRACT

Climate change is an increasingly pervasive global topic, but how much of this discussion is accurately understood by students? Fully comprehending the small fluctuations associated with long term changes in temperature and precipitation is a daunting task for the general public, let alone for middle-level adolescents. This study examines students' understanding of weather, climate and climate change. Forty-seven students, ages 12-14 from the Appalachian region of the US, were surveyed before, immediately after, and six months after a standards-based unit of instruction. The study utilized a questionnaire developed by Boon (2009) with additional questions related to weather and climate. Qualitative data were analyzed using a constructivist framework and student responses were examined for understanding of the main content ideas. The students' understandings were analyzed over time for shifts and were also compared with previously published research (Bodzin et al., 2014; Boon, 2009). Students made improvements in some aspects of understanding with instruction but not all gains persisted to six months post instruction. Students' distinctions between weather and climate were altered by instruction, persisted, and continued to improve with time. Students demonstrated a general understanding of the differences between weather and climate but struggled when asked to apply this knowledge to specific situations. Some improvements in students' basic understanding of the greenhouse effect were evident, but some of these improvements degraded with time. While instruction was able to temporarily improve understanding of greenhouse gases, and the benefits of the greenhouse effect, overall students did not retain this understanding over the long term.

Keywords: earth science education, longitudinal study, scientific literacy, climate literacy

Introduction

One of the most important challenges facing the citizens of the 21st century will undoubtedly be climate change. Yet, understanding climate change remains problematic (Dawson, 2015; Khalid, 2003). Distinguishing small fluctuations from long term changes in temperature and precipitation is challenging for the general public, let alone for the adolescent (Harker-Schuch & Bugge-Hendrikson, 2013; Lambert et al., 2012). Unfortunately, students may only receive instruction on this general environmental science topic in middle-school and in a general science course during their freshman year of high school. This study examines the understanding of weather, climate and climate change, of Appalachian middle-school students, before, immediately after, and 6 months after a standards-based unit of instruction prior to adoption of the Next Generation Science Standards (NGSS). Future research will monitor how these middle-school students' understanding 1) evolves through high school and 2) compares with students in this area after adoption of NGSS.

A better understanding of what students know during the adolescent age, when they receive the most instruction on environmental issues, can be helpful for scientists and educators as they prepare scientifically literate adults. To this point, two studies (Boon, 2009; Bodzin, Anastasio, Sahagian, Peffer, Dempsey, & Steelman, 2014) provided useful research in this area. However, both studies assessed student understanding at one point in time only. The current study adds to the research base because it assesses students' longitudinal knowledge (*before*, *immediately after, and 6 months after* a standards-based unit of instruction) of the earth-atmosphere system. Additionally, this research study positions the analysis within a constructivist framework, where students are recognized as being owners of their own knowledge (Carr, Barker, Bell, Biddulph, Jones, Kirkwood, Pearson and Symington, 2013; Von Glasersfeld, 2013). This positioning allows for an analysis of student thinking and subsequent recommendations for classroom teachers regarding productive instructional practices. As such, this research provides preliminary data analyses that support continued research to further investigate students' understanding of weather, climate and climate change as they progress through high school.

Background

Student Distinctions Between Weather and Climate

Weather describes the atmospheric conditions over short-term duration (minutes, hours, days, months, and years), while climate describes these same conditions averaged over at least a 30-year period over a much wider area (National Climatic Data Center, 2008). Researchers have established that both middle-school and high-school students have problems distinguishing between weather and climate (Papadimitriou, 2004; Lombardi & Sinatra, 2012). Dawson (2015) found that high school students use the terms 'weather' and 'climate' interchangeably. Bodzin et al. (2014) found that the majority of middle-school students recognized that climate changes at a much slower rate than weather, but few students understand that a region's climate describes a region's weather conditions and that this changes on the order of decades. The majority of middle-school students felt that "climate is defined as weather patterns that change on a scale of at least a few *weeks*" rather than the correct response of *decades* (Bodzin, et al., 2014). Undoubtedly, an understanding of the greenhouse effect and climate change requires that students be able to differentiate between weather and climate (Jarrett, Ferry, & Takacs, 2012).

It is only natural that people use their experiences with local weather to make critical inferences about global climate (Read et al., 1994). Read et al. (1994) suggested that people do, in fact, use their short-term weather experiences (like heat waves or cold spells) to make judgments about longer term climate trends. Similarly, preservice elementary teachers cited recent weather events (such as a summer heat wave) to serve as evidence of global warming (Papdimitriou, 2004). Other research has shown that 60% of high school students indicated that "climate often changes from year to year" (Gowda et al., 1997, p. 2236). Additionally, 15% of these same high school students indicated that they had personally witnessed evidence of climate change. Gowda et al. (1997) claimed that these evidences of climate change were "memorable weather events" (p. 2236) (e.g. a flooding event, a hot summer, or lack of snow at Christmas).

Additional confusion between weather and climate may result from a students' perception and understanding of deep time (Lombardi & Sinatra, 2012). Deep time is often referred to as geological time and has been shown to be challenging for students to understand (Libarkin et al., 2005; Prather, 2005). Lombardi and Sinatra (2012) examined undergraduate students to determine if there was a relationship between their understanding of deep time and their distinctions between weather and climate. They found that a greater knowledge of deep time and improved perceptions of human-induced climate change explained a significant portion of the variance in students' understanding of weather and climate distinctions. Nevertheless, students have been shown to improve their differentiation between weather and climate with a relatively brief intervention (Lombardi & Sinatra, 2012).

Student Understanding of Climate Change Issues

Middle and high school students often confuse climate change with unrelated environmental issues and therefore, have a limited understanding of environmental responses to climate change (Bofferding & Kloser, 2015). Students understand that carbon dioxide plays an important role in climate change but are not familiar with other greenhouse gases (GHG). Specific alternative conceptions include naive understanding about increases in GHG and ozone depletion (Bodzin et al., 2014; Bostrom et al., 1994; Rye, Rubba, and Wiesenmayer, 1997), inability to identify GHG (Bodzin et al., 2014;Bofferding & Kloser, 2015), GHG distribution in the atmosphere (Bodzin & Fu, 2013), and global climate change impacts on other Earth systems (Shepardson et al., 2009). Additionally, students often attribute air pollution or acid rain to climate change (Bofferding & Kloser, 2015). Students lack the complex understanding of climate change and often demonstrate an oversimplified understanding as a "unidirectional linear cause-effect" model (Shepardson et al., 2014). Additionally, students struggle with identifying and associating appropriate actions that might reduce climate change (Bodzin et al., 2014, Boyes & Stanisstreet, 1993; Boyes et al., 2009; Kilinc et al., 2011). These studies have shown some success with actions such as reducing car usage, using more fuel-efficient cars, less electricity and more alternative energy sources but remaining challenges associated with litter, pollution, endangered species, insecticides and nuclear energy.

