

## **WEAVING TOGETHER CLIMATE SCIENCE AND CHEMISTRY EDUCATION IN AN AFRICAN CONTEXT**

Darrell Vandenbrink, Brian Martin, and Peter Mahaffy\*

The King's Center for Visualization in Science, the King's University College, Edmonton,  
Alberta, Canada T6B 2H3

\*Corresponding author email – [peter.mahaffy@kingsu.ca](mailto:peter.mahaffy@kingsu.ca)

### **ABSTRACT**

Integrating meaningful contexts into chemistry education offers potential benefits for both students and instructors. Weaving together the teaching and learning of chemistry with the rich context of climate science provides opportunities for educators to increase student motivation, enhance classroom experiences and equip students to use fundamental understanding of science and problem-solving skills to begin to address some of our planet's most important and complex challenges. Improved climate literacy is especially important to African students and teachers because of Africa's vulnerability to climate change. This paper describes the development of a new set of interactive, web-based resources, *Visualizing and Understanding the Science of Climate Change* ([www.explainingclimatechange.com](http://www.explainingclimatechange.com)), which explores various climate topics and illustrates ways in which connections between chemistry and climate change can be drawn out in chemistry courses at the secondary and post-secondary level. Dual goals are to improve chemistry conceptual understanding and to empower African students to understand and effectively respond to the climate challenges currently facing their continent. [AJCE, 3(2), June 2013]

## **INTRODUCTION**

### **Teaching and Learning Chemistry in Meaningful Contexts**

Meaningful contexts for the teaching and learning of chemistry can enrich the experience of students in their encounters with chemistry at the secondary and postsecondary level (1, 2). By integrating contexts that matter to students with the learning of chemistry concepts, chemistry educators may increase student motivation, facilitate better understanding of chemistry concepts, make teaching more satisfying for instructors, and equip students to apply their understanding to important real-world contexts - thus working at higher levels on learning taxonomies (3). However, teaching chemistry in this way, especially to cohorts of students majoring in science, is unfamiliar to many students and chemistry educators. Even experienced teachers in a teacher development course for teaching chemistry concepts in contexts experienced difficulty linking meaningful contexts with introductory chemistry content (4, 5). Thoughtful attention to providing the right resources to support learning and teaching is one of the necessary conditions for successful implementation of rich contexts in chemistry teaching, and is the focus of this paper.

As an example, consider a chemistry educator at the secondary or introductory post-secondary level in Addis Ababa who is covering a unit on phases, and is introducing the concept of vapor pressure of gases and its dependence on temperature. How can this educator present the topic so that it is not a set of isolated, irrelevant facts? How can students in this chemistry course be helped to see how important the tools of chemistry are to their lives?

To demonstrate the relevance of the chemistry content, the educator might show how the concept informs a significant challenge faced by the students. One such global challenge, with integral connections to chemistry, is climate change. The current and projected effects of climate

change upon the entire globe are well-documented; however, Africa faces some particularly vexing climate change challenges, many of which result from human activity elsewhere in the world. Chemistry education has an important role to play in equipping the next generation of scientists and citizens to address those challenges.

### **The Challenge of Climate Change for Africa**

Some of the greatest impacts of planetary-scale changes in the earth's climate systems will be felt far from the largest sources of greenhouse gases that contribute in such a substantial way to global climate change. African climate is highly diverse and variable, and the livelihood of many Africans heavily depends on the climate (6). Because of this, Africa is considered to be particularly vulnerable to climate change (6, 7). An especially important vulnerability results from the modeled impact of climate change on water availability, which is a major concern in sub-Saharan Africa (6). Due to climate change, by the 2050s, the population at risk of increased water stress is projected to be somewhere between 350 and 600 million Africans, although the regional impact of climate change on precipitation is highly variable (7, 8). In addition to the resulting shortages in drinking water, changes in rainfall patterns are expected to reduce agricultural productivity (9, 10). Because food shortages are already a reality for many African countries, the adverse effects of climate change on agriculture are a serious concern (11).

Africa is also the continent with the lowest life expectancy (12). Health issues are expected to intensify due to climate change because, according to models, climate change will lead to the increased frequency, intensity and duration of heat waves (13). These heat waves will have particularly severe effects on children, increasing their vulnerability to disease, and raising morbidity and mortality rates (14).

Finally, social conflict may be exacerbated by extreme precipitation conditions—conditions of either severe wetness or severe dryness (15, 16). Because climate change is projected to generate more extreme rainfall events in Africa, in which extended periods of dryness are interspersed with violent storms, climate change may contribute to higher frequency or severity of social conflict (15).

### **The Importance of Climate Literacy and Chemistry Education in Africa**

Due to the particular vulnerability of African countries to climate change, increasing climate literacy among Africans is crucial to equip the next generation of Africans to understand the challenges and know how to respond to them effectively. Since climate science builds on fundamental knowledge of chemistry and other sciences, an important opportunity is presented in chemistry classrooms and laboratories to build connections between climate literacy and chemistry concepts.

What approaches to integrate the learning of chemistry concepts with climate literacy objectives could be taken by our Addis Ababa chemistry educator, who is teaching about phase changes of water? By drawing a deep connection between vapor pressure dependence on temperature and the effect of climate change on water resources in Africa, the educator can enable students to understand the concepts about physical properties and phase changes, while building literacy about the impact of climate change on students' lives. This simple scenario illustrates the power of using climate change as a rich context for teaching and learning fundamental chemistry principles. With knowledge of both the fundamental science and the implications for changing climate, students can be encouraged to consider their responsibility to respond to climate change, and to make informed decisions that help address the issue.

## THE RESOURCES – VISUALIZING AND UNDERSTANDING THE SCIENCE OF CLIMATE CHANGE ([www.explainingclimatechange.com](http://www.explainingclimatechange.com))

### An Overview

We report the development and dissemination of an interactive, web-based educational resource, targeting students, educators, and the general public, designed to help bridge the gap between climate literacy and fundamental chemistry principles. The interactive, web-based resources, *Visualizing and Understanding the Science of Climate Change*, can be accessed at [www.explainingclimatechange.com](http://www.explainingclimatechange.com). Resources were created over a period of five years as an International Year of Chemistry legacy project by students and faculty at the King's Centre for Visualization in Science, under the umbrella of an International Union of Pure & Applied Chemistry (IUPAC) project. Partners collaborating on the project, and providing review of the resources by both scientists and educators include the Royal Society of Chemistry (RSC – UK), the American Chemical Society (ACS – USA), the Federation of African Societies of Chemistry (FASC), and UNESCO.

