OUR CLIMATE, OUR CHANGE - USING DIGITAL LEARNING OBJECTS TO PRESENT THE COMPLEX SCIENCE OF GLOBAL CLIMATE CHANGE

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ABSTRACT

Global Climate Change (GCC) is arguably one of the most significant challenges ever faced by humankind. The complex science of GCC leaves the general public and teachers at both secondary school and tertiary levels perplexed.. There is a profound need for high quality teaching materials addressing this challenging topic. In response to this need, The King's Centre or Visualization in Science (Edmonton, Canada) has developed a broad range of digital learning objects addressing many aspects of Global Climate Change. The DLOs range from simulations of the basic science behind greenhouse gas heating, the understanding of evidence for climate change and how it is produced to models of global CO2 concentration and climate change. We also present outcomes from a joint project with The International Union of Pure & Applied Chemistry, The American Chemical Society, The Royal Society of Chemistry and UNESCO to weave these materials into teaching modules adaptable to many international curricula at different levels.

KEYWORDS

Applets, Digital Learning Objects, Visualization, Global Climate Change, Greenhouse Gases, Curriculum Development

INTRODUCTION

> "Re-stabilization of earth's climate is the defining challenge of the 21st century. The unprecedented scale and speed of global warming and its potential for large-scale, adverse health, social, economic and ecological effects threatens the viability of civilization. The scientific consensus that society must reduce the global emission of greenhouse gases by at least 80% by mid-century at the latest, in order to avert the worst impacts of global warming and to re-establish the more stable climatic conditions that have made human progress over the last 10,000 years possible Without preventing the worst aspects of climate disruption, we cannot hope to deal with the other social, health and economic challenges that society is facing and will face in the future." (American College and University President's Climate Commitment)

> "More than ever, universities must take leadership roles to address the grand challenges of the twenty-first century, and climate change is paramount amongst these". (Michael M. Crow, President, Arizona State University)

Crow summarizes the compelling challenge to and response by the presidents of 665 American colleges and universities – representing a third of the U.S. student population – who have signed the American College and University President's Climate Commitment. They have agreed to implement campus sustainability efforts, greenhouse gas (GHG) inventories, and climate action plans, and to integrate sustainability into the curriculum as an integral part of the educational experience.

The presidents' commitment responds to urgent calls from US and global science and science education communities to provide citizens of the world with the knowledge and skills needed to address the critical, systemic challenges faced by the world in the 21st Century. There is perhaps no better example of such a defining challenge than mobilizing disciplinary and interdisciplinary science education resources to understand and address the re-stabilization of earth's climate.

The US interagency Climate Change Climate Literacy initiative suggests that over the next several decades encompassing the professional careers of the students who are currently entering university classrooms, climate change is expected to have an increasing impact on human and natural systems - affecting human health, biodiversity, economic stability, national security, and accessibility to food, water, raw materials, and energy. To prepare graduates to adapt to these new conditions (and benefit from new economic opportunities they create) will require both the ability to understand climate science and the implications of climate change, as well as the capacity to integrate and use that knowledge effectively.

Yet there is a pervasive and global disconnect between actual climate science knowledge and perceived knowledge (Dupigny-Giroux, 2008). Recent research on public attitudes and misconceptions about climate change (Krosnick, 2006; ABC News, 2007; Leiserowitz et al., 2008) shows that most American adults believe that climate change is happening. But without a solid public understanding of the causes of anthropogenic climate change and potential solutions, individuals are left with "overwhelming, frightening images of potentially disastrous impacts, no clear sense of how to avert this potentially dark future, and therefore no way to direct urgency toward remedial action." (Moser, 2004; Niepold, 2007)

A review of five decades of science education relating to climate in general and climate change in particular demonstrates that basic climate science has not been well addressed at either the K-12 or post secondary levels in science education curricula. Key misconceptions and misinformation about basic climate science; the role of human activities and reliance on fossil fuels on the climate system; and the level of consensus among the climate research community about the issues, are commonly held by students, teachers, politicians, and members of the public. (McCaffery, 2008). Global studies corroborate these findings (Dikmenli, 2010; Sundblad, 2009).