These issues in student understanding have been confirmed in many international studies throughout many different countries. Dawson's study (2015) revealed that Australian students identified carbon dioxide as the only GHG. Likewise, Fisher (1998) reported that Australian students associated GHG with the ozone layer. Similarly, Boon (2009) compared Australian students with British students and that both held similar misconceptions related to GHG and climate change. Additionally, Australian, Norwegian and Turkish students held some level of understanding of the greenhouse effect but held misconceptions regarding both the ozone layer and greenhouse effect (Kilinc et al., 2011).

Impact of Instruction on Climate Change Understanding

Even though students' understanding about climate change has been well documented, research literature suggests that these misconceptions can be modified through effective instruction (Bodzin & Fu, 2013). Lectures on climate change were shown to slightly improve Austrian and Danish students' understanding about climate change (Harker-Schuck & Bugge-Hendrikson, 2013). Visualizations and virtual experiments were shown to be effective in improving Year 6 student understanding of global climate change (Varma & Linn, 2011). A three-week intervention using a variety of instructional techniques that focused on climate change being a socioscientific issue statistically improved Year 10 student understanding (Klosterman & Sadler, 2010). Similarly, McNeill and Vaughn (2012) found similar results in Year 11/12 students after an 11-lesson unit which targeted climate change and environmental action. Middle-school climate change instruction which utilized critical evaluation and plausibility appraisal promoted greater understanding of socio-scientific topics and increased use of scientific thinking when considering alternative explanations (Lombardi, Brandt, Bickel, & Burg, 2016). Similar to this current study, all of these studies relied on heavy collaboration between the researcher and teacher to deliver effective instruction. While many studies show changes in student understanding of climate change, measures of the persistence of that knowledge months after instruction, is noticeably absent in the literature.

Research Focus and Questions

This study compared students' understanding of weather, climate and climate change before (t_1) a unit of instruction on these topics, immediately after (t_2), and six months post instruction (t_3) which took place in 2011-2012 before the NGSS were adopted in 2016.
This study explored the following two research questions:

(1) What are Appalachian middle-level students' understandings about weather, climate and climate change?

(2) Following a standards-based unit of instruction, how do these understandings persist over time: immediately post instruction (t_2) and after 6 months of time (t_3)?

Methodology

Participants

Forty-seven students between the ages of 12-14 years old participated in this study. The middle school is located in a suburban area of a mostly rural Appalachian state with a total enrollment of approximately 600 students of which 95% identify as white. As it is imperative to establish the context and influence of community, this middle school is located within a state that is predominantly supported by the coal industry. Obtaining approval for curriculum standards addressing climate change has proven to be a challenge given the influence of extractive industries and the dependence of residents on them for their livelihoods. This context develops unique and important cultural experiences for students in this region and naturally affects their perceptions about the consequences of mining, extracting and processing coal. The researchers recognize the potential impacts here on students' understanding about topics such as climate change and this is discussed more in the results section. The targeted student population included a range of academic abilities but did not include any students with identified disabilities because the school did not have access to sufficient support services for all academic teams. Students were placed in these academic teams based upon two factors: 1) the lack of an identified learning disability and 2) their math course requirements. Three teams were included in this study which included one team of 7^{th} graders taking Algebra I and two teams of 8^{th} graders. The majority of the 8^{th} graders were taking Algebra I, but a few were enrolled in Geometry from the nearby high school.

Assessment Measure Development

Previously published research provided the international comparison dataset as well as the majority of the assessment measure. The Boon study (2009) included the following: 168 year 10 (ages 14-15) and 183 year 8 (ages 12-13) students from a northern UK city and 79 year 8 (also ages 12-13) students and 310 year 10 (ages 14-15) students from four schools in a Queensland, Australia city. Both of these studies in Australia and the UK were conducted when there was a high level of media coverage of the phenomena in each of the countries due to unseasonal weather patterns and political debates taking place in both countries. Relatively little media coverage was present in the US as the political climate was focused on economic issues associated with the recession of 2011. Boon developed the initial assessment measure after two pilot tests were conducted on a class of year 8 students in the UK (2009). Boon examined the student responses and selected the most suitable questions from the two trial administrations.

The present study utilized Boon's previously published questions (Boon, 2009) which included multiple choice, yes/no, and constructed response type questions. To add depth to the assessment measure, additional questions related to weather and climate, not included in Boon's study, were developed and included. These additional weather and climate questions were developed by the lead author who is a meteorologist, and the questions were read for face validity (Creswell, 2008) by meteorologists at the National Weather Service. The questions push the participant to think beyond memorized definitions and were developed to ascertain participant understanding of real-world application differences between weather and climate. The complete assessment measure used in this study can be found in Appendix A.

The assessment measure was given to 47 year 7 and 8 students (ages 12-14) at three different time periods during the 2011-2012 academic year: 1) t_1 - before instruction, 2) t_2 - immediately post instruction, and 3) t_3 - six months after instruction (delayed post) by the students' usual science teacher. The portion of students with parental consent also participated in semi-structured group interviews at the delayed post time period (t_3). The interview questions can be found in the Appendix B. The group interviews were used to add clarity and depth to the student responses on the weather and climate questions particularly. Students were a convenience sample based on the willingness of the classroom teacher to provide instructional time for the lead author to provide the unit of instruction (described below).

A total of 20 questions were used on the assessment measure, some of which, were divided into multiple prompts resulting in 43 items requiring student responses. Of these items, 22 were used in this study. To tease out student understanding of aspects of weather and climate change, these questions were grouped into three categories: weather and climate (9 items), human actions and the greenhouse effect (6 items), and greenhouse gases (7 items). Paired-comparison two-tailed t-tests were performed between each administration of the instrument with the basic assumption that the differences in scores were normally distributed in a class with little to no instruction on climate change. A confidence interval of 95% was chosen to determine the mean differences. The tests were used to compare student knowledge of climate change prior to instruction (t_1 - pretest) with knowledge post instruction (t_2 - posttest), student knowledge post instruction (t_2- posttest) with knowledge six months post instruction (t_3- delayed posttest), and finally student knowledge prior to instruction (t_1- pretest) with knowledge six months post instruction (-t_3 delayed posttest). Normalized gains (<g>) and effect sizes were calculated overall and for each of the assessment measure categories: weather vs climate and greenhouse effect to indicate effectiveness of instruction in promoting conceptual understanding. The "average of gains" method was used since it was possible to match the student data.