*Visualizing and Understanding the Science of Climate Change* is organized into nine lessons, and addresses a variety of climate topics, with a strong emphasis on drawing connections to underlying chemistry concepts (Figure 1; Table 1). Simulations, videos and assessment items are included within each lesson, to help facilitate the user's learning. Every lesson is also followed by "Test Your Knowledge" questions, which students may employ to reinforce their understanding or which educators may use to test the knowledge of their students. In addition, pop-up definitions and an extensive glossary allow users to acquire familiarity with the many terms that are fundamental to the science of climate change.

## Visualizing and Understanding the Science of Climate Change

"Education in and about chemistry is critical in addressing challenges such as global climate change, in providing sustainable sources of clean water, food and energy and in maintaining a wholesome environment for the well being of all people..." -UN International Year of Chemistry resolution

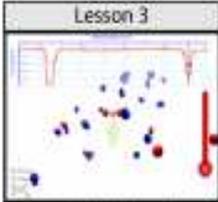
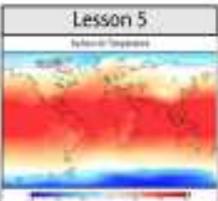
<p style="text-align: center;">Lesson 1</p>  <p style="text-align: center;">Introduction to Earth's Climate</p>	<p style="text-align: center;">Lesson 2</p>  <p style="text-align: center;">Is Climate Change Happening?</p>	<p style="text-align: center;">Lesson 3</p>  <p style="text-align: center;">Heating it Up: The Chemistry of the Greenhouse Effect</p>
<p style="text-align: center;">Lesson 4</p>  <p style="text-align: center;">Climate: A Balancing Act</p>	<p style="text-align: center;">Lesson 5</p>  <p style="text-align: center;">A Global Issue: The Impacts of Climate Change</p>	<p style="text-align: center;">Lesson 6</p>  <p style="text-align: center;">Greenhouse Gases: A Closer Look</p>
<p style="text-align: center;">Lesson 7</p>  <p style="text-align: center;">Climate Feedback Loops</p>	<p style="text-align: center;">Lesson 8</p>  <p style="text-align: center;">Climate Change and the Oceans</p>	<p style="text-align: center;">Lesson 9</p>  <p style="text-align: center;">What Now? Responding to Climate Change</p>

Figure 1. Opening screen of *Visualizing and Understanding the Science of Climate Change* (click on the image to link directly to the resource)

Table 1. Lessons and Key Ideas in *Visualizing and Understanding the Science of Climate Change*

Lesson	Key Idea 1	Key Idea 2	Key Idea 3	Key Idea 4	Key Idea 5
<b>1. Introduction to Earth's Climate</b>	What is Climate?	Earth's Unique Climate	Earth's Atmosphere	Regional Climate Differences	Temporal Climate Differences
<b>2. Is Climate Change Happening?</b>	Ice Cores	Temperature Trends	Trends in Atmospheric Gases	Relationships Between Trends	The Past 250 Years
<b>3. Heating It Up: The Chemistry of the Greenhouse Effect</b>	Temperature and Energy in Earth's Atmosphere	Properties of Gases	Absorption and Emission of Radiation	Atmospheric Molecular Interactions	Are All Greenhouse Gases the Same?
<b>4. Climate: A Balancing Act</b>	What is a Radiation Balance?	Incoming Solar Radiation	Reflection of Solar Radiation	Emission of Solar Radiation	The Greenhouse Effect
<b>5. A Global Issue: The Impacts of Climate Change</b>	Polar Regions	Coral Reefs	Vector-Borne Disease	Extreme Weather	Biodiversity
<b>6. Greenhouse Gases: A Closer Look</b>	Water Vapour	Carbon Dioxide	Methane	Nitrous Oxide	CFCs and Super Greenhouse Gases
<b>7. Climate Feedback Loops</b>	What is a Feedback Loop?	Carbon Dioxide as a Thermostat	Methane Feedbacks	Water Feedbacks	The Mountain Pine Beetle
<b>8. Climate Change and the Oceans</b>	The Global Regulator	Energy Balance	Ocean Acidification	Carbon Speciation	Immeasurable Importance
<b>9. What Now? Responding to Climate Change</b>	Our Children's World	Powering the Future	A Mosaic of Solutions	The Human Element	Our Window of Opportunity

### Design Principles of *Visualizing and Understanding the Science of Climate Change*

The pedagogical design of *Visualizing and Understanding the Science of Climate Change* is fundamental to its effectiveness in improving climate literacy and teaching underlying chemistry principles. Principles incorporated into the design include interactivity, guided inquiry and self-assessment (17). The resource is highly interactive, containing numerous simulations in which the user is able to adjust the conditions of a system and observe the results. Other work suggests that a high degree of interactivity can be effective in facilitating student learning (17). In explainingclimatechange.com, students are guided through an inquiry process, rather than told facts that need to be memorized (17). For this reason, when data is presented, the resource does

not directly state the conclusions that can be made. Instead, directive questions are employed to encourage the user to interrogate the data and arrive at the appropriate conclusions independently. Finally, the resource integrates numerous formative and summative assessment items, which reinforce the information that has been presented and allow the users to ensure that they have understood the key concepts. These self-checks also help to maintain focused time on task, preventing the user from clicking rapidly through the resource.

### **Key Topics in *Visualizing and Understanding the Science of Climate Change***

#### **Climate Change and Water**

Various sections of the resources address the connection between climate change and the water cycle, which, as noted above, is of particular concern in the African context. In Lesson 6, *Greenhouse Gases: A Closer Look*, the user is able to visualize the effect of increased temperature on water evaporation through an interactive graph and animation (Figure 2). The warming trend associated with climate change results in increased concentrations of atmospheric water vapour through higher rates of evaporation. Because the user has learned that water vapour is a greenhouse gas, questions guide the user to consider how increased evaporation of water results in a positive feedback loop that compounds the effect of climate change. However, increased atmospheric moisture may also increase local cloud cover, which contributes to increasing earth's albedo and is an example of a negative feedback loop. These opposing feedbacks are complex and can operate on both different geographical and time scales.

