# Sustainability in the Chemistry Curriculum

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# Sustainability in the Chemistry Curriculum


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# Foreword

The ACS Symposium Series was first published in 1974 to provide a mechanism for publishing symposia quickly in book form. The purpose of the series is to publish timely, comprehensive books developed from the ACS sponsored symposia based on current scientific research. Occasionally, books are developed from symposia sponsored by other organizations when the topic is of keen interest to the chemistry audience.

Before agreeing to publish a book, the proposed table of contents is reviewed for appropriate and comprehensive coverage and for interest to the audience. Some papers may be excluded to better focus the book; others may be added to provide comprehensiveness. When appropriate, overview or introductory chapters are added. Drafts of chapters are peer-reviewed prior to final acceptance or rejection, and manuscripts are prepared in camera-ready format.

As a rule, only original research papers and original review papers are included in the volumes. Verbatim reproductions of previous published papers are not accepted.

**ACS Books Department**

# From the Editors

*"This planet came with a set of instructions, but we seem to have misplaced them."*

Paul Hawken, The Unforgettable Commencement Address, 2009

We dedicate this book to our many colleagues who have dedicated their talents to rethinking the undergraduate chemistry curriculum. They have explored and tested new pedagogical approaches in order to better convey the excitement and centrality of chemistry. They have contributed to the research on how people learn chemistry. We are in their debt.

We also recognize our colleagues who have produced new curricular materials in response to the question of "*What do our students need to learn?"* As our students change and as our world changes, these colleagues have recognized that so must the topics we explore in our classrooms and laboratories change. We are in their debt as well.

Like our colleagues, we who have contributed to this book address the question of *"What do our students need to learn?"* Both as individual authors and collectively in this book, our voices resound with one answer: 'sustainability.'

Admittedly, some consider sustainability merely to be one item in a longer list of topics that compete for space in the chemistry curriculum. For example, shouldn't we be including more polymer chemistry? Isn't material science one of the most exciting topics with which to engage students? And shouldn't energy be the centerpiece of our explorations? Indeed, many topics are intriguing, compelling, and timely.

Why sustainability?

At the risk of answering one question with another, we respond: "*To what end do we teach any particular topic?*"

Here, sustainability holds the trump card. There won't be a future for us, for our discipline, or for modern society as a whole unless we and our students put our talents to work on behalf of the life support systems on our planet: its air, water, and soil. To this end, we must weave the concepts of sustainability into our chemistry courses and laboratory experiments.

As we do this, we need good questions about how we can live sustainably. We also need the means to find good answers to these questions. Chemistry provides foundational knowledge for both. Those armed with this knowledge are poised to play a central role in improving the quality of our lives, of our ecosystems, of our economies, and ultimately of our planet.

Those who contributed to this volume well understand the connections between chemistry, students, teachers, and our planet. We extend our thanks to them for speaking at the 2010 ACS national meeting in San Francisco, for being willing to commit their ideas to paper, and above all, for bringing sustainability to their chemistry students.

Sincerely and with our gratitude,

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# Preface

*"We especially need imagination in science. It is not all mathematics, nor all logic, but it is somewhat beauty and poetry."*

- Dr. Maria Montessori

It gives me great pleasure to write about the intersection of three things near and dear to my heart: chemistry, education, and sustainability. In my opinion, there has never been a better time to be a chemist or a Chemistry professional. Now more than ever we are facing pressing world challenges of ***energy*** (identifying alternate energy), ***food*** (ensuring the food supply), ***water*** (providing clean water), and ***human health*** (enabling individualized medicine); and to solve these challenges will require chemistry and the related chemical sciences.

There could be no better year to call attention to this than 2011, the International Year of Chemistry. Not only are we celebrating the contributions of Women in Science with the 100$^{th}$ Anniversary of Madame Curie winning the Nobel Prize in Chemistry, but also we are celebrating the wonderful things that chemistry brings to our every-day lives from computers to cell phones, from insulation to solar energy ….to name a few.

But let's pause for a moment and ask if we are innovating sustainably, that is, innovating in a way that will not jeopardize the needs of future generations (*1*). And, if not, how and when will we learn the skills to innovate sustainably? This is not a trivial question.

