New project-based instructional modules improve climate change literacy (research to practice)

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Introduction

The scientific community now recognizes with a very high degree of confidence that industrial and agricultural activities have had and continue to have a profound impact on Earth's climate.[1] The anthropogenic release of greenhouse gases into the atmosphere from these activities is causing a discernible warming and general instability of our planet's climate.

It is time to help the general public understand climate science, the potential impacts of climate change, and the actions required to mitigate and adapt to these changes. The knowledge, behaviors, and attitudes related to climate change can be broadly defined as "climate science literacy." NOAA, AAAS, and others recently published a guide to climate literacy[2] that defines attributes of a climate-literate person. Achieving this type of literacy requires educational programs that will shape citizens' knowledge about the biophysical environment and its associated problems, raise awareness of how to solve these problems, and provide motivation to work toward their solutions.[3] It is hypothesized here that inquiry and project-based pedagogical approaches, which have been shown to increase students' environmental and energy related literacy,[4,5] could provide a foundation and framework for strengthening students' climate science literacy.

Project-based learning has been suggested as the most effective approach for teaching and learning science process skills and content.[6] The curriculum is generally centered on a real-life problem or project. Students learn and apply science content and skills that are relevant to their project solution.[7,8] The technique improves student retention of science concepts, mainly because students learn more when they are interested and actively involved in what they are doing and when they understand the relevance of the material to their own lives.[9] According to Hurd,[10] science instruction that is project/inquiry based, student-centered, and presented in a framework that relates to the "life world" of the student better prepares them as "productive students in today's world," effectively closing the gap between academic science and science for the citizen. Hurd further argues that, to fully modernize science, it should be connected to the "here and now," to our technology-based society, and experienced by students within a personal and civic context.[11]

Climate issues are particularly *relevant* to today's students, and are readily positioned within a societal context. They encompass a broad range of interconnected themes, providing ample opportunity to integrate not only STEM subjects but also social, political, economic and environmental considerations. Integrating these themes in a scientific problem solving activity enhances students' awareness of the "holistic" nature of STEM in today's world, requires critical thinking and analysis, and provides opportunities for collaboration and team work. These are

essential components of the 21ˢᵗ Century skill set needed for innovation and world leadership (e.g., Ruiz-Primo, 2009).

Objectives and Project Overview

The intent of this paper is to share results of a three-year project funded by the NASA NICE (NASA Innovations in Climate Education) program. The [Project-Based Global Climate Change Education](#) program at Clarkson University in New York State included the development and dissemination of new inquiry and project-based climate change instructional modules that incorporate data, models and resources from NASA and other federal agencies. The project included two Summer Institutes and a series of one-day professional development workshops for middle school and high school science teachers, followed by their use of the modules in their own classrooms. Instructional modules were developed by faculty and students at Clarkson University and teachers who participated in the first institute in August 2010. A climate literacy survey, which was developed and tested as part of this project, was used to assess changes in the climate literacy of both the teachers who participated in the Summer Institutes and their students in classes during the 2011-2012 academic year (AY12).

The basic premise of this project is that climate literacy education programs should address both content knowledge and problem solving skills. Effective instruction must incorporate scientifically-based knowledge and observations, not opinion-based beliefs. Equally important is the need to foster critical thinking, problem solving, and decision-making skills so that students are better able to apply knowledge and skills in confronting and analyzing new, unfamiliar situations. Accessing and analyzing real earth science and energy system data and model projections are fundamental to these inquiry and project-based modules. NOAA, NASA, IPCC and DOE databases are used extensively. This use of real-world data facilitates a focus on the science, mathematics and engineering applications, the exploration of questions related to the causes and impacts of climate change and the nature of policy or engineering interventions to mitigate these changes. This data-driven approach also minimizes the emotional and politicized issues.