Interviews

After completing the 6-months post instruction assessment measure (t_3), students participated in small group semi-structured interviews with the same single member of the research team. The semi-structured group interviews lasted 30 minutes and questions to the participants focused on the weather and climate statements particularly. Four sets of interviews with four participants each were conducted for a total of 16 students (those students who had submitted a parental permission form for the interviews). All interviews were audio recorded and transcribed. The primary focus and purpose of the interviews was two-fold: 1) to gather feedback on the weather and climate statements which were developed for this study and 2) provide opportunity for students to vocalize their thinking about these topics which would help us interpret their survey results. The semi-structured group interview protocol is provided in Appendix B.

Themes found in responses to the interview questions provided insights into questionnaire responses. As described by Cohen, Marion and Morrison (2002), a content analysis was performed on the interview transcripts. As is customary with content analysis, "categories are usually derived from theoretical constructs or areas of interest devised in advance of the analysis" (p.475). The initial categories used for this study were: greenhouse effect, greenhouse gases, climate, climate change and weather. Members of the research team coded the transcripts independently looking for both "correct response" as well as student statements that revealed the reasoning connected to the response for the predetermined categories. Developing and using these primary categories allowed the researchers to focus in on the most relevant remarks made in the interviews. Upon completion of the content analysis, researchers re-examined the data pieces selected and looked for overlap and resonance with regard to major themes and understandings. For example, one theme that emerged was the idea that what happens in nature is cyclical and "just happens." This idea was expressed by several students and often cited as a reason for natural phenomena. These data were then used to better understand some of the quantitative responses linked to understanding of climate change. Appendix C contains a diagram of the coding scheme with sample quotes included for further clarity.

Unit of Instruction

In the fall of 2011, a 10-day unit of instruction was provided by the lead author who served as a temporary teacher to the 12- to 14-year-old students. The unit was based on the state standards and NSES for grades 5-8 which were in effect at the time. The unit of instruction was based primarily on the instructional standards for the state rather than on the assessment measure which had been developed by Boon. To avoid "teaching to the test," the unit was developed with the most relevant concepts as described in the state and national standards. As expected some of these concepts are not included on the assessment measure, but still do play a role in supporting students' content knowledge development in related areas. Likewise, some aspects of the assessment measure were not directly addressed because they were not prevalent in the state standards. This paper will focus on those aspects of the assessment measure which were included in instruction.

At the time of the research, climate change and the greenhouse effect were absent from both state and national standards in the middle school curriculum. Some additional instruction was provided to students which went beyond the expected middle school curriculum regarding the greenhouse effect particularly. The Appendix D presents a comparison of the state standards, the lesson's essential question, the student learning objectives, a summary of the lesson, and the corresponding question number on our assessment measure. Each lesson was presented over a 2-day period. The majority of instruction (80% instructional time) focused on those concepts directly related to weather and climate which were clearly specified in both state and national standards, which did not necessarily have questions addressing these topics in Boon's original assessment measure. The remaining instruction targeted ideas related to GHG and climate change, particularly the role that GHG have in mitigating day vs. nighttime temperatures and how they may impact climate change which extended beyond the minimum state standards. Data and evidence of changing amounts of carbon dioxide were also shown and discussed to launch student thinking regarding our atmosphere with an enhanced greenhouse effect.

The five-lesson unit of instruction was based on the 5E Learning Cycle (Bybee et al., 2006). Students were initially engaged with the activation of prior knowledge (Engage phase), then they actively collected evidence as they explored (Explore phase). In the third E students made sense of their evidence by building new scientific explanations (Explain phase) and then they were given a new situation where they applied their new understanding (Elaborate phase). Finally, students' understanding was evaluated throughout the lesson to determine if further instruction was necessary (Evaluate phase).

Findings and Results

As described previously, our assessment measure naturally divides into three groups of themed questions which focus on: differentiating weather and climate, the greenhouse effect, and greenhouse gases. The following discussion subheadings are based on these themes.

Weather vs. Climate

Nine questionnaire statements required students to choose either weather or climate as the cause of various phenomena. The percentage and frequency (n) of correct responses for each statement is provided in Table 1. On the pretest, students correctly identified weather or climate prompts 63% of the time. Students demonstrated prior knowledge on only two of the nine items: almost all students accurately associated weather with snowfall during winter storms (90%) and a majority associated climate with changing bird migrations (77%). Students scored less than 75% on the remainder of the items. Students had the most difficulty with two statements: "c. a summer heat wave with very hot temperatures" (38%) and "several decades with the most hurricanes ever recorded" (47%).

Following the unit of instruction (t_2), 75.2% students correctly identified weather or climate prompts. The significant increase in posttest scores indicated instruction was able to improve student distinction between weather and climate. At the end of instruction, while scores increased on seven of the nine items, students only made significant gains ($p< 0.05$) on three statements, "a summer heat wave with very hot temperatures" (which they struggled with on the pretest (t_1)), "a major outbreak of tornadoes with loss of life" and "a summer season with the most hurricanes ever recorded." Instruction was not able to significantly alter student perceptions on the "increase in hurricanes over several decades." Largest gains were made on the summer heat wave statement. Normalized gain and effect size calculations suggest modest or medium conceptual gains from pre to posttest (Figure 1).

After six months (t_3), student perceptions of weather and climate continued to increase significantly ($p<0.05$). Improvements were measured between post instruction (t_2) and six months after instruction (t_3) ($p < 0.05$) on two statements: drying up of a large lake*,* a ten-year period with the most hurricanes ever recorded. Normalized gains and effect size suggest medium conceptual gains in the time between instruction and the delayed posttest (t_3) (Figure 1).

Table 1

Percentage (%) and Frequency (n) of Correct Responses

Weather-climate prompt (correct response)	**Pretest % items correct (n)**	**Post test % items correct (n)[1]**	**Delayed post % items correct (n)[2]**	**Pretest to delayed post[3] % change**
a) drying up of a large lake *(climate)*	57% (27)	68% (32)	89% (42)*	32%*
b) a winter storm that dumps a large amount of snow *(weather)*	89% (42)	94% (44)	97% (46)	8%
c) a summer heat wave with very hot temperatures *(weather)*	38% (18)	64% (30)*	72% (34)	34%*
d) leaves budding out on trees earlier and earlier in the spring *(climate)*	66% (31)	74% (35)	74% (35)	8%
e) a warmer winter without any major snowstorms *(weather)*	64% (30)	62% (29)	74% (35)	10%
f) a major outbreak of tornadoes with loss of life *(weather)*	72% (34)	96% (45)*	91% (43)	19%*
g) birds migrating to warmer areas later and later in the fall *(climate)*	77% (36)	87% (41)	89% (42)	12%
h) a summer season with the most hurricanes ever recorded *(weather)*	62% (29)	85% (40)*	83% (39)	21%*
i) a ten-year period with the most hurricanes ever recorded *(climate)*	47% (22)	47% (22)	85% (40)*	38%*
Category Averages (st dev)	**63.6% (19.2)**	**75.2%* (17.5)**	**85.2%* (17.0)**	**18%**