When my son was in middle school, I remember him saying, "*Mom, mom, you would have everyone believe that everything is based on chemistry!*" …and they say, "*kids don't listen*". The message here is that kids do listen but we have to tell them; and we have to tell them in a way that is engaging, actionable, and empowering.

Why integrate the tenants of sustainability into chemistry curricula? Answer: to accelerate the pace of innovation, sustainable innovation; innovation that makes sense environmentally, socially, and economically. Sustainable chemistry is not a separate message, it IS the message; just as the new DOW Solar Shingle is not added on top of the roof, it IS the roof (*2*).

Companies have come to see that ascending the ladder of sustainability to a position of leadership means moving up the rungs one-by-one from denial, to compliance, to compliance plus, to implementation and then, in the ultimate step, to integration. Integrating sustainability into everything we do from instituting responsible operations, to selecting partners for change and innovating sustainable solutions. Industry needs academe to prepare their graduates to ascend the ladder with skill and agility. This can only be done by integrating sustainability expeditiously into chemistry curricula.

To achieve this integration is NOT to add additional courses but rather to add the lens of sustainability (*3*), to chemistry curricula for both majors and non-majors alike. In the case of chemistry majors, the objective is to develop a future workforce that is already schooled in systems thinking, life cycle assessment, and green chemistry & engineering; a workforce that is predisposed to making decisions with the future in mind and thereby producing "sustainable materials by design". In the case of non-majors, the goal is to develop a science literate populous inclined to adopt sustainable lifestyles and "wired" to make decisions with the future in mind. Such curriculum enhancements could and should be used to refresh and enrich our existing workforce, as well as inform smart and effective policy (e.g., energy policy).

This ACS Monograph is a wonderful catalyst to propel us forward on this humbling yet exhilarating journey. As an R&D director, an ACS past president, a mom, and a friend, I thank you, for all that you have done and all that you are going to do. It will take all of us working together to create a sustainable planet. So, let's get started!

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1. Definition of sustainable development from the Brundtland Commission of the United Nations on March 20, 1987: "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs".
2. The DOW POWERHOUSE™ Solar Shingle is a registered trademark of The Dow Chemical Company, www.dowsolar.com.
3. The "lens of sustainability" is a concept coined by others and discussed in Chapter 7 of this monograph. *Sustainability in the Chemistry Curriculum*; Middlecamp, C. A., Jorgensen, A., Eds.; ACS Symposium Series No. 1087; American Chemical Society: Washington, DC, 2011.

**Catherine T. "Katie" Hunt**, Ph.D.
2007 President of the American Chemical Society

# Chapter 1

# ACS and Sustainability: Vision for Now and the Future

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The American Chemical Society (ACS) has made sustainability a central theme for the Society, with a key strategy to address global challenges, especially sustainability, through chemistry. Sustainability is a very broad topic, encompassing such important issues as food, energy, water, air, health and education. Chemistry is key and critical to success in sustainability. Indeed, chemistry may be viewed as the central science, connecting all other sciences at the molecular level, and providing the basis for understanding both negative and positive impact on the environment, as well as generating specific improvements. This article speaks to the topic of sustainability both in broad dimensions and in the context of chemistry and the American Chemical Society.

## What Is Sustainability?

Sustainability has become a ubiquitous term, widely used, and sometimes misused. We should begin with careful consideration of its definition. Gro Harland Brundtland, provided a concise description in the report of the World Commission on Environment and Development of the United Nations, titled Our Common Future, in 1987 (*1*).

> "Sustainability is meeting the needs of the present without compromising the ability of future generations to meet their needs."


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Despite being nearly twenty-five years old, this provides a broad vision of sustainability,

A more specific definition for sustainable development comes from the United Nations Educational, Scientific, and Cultural Organization (UNESCO), including the "triple bottom line" with regard to social, economic, and environmental interests, as depicted in Figure 1 (*2*).