The inquiry approach and core content included in these modules are well aligned with the recently published Framework for K-12 Science Education.[12] The climate change science in these modules covers aspects of the disciplinary core subjects (Dimension 3) and most of the cross cutting concepts (Dimension 2). Inquiry and analysis are also authentic ways to include most of the science and engineering practices (Dimension 1) included in the framework. Engaging students in a holistic, inquiry and project-based climate change module, where student-centered activities are thematically tied to the solution of an overarching problem, may be a more effective learning strategy than a more traditional lecture-based approach where information is fed to students without requiring them to actively investigate and formulate their own analysis of the extent, causes and responses to our changing climate.

Developing Climate Change Project Modules

Educational resources currently available to support climate topics in the classroom can be overwhelming, especially for teachers who want to integrate and synthesize materials into a

comprehensive project- or inquiry-based experience. Federal agencies (NOAA, NCAR, DOE, etc.) have rich databases and image files that are valuable resources for classroom use. However, teachers generally do not have the time or support to find and navigate these materials to develop interesting projects. With NASA funding, our project was able to facilitate collaboration among science teachers (who understand projects that would engage their students and their quantitative skill levels), university faculty (who understand the STEM components and connections of various climate change issues), and engineering undergraduate students (who have the time and skills to find and organize all of the required data for an effective project) to collectively organize and produce instructional modules that are ready for the classroom. The initial development of these modules was completed during the eight-day 2010 Summer Institute for middle school (MS) and high school (HS) teachers. The modules were field tested and revised by the project PI team and Summer Institute participants throughout the 2010-2011 school year. These revised instructional modules formed the basis for the shorter five-day Summer Institute in 2011and allowed the focus to be more on developing teachers' skills in accessing and analyzing data for the modules already created. In both Summer Institutes, targeted lectures were provided to address the fundamentals of climate science and modeling basics, greenhouse gas (GHG) emissions and sources, mitigation strategies, and policies and their implications.

Project modules

Twelve separate instructional modules have been developed and are available at our web site (http://www.clarkson.edu/highschool/climate_ed/modules/index.php). The modules include aspects of basic climate science; impacts of climate on the physical and living environment; human activities that cause and can mitigate climate change; and adaptations to inevitable climate change. Several tutorials were also written and are provided to help the instructor learn the requisite technology skills to access and interpret the data necessary to teach the modules. These skills range from basic use of Google earth and MS Excel to the use of resources that enable access to over a century of temperature data from around the world[13] or results of global circulation model (GCM) predictions.[14]

The basic approach used in several of these modules is illustrated in Figure 1, which uses the Arctic Ice Module as an example. In this inquiry-based module, students use a variety of graphical and quantitative approaches to assess the historical loss of ice in the Arctic Ocean and the correlation of this ice loss to changes in surface temperatures over the ocean and land. The depth of analysis can range from using graph paper and counting squares to estimate and compare ice cap coverage area (MS students) to linear regressions and calculating the slope to generate a simple empirical model for the rate of ice loss (HS) or ice loss as a function of average temperature. Extension activities include a more in-depth analysis of GCM predictions of temperature anomalies at the Arctic Circle that can be used to extrapolate the simple correlation models into the future (with caution!). Guided discussion questions focused on societal or wildlife impacts connect the quantitative STEM analysis with topics that are of concern to many students.
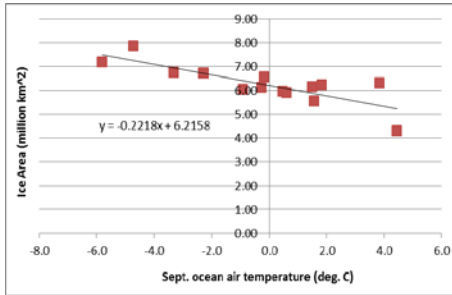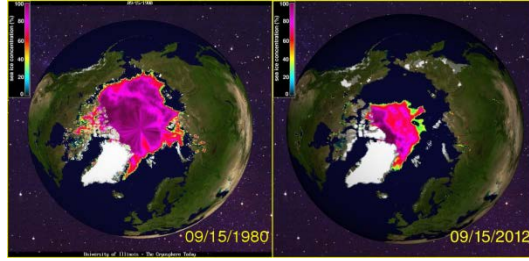
Essential Question: How has and will Arctic Ocean sea ice change?