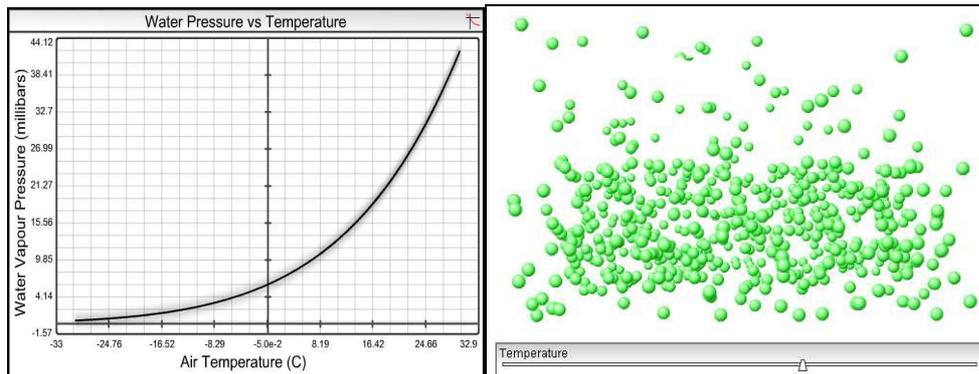


Figure 2. The temperature dependence of water vapor pressure displayed with an interactive graph and animation (*click on the images to link directly to the learning tools*)

The concept of water feedbacks is explored in greater detail in Lesson 7, *Climate Feedback Loops*. In addition to the feedback effects described above, increased global temperatures also lower earth's albedo through the melting of polar snow and ice. Using the *Polar Ice Cap Measurement Learning Tool*, the user is able to measure the area of polar ice from different years and observe and quantify the decrease in polar ice over the past 3 decades (Fig 3).



Figure 3. Using an Interactive Tool to estimate the area of polar ice in the year 2010 (*click on the image to link directly to the learning tool*)

At first encounter, African students may not consider the shrinking of polar ice to be of great regional relevance, but the user learns in Lesson 4, *Climate: A Balancing Act*, that loss of polar ice lowers earth's albedo, which leads to greater absorption of solar radiation and amplified warming. Because of African vulnerability to climate change, any process that intensifies the effects of climate change holds importance for Africans, including the melting of polar snow and ice. Furthermore, substantial populations living in African coastal cities will be affected by even moderate sea level rise.

Lesson 5, *A Global Issue: The Impacts of Climate Change*, touches on the issues of water availability and soil moisture, discussing the effect of climate change on the frequency of extreme weather events such as heavy rainfall and drought. In this lesson, the user is encouraged to consider the societal and economic implications of increased instances of both heavy precipitation and drought. The user is also able to examine simple models for these predictions using the *Visualizing Global Climate Change Learning Tool*. With this tool, the user can observe the modeled evaporation differences in various cities around the globe, relative to an average reference value from 1960 – 1990, as projected by various Intergovernmental Panel on Climate Change (IPCC) Special Reports Emissions Scenarios (18). For example, the tool projects that by 2100, the city of Lagos may experience higher evaporation than the 30-year average for the reference period of almost 0.5 mm/day under the moderate A1B emissions scenario (Figure 4). With increased evaporation, soil moisture would be decreased, consistent with projections that climate change will likely lower agricultural productivity. These models were created from the IPCC Scenarios by using the Educational Global Climate Modeling or EdGCM software, which is an extensive suite of climate modeling tools developed at NASA's Goddard Institute for Space Studies (19).

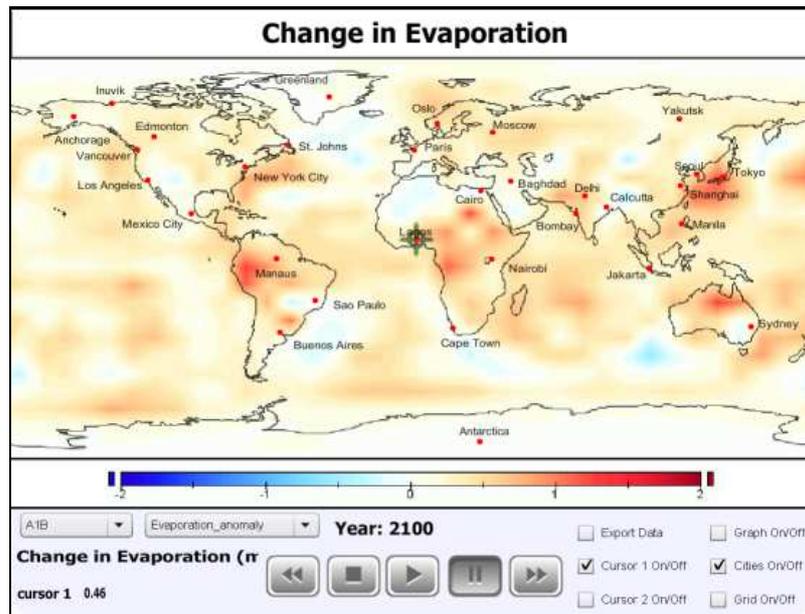


Figure 4. Change in evaporation (from the 30-year average reference value) by the year 2100, with the city of Lagos highlighted (*click on the image to link directly to the learning tool*)

### Evidence for Climate Change

Students may have little experience in evaluating scientific claims, and in discriminating between scientific evidence for climate change and the claims made by a few contrarians, who publically dispute the conclusion that temperature increases since the Industrial Revolution have a human signature. Data does show that earth has experienced numerous and regular natural temperature fluctuations throughout our planetary history. Interrogating the evidence can help the user see and understand what we do know about the connection between human activity and the current surface air temperature rise.

In Lesson 2, *Is Climate Change Happening?*, the user is introduced to the study of ice cores, which climate scientists use to reconstruct the average temperatures of the earth hundreds of thousands of years ago. The *Isotope Ratio Mass Spectrometry (IRMS) Learning Tool* (Figure 5) describes how the isotopic ratios of oxygen or hydrogen in specific ice core layers are

analyzed using Isotope Ratio Mass Spectrometry to provide a proxy measurement of Earth's temperature over time. The *Ice Core Extraction and Analysis Learning Tool*, also shown in Figure 5, describes how ice cores are extracted, preserved and analyzed.



Figure 5. Opening screens of the *IRMS* and *Ice Core Extraction and Analysis Learning Tools* (click on the image to link directly to the learning tools)

Analysis of proxy temperature measurements from isotope ratios of water in ice cores clearly indicates that Earth's temperature has fluctuated dramatically in the past. With the *Climate Trends Learning Tool*, the user is able to interact with and ask questions of the graphical presentation of historical temperature and greenhouse gas trends. As shown in Figure 6, the tool displays the Earth's average temperature over the past 800,000 years, based on the ratio of heavy to light water in ice core samples.