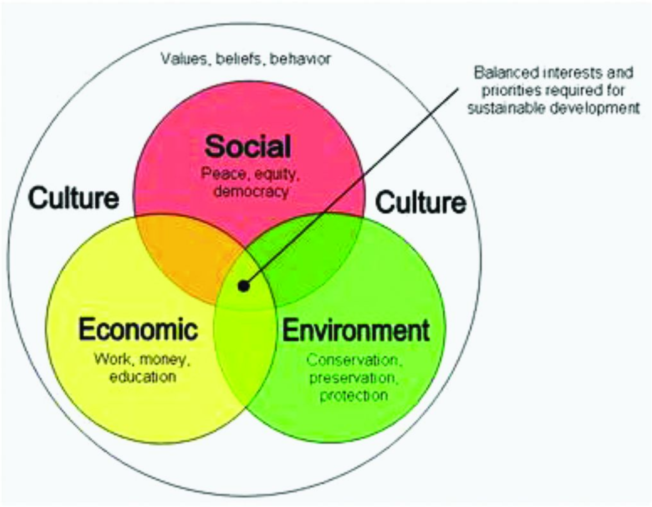


*Figure 1. Sustainable Development.*

These three interests, or perspectives, occur against a backdrop of culture, which is shaped by values, beliefs, and behaviors. Social interests include such topics as human rights, peace and human security, gender equity and cultural diversity, health and governance. Economic interests include poverty reduction, work, money, corporate responsibility, education, market economy and enterprise. Environmental interests include conservation, preservation, and protection of the current environment for future generations, natural resources (water, energy, agriculture, and biodiversity), climate change, rural development, sustainable urbanization, and disaster prevention/mitigation. When all three perspectives are aligned, in the context of culture, we have sustainable development.

This comprehensive definition of sustainable development complements the simple verbal description, providing robustness for discussion and action. It demonstrates the interactions between the multiple aspects of sustainability, and provides a framework for effective implementation of different types of initiatives leading to sustainable development.

Both definitions are useful and complementary. The historical definition provides a simple understandable way to describe a vision of success for the general public, decision-makers, students, and professionals. The more robust description is more useful to the community of professionals that are working to


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implement sustainable development. As a result, ACS is using both definitions, the first as a vision statement, and the second as a strategic framework.

Sustainability is supported by and is built upon the foundational role of education, which must be the mechanism for "furthering the common understanding and common spirit of responsibility so clearly needed in a divided world," as stated in Our Common Future (*1*). "In particular, the Commission is addressing the young. The world's teachers will have a crucial role to play in bringing this report to them." This 1987 report of the World Commission on the Environment and Development was chartered by the United Nations in 1983 to provide a framework to address human needs.

Education must also reach a broad audience. "If we do not succeed in putting our message of urgency through to today's parents and decision makers, we risk undermining our children's fundamental right to a healthy, life-enhancing environment. Unless we are able to translate our words into a language that can reach the minds and hearts of people young and old, we shall not be able to undertake the extensive social changes needed to correct the course of development." This message is even more vital and critical today than it was in 1987 when the report was written.

A less traditional view of sustainability applies to the organizational, institutional, and societal dimension. We frequently talk about "continuity" in organizations, whether education, industry, governmental, or non-profit, as an important part of effectiveness. Sustainability goes beyond continuity, and requires that we ensure the future viability and vitality of our structures. This requires that we examine and strengthen both the people and the processes to ensure future success. The ACS vision of sustainability recognizes the role that institutions from all sectors must play in a successful outcome.

## Sustainability in Context

Sustainability should be viewed in the context of the United Nations Millennium Development Goals (MDGs), the UN International Year of Chemistry – 2011 (IYC2011), and the ACS Strategic Plan: 2010 and Beyond. The UN MDGs, listed below, had their genesis in the UN Millennium Declaration of 2000 (*3*), and were formulated under the UN Millennium Goals Project, commissioned in 2002 and presented to the UN General Assembly in 2005 (*4*).