Historical Perspective

Pose question

How has the area of ice changed from early 1900s to the present day?
Can connections be made between the air or ocean temperature and ice extent?

Gather information

Interpret data

$y = -0.2218x + 6.2158$

Communicate findings

In the period 1994-2008, the Arctic region lost ~0.22 million km^2 ice for every degree (°C) rise in ocean air temperature in the region -154° to +154° longitude at 80° latitude.

Future Perspective

Pose question

How is temperature predicted to change in the Arctic?
What can you infer about the Arctic polar ice cap as a result of the predicted temperature changes?

Gather information

IPCC DDC maps tool was used to look at 20 year temperature anomalies for the region 78-82° latitude and -154 - +154° longitude.

Interpret information

Temperature Anomaly
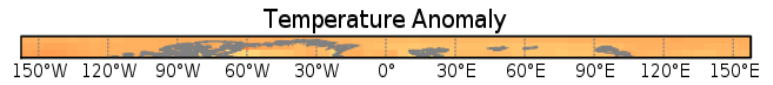
Temperature predicted to be ~5°C warmer by the end of the century. (SR A2 scenario, anomaly relative to 20th century average)

Communicate findings

Extrapolating from the graph above, a 5°C increase should result in an additional loss of at least 1.1 million km^2 of sea ice by the end of the century.

Figure 1: Sample Project-based Climate Change Module: Understanding Climate Induced Changes in Arctic Ice
(developed by W. Armington and S. Powers Clarkson University
http://www.clarkson.edu/highschool/climate_ed/modules/index.php)

Several modules have a human activity or energy focus and provide opportunities for integrating engineering with science and mathematics content. As an example, the Power Profiler module includes activities associated with energy efficiency and electric power production, including the generation of a poster depicting the entire electricity lifecycle (e.g., coal mining to electricity use). The culminating activity is the use of an on-line EPA database to explore regional differences in the mix of energy sources used for electricity generation and the associated impact on regional GHG emissions. Figures 2 and 3 illustrate the analyses that could be completed by high school students using the EPA Power Profiler tool. The analysis of electricity generation and associated greenhouse gas emissions completed in the sample is for upstate New York (NYUP) and Denver CO.
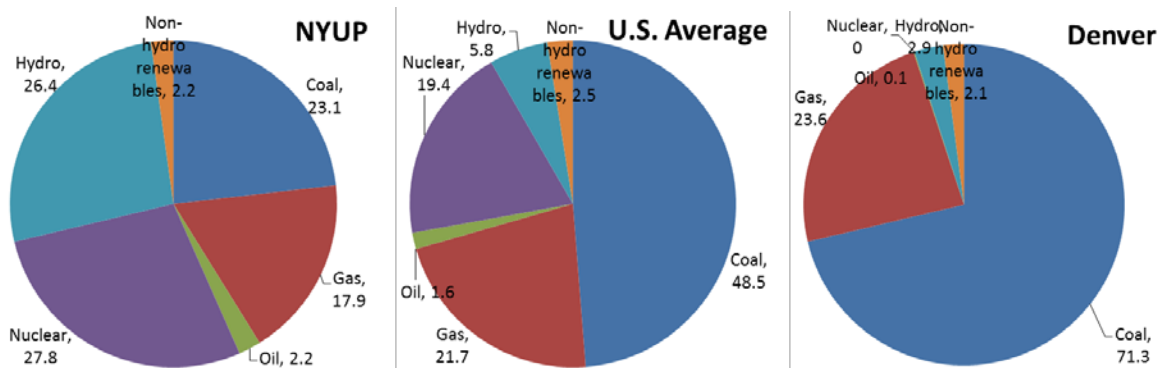
Figure 2: Electricity generation mix in upstate NY and Denver versus the National average
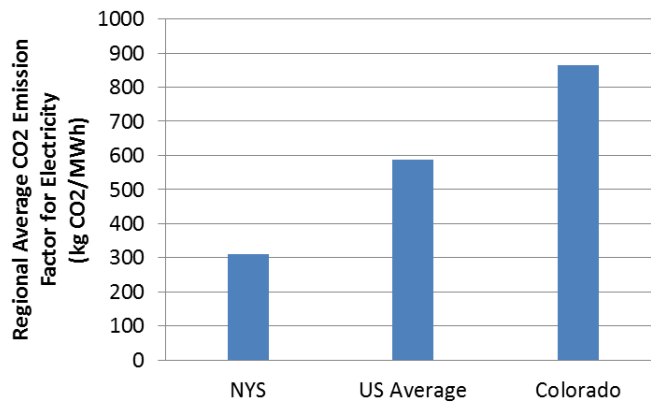(2007 values from the U.S. EPA Power Profiler)