Note. *significant changes $p<0.05$, [1]pretest to post test, [2]post test to delayed posttest, [3]pretest to delayed posttest

Figure 1

Pre-, Post-, and Delayed Post-Test Means, Standard Deviations, Normalized Gains and Effect Sizes

	Statistics	PreTest		Post Test		Delayed Post test			Change
Prompt Category			Pre to Post Change		Change Post to Delayed Post		Change Pre to Delayed Post		
Weather (9 prompts)	Mean	63.6%		75.2%*		84.2%			
	Std Dev	19.2		17.5		17.0			
			0.32		0.36		0.56		Norm. Gain
			0.60		0.51		1.1		Effect Size
Greenhouse Gases (7 prompts)	Mean	52.9%		62.6%		58.7%			
	Std Dev	15.5		15.3		18.4			
			0.21		-0.11		0.12		Norm. Gain
			0.63		-0.21		0.31		Effect Size
Human Actions (6 prompts)	Mean	39.7%		55.0%		51.4%			
	Std Dev	29.6		24.8		25.2			
			0.25		-0.08		0.19		Norm. Gain
			0.52		-0.14		0.44		Effect Size
Overall	Mean	48.8%		59.7%		59.7%			
	Std Dev	10.8		11.7		11.1			
			0.21		0.0		0.21		Norm. Gain
			1.0		0.01		1.0		Effect Size

Note. *significant change $p<0.05$.

Qualitative interviews offered a look into the benefit of students talking in the presence of one another. For example, one student when responding to the statement "the climate where I live changes from day to day" emphatically stated "I strongly disagree because climate doesn't change from day to day." Another student agreed and replied, "Because it takes like 30 years to change climate." Discussions such as this one offer students the opportunity to add more detail to an already correct response and simultaneously reveal student thinking.

Greenhouse Effect & GHG

Question 15 asks students about the benefits of the greenhouse effect. Only 13% of students recognized the importance of the greenhouse effect and its benefits to humans prior to instruction (t_1). This significantly increased ($p<0.001$) to 49% following instruction (t_2). Unfortunately, students reverted back to their prior understanding six months later (t_3) when only 19% answered this prompt correctly, a significant decrease ($p< 0.001$). Almost 50% of the students indicated on the delayed posttest (t_3) that the greenhouse effect was harmful to the Earth. This appears to contradict the student responses during the interviews when students were asked about living on a planet with greenhouse gases. The students overall indicated they would need the greenhouse gases to stay warm. "I'd like to live on a planet with greenhouse gases because they keep it heated. Without them it would just be cold, and we couldn't live on a planet that didn't have them?"

Item 16 asks students to identify specific greenhouse gases. Carbon dioxide was identified as the main greenhouse gas by only 51% of the students on the pretest (Question 16: from a choice of only oxygen, nitrogen and CO_2). Students were significantly ($p<0.05$) more likely to identify CO_2 as the correct GHG of the three provided following instruction (68%) with no significant change six months later (t_3).

Question 17 asked students to identify greenhouse gases from a list including oxygen, carbon dioxide, nitrogen, methane, water vapor, argon, and nitrous oxide. Prior to instruction (t_1) students were able to identify carbon dioxide as a greenhouse gas 81% of the time. They were also able to indicate correctly that argon is not a greenhouse gas 76% of the time. Following instruction (t_2) students were still correctly identifying carbon dioxide and argon. Students made significant gains in their ability to identify examples and nonexamples of GHG following instruction including water vapor ($p<0.001$), carbon dioxide ($p<0.01$), oxygen ($p<.01$), and methane ($p<0.05$). In support of this, students consistently identified carbon dioxide as a GHG during interviews (t_3). Students in each interview group also recognized that methane contributed as a GHG, but the explicit identification of water and nitrous oxide was missing. On the posttest (t_2), 49% of students correctly identified nitrous oxide as a GHG but no progress was made. There was no change in the perception of students who incorrectly identified nitrogen (23%) or argon (77%) as GHG.

Curiously, six months later (t_3) students were less likely to identify carbon dioxide ($p<0.01$) and water vapor ($p<0.01$) as GHG, reverting back to their pretest understanding, but students were more likely to correctly identify nitrous oxide ($p<0.05$) as a GHG. As indicated in the interviews some of the correct answers could be attributed to logical guessing. We use this term to identify an answer choice that is not completely understood by the student but does connect to something that they remember. Unit instruction was able to improve student understanding of GHG, specifically carbon dioxide, methane, water vapor, and nitrous oxide. Overall the lesson was not successful in changing preconceptions over the long term since the scores for carbon dioxide, nitrogen, and argon reverted back to pretest levels. During semi-structured interviews, students were asked how greenhouse gases impact our planet. While student groups all identified them as something that warms our planet, only rarely did they suggest that they were a benefit. Once prompted, students responded that they were beneficial to the planet, but the fact did not arise when asked how they impact the planet. Students may be transferring the negativity associated with increasing GHG, forgetting they are needed to support life on our planet. All student groups made a connection between the ozone layer and the greenhouse gases. Including statements like: "It makes holes in the ozone layer" and "It hurts the ozone layer."

Human Actions & Greenhouse Gases

Item 19 assessed students understanding the effects of six human actions on greenhouse gases. Before instruction (t_1), 68% of students attributed GHG to a combination of human and natural sources. Although not significant, instruction was able to increase that percentage to 79% (t_2) but six months later the number of correct responses dropped lower than the pretest to 60% (t_3). More students were likely to attribute GHG production to burning of fossil fuels on the delayed posttest (t_3) than on the pretest (t_1). This is not surprising given the discussions in the interviews. Many students were consistently reluctant to acknowledge the role humans play in production of GHG. For example, in one group, when students were asked "Are greenhouse gases more from natural sources or more from man-made sources? Every student responded, "Natural." In another group when asked: "…do you believe that humans are causing our climate to change, presently? One student replied, "I think we're having an impact on it but it's not completely on us." Again, all students agreed with this idea, "Yeah, like I think it is sort of us, like I think we do have an impact on it, but it's not all of us doing it. It's happening naturally too." Students consistently expressed this idea. For example, another student in another group said, "I just, I mean it's been going on like this for a long time. Stuff's been getting hotter and stuff's been getting colder. That's just how things roll" and most students in the group agreed.