In this paper we summarize a number of key initiatives now underway in North American schools and universities to address climate change education. We also discuss and broad range of Digital Learning Objects (DLOs) created at The King's Centre for Visualization in Science (KCVS) that are intended to foster the development of climate change literacy within our students.

IDENTIFYING ESSENTIAL PRINCIPLES OF CLIMATE CHANGE EDUCATION

Analysts have concluded that climate change science, with its complex links to both natural processes and human activity, has fallen into a systemic hole in the science education system (McCaffery, 2008). Relegated to a subtopic of weather in many K-12 classrooms, climate change science has traditionally not been explicitly addressed in a substantial way in the National Science Education Content Standards (NSES) or the AAAS Science Literacy benchmarks. NSES content standards, for example, don't even mention a human impact on climate (McCaffery 2008). Despite the commitment of university and college presidents, the increasing fractionation of knowledge (Bordogna, 1991) at the undergraduate level poses additional challenges to moving the bar toward climate science literacy for students who come from high school with poor understanding of climate science fundamentals. For a variety of reasons, undergraduate biology, chemistry, and physics curricula have been reticent to address this defining educational and interdisciplinary global challenge.

In North America a comprehensive and authoritative attempt to catalyze responsive action to address these concerns has been launched by the U.S. Climate Change Science Program (CCSP), which integrates federal research on climate and global change, as sponsored by thirteen federal agencies. CCSP has set out a climate literacy framework, Climate Literacy: the Essential Principles of Climate

Science (US Climate Change Science Program, 2009). Developed by collaboration among NOAA, NASA, AAAS, and a distinguished group of scientists and educators, this Framework defines a set of essential principles and scientific thinking skills that a climate literate person should understand. In this way, it provides a common set of learning goals that are scientifically accurate and pedagogically sound. The Framework has now also been endorsed by American Meteorological Society, National Center for Atmospheric Research, Association of Science and Technology Centers, GLOBE, ESIP Federation, North American Association for Environmental Education and numerous other organizations. The framework's seven essential principles of climate science and identified underlying science concepts required to achieve climate literacy are shown in Table 1. Examination of this framework suggests compelling and urgent roles for science education in addressing some of the key cognitive gaps and misconceptions documented by research.

Table 1. Climate Literacy: The seven essential principles of climate science, underlying science concepts

Principle	Underlying science concepts
1. The sun is the primary source of energy for Earth's climate system.	Energy transformation; wavelength, frequency, and energy relationship; Earth's radiation balance; heat and temperature
2. Climate is regulated by complex interactions among components of the Earth system.	Complexity of natural systems; interactions among Sun, ocean, atmosphere, clouds, ice, land, and life; the nature of the ocean, and its absorption of solar energy; density driven ocean currents and atmospheric circulation; greenhouse gases and their effect on climate; biogeochemical cycles that move components among reservoirs; airborne particulate matter and effect on climate; equilibrium of Earth's systems and positive and negative feedback loops.
3. Life on Earth depends on, is shaped by, and affects climate.	Conditions required for organisms to survive; effect of greenhouse gases on phases of water; evidence for climate record on geological time scale; climate in the last 10,000 years; life as a driver of the global carbon cycle; subtle chemical changes in the atmosphere
4. Climate varies over space and time through both natural and man-made processes.	Difference between climate and weather; nature of and evidence for climate change; spatial and temporal considerations; effects on climate of natural processes and human activity
5. Our understanding of the climate system is improved through observations, theoretical studies, and modeling.	Behaviour of earth's climate can be understood and predicted using experimental evidence and models to explain; nature of evidence for climate record
6. Human activities are impacting the climate system.	Evidence for impact of human activity on climate; residence time of atmospheric gases; impact of energy use, deforestation, population growth, industrial activity; positive and negative impacts of changing climate
7. Climate change will have consequences for the Earth system and human lives.	Melting of glaciers; sea-level rise; distribution of freshwater resources; extreme weather; changing chemistry of ocean water; changing habitat for vectors for disease; human health and mortality rates

The AAAS Project 2061 has recently provided resources to help American teachers integrate climate change science into K-12 curricula (AAAS Project 2061, 2007). In Canada provincial ministries of education have incorporated climate change topics into elementary and secondary science curricula yet few systematic attempts have been made to develop contextualized materials for undergraduate science majors. Indeed, there is resistance to introduce climate change topics into "mainstream" physics, chemistry and biology curricula in both university-track secondary curricula and undergraduate curricula. An underlying sentiment seems to suggest that teaching climate-related topics will necessarily require a diminution of "more important" discipline-specific topics. Shouldn't we, however, teach science to science students 'as if our planet matters' (Middlecamp, 2007)?