Figure 3: Comparison of regional electricity emission factors for CO_2

New York State has abundant water resources and has harnessed the power of several major rivers (Niagara, St. Lawrence) and many smaller rivers to produce hydroelectric power. There are also several nuclear power plants that operate with nearly negligible greenhouse gas emissions. NYS clearly relies less on fossil fuel, especially coal, than the Nation (on average) and far less than Denver (Figure 2). Nuclear (~28%) and hydroelectric power (25%) are much more important than coal in NYS.

These differences in the electricity generation mix are reflected in variable GHG emissions (Figure 3). The U.S. Power Profiler reports CO_2 emissions from the stack. Other GHGs and lifecycle impacts are not included in these values. The National average CO_2 emission factor (587 kg CO_2/MWh) is nearly twice that for NYS (310 kg CO_2/MWh). Denver's emission factor (865 kg CO_2/MWh) is 2.8 times higher than NYS. Because NYS electricity generation mix is relatively low on the CO_2 production scale, there could be less driving force to reduce these emissions. These state or regional values are used in most personal carbon calculators. Thus, someone in NYS who uses a lot of electricity might not see the same need to reduce their electricity consumption as someone in Colorado or Nebraska (emission factor > 800 kg CO_2/MWh), where nearly all of the electricity is generated from coal. However, because NYS as a whole ranks very high in electricity consumption, there is still a concern and still a significant need to reduce electricity related GHGs.

Assessment

The assessment plan for this project focused primarily on evaluating the effectiveness of the new instructional modules by measuring changes in targeted content and personal competencies and attitudes related to global climate change among participating students. We also evaluated similar changes among teachers who participated in the two summer institutes. Both groups were assessed using quantitative Climate Literacy content and attitude competence surveys that were administered pre- and post-course (for students) or workshop (for teachers) participation.

Different versions of the Climate Literacy Survey were developed and used for teachers, HS, and MS students, each containing a combination of multiple-choice (content based) and Likert-type scale (affective, behavioral) items. The general goal of this instrument development effort was to create a comprehensive, valid and reliable measure of climate science literacy,[2] which is appropriate for use in middle and high school classrooms. The survey was developed according to established psychometric principles and established methodologies for creating valid, reliable written surveys in the educational and sociological sciences.[15] These steps included:

1. Define content objectives for the survey: Primarily guided by "Essential Principles of Climate Science Literacy;"[2]
2. Develop Item Pool: Items (questions) were adapted, by permission, from a variety of existing measures that seek to gather information about people's climate change knowledge, their behaviors related to activities that impact climate change, and their attitudes/feelings toward climate change. Selected items were matched to content objectives;
3. Pilot Testing: Two pilot surveys were administered to college students – an item pilot (105 students) to test/evaluate full item pool, and a second pilot (360 students) to test retained items;
4. Evaluate and revise: Based on results of second pilot, a final survey instrument was developed for adults/college students;
5. Review by experts: Final survey items were reviewed by HS and MS teachers;
6. Pilot Testing: Recommended items pilot tested among 204 HS and 241 MS students;
7. Define final surveys: Items retained from pilot analysis formulated into final surveys for HS and MS students.