Additionally, understanding climate change includes the knowledge of impacts of human actions on the amount of GHG in the atmosphere which was addressed in question 20. Students were required to identify how each of the six human action prompts would impact the amount of GHG. Prior to instruction (t_1), 50% or higher of the students could correctly identify impacts of burning fossil fuels, planting trees, and using alternative energy sources (Table 2). Students significantly improved on all of these ($p<0.05$) on the posttest (t_2). Almost 70% of students recognized the impact of driving automobiles prior to instruction with no significant change afterward. Students had the most difficulty determining relationships between GHG and a c) expanding the size of the ozone hole or e) insulating buildings both before and after instruction. Six months after instruction (t_3) significant gains occurred for both of these items ($p<0.05$). This initial struggle was not surprising given the confusion, discussed above, that students have understanding the relationship between the ozone layer and GHG.

Table 2

Percentage (%) and Frequencies (n) of Correct Responses

Human Actions prompts	**Pretest % correct (n)**	**Post test % correct[1] (n)**	**Delayed Post % correct[2] (n)**	**Pre to Delayed post % change[3]**
a) burning of oil or coal for fuel	55% (26)	83% (39)*	68% (32)	13%
b) planting trees and forests	47% (22)	66% (31)*	62% (29)	15%
c) expanding the size of the ozone hole	4% (2)	17% (8)	19% (9)	15%*
d) using alternative energy sources such as solar power and wind	53% (25)	68% (32)*	60% (28)	7%
e) insulating buildings to prevent heat loss/gain	11% (5)	17% (8)	32% (15)	21%*
f) driving automobiles	68% (32)	79% (37)	68% (32)	0%
Category averages (Std Dev)	**39.7% (29.6)**	**55.0%* (24.8)**	**51.4%* (25.2)**	**11.8%***

Note. *significant changes $p<0.05$, [1]pretest to post test, [2]post test to delayed posttest, [3]pretest to delayed posttest

Discussion

Our first research question focused on Appalachian middle school students' perceptions of weather, climate, and climate change. Results of this study indicated that the students acknowledged that the Earth's climate changes. Students exhibited increased understanding about basic concepts concerning weather and climate using the length of time as the distinguishing factor. Students were clear about how greenhouses work and the necessity of GHGs to moderate temperature on earth. Students attributed both natural and man-made factors to global warming. But digging deeper into all these general ideas, revealed many areas where students continue to wrestle with accurate scientific content.

Our second research question targets the persistence of these understandings and how they may or may not have changed after six months without further targeted instruction. Results for the greenhouse effect and GHG showed increased students' understanding but these increases are short-lived, essentially disappearing six months post instruction (t_3). Students particularly struggled with recognizing the benefits of the greenhouse effect. Instruction was able to alter this understanding, but this gain was lost over time. We choose to look at these results as evidence that students need increased time and consistent exposure to successfully develop the complex understandings needed to both understand these ideas and to mesh them with common worldview ideas. These common worldview ideas are often scientifically inaccurate, but more likely to be personally comfortable (Clifford & Travis, 2018). Some of the critical questions regarding the benefits of the greenhouse effect and the sources of the GHG were quite troubling because of the decay in understanding over time. In fact, more students were likely to attribute GHG production to only the burning of fossil fuels on the delayed posttest (t_3) than on the pretest (t_1). These results, while disappointing, are not surprising given the complicated nature of the greenhouse effect and the low percentage of adults that correctly understand the greenhouse effect.

During the semi-structured interviews, students consistently identified "time" as the critical factor in distinguishing between climate and weather effects. References to daily and weekly phenomena representing weather were consistent. Sample statements included "weather is like a weekly thing," "weather is more daily than weekly" and "it takes 20- and 30-year period for a climate to change." While students did not express the exact same understandings about weather and climate (i.e., weekly vs. daily) they were clear that weather was differentiated from climate by lengths of time. However, when asked to apply that criteria to weather- and climate-influenced events, pretest responses revealed many ideas that were scientifically inaccurate. These results are consistent with previous research findings (Spiropoulou et. al. 1999; Read et. al. 1994; Gowda, Fox, & Magelky, 1997; Papadimitriou, 2004; Lombardi & Sinatra, 2012) and offer us recommendations for teaching in the future which are summarized in the Conclusions.

A closer look at the students' responses during the interviews reveals important sense-making and indicates complexity behind students' choice of words (Prain, 2006). For example, during the interview Ashley responds to a question about the weather where she lives with the following, "...but here it's like we have mild winters and not very hot summers. It means that the *climate* changes a lot." Ashley's use of the word climate could be interpreted as simply "incorrect" or it can be viewed as a sensible interchange of the terms weather and climate. Students invoke terms that make sense to them, in the vernacular or everyday, without considering the scientific meaning. In this way we see Ashley's response as sensible but scientifically inaccurate. This subtle difference in interpretation matters because it offers teachers a different way to engage with students beyond simply identifying their inaccuracies and correcting them. Teachers can open a discussion around "everyday" use of terms and "scientific" use of these terms which can assist students in developing more sophisticated scientific understandings (Hammer & van Zee, 2006).

Additionally, we compared our students' delayed post scores with the previously published research with similarly aged students. Since the assessment measure was built upon previous published research, it is easy to compare these results with Boon's (2009) study which included students' understanding of these issues in two different decades and locations: UK students in 1991 and Australian students in 2001. Only 26% of Appalachian middle schoolers knew that the sea level would rise with a warmer climate, while 76% of Australian and 66% of UK students knew this. This trend was observed in the interviews where students were clearly still working through the outcomes of global warming on sea levels. The outcome that students, regardless of country or decade, knew most accurately was that polar ice caps would melt under the influence of a warmer climate (83% Appalachian, 85% UK, and 85% Aus). This was the only question in which there was no significant difference across all comparisons. Again, given the relatively straightforward connection between increased temperature and melting ice this makes sense.

Another outcome question that was asked of these students was the following: How might these actions impact the GHG in our atmosphere? This question requires students to evaluate certain actions that they could take and determine if they might increase or decrease the amount of GHG in our atmosphere. Interestingly, all 3 groups of students did similarly well on 1 action: using alternative energy. Approximately, 60% of all three groups of students knew that these actions would decrease the amount of GHG in our atmosphere. The groups answered differently to the following two actions: burning oil or coal (68% Appalachian, 80% UK, and 83% Aus) and driving automobiles (68% Appalachian, 76% UK, and 84% Aus). Interestingly, the greatest source of anthropogenic carbon dioxide (burning fossil fuels) was only accurately identified by just 68% of Appalachian students which live in an important coal source region of the country.