Goal 1: Eradicate extreme poverty and hunger
Goal 2: Achieve universal primary education
Goal 3: Promote gender equality and empower women
Goal 4: Reduce child mortality
Goal 5: Improve maternal health
Goal 6: Combat HIV/AIDS, malaria and other diseases
Goal 7: Ensure environmental sustainability
Goal 8: Develop a Global Partnership for Development

"The Millennium Development Goals (MDGs) are the world's time-bound and quantified targets for addressing extreme poverty in its many dimensions-income poverty, hunger, disease, lack of adequate shelter, and exclusion-while promoting gender equality, education, and environmental sustainability. They are also basic human rights-the rights of each person on the planet to health, education, shelter, and security" (*5*). These goals are targeted for completion in 2015, and there has been considerable effort on them over the past eleven years, since they were first endorsed by the UN General Assembly in 2000, and the plan fully defined in 2005. There is a strong dimension of sustainability in each of these very important goals, whether or not it is explicitly mentioned. There are both content and systems aspects to each of these goals. In other words, there are specific knowledge or result aspects that are necessary for success to occur, but these, alone, will not be necessarily be sufficient without the systems or organizational dimensions that must be addressed to allow implementation..

Sustainability should also be considered in the context of the UN International Year of Chemistry 2011 (*6*) which deals with "Chemistry – our life, our future," and its goals to:

- Increase the public appreciate of chemistry in meeting world needs;
- Increase interest of young people in chemistry;
- Generate enthusiasm for the creative future of chemistry;
- Celebrate the 100the anniversary of the founding of the International Association of Chemical Societies (now the International Union of Pure and Applied Chemistry (IUPAC) and of the award of the Nobel Prize in Chemistry to Mme Maria Sklodwoska Curie – providing an opportunity to recognize the contributions of women to the chemical sciences.

Sustainability provides a common theme for focus in all four goals of IYC 2011, and the visibility that IYC 2011 affords will provide heightened opportunities for communication and activities that can be shared across the global chemical community. A worldwide "Water Experiment" will provide kits for students across the globe to test water, and understand the elements of clean drinking water. Many countries are planning other specific events with sustainability as a central theme. Science Cafes have been held, and ACS will host topical webinars related to sustainability. Even more importantly, ACS and other organizations are formulating plans to continue specific initiatives of IYC beyond 2011, with sustainability being one of the prevalent unifying themes.

The ACS Strategic Goals – 2010 and Beyond (*7*), listed below, also provide context for sustainability, particularly Goal 3, to address global challenges.

1. Provide Indispensable Information
2. Engage Global Community
3. Address Global Challenges
4. Communicate with the Public
5. Advocate for the Profession
6. Maintain Financial Health

As part of Goal 3, ACS formulated an overarching plan for addressing global challenges, e.g. sustainability, shown in Figure 2, with seven areas of activity that will be presented more fully.

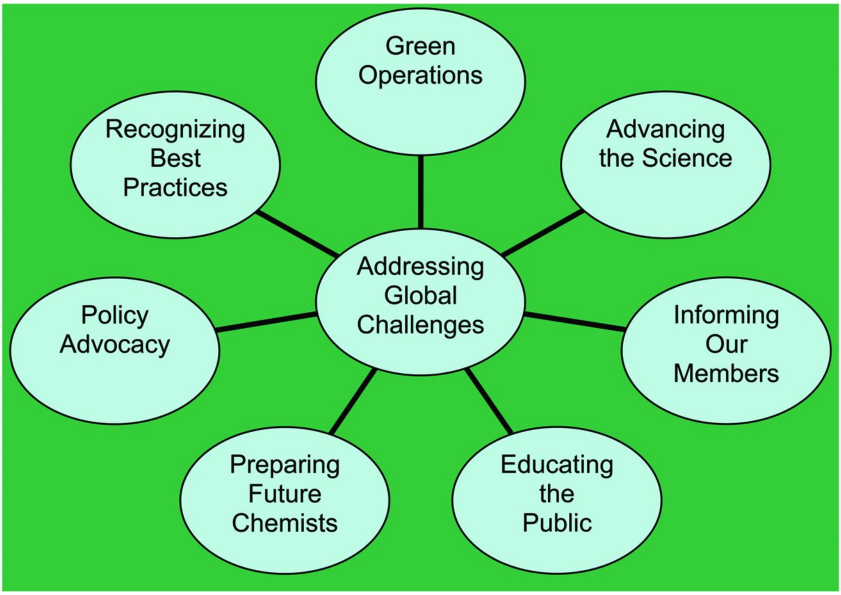


*Figure 2. Working Together for a Sustainable Future - A CALL to Action: Collaborate, Advance, Learn, Lead (6).*

## ACS Initiatives to Address Global Challenges

**Advancing the Science** that supports work on global challenges and sustainability is one of the most important ways that ACS is addressing global challenges. Our goal is to provide indispensable and information that addresses sustainability (*8*). Three recent initiatives that have made significant progress in this area are: increased sustainability content in technical meeting programming, Global Innovation Imperatives (Gii), and Chemical Sciences and Society Symposia (CS3).

