With my 2009 – 2010 academic year iSTEM grant, I developed a climate change curriculum and conducted a research study on undergraduate students’ understanding of climate change. My accomplishments related to curriculum include: the development of a climate change curriculum and a set of keystone lessons that address specific areas in which students tend to hold incorrect ideas; distribution of the climate change curriculum and keystone lessons to Department of Atmospheric and Oceanic Sciences (ATOC) professors and outside entities; analysis of the effectiveness of a keystone lesson through pre- and post-assessments; and development of a white paper describing the preliminary results of my analysis. My research on students’ understanding of climate change is ongoing, but I presented my preliminary findings to science education researchers and teachers.

I taught the climate change curriculum and keystone lessons to my Summer 2009 class, ATOC 1060 – “Our Changing Environment”. I conducted pre- and post-assessments around two of the keystone lessons. I compiled the results of a study of students’ understanding of the nature of science in response to a class project in a white paper titled, “Identifying Students’ Views of the Nature of Climate Change Science in ATOC 1060: Does a Transformed Curriculum Improve Understanding?” I shared these findings and my climate change curriculum with others during poster sessions hosted by ATOC (December 2009) and iSTEM (September 2009). I also distributed the curriculum to ATOC faculty, graduate student-instructors, and outside entities such as the Laboratory for Atmospheric and Space Physics (LASP) Office of Outreach and Communication.

I designed and gathered data for a study that investigates how students learn about climate change while experiencing a climate change curriculum. I investigated the following research questions during the Spring 2010 semester in a 215-student section of ATOC 1060 - “Our Changing Environment”, taught by a department lecturer.

• What are the climate change perceptions held by undergraduates before they take ATOC 1060?
• What are their perceptions at the end of the class?
• How do students’ climate change perceptions transform throughout the semester?

I administered a pre/post-class questionnaire to capture students’ perceptions of climate change. Using the results of the pre-class questionnaire, I selected five students who each represented a different level of climate change understanding. I interviewed these students 4 times throughout the semester using a protocol designed to capture their understanding of climate change, aspects of the class that helped them learn, and elements of climate science of which they remain skeptical. The interviews were conducted after discussions of significant concepts that may have affected their climate change understanding. In conjunction with the interviews, I routinely took observational field notes during the ATOC 1060 lectures, evaluated classroom
artifacts (exams, homeworks, and lecture slides), and conducted interviews with the professor.

Based on analysis of a portion of the data, I composed a preliminary findings report in April 2010. I discussed these preliminary findings during presentations through the University of Colorado’s Discipline Based Education Research Group (DBER, April 2010), LASP Education Outreach (May 2010), and the Cooperative Institute for Research in Environmental Sciences (CIRES) Outreach (June 2010). I am currently analyzing and synthesizing the remainder of the data and will develop a publishable report by the end of the summer.

The remainder of this report summarizes results of the work described above, presented in three sections: Climate Change Keystone Lessons, Nature of Climate Science White Paper, and Preliminary Findings on Students Climate Change Understanding.

Keystone Lessons

I developed six lesson plans that professors can use to instruct climate change, called “keystone lessons”. Each keystone lesson targets students’ potential incorrect preconceived notions identified by previous research. The lessons aim to address students’ incorrect notions while utilizing teaching methods that are different than those in normal lectures. These keystone lessons were a large part of a transformed climate change curriculum that I created and utilized while instructing ATOC 1060 during the Summer of 2009. The following is an overview of each keystone lesson.

Keystone Lesson 1: The Greenhouse Effect
Much research has been done to identify possible incorrect ideas about the greenhouse effect (McCaffrey and Buhr, 2008). The research concluded that many of the researched students do not understand the difference between incoming short wave radiation and outgoing long wave radiation and the concept of selective absorption. This may be prevalent in college classrooms, including ATOC 1060. Professors using this keystone lesson will pre-assess students’ understanding of the greenhouse effect and use teaching activities that promote student-professor interaction. This lesson uses 3 teaching methods to discuss greenhouse effect concepts, including computer simulation, computation, and presentation.