DEVELOPING DIGITAL LEARNING OBJECTS FOR TEACHING AND LEARNING ABOUT CLIMATE CHANGE – CONCEPTUAL AND PEDAGOGICAL CHALLENGES

Apart from the need to achieve climate literacy, understanding complex systems is fundamental to developing an authentic understanding of science, and understanding is needed to guide responsible action. Climate change represents a classic complex system. "The spatial scale is global; the time scale dwarfs normal human concerns; and the dynamics of the climate are exquisitely complex and imperfectly understood." (Sterman, 2002) The complexity of systems such as our climate makes them difficult to understand because they are composed of multiple interrelated levels that interact in dynamic ways (Hmelo-Silver, 2007). Additional pedagogical challenges are introduced by the requirement for learning concepts from different disciplines. Learning science through complex systems poses major pedagogical challenges, particularly to disciplinarily oriented undergraduate science education that is delivered primarily by conventional lecture-based pedagogies. This challenge calls for new tools and new resources to help learners cross disciplinary boundaries, and new inquiry-based pedagogies to facilitate learner engagement with complexity Structure-Behavior-Function theory (SBF) research on differences in expert-novice understanding of complex systems (Hmelo-Silver, 2007) suggests that the largest differences in understanding between expert and novice groups is in understanding causal behaviours and functions. Making connections among different levels of a complex system increases working memory load, and requires mental simulation to construct complete mental models (Graesser, 1999; Narayanan & Hegarty, 1998).

Many of the concepts underlying the science of climate change involve concepts for which learner conceptual understanding must result in the use of informed imagination to construct robust mental models. Think of the challenge for a first year student trying to imagine correctly how 'greenhouse gases' function at the molecular-level as an anthropogenic driver for earth's changing radiation balance. A robust mental model requires the synthesis of fundamental knowledge about the interaction of electromagnetic radiation with molecules, leading to the ability to picture interaction of trace amounts of colourless carbon dioxide gas with invisible infrared radiation, and subsequent interaction of vibrationally excited carbon dioxide with IR-inactive atmospheric nitrogen and oxygen gases causing tropospheric warming

Achieving climate literacy in the framework of complexity brings an opportunity for undergraduate physics and chemistry education to embrace pedagogies shown by research to facilitate student engagement with and understanding of science concepts. The use of pedagogical tools based on misconception-informed (Libarkin & Anderson, 2005) interactive visualizations (Geelan & Mahaffy, 2009), case-based approaches (Herreid, 1994), and guided inquiry strategies (Moog, 2008) have been shown to be effective in supporting student learning and are becoming more widely used in undergraduate physics and chemistry courses. Yet the availability of context- and content-rich resources that are linked to curricular learning outcomes in introductory physics and chemistry is a significant barrier to more widespread adoption of new pedagogical approaches.

DIGITAL LEARNING OBJECTS DEVELOPED BY THE KING'S CENTRE FOR VISUALIZATION IN SCIENCE

The King's Centre for Visualization in Science (www.kcvs.ca) is located in Edmonton, Canada and is funded by the Canadian National Sciences and Engineering Research Council through the CRYSTAL Alberta research centre, and generous support from The King's University College. The centre is directed by the two authors, is “staffed” by undergraduate students from a variety of disciplines and has a mandate to produce visualizations (DLOs) to facilitate teaching and learning in selected areas from elementary school through undergraduate and in a broad range of disciplines. The DLOs include applets written in FLASH/AS3 for ease of use across platforms and to facilitate use via the world wide web. Included in our work is an extensive set of DLOs devoted to climate science and to ameliorating some of the problems and deficiencies alluded to in the previous section. The climate science DLOs produced by our centre can be organized into the following groupings which address most of the concerns identified in Table 1:

1. **(Applets addressing Table 1, principles 1 and 2):** DLOs that teach the chemistry and physics of processes important to climate and climate change. Figure 1 shows two applets that do this. The first (on the left) (***Collisonal Heating by CO_2 in the Atmosphere***) illustrates how carbon dioxide, through collisional de-excitation is able to absorb infrared radiation from the Earth and transfer this energy to nitrogen and oxygen molecules. The second applet (***CFCs in the Atmosphere***) shows how CFCs respond to radiation in different parts of the electromagnetic spectrum. Other applets include ***The Structure of the Atmosphere*** (an interactive applet illustrating the 4 major layers of the atmosphere), ***Infrared Spectral Windows*** (an applet that shows the modes of action of 8 key greenhouse gases) and ***Planet*** which allows users to vary the greenhouse gas concentration, albedo and distance of a hypothetical planet from the sun. ***Planet*** (still in beta test) helps students understand the critical role of GHGs in providing a habitable climate on our planet and addresses a common misconception about GHGs …………..

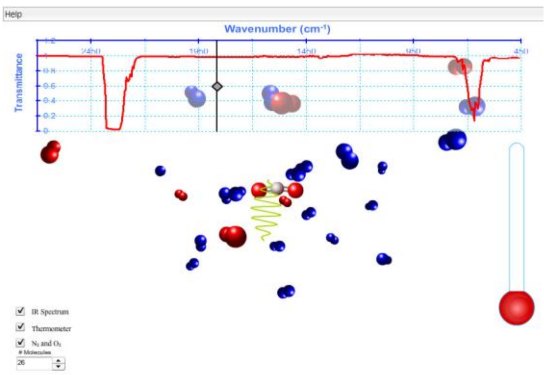

Figure 1a. Applet that shows how CO_2 heats the atmosphere

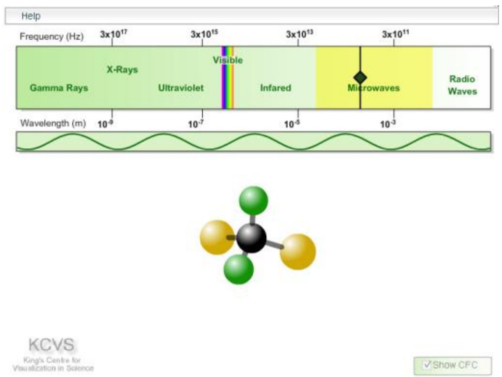

Figure 1b. Applet illustrating the interaction of a CFC molecule with different wavelengths of light

2. **(Applets addressing Table 1, principles 3, 4 and 5):** DLOs that teach about the data sets that inform us about global climate change. Figure 2 shows the applet ***Ice Core Research*** which includes an interactive section in which students are able to analyze ice core samples through a simulation of a mass spectrometer and an isotopic ratio analysis to deduce temperature and CO2 concentration data at different position in the ice core. The ice core data is real data taken from the National Ice Core Library, Greenland data sets. The DLO also contains movie clips and interactive quizzes. Figure 3 shows a sample screen from one of the activities contained within this DLO. .

Figure 2. The DLO Ice Core Research which contains a suite of teaching resources and applets dealing with the collection and analysis of ice cores

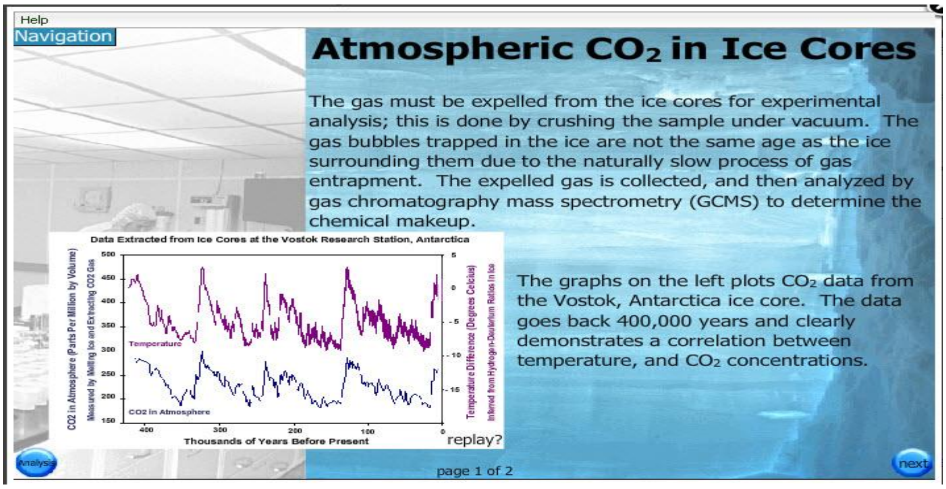

Figure 3. Sample page from the DLO Ice Core Research.