The resulting survey instrument measures a respondent's climate literacy according to their performance on three instrument subscales:

Cognitive:	Affective	Behavioral
5 option multiple choice	5-point Likert-type scale	5-point Likert-type scale
21 items (HS),	14 items, including	9 items
19 items (MS)	5 self-efficacy items	

The internal consistency reliability of each subscale, as measured by Cronbach's alpha, ranges from 0.78-0.86 (cognitive), 0.87-0.89 (affective) and 0.84-0.85 (behavioral), all satisfying generally accepted criteria for internal reliability of educational surveys (at least 0.7 for a set of items in social science scales[16] and as low as 0.60 for educational assessment scales[17,18]).

The appropriate versions of the survey were administered using an on-line Zoomerang™ platform before and after the educational intervention. The adult-version of the survey[19] was administered to teachers in June before the Summer Institute and on the last day of each Institute in August. Student surveys were administered early in AY12 and at least three weeks after the climate change modules were taught in each classroom. Statistical applications, including Wilcoxin signed rank test, have been used to evaluate pre/post changes in student and teacher responses. Analyses were conducted with Microsoft excel and the *Statistical Package for Social Sciences* (SPSS) Statistics Version 17.

A pre- and post-climate literacy survey administered to 23 teachers who participated in the Summer Institutes showed statistically significant gains ($p < 0.01$) in their climate-related content knowledge and affect (Figure 4). Changes in responses to the behavior subscale and self-efficacy items were not significant.
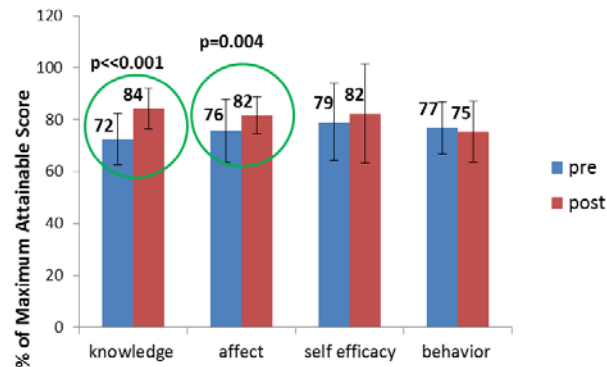

Figure 4: Results of climate literacy survey show statistically significant
improvements ($\alpha = 0.05$) in the knowledge and affect of 23 teacher participants.
Results based on matched pre/post mean survey responses; error bars represent $\pm$ 1 SD.

In all, 9 HS and 3 MS teachers successfully completed the assessment protocol with their students in AY2012, yielding 200 HS and 227 MS matched pre/post climate literacy surveys. Both groups of students demonstrated significant gains in climate-related content knowledge ($p<<0.001$) and affect ($p<0.01$) (Figure 5). MS students also experienced significant gains in their climate-related self-efficacy ($p=0.03$), with no significant change in self-efficacy for HS students and no change in either group on the behavioral subscale. Post-scores were remarkably similar for the two groups of students; reported as percent of maximum attainable score for

HS/MS students: 59%/58%, knowledge; 65%/64%, affect; 71%/72%, self-efficacy, and 63%/62%, behavior.
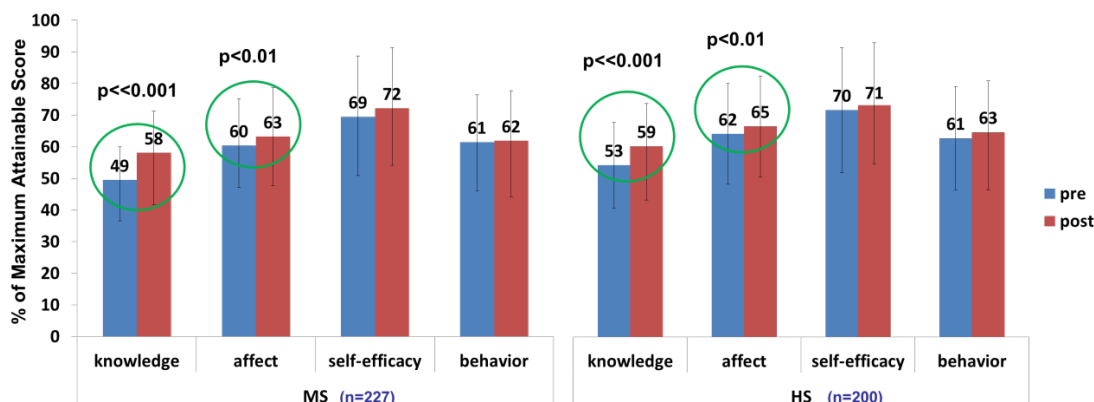

Figure 5: Results of climate literacy survey show statistically significant improvements (α=0.05) in the knowledge and affect of middle and high school participants Results based on matched pre/post mean survey responses; error bars represent ± 1 SD.