Keystone Lesson 2: “Interview a Scientist” Project and Poster Presentation
The vast majority of students in introductory atmospheric science classes at the University of Colorado are non-science majors. These students may have minimal experience with scientific research. Having an understanding of scientific research is important because it is often referenced in the media and in conversations. We often read in articles or see on television that… “Scientists have discovered…”. However, without proper scientific literacy, one can only imagine HOW scientists make their discoveries and how they conduct their research. A non-science major may never have the opportunity to understand the details associated with scientific research, such as fieldwork, lab work, analyzing data, and developing models. This project should fill this knowledge gap, and at the same time, allow students a better
understanding of climate science. When students later go to their jobs, they may better know what takes place in a science research lab and perhaps can critically understand the media on scientific research.

**Keystone Lesson 3: Your Carbon Footprint**
For homework, students use an on-line calculator to estimate their carbon footprint. They also use the same site to calculate their “friend’s” footprint. Their homework assignment requires them to compare and contrast the two for the purpose of identifying aspects that increase or decrease their footprint. In class groups, students discuss their footprints with each other, identify ways they can reduce their individual footprints, and identify ways society as a whole can reduce its footprint. This keystone lesson incorporates a fun activity (the on-line calculators are entertaining) with critical thinking on climate solutions. Students’ invention of feasible climate solutions will show them that they can make a difference, and hopefully reverse “we can’t do anything about climate change” mentalities.

**Keystone Lesson 4: Weather vs. Climate**
Sometimes people think that climate is the same as weather. They may mistakenly think that a change in the weather, such as a warm day in December, is climate change. Confusion over the definition of climate can cause confusion in many other atmospheric science related topics such as climate models, feedback loops, paleoclimate. This keystone lesson prompts students to look at climate data and determine the difference between weather and climate. The professor guides discussion that climate is the average temperature and precipitation of an area over a long period of time, and weather is the day-to-day state of the atmosphere.

**Keystone Lesson 5: The Carbon Cycle**
In order to conceptualize global warming, students need to understand the carbon cycle. Students may often hear reports of “excess” carbon or CO₂ being released into the atmosphere causing major havoc on our climate system. To fully understand this statement and understand climate change solutions, students need to understand where this carbon comes from. Before taking a climate class, students may think that carbon acts similar to water and can condense into clouds and precipitate (Madsen et al., 2007). Students should know that carbon is and has been continuously cycled by processes including photosynthesis, respiration, decomposition, lithification, and combustion. Earth’s creation of fossil fuels took millions of years, and now humans are combusting these molecules at a fast rate. This quick release of CO₂ into the atmosphere causes our climate concerns. This keystone lesson prompts students to identify sources and sinks of carbon in the atmosphere from their current knowledge and then adds conceptual knowledge through collaborative learning and a video.

**Keystone Lesson 6: Feedback Loops**
In order to understand climate change and the Earth system, students must understand feedback loops. Students may incorrectly think that negative feedback loops cause something to decrease and positive feedbacks cause something to increase. The correct notion is that a
system that has a built-in negative feedback will mitigate a perturbation and a positive feedback will exacerbate a perturbation. This keystone lesson uses strategies such as group work, exit tickets, and lecture to teach students positive and negative couplings, positive and negative feedback loops, and unstable and stable equilibrium.

**Nature of Climate Science White Paper**

Keystone lesson 2, “Interview a Scientist” Project and Poster Presentation, is geared to teach the “Nature of Science” (NOS): how scientists conduct research and develop conclusions. I developed this project to improve students’ understanding of the “how science is done.” Before and after the project, I administered a “View of science” questionnaire to see if students’ views changed. I composed a white paper on my analysis and findings titled, “Identifying Students’ Views of the Nature of Climate Change Science in ATOC 1060: Does a Transformed Curriculum Improve Understanding?”

I adapted my short pre/post questionnaire from a questionnaire by Lenderman et al (2002) called the “View of Nature of Science-Form C”, or VNOS-C. I administered the questionnaire on the fourth and 20th days of the 22-day semester. 25 of the 42 students enrolled in the class completed both questionnaires. For the white paper, I analyzed students’ pre and post answers to the following 2 questions:

- From what you know, how is climate change research conducted?
- Do you think scientists agree about the extent of climate change and its consequences? Why or why not? Compose a scenario to explain your reasoning.

Prior to analyzing student responses, I developed a continuum by which to code their answers. The continuum goes from naïve to expert views, as shown on Figure 1.