Figure 6. Temperature records from the past 800,000 years determined from analysis of ice core data from *Climate Trends Learning Tool* (click on the image to link directly to the learning tool)

Figure 6 illustrates the fluctuations in mean global temperature over an 800 ka span and clearly shows many glacial and inter-glacial periods. The difference in average surface temperature for one of these episodes is on the order of magnitude of 8 – 10 °C, but much greater at the poles. The resource leads the user through a worked example in which earth's average temperature is found to have fluctuated more than 10°C. Unsurprisingly, one may then ask why most climate scientists' claim that the current increase in earth's average temperature is caused by human activity and is not due to natural causes. One key element to making sense of the difference since the Industrial Revolution is analysis of the rate of change of temperature. The resource directs the user to find a rapidly rising temperature period over the past 800,000 years, and use a slope-measuring tool to find that, in the past, temperature changes occurred very slowly, often near a rate of about 0.001°C per year during the periods of steepest rise. Carrying out the same analysis for the past 100 years shows a rate of change an order of magnitude

greater, about  $0.01^{\circ}\text{C}$  per year. The difference in slopes suggests that something profoundly different is happening now and points to an anthropogenic signature in the recent data set.

The *Climate Trends Learning Tool* can also be used to show that the recent rapid increase in temperature is strongly correlated with increases in the atmospheric concentrations of several greenhouse gases, including carbon dioxide (Figure 7).

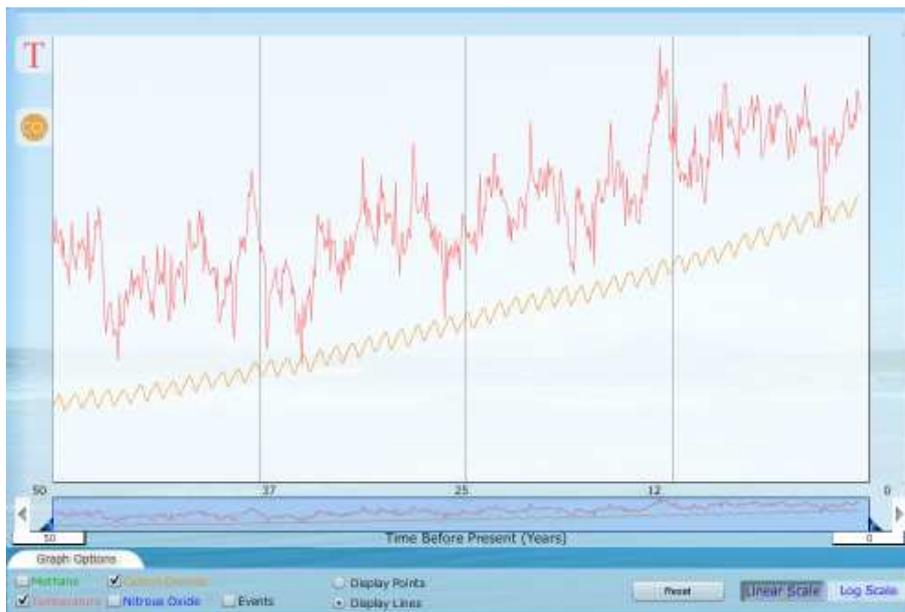


Figure 7. Average temperature and atmospheric carbon dioxide concentration for the last 50 years, from *Climate Trends Learning Tool* (click on the image to link directly to the learning tool)

By illustrating the correlation between the rapid increase in atmospheric carbon dioxide and the increase in temperature, this learning tool suggests that anthropogenic emissions of greenhouse gases are associated with climate change. As Lesson 2 illustrates the connection between atmospheric greenhouse gas concentrations and earth's average temperature, the user may draw the conclusion that climate change is the result of human activity, rather than natural causes. The user is cautioned, however, to understand the difference between a strong correlation and a cause-effect relationship.

### Linking Absorption of Electromagnetic Radiation by Molecules and Climate Change

Although the correlation between greenhouse gases and rising global temperatures is highly suggestive, one must understand the mechanism by which greenhouse gases warm the atmosphere in order to definitively grasp the connection between human activity and climate change. This concept is the focus of Lesson 3, *Heating it Up: The Chemistry of the Greenhouse Effect*. With the *Collisional Heating Learning Tool*, the user interacts with a visual model for how greenhouse gas molecules absorb infrared (IR) radiation at the wavenumbers required for vibrational excitation of molecules (Figure 8). The process of collisional de-excitation results in an increase in temperature, as vibrationally excited greenhouse gas molecules transfer energy to atmospheric gases such as  $\text{N}_2(\text{g})$  and  $\text{O}_2(\text{g})$ , which are unable to directly absorb IR radiation. This provides an important context and motivation for understanding the kinetic-molecular theory.

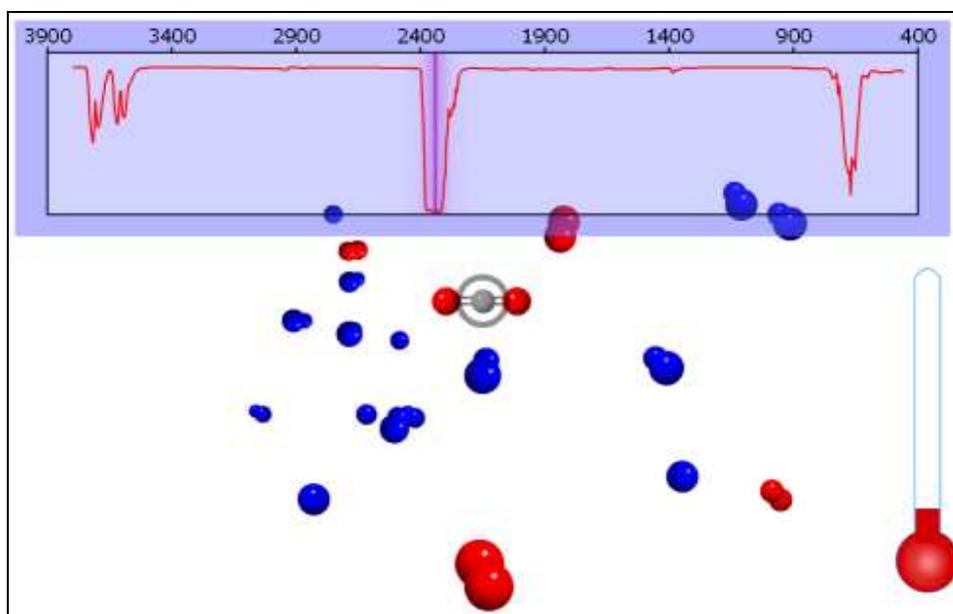


Figure 8. Absorption of IR radiation by a greenhouse gas molecule and collisional de-excitation in the *Collisional Heating Learning Tool* (click on the image to link directly to the learning tool)

Lesson 3 also encourages the user to consider why greenhouse gases differ in their effect on atmospheric temperature by analyzing various factors that contribute to the radiative forcing of a gas. To facilitate the user's analysis, the *Infrared Spectral Windows Learning Tool* displays the laboratory IR spectra of several greenhouse gases, allowing the user to observe the intensity and spectral regions of IR absorption for each of these gases. The blackbody emission curve of the earth can also be superimposed on top of the laboratory spectra, allowing the user to evaluate the significance of the IR spectral region in which a particular greenhouse gas absorbs strongly. As the user considers these factors that affect the importance of a greenhouse gas, the user obtains a solid understanding of the global warming potential of a gas, which is an important climate literacy concept. This is demonstrated in Figure 9, which shows that CFC-11, present in only ppt levels in earth's atmosphere, and largely emitted from outside of the African continent, is nevertheless a contributor to climate change in Africa.