Tables 1 and 2 provide a few examples that illustrate the types of gains made by students (middle/high school combined scores). While they still showed a lack of understanding of the scientific nature of the greenhouse effect, students were generally much more cognizant and concerned with the causes and impacts of climate change following participation in the climate change module.

Table 1. Sample Gains on Cognitive Items, Combined MS/HS Student Scores

Example Questions	Pre-test average	Post-test average
Which of the following is the greenhouse gas of most concern from a global warming point of view? **CO$_2$**	**69**	**78**[**]
Which of the following best describes how greenhouse gases can make the atmosphere warmer? **They absorb energy at certain wavelengths in the atmosphere.**	**14**	**19**[**]
Which of the following best describes the relationship between the greenhouse effect and global climate change? **An increase in the greenhouse effect may be causing global climate change.**	59	61
Which of the following (**burning fossil fuels**; the upper atmosphere ozone hole; livestock production) is the most significant cause of global climate change?	47	78[NA]
Building more nuclear power plants (**will**/will not) help reduce or slow down global climate change.	**52**	**60**[*]

Bold values indicate a significant pre/post difference at:
[*]p<0.05
[**]p<0.01
[NA] Students selected between alternatives – not possible to calculate statistical significance.

Table 2. Sample Gains on Affective Items, Combined MS/HS Student Scores

Example Questions (followed by Likert-type response option)	Pre-test response	Post-test response
How much do you feel you know about global climate change? (% responding a lot/quite a bit)	**15**	**54**[***]
How convinced are you that global warming is happening? (% responding completely/mostly)	**67**	**77**[***]
How serious you consider global warming to be a threat to each of the following: (% responding urgent/very serious)		
• Plants and animals	60	63
• People in other countries	**39**	**45**[**]
• People in the United States	37	40
• People in your local community	22	24

Bold values indicate a significant pre/post difference at:
[**]$p<0.01$
[***]$p<0.001$

Conclusions

Clarkson University's NASA-funded Project-Based Global Climate Change Education project has created and disseminated several instructional modules for middle and high school teachers. Fundamental to these inquiry-based modules are questions about climate change or mitigation efforts, the use of real-world data to explore historical climate changes, and review of IPCC model results to understand predictions of further changes over the next century. Our approach for inquiry and analysis are also authentic ways to include the engineering practices included in the framework.

Assessment has shown that our teacher professional development opportunities and the use of project-based modules in the classroom have been effective. A pre- and post-climate literacy survey showed statistically significant gains in teachers' and students' climate-related content knowledge and affect. Changes in responses to the behavior items were not significant.

The teacher and student audiences have both responded in a positive manner to the use of real-world data and situations. These projects are relevant to the students. However, the most significant barrier to their implementation has been the expectation that both teachers and students have rudimentary quantitative skills. We have found that teachers' level of experience with finding and interpreting real data and some modest manipulation of the data to be widely varying. Many teachers are excited and engaged in the data analysis process. Others struggle with quantitative skills, leading to the presentation of some of the modules as a recipe for downloading and graphing data rather than an inquiry into climate change problems or solutions. Similar wide ranges of quantitative skills have been observed in our undergraduate students.[19] These observations point to the need for students at any level to have strong fundamental STEM skills in order to approach engineering analysis projects. At the same time, our design of such experiences must recognize the breadth of capabilities with built in alternative approaches for teachers to integrate real-world earth and energy system projects in their class rooms in a way that they are comfortable yet their students are challenged with student-centered approaches to learning.

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