Although the studies were slightly different, comparisons can also be made with the students' assessed from an urban area in the NE (Bodzin et al., 2014) at roughly the same time period (2011-2012). Both groups of students held basic understandings of the differences between weather and climate but were unable to apply this rudimentary understanding when considering the complex interactions between weather and climate and the timescales associated with changes in climate. Bodzin's students struggled more with identifying the appropriate GHG and not recognizing the importance of water vapor as a GHG (only 23.3% of the Bodzin students correctly identified the 3 gases -- carbon dioxide, water vapor, and methane-- provided on their multiple choice question) yet the students in this study were more successful: 62% selected carbon dioxide, 65% water vapor and 55% methane as a GHG.

Bodzin et al. (2014) also asked students to provide types of human activities that are causing long-term increase in carbon dioxide levels whereas our study asked students to categorize certain actions and how they might impact the amount of GHG in the atmosphere. The Bodzin study reported that 61.2% of students provided adequate responses that were vague but accurate (including transportation use, using more heat in the winter and air conditioning in the summer, burning fossil fuels, etc). The current study found the following accurate associations between actions and impacts on GHG amounts in the atmosphere: 68% for burning oil or coal for fuel (*increase GHG)*; 62% for planting trees and forests (*decrease GHG*), 19% for increasing the ozone hole (*does not impact GHG)*, 60% for using alternative energy sources (*decrease GHG*), and 68% for driving automobiles (*increase GHG*). So, in general with the exclusion of the expected confusion of the ozone hole, approximately 60% of students could accurately categorize these actions which was quite comparable to the 61.2% of students with adequate responses in the Bodzin et al., (2014) study. This finding also opens up an opportunity to invoke student sense making in the research analysis. As previously mentioned, students often conflate the hole in the ozone layer with GHGs and climate change. On the surface this may just seem incorrect, but it actually makes sense if we look at the ideas behind the two phenomena. Both phenomena (the ozone hole and climate change) have to do with atmospheric processes, and both are considered environmental issues. It should not surprise teachers then that students conflate and confuse the two. We suggest that by helping students see that these two phenomena *are* related, students can develop deeper understandings of both content ideas.

The 5E model used as an instructional tool for this study, builds on the ideas of Driver et. al. (2014) and Hammer and van Zee (2006) in that the instructor was intentional about incorporating students' lived experiences and ideas into the explanation and evaluation phases of the unit. In this way students' experiences became a part of the curriculum. Even when students expressed "misconceptions" the teacher was open to seeing how these developed and how they could be extended toward more "correct" and "scientific" explanations. The persistent increase in correct responses for several questions and topics would then suggest that this method of instruction shows promise for these topics. Given that the increases in correct responses did decay over time for some areas, additional activities and/or extending the time for instruction are recommended.

Limitations and Future Work

Several limitations should be noted particularly the small sample size and the convenience sampling technique. Researchers were only able to provide the unit of instruction to a school within driving distance from the university. Other classrooms were contacted but this classroom and teacher were willing to work with the researcher who delivered the unit of instruction. The limited sampling size does call to question the generalizability of the results, but the students do represent a cross-section of the broader school community. Additionally, interviews with students were only conducted once at the delayed post instruction time frame (t_3). Conducting interviews with students at each time frame would allow a deeper discussion on student content retention, persistence of alternative conceptions, and how learners construct knowledge.

Since this study, the state has adopted an "adapted" version of the Next Generation Science Standards. In fact, this adaptation was a direct result of the political climate when a member of the state Board of Education changed the wording for several standards related to climate change. For the middle school standard, the state board of education changed the standard "MS-ESS3-5: Ask questions to clarify evidence of the factors that have caused the rise in global temperatures over the past century" to "S.6.ESS.6 ask questions to clarify evidence of the factors that have caused the change in global temperatures over the past century." This could be considered as one piece of evidence of the "cultural bias" that makes these topics challenging to instruct, particularly in this area which is so strongly supported by the coal industry. We plan to establish this initial research as a baseline of student understanding prior to NGSS implementation. Additional studies will be conducted to determine whether simply adding the required content to the curriculum significantly improves student understanding. We plan to assess a new group of middle-level students who will be receiving instruction after the adoption of the NGSS standards for this state and compare these two groups of students 1) at the middle-level and again 2) at the secondary-level when the standards will more fully align with the assessment measure.

Conclusions

We know from research that students struggle to understand the long-term idea of climate vs. weather. While they do consistently include time as a factor that differentiates the two, answering questions that are more outcome- and application-oriented remains challenging. Students seem to develop an understanding of weather as evidenced by the increase in score immediately after instruction for three weather items on the assessment measure. This makes sense if we consider that weather, on a daily basis, is what students experience first-hand themselves. Climate changes over decades of time are less likely to be understood by students as they are less acutely felt by them. The largest measured improvements in understanding were made in the statement regarding a heat wave in the summer. However, as evidenced by the delayed post (t_3), two climate related items, substantially improved over time. Recognizing this as an expected result for adolescents has implications for curriculum design in the future. A solid understanding of weather can potentially support a better understanding of climate. Recommending that teachers include specifics in instruction is a key take-away from this research. For example, while we know that students make the connection between melting polar ice caps and global warming, students did not make that connection to rising sea levels. Drawing more causal connections and specifically discussing how the changing temperature does, in fact contribute to rising sea levels would help students make this multi-step connection.

Instruction resulted in short-term improvements but only a few changes were still evident six months after GHG and greenhouse effect instruction. Not surprisingly, well documented areas of confusion remained unaltered. Students had the most difficulty determining relationships between GHG and expanding the size of the ozone hole or insulating buildings although this did significantly improve from pre (t_1) to 6 months post instruction (t_3). However still only 15% and 21% (respectively) answered these questions correctly. This is not surprising at all given the confusion, discussed above, that students have about the relationship between the ozone layer and GHG which has been well documented in prior research. Our work supports that which has been previously supported by research like Hammer and van Zee (2006), we should approach students' ideas as "common sense" because many times "incorrect" student ideas (commonly called misconceptions) are actually quite sensible given students' experiences in the world, particularly as set within the cultural context of the local community. Unless as teachers, we understand where students are coming from in their thinking, and this includes conceptual and cultural sense-making, it is highly unlikely that the foundations of students' conceptual ideas will be open to long-term change (Von Glasersfeld, 2013).

Using a constructivist theoretical framework and expecting that students will try to make sense of the questions they are asked, can support teachers to reframe instructional approaches. If teachers assume that students' responses are not just "wrong," but rather conceptually incomplete and often, sensible, teachers can view students' learning in a more productive way. Given this theoretical lens the results presented here and elsewhere are not surprising and offer science educators a way to see logical sense making in many of the ideas that students revealed. We share here a quote by Driver at al. that captures the nature of the way that we see the student responses.