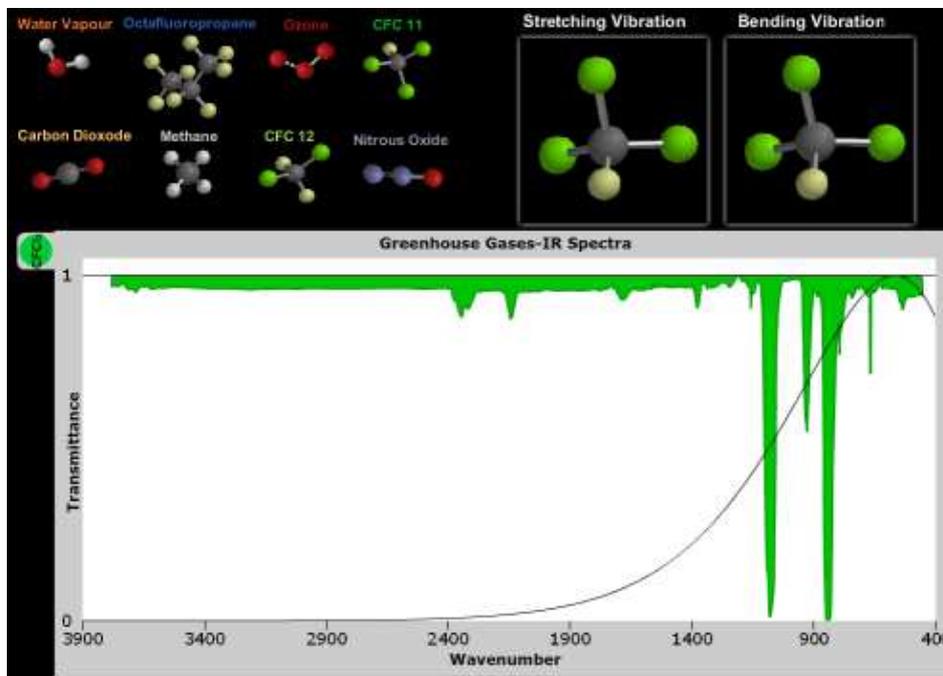


Figure 9. Laboratory infrared spectrum of CFC-11 with Earth's emission curve superimposed in the *Spectral Windows Learning Tool* ([click on the image to link directly to the learning tool](#))

### **Climate Change and the Future**

While the underlying science of climate change is important for developing a basic understanding of the issue, the general public is most often concerned with the consequences and mitigation of the problem (20). Therefore, after the user has explored how humanity's decisions have affected and will affect earth's climate, the final Lesson 9, *What Next? Responding to Climate Change*, challenges students and teachers to consider how energy choices can either alleviate or exacerbate anthropogenic climate change. The Lesson makes use of two interactive learning tools, the *Carbon Stabilization Wedges* and the *CO<sub>2</sub> Footprint Learning Tool*.

The *Carbon Stabilization Wedges Learning Tool* allows the user to explore various strategies and currently existing technologies with the potential to stabilize annual carbon dioxide emissions at current levels, thereby preventing an additional 200 GT of carbon from entering the atmosphere over the next 50 years (Figure 10). Building on the Princeton Carbon Mitigation Initiative (21), the tool breaks down this challenge into one of removing eight smaller "wedges" of carbon from the projected emissions graph. Each of these wedges represents 25 GT of anthropogenic carbon that is prevented from entering the atmosphere over a 50 year period. With this framework, the tool enables the user to adjust conditions related to various mitigation strategies and observe the resulting effect on projected carbon emissions.

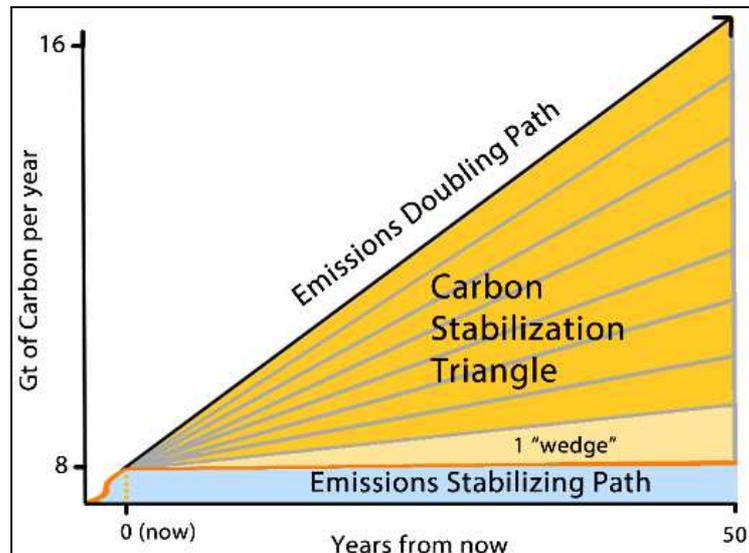


Figure 10. Projected carbon emissions according to two emission paths and the eight Carbon Stabilization Wedges, as illustrated in Lesson 9, Key Idea 2 of *Visualizing and Understanding the Science of Climate Change* ([click the image to access the resource](#))

By exploring the tool, the user quickly learns a key concept: no single mitigation strategy will be sufficient to stabilize emissions, but a mosaic of solutions could be effective. Only if various strategies (within the categories of Efficiency, Decarbonization of Power, Decarbonization of Fuel, and Forests and Agricultural Soils) are implemented simultaneously can all of the “wedges” be removed from the projected emissions graph, stabilizing emissions at current levels. The tool also indicates the realism of a given set of conditions. Therefore, the user learns that, by scaling up several technologies or by employing several new practices, stabilization of carbon emissions is a feasible goal. Particularly relevant in the African context might be energy efficiency measures and the reductions in carbon emissions possible through reducing tillage of agricultural land.