3. **(Applets addressing Table 1, principle 5):** Another important suite of DLOs are those that deal directly with outcomes from climate simulations. We have created an extensive library of simulations using the climate simulation program EdGCM which a joint product of Cornell University and NASA and puts a research grade climate simulation tool in the hands of educators. Figure 4 shows the DLO ***Climate Simulation*** which is an interactive GUI that allows students to investigate climate models based on scenarios developed by the Intergovernmental Panel on Climate Change. The simulation dates are from 1950 to 2100 and include such parameters as temperature, temperature anomaly, precipitation, soil moisture and snow and ice cover. Students are able to select any region of the world and compare this to another region as well as both look at data graphically and export data for further analysis. Figure 4 shows a comparison of air temperature anomaly for different regions on the globe. .

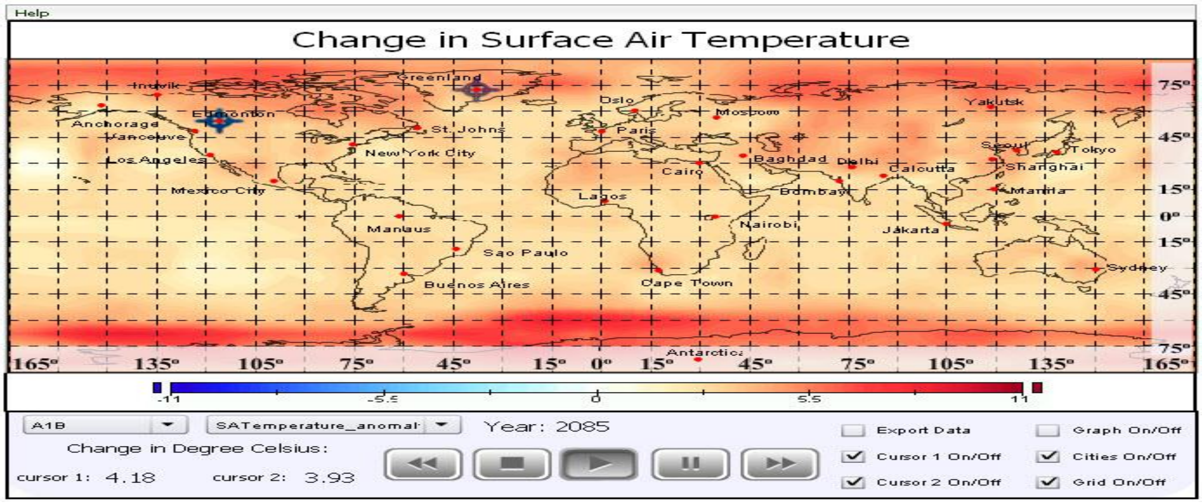

Figure 4. Sample screen from the applet Climate Simulation showing air temperature anomaly for the year 2085 based on the IPCC scnenario A1B

4. **(Applets addressing Table 1, principles 5, 6 and 7):** A final set of DLOs are devoted to questions of climate change policy. The DLO Climate Change Questionnaire is a playful opportunity for students to interact with a narrative that presents them with life style questions. Their responses are evaluated by a decision/response algorithm and based on these responses one of the IPCC climate change scenarios is selected. The student is then presented with a modified version of the Climate Simulation applet discussed in part 3 above that has the appropriate scenario selected. Another climate policy DLO is Global Carbon Dioxide Footprint and Model shown in Figure 5. This applet allows the user to adjust per capita greenhouse gas emissions for the major continental regions of the globe. Based on the either current per capita emissions or possible future emission profiles a projection of atmospheric CO2 for the next 150 years is calculated with 1990 as the starting point. The model is a 4 compartment CO2 model that is numerically solved. Population data is based on UN global population projections for the next 150 years and is incorporated into the applet.