Pupils come to science lessons with ideas about the natural world. Effective science teaching takes account of these ideas and provides activities which enable pupils to make the journey from their current understandings to a more scientific view. (Driver, Squires, Rushworth, & Wood-Robinson, 2014, p. xiv).

In their book on secondary students' understanding of science concepts (2014), Driver and her colleagues stress how understanding where students are in their scientific thinking and recognizing where that thinking comes from, are critical to helping students on their journey to a more scientific view of the world. Despite being grounded in student sense-making, and helping teachers think about how to teach science, constructivism was, for many years, used as a way to dismiss student ideas as incorrect and a justification for those ideas to be completely changed as a part of instruction (Osborne, 1996). In contrast to this, Driver and colleagues suggest that we see student understandings as a starting point and a place to work from. It is critical that we recognize that experiences that students have in their real world lives inform the scientific understandings that they eventually develop. Instead of fighting with students' emergent ideas, educators can embrace them and use them as a launching pad for more sophisticated learning. We operate from previously mentioned Hammer and Van Zee (2006) frame of mind as we look at the challenges and opportunities the students in this study afford us as educators looking to understand students' ideas on climate, weather and the greenhouse effect.

The publication of the NGSS document has helped address the importance of climate change inclusion throughout K12 education. Prior to the adaptation and adoption of the NGSS in this Appalachian region, climate change was only addressed in high school environmental science and advanced earth science electives. Weather was taught in elementary and middle school with little mention of climate. Now with NGSS performance expectations driving the curriculum, students are introduced to weather as early as kindergarten and exposed to climate in third grade. Additionally, the weather and climate science topics are reinforced in fifth grade, middle school, and high school. This would suggest that states that adopt NGSS should have more structured reinforcement of concepts throughout their education perhaps avoiding students' reverting to previously held misconceptions about climate change. Those states who do not adopt NGSS should scaffold weather and climate standards throughout elementary, middle, and high school to ensure gains in climate science understanding is not lost for lack of engagement.

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Appendix A: Assessment Measure

1. Do you agree to participate in this research study? By selecting Yes, you agree to participate in this research study, which is collecting information from students around the world on their understanding and feelings about the greenhouse effect and climate change. You will not be asked to provide any personally identifiable information, and your participation is completely voluntary. You do not have to answer any questions that may make you feel uncomfortable. At any point in the questionnaire, you may choose to not participate and not submit your questionnaire.

- Yes
- No

2. What is the name of the city where your school is located?

3. What is the name of the state where your school is located? If you live outside the United States, please include your country as well.

4. If you know it or your teacher provides it to you, what is the latitude of your school?

5. If you know it or your teacher provides it to you, what is the best description of your climate zone (according to the Koppen-Geiger climate classification)?

- A – Equatorial
- B – Arid
- C - Warm Temperate
- D – Snow
- E - Polar

6. Think of the weather and climate you have experienced in the last few weeks. Has it been warmer, colder, or the same as a typical season?

- Warmer
- Colder
- the same

7. Which of the following is best explained by a change in the weather or the climate? (Answer choices are “weather” or “climate”)

 7a. drying up of large lake over man years
 7b. a winter storm that dumps a large amount of snow
 7c. a summer heat wave with extremely hot temperatures
 7d. leaves budding out on trees earlier and earlier in the spring over many years
 7e. a warmer winter without any major snow storms
 7f. a major outbreak of tornadoes with loss of life
 7g. birds migrating to warmer areas later and later in the fall over many years
 7h. a summer season with the most hurricanes ever recorded
 7i. a ten year period with the most hurricanes ever recorded

8. Does Earth's climate change?

- Yes
- No

9. What are possible causes or factors that might contribute to the change (or stability--lack of change) in the earth's climate?
10. Have you ever been in a greenhouse on a warm summer's day?

- Yes
- No

11. Do you think it is warmer or cooler inside a greenhouse than outside?

- ***warmer
- cooler
- the same
- I don't know

12. Explain why this might be so

13. What do you think the "greenhouse effect" is?

14. How might the "greenhouse effect" impact the earth's climate?

15. The "greenhouse effect"...

- ***benefits humans
- harms our earth
- does nothing to humans or earth
- I do not know

16. Which of the following do you think is the main "GHG"?

- Oxygen
- ***Carbon Dioxide
- Nitrogen

17. Which of the following are "GHG," if any? (You can choose more than one response.)

- Oxygen
- ***Carbon Dioxide
- Nitrogen
- ***Methane
- ***Water vapor
- Argon
- ***Nitrous Oxide

18. What do you think the outcomes of a warmer climate will be?
(answer choices include “different locations will change differently”, “significantly decrease”, “decrease”, “will not change”, “increase”, “significantly increase”)
18a. sea levels will…
18b. rainfall will…
18c. sunshine will..
18d. farmers crops will be….
18e. the ice caps in the North and South Poles will…