The *CO<sub>2</sub> Footprint Learning Tool* is particularly relevant to understanding the potential effects of future human action in an African context. The tool allows users to build various carbon dioxide emission scenarios and observe the impact on atmospheric CO<sub>2</sub> levels. This is

done by numerically solving a complex, seven-compartment model that traces the exchange of CO<sub>2</sub> with planetary sinks and sources. A component is included that ties directly to population growth models and per capita CO<sub>2</sub> emissions defined over a regional level. In Lesson 9, the user is initially encouraged to utilize the tool to understand the relative magnitude of per capita carbon dioxide emissions for each continent, as well as each continent's total carbon dioxide emissions. It becomes immediately evident that the average carbon dioxide emissions from an African person is much lower than the average emissions from an individual living on any another continent (Figure 11). Because earlier lessons have addressed the significance of carbon dioxide emissions, the *CO<sub>2</sub> Footprint Learning Tool* exposes the user to an unfortunate reality: although Africa is believed to be the most vulnerable continent to climate change, Africans have done relatively little to contribute to the severity of the problem (6, 7).

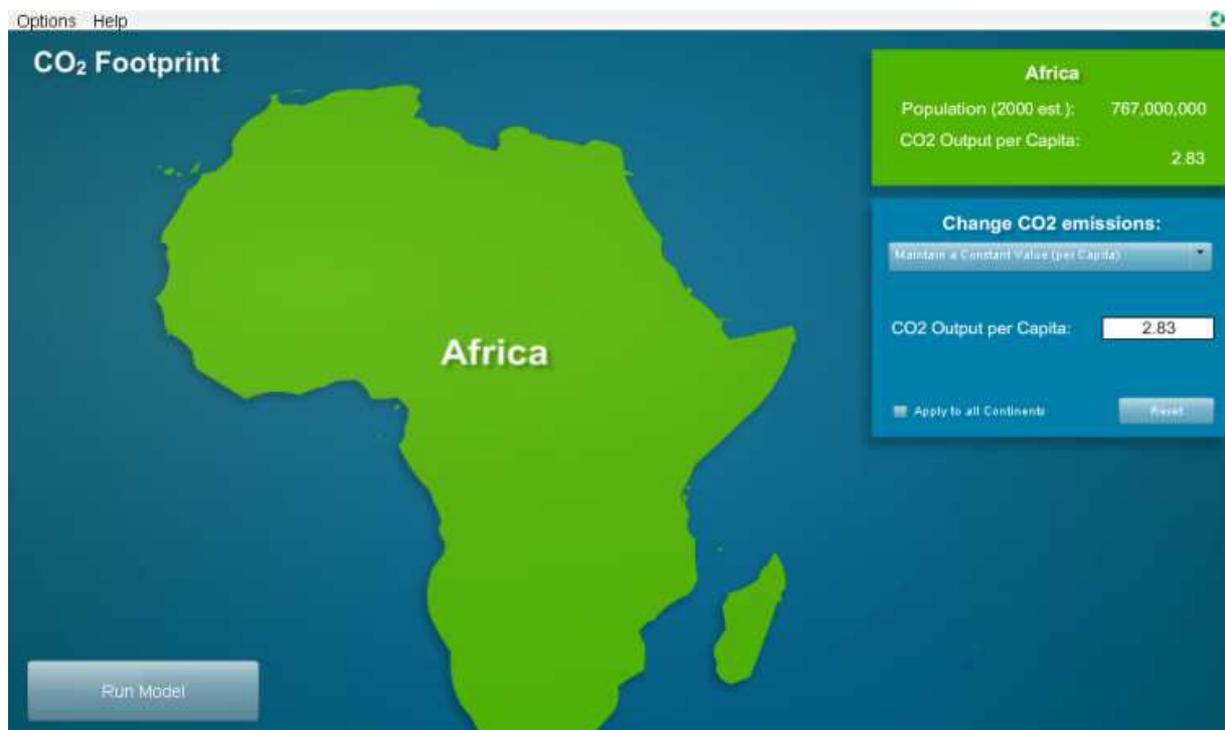


Figure 11. Per capita CO<sub>2</sub> emissions for Africa in the *CO<sub>2</sub> Footprint Learning Tool*, from Lesson 9, Key Idea 1 ([click on the image to link directly to the learning tool](#))

Using this model, a user can adjust emission rates for a continent and observe the resultant atmospheric concentration of carbon dioxide until the year 2140. Growth scenarios on one continent can be applied to the world, to explore global effects of mitigation scenarios. For instance, the user could run a model in which each continent continues to emit at current levels and demonstrate that the atmospheric carbon dioxide concentration is expected to grow from the recent milestone of 400 ppm to above 600 ppm by the year 2100. Alternatively, one can simulate the effect of different scenarios for increased emissions. In Lesson 9, the user explores the consequence of growing emissions from Asia, which is a likely scenario considering Asia's rapid industrialization and rising energy requirements. When a linear growth model of 10% is applied to Asia's emissions, the concentration of atmospheric carbon dioxide is expected to drastically increase, reaching a value of about 900 ppm by 2100, even while the other continents maintain stable emissions (Figure 12).