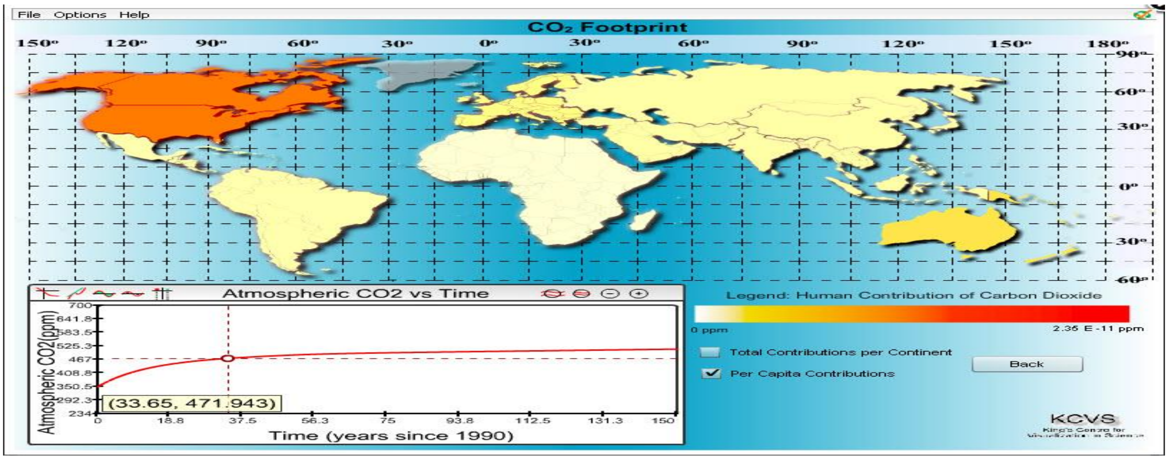

Figure 5. The applet Global Carbon Dioxide Footprint and Model

The DLOs described above have been presented at numerous national and international conferences as well as in workshop settings with teachers. One of us (Mahaffy) has presented many of these applets at more than a dozen international conferences on 6 continents over the past 5 years. Feedback garnered in these interactions has been valuable and has helped ensure that the DLOs are both robust, relevant and classroom "friendly". We are currently leading an International Union of Pure & Applied

Chemistry project with participation by The American Chemical Society, The Royal Society of Chemistry and UNSECO to weave these assets into forms adaptable to curricula around the world.

GAUGING THE EFFICACY OF APPLETS AND DLOS IN ADDRESSING STUDENT UNDERSTANDING OF CLIMATE CHANGE

An abiding and critcal question to ask is "are these applets and DLOs effective in achieving the aims that we have described in this paper?" At this point in time we cannot offer a significant body of empirical evidence to answer the question. Anecdotal evidence provided by teachers suggests that we are at least providing the tools that teachers will need to bring these topics into classrooms (and curricula) in an engaging and credible way. Many of the applets described here are also being used in a large scale Australian study (Geelan, Mahaffy and Martin, 2009) that will help provide more concrete evidence concerning the effectiveness of these resources. Some preliminary results which indicate that students do demonstrate a significant gain in understanding of the chemistry DLOs that we have produced has been presented by Geelan et al. (2009,2010) While this is encouraging we await the results of more studies to help clarify both the efficacy of resources such as these and to also help us identify possible "best practices" when developing DLOs and applets.

CONCLUSION

The DLOs described above have been strategically designed to address many of the concerns summarized by Table 1. We have also been mindful of how these DLOs and the applets that they contain can be used to support collateral curricular aims in both physics and chemistry education. One continuing challenge for our project is to work with partnering educators and ministries of education to develop ancillary support materials that will add to the usefulness of these resources. It is our fervent hope that robust, well crafted resources will lift the topic of climate science and global climate change from the relative obscurity it now receives in most curricula to a place or prominence. From there it can not only serve disciplinary needs in helping students understand topics in chemistry and physics but more significantly, enable them to understand more fully the complex climate change issues that their generation must face.

We invite teachers to visit The King's Centre for Visualization in Science web site at: http://www.kcvs.ca/ . The resources are freely available and we would welcome contact, feedback and possible future collaborations.

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