19. GHG originate...

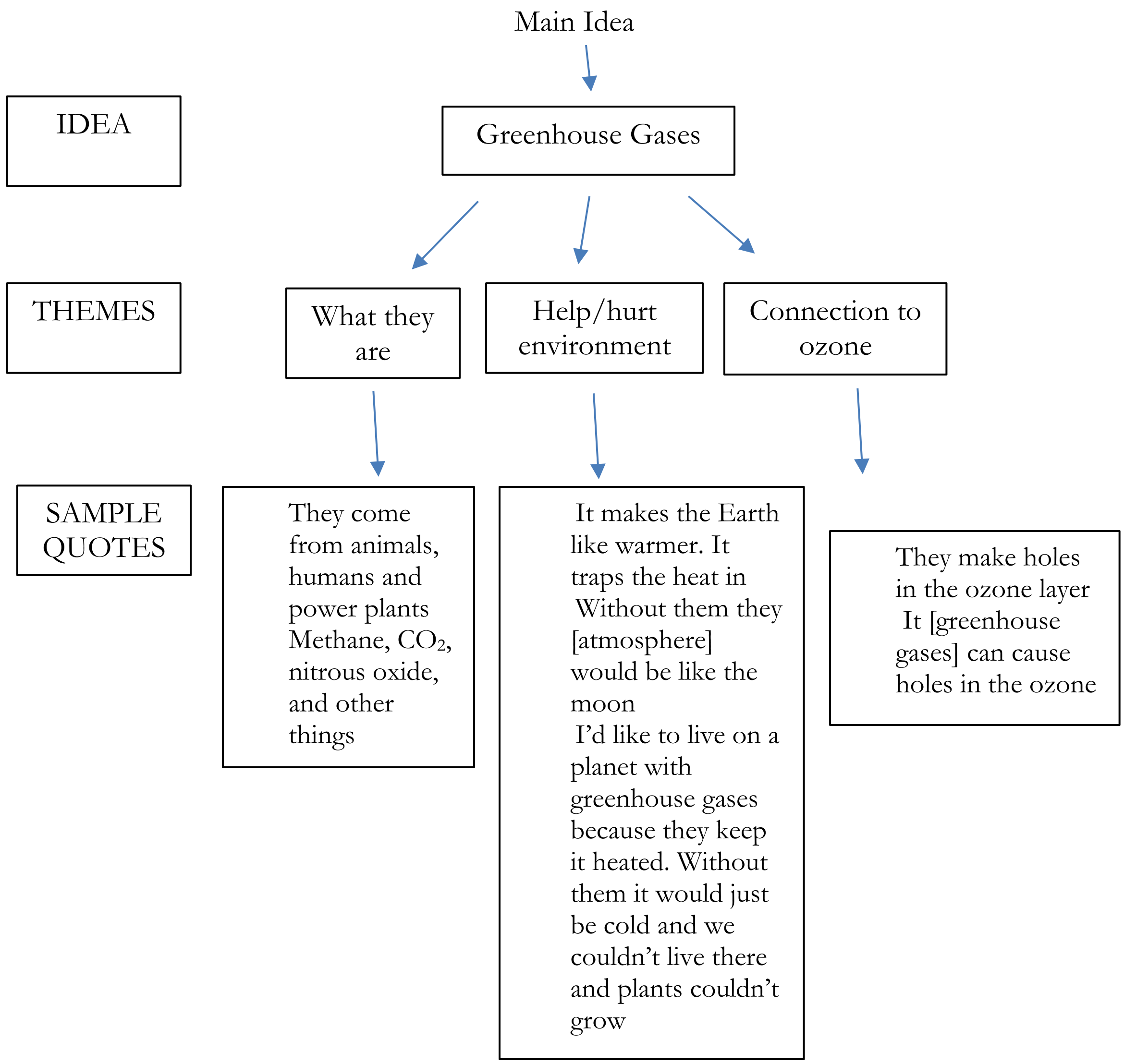
- entirely from human activity.
- entirely from natural sources.
- entirely from fossil fuels.
- ***from a combination of human and natural sources.

20. How might these actions below impact the amount of GHG in our atmosphere?
(answer choices are traditional 5 point likert -- significantly increase to significantly decrease)
20a. burning oil or coal for fuel
20b. planting trees and forests
20c. expanding the size of the ozone hole
20d. using alternative energy sources such as solar power and wind
20e. insulating buildings to prevent heat loss/gain
20f. driving automobiles

Appendix B: Semi-structured Group Interview Questions

1. What's the difference between weather & climate?
2. Weather vs. climate – Do you agree/disagree with the following statements:
    a. The clothes that people wear are influenced by the weather.
    b. The weather where I live changes dramatically.
    c. The climate where I live changes from day to day.
    d. Changes in the weather means that the climate will change.
    e. The clothes available to buy in my local stores are influenced by the local climate.
3. What are the greenhouse gases? How do the greenhouse gases impact our planet? Where do greenhouse gases come from? Would you like to live on a planet with greenhouse gases in the atmosphere?
4. What was the weather like this past winter? How did it compare to "normal"?
5. What has the weather been like this spring?
6. How do you think our weather is related to what people call "global warming"?
7. How do you think "global warming" is related to climate change?
8. What do you think the outcomes of a warmer climate will be? How would our planet be changed if it became warmer?
    a. Relate to changing sea levels, farm crops, rainfall, sunshine, ice caps
9. Do you think the earth's climate can change? If so, what are possible causes that may lead to that change?
10. Do you believe that humans are causing the climate to change?

Appendix C: Coding Scheme Example



Appendix D: Unit Summary

Summary of the unit of instruction with the State Standard (valid in 2011), corresponding Essential Question, student learning objective, and 5E lesson cycle summary and question numbers that corresponded to this topic in the student questionnaire.

Day	Standard	Essential Question	Learning Objective	Summary	Q
1-2	SC.O.8.2.28 determine the impact of oceans on weather and climate; relate global patterns of atmospheric movement on local weather.	What is the relationship between weather & climate?	Students will differentiate between weather & climate.	The lesson introduces students to the ideas of weather and climate and how these two ideas are similar but yet different. During a PowerPoint discussion, students will utilize student response clickers to evaluate their understanding. In Elaboration, student examine the GLOBE Program global maps which demonstrate the factors which control Earth's climate.	7
3-4	SC.O.7.2.32 explain how changing latitude affects climate.	What causes the seasons?	Students will evaluate the influence of latitude on climate.	Students conduct a lab experiment using infrared thermometers and a table top globe that is situated 20 cm from a 100 watt bulb light source to determine the impact of the tilt of the axis of rotation on the surface temperature. In Elaboration, students reexamine the GLOBE Program maps of insolation and surface temperature across different months to find a pattern.	NA
5-6	SC.O.8.2.32 explain phenomena associated with motions in sun-earth-moon system (e.g., eclipses, tides, or seasons).	How's does the Earth's rotation & revolution impact the seasons?	Students will examine evidence of the Earth's rotation and revolution on the seasons.	Students consider evidence that they have collected (in their daily lives and also in the previous lesson) which can be used to support ideas related to Earth's rotation and Earth's revolution around the sun. Several movies are shown to provide further evidence of this large scale interaction between the Earth and the Sun.	NA
7-8	SC.O.7.2.27 examine the effects of the sun's energy on oceans and weather (e.g., air masses, or convection currents).	How does specific heat impact the Earth's climate?	Students will describe the influence of Earth materials on local climate.	Students collect data using heating lamps, thermometers and different earth materials to see how they respond to being heated and cooled. In Elaboration, students were given monthly average temperatures and annual rainfall amounts to graph of two cities in North America which have significantly different weather patterns because of their location and proximity to the ocean.	9
9-10	SC.O.7.2.27 examine the effects of the sun's energy on oceans and weather (e.g., air masses, or convection currents).	How can GHG be considered both a friend and an enemy?	Students will examine evidence of the effects of greenhouse gases on the atmosphere.	Students measure changing temperatures inside two tennis ball cans with 5 cm of water and 1 can with Alka-Seltzer tablets to release Carbon Dioxide. Student discuss/examine the role of GHG in the heat balance of the atmosphere and the evidence of an enhanced greenhouse effect with increasing amounts of CO2. In Elaboration, students consider the gases in the atmosphere and the daytime/nighttime temperature extremes of Earth, the Moon, Mercury, Venus and Mars.	13, 14, 15, 19, 20