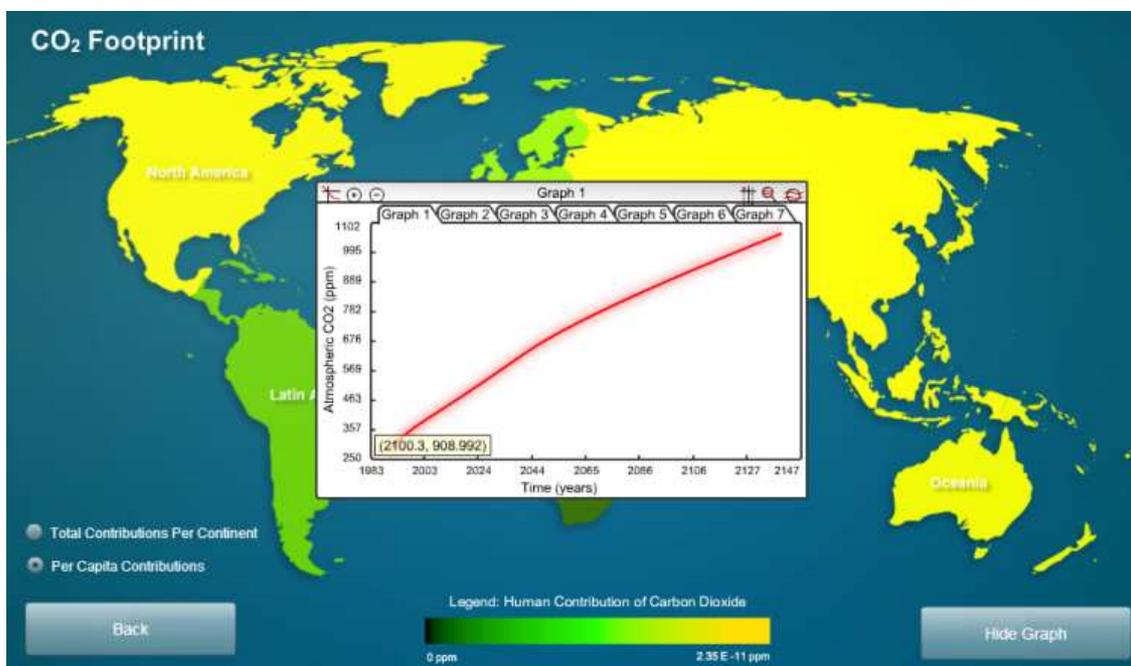


Figure 12. Projected atmospheric carbon dioxide concentration, based on 10% linear growth of Asian emissions and stable emissions for all other continents (*click on the image to link directly to the learning tool*)

The tool can also strikingly demonstrate the positive effect of low emission rates. For instance, if the per capita emission rate of Africa is applied to the rest of the world, the model predicts that atmospheric carbon dioxide concentrations will only rise from the present day value of 400 to 460 ppm by 2100 (Figure 13). This value is much lower than the projected CO<sub>2</sub> levels based on current emission rates. Although this exercise highlights the need for action in other continents, it also points out the challenge of maintaining low African emissions, even as African nations seek greater industrialization and economic growth.

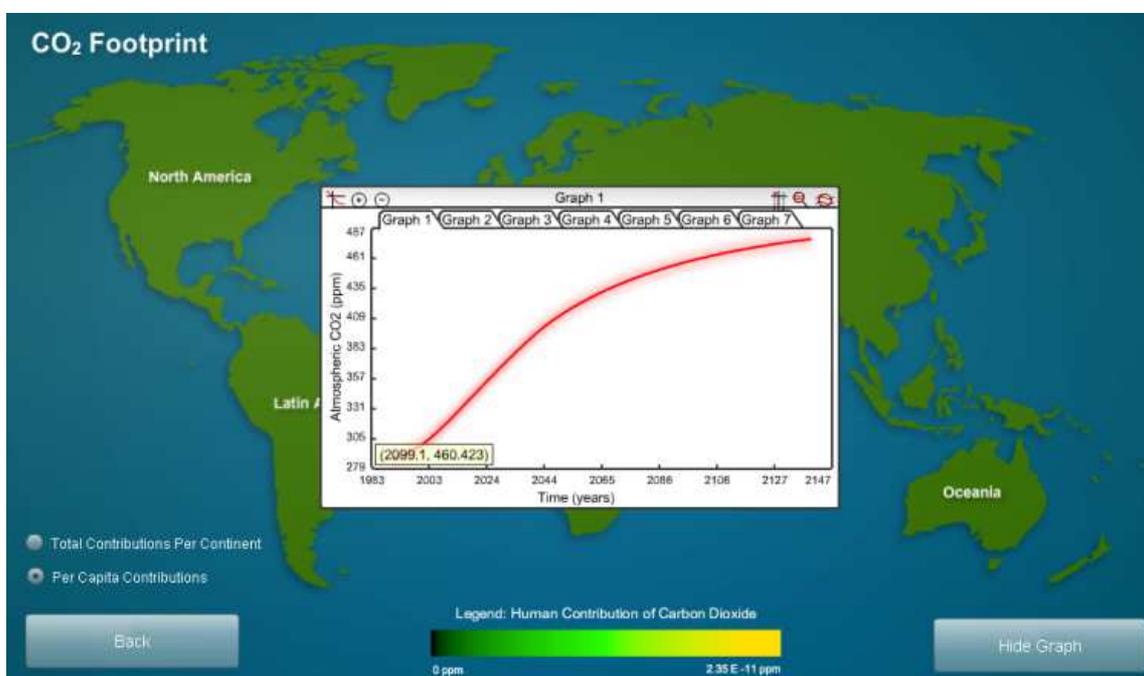


Figure 13. Projected atmospheric carbon dioxide concentrations with African per capita emission levels applied to all continents (*click on the image to link directly to the learning tool*)

Human emissions of carbon dioxide and the consequent increases in atmospheric carbon dioxide concentrations could provide rich contexts for various chemistry concepts and principles. Anthropogenic carbon dioxide emissions are primarily caused by combustion reactions, which are often used as core examples in chemistry to teach a variety of topics. The reactions which result in carbon dioxide emissions may also be used to introduce stoichiometric principles, and

ideas of atom economy and efficiency based on green and sustainable chemistry principles. Green chemistry is a topic which is gaining a strong foothold in chemistry curriculum at the post-secondary level. Carbon dioxide emissions are also fundamentally tied to the human requirement of energy, which could frame a discussion of thermochemistry. Chemistry educators may devise other creative ways to use human carbon dioxide emissions and the consequences for Earth's future as a rich context for chemistry education.

### **VC3: USING OTHER CLIMATE SCIENCE RICH CONTEXTS TO INTRODUCE CHEMISTRY CONCEPTS**

In a project that has built considerable synergy with the development of resources for explainingclimatechange.com, the King's Centre for Visualization in Science is also a partner in a North American research group that is developing and piloting five topics taught in general chemistry through rich climate science contexts. The *Visualizing the Chemistry of Climate Change* (VC3, [www.vc3chem.com](http://www.vc3chem.com)) project has developed three climate topics to weave into the teaching of isotopes and atomic structure, gases, and acid-base chemistry and solution/precipitation equilibria. These three topics have been piloted in US and Canadian universities and colleges, and the research team is assessing whether gains in both chemistry conceptual understanding and climate literacy are achieved in first year university chemistry students through this approach. The concept question for introducing isotopes is a context related to temperature proxy measurements from ice core data; the concept question for gases is related to determining whether a gas is a greenhouse gas; and ocean acidification is used as the rich context to introduce acid-base chemistry and equilibria related to solubility and precipitation. A

fourth topic is presently under development, related to the coverage of thermochemistry in the first-year university chemistry curriculum.