**Figure 1: View of Science Continuum**

**More Naïve Views**

**Middle of the Road**

**More Expert Views**

I compiled responses from a group of professors within the ATOC department to create the expert viewpoint. I developed the naïve viewpoint by looking at sample coding schemes for the VNOS-C (Lenderman, et al. 2002) and developed similar codes for my specific questions.

I ranked students’ responses on this a naïve-to-expert view continuum and compared each students’ pre-class ranking and post-class ranking to see if there was movement in the students’ nature of climate science understanding along the continuum.
The improvement in understanding for question 2 is apparent when looking at the movement of student’s pre to post understanding, along the continuum. Figure 2 presents the number of students whose level of understanding moved down (towards naïve), stayed the same, or up (towards expert).

**Figure 2: Count of Student Movement Along the Level of Understanding Continuum**

Student responses exhibited an average movement toward expert views for question 2, dominated by the 18 students who moved towards more expert views. In question 1, eight students moved towards more naïve view, 9 students moved towards more expert views, while 8 students did not change. The opposite movement of the 8 students towards naive and 9 students towards expert counterbalance so the average movement of the 25 students is close to zero and insignificant.

One explanation for the lack of improvement in question 1 could be the absence of numerous explicit connections between the student project and the nature of climate science. The only time that this learning goal was explicitly stated was on the assignment sheet: “The purpose of this assignment is to gain an understanding of how scientists conduct atmospheric science or climate change research, learn about a specific project, and share your findings with your classmates.”

A review of the Nature of Science research by Abd-El-Khalick and Lenderman (2000) showed that lessons where the Nature of Science is taught implicitly through inquiry (such as my poster presentation lesson) do not achieve a significant amount of success. Explicit Nature of Science lessons were more successful in improving students’ conceptions.

College students may still have a difficult time using their experiences to understand big-picture questions. Professors can help our students by assisting them in making the connection. It is important for students to develop independent thinking processes, but if they are not there yet, perhaps explicit statements at the end of lessons will help them on their way. Adding class discussion and debriefing sessions with strategically placed professor guidance will help science educators move their students towards the expert understanding end of the continuum.

**Preliminary Findings on Students Climate Change Understanding**

My preliminary findings for the research study designed to investigate students’ understanding of climate change are from analysis of a portion of the interview data and field notes. The interview data allowed me to focus on the research question, “How do student’s climate change conceptions transform as they experience a climate change curriculum, such as the one in ATOC 1060 – Our Changing Environment?” by allowing me to see into the “black box” of student learning.
For the preliminary report, I wanted to find out what aspects of class, such as data, processes, and evidence, convinced students that climate change is happening due to human influence. I call these key aspects that foster climate change understanding “Big Picture Topics”. I focused on the big picture topics because there is an immediate need to identify these for climate change instructors.

Based on this study and prior research, I determined that understanding the following 5 topics is key to understanding basic climate science and preventing misconceptions. These topics are:

- The difference between weather and climate,
- The greenhouse effect,
- The carbon cycle,
- Climate feedbacks in the Earth system, and
- Natural versus anthropogenic climate change.

These topics emerged from interviews and are documented in literature (McCaffrey and Buhr, 2008) as critical to understanding climate change. I identified them in the interview data because understanding of the topic often alleviated a students’ struggle in climate change understanding.

I suggest that climate change instructors address these 5 topics explicitly at the beginning of the class in order to clarify any confusion that the students may have. Students’ possible climate change confusion may result from out-of-class influences such as the media, their peers, or prior incorrect ideas, causing them to come to class with questions such as “is climate change really happening?” or “I heard that climate change is entirely natural, is this true?” Addressing the 5 big picture topics up front should give an immediate answer to these overall questions and prevent additional incorrect conceptions, which could arise from layering students with too much unconnected scientific information. After introducing these 5 big picture topics, instructors can teach supporting fundamental concepts associated with atmospheric and oceanic circulation. Textbooks often introduce these before the big picture climate change topics, but I do not recommend this order. Teaching students the basic answer to their big-picture questions up-front will address students’ climate science confusion that could be promulgated by out-of-class forces and hopefully start the students’ internal process of clarifying this confusion.

References