## CONCLUSIONS

*Visualizing and Understanding the Science of Climate Change* and the related *Visualizing the Chemistry of Climate Change* (VC3) project seek to implement best practices in the design and use of interactive web resources, as they weave together the dual goals of improving climate literacy and explaining foundational chemistry principles. African chemistry educators, such as the representative instructor introduced in the opening section of this paper, will find particularly strong connections to climate topics related to the water cycle, and can make use of resources to effectively teach concepts such as phase changes, vapor pressure, and the chemistry of water within a real world framework. With *Visualizing and Understanding the Science of Climate Change*, African chemistry educators can motivate student learning and enhance the classroom experience by relating fundamental chemistry principles to meaningful, real world challenges. In so doing, steps may be taken toward empowering students to understand and effectively respond to the challenges which climate change presents to the African continent.

## REFERENCES

1. Mahaffy, P. (2011). The Human Element: Chemistry Education's Contribution to our Global Future. In J. Garcia (Ed.), *The Chemical Element: Chemistry's Contribution to our Global Future*. Weinheim: Wiley-VCH, Chapter 4.
2. Oloruntegbe, K. O.; Ikpe, A. (2011). Ecocultural Factors in Students' Ability To Relate Science Concepts Learned at School and Experienced at Home: Implications for Chemistry Education. *J. Chem. Educ.*, 88(3), 266-271.
3. Bennett, J.; Hogarth, S.; Lubben, F. (2003). A systematic review of the effects of context-based and Science – Technology - Society STS approaches in the teaching of secondary science. In *Research Evidence in Education Library*. London: EPPI-Centre.

4. Stolk, M.; Bulte, A.; De Jong, O.; Pilot, A. (2005). Teaching concepts in contexts: designing a chemistry teacher course in a curriculum innovation. In K. Boersma, M. Goedhart, O. De Jong, and H. Eijkelhof (Eds.), *Research and the quality of Science Education* (pp. 169-180). Dordrecht, The Netherlands: Springer Publishers.
5. Stolk, M.; Bulte, A.; De Jong, O.; Pilot, A. (2006). Empowering teachers for designing context-based chemistry education. In I. Eilks and B. Ralle (Eds.), *Towards Research-based Science Teacher Education* (pp. 159-170). Aachen: Shaker Verlag.
6. Scholes, B.; Ajavon, A.; Nyong, T.; Tabo, R.; Vogel, C.; Ansorge, I. (2008). Global Environmental Change (including Climate Change and Adaptation) in sub-Saharan Africa. ICSU Regional Office for Africa.
7. Boko, M.; Niang, I.; Nyong, A.; Vogel, C.; Githeko, A.; Medany, M.; Osman-Elasha, B.; Tabo, R.; Yanda, P. (2007). Africa. Climate Change 2007: Impacts, Adaptation and Vulnerability. In M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, (Eds.), *Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, (pp. 433-467). Cambridge, UK: Cambridge University Press.
8. James, R.; Washington, R. (2013). Changes in African temperature and precipitation associated with degrees of global warming. *Climatic Change*, 117, 859-872.
9. Wilk, J.; Andersson, L.; Warburton, M. (2013). Adaptation to climate change and other stressors among commercial and small-scale South African farmers. *Regional Environmental Change*, 13, 273-286.
10. Blanc, E.; Strobl, E. (2013). The impact of climate change on cropland productivity: evidence from satellite based products at the river basin scale in Africa. *Climatic Change*, 117, 873-890.
11. Berg, A.; de Noblet-Ducoudre, N.; Sultan, B.; Lengaigne, M.; Guimberteau, M. (2013). Projections of climate change impacts on potential C4 crop productivity over tropical regions. *Agricultural and Forest Meteorology*, 170, 89-102.
12. Life expectancy: Life expectancy by WHO region. World Health Organization Global Health Observatory Data Repository. <http://apps.who.int/gho/data/view.main.690?lang=en> (accessed May 10, 2013).
13. Meehl, G. A.; Tebaldi, C. (2004). More intense, more frequent, and longer lasting heat waves in the 21<sup>st</sup> century. *Science*, 305(5686), 994-997.
14. Zhiwei, X.; Etzel, R. A.; Su, H.; Huang, C.; Guo, Y.; Tong, S. (2012). Impact of ambient temperature on children's health: A systematic review. *Environmental Research*, 117, 120-131.
15. Hendrix, C. S.; Salehyan, I. (2012). Climate change, rainfall, and social conflict in Africa. *Journal of Peace Research*, 49(1), 35-50.
16. Raleigh, C.; Kniveton, D. (2012). Come rain or shine: An analysis of conflict and climate variability in East Africa. *Journal of Peace Research*, 49(1), 51-64.
17. Martin, B., Mahaffy, P. (2013). Using Visualizations of the Science Behind Climate Change to Change the Climate of Science Teaching. In J. Suits (Ed.), *Pedagogic Roles of Animations and Simulations in Chemistry Courses*. Washington D.C.: American Chemical Society (in press).
18. Nakicenovic, N. (2000). Special Report on Emissions Scenarios; Special Report for the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.
19. Educational Global Climate Modeling Home Page. <http://edgcm.columbia.edu/> (accessed May 31, 2013).

20. Somerville, R. C. J.; Hassol, S. J. (2011, October). Communicating the science of climate change. *Physics Today*, 48-53.
21. Princeton University Carbon Mitigation Initiative. <http://cmi.princeton.edu/wedges/intro.php> (accessed May 13, 2013).

## ACKNOWLEDGMENTS

Collaborators on the *Visualizing the Science of Climate Change* project are chemists and educators from the Royal Society of Chemistry (RSC - UK), UNESCO, the International Union of Pure & Applied Chemistry's Committee on Chemistry Education (IUPAC CCE), the American Chemical Society (ACS - USA), and the Federation of African Societies of Chemistry (FASC). A full list of individuals contributing to the project is at <http://www.explainingclimatechange.ca/Climate%20Change/aboutContainer.html>. Collaborators on the VC3 project are M. Towns (Purdue University and PI for the NSF Award), M. Kirchhoff and L. McKenzie (American Chemical Society), C. Middlecamp (University of Wisconsin), A. Versprille (Purdue University), T. Holme (Iowa State University, evaluator), and P. Shepson (Purdue University). KCVS undergraduate research students who have contributed to every aspect of the development of the interactive resources on climate science and chemistry are D. Dawe, B. Dodds-Scott, D. Dykstra, D. Eymundson, N. Franck, K. Genuis, T. Keeler, N. Mahaffy, D. Maslanko, M. Price, A. Schwalfenberg, A. Thompson, K. Tjostheim, A. Vandehoek, and D. Vandenbrink. Funding has been provided by the Natural Sciences and Engineering Research Council of Canada through the CRYSTAL Alberta and Undergraduate Student Research Award programs and by the National Science Foundation (CCLI Award #1022992 for VC3).