Beginning in 2007, ACS increased emphasis on sustainability as a programming topic at ACS technical meetings with the result that sustainability now represents more than 50% of the National Meeting content. This emphasis is accomplished through the Technical Divisions of ACS, who hold the responsibility for programming at National Meetings. The increased emphasis has occurred in Presidential Symposia, Presidential Events, multidisciplinary and thematic programming, and divisional, as well as committee, symposia.

**Global Innovation Imperatives (Gii)** is a collaborative alliance between ACS and the Society of Chemical Industry, supported within ACS by the Committee on Corporation Associates (CCA) and the Office of International Activities (*9*). Gii fosters innovative solutions to imperatives of global significance (e.g. clean water, food and health, etc.), by sharing and expanding the knowledge and experience of ACS and SCI members. The first imperative chosen for focus is water, which varies widely in purity and availability across the world, both


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for human consumption and to sustain industry and development. Participants in Gii include innovation leaders, business executives, academic/education leaders, multinational businesses, non-government organizations, and governments. Gii sponsored activities at both the San Francisco and Boston ACS National Meetings in 2010. It has also sponsored special focused meetings:

- "The Water Framework Directive - What are the Business Opportunities?" 25 March 2010 at FERA in York, UK (*8*).
- "Biorenewable Fuel & Fertiliser - Realising the Potential", 24 March 2010, also at FERA in York, UK (*10*).
- Symposium in *Sustaining Water Quality* organized by Sut Ahuja, William Cooper and Matthew Larsen for presentation at the 240th ACS National Meeting in Boston, MA, August 22-23, 2010 at the Renaissance Boston Waterfront Hotel.
- "International Workshop on Sustainability and Water Quality," New Delhi, India, January 2011 (*11*).

The Gii events have linked key stakeholders for discussion and planning, and have resulted in specific local initiatives to address water issues.

**Chemical Sciences and Society Symposia (CS3)** is a collaborative effort of the chemical societies and funding agencies of the US, Germany, China, Japan and the UK, to hold a series of symposia, with each one focused on a key societal challenge and the role of chemical research in addressing the challenge (*12*). Topics for each symposium are selected by an organizing committee with members from each country, with each meeting held in one of the sponsoring countries.

"Reaching for the Sun" was the first CS3 symposium, held in southern Germany in July 2009, and hosted by the German Chemical Society (Gesellschaft Deutscher Chemiker, GDCh). Thirty eminent chemists from the organizing countries, both researchers and representatives of funding agencies, met to discuss the current state of solar energy research. Meeting participants prioritized scientific challenges that must be met to enable effective use of solar energy and made recommendations for productive areas of future research; these included mimicking photosynthesis using synthetic materials, employing biomass to convert sunlight to usable energy, creating innovative photovoltaics, and storing solar energy in batteries and as fuel. A white paper of the proceedings was published, entitled "Powering the World with Sunlight" (*13*), for use with policymakers to influence future research and funding directions.

The 2$^{nd}$ Annual CS3 symposium, on "Sustainable Materials Research," was hosted by the Royal Chemical Society (RSC) in the United Kingdom in July 2010. The 3$^{rd}$ Annual Chemical Sciences and Society Symposium will be hosted by the Chinese Chemical Society in Beijing, China, in September 2011, on the topic of "Chemistry for Health."

As a result of these meetings, parallel international governmental funding has been achieved for key research areas and initiativres.

**Educating the Public** is a second area of ACS activity in addressing global challenges, and focuses on promoting the importance of, and how chemistry addresses, sustainability. The initiatives include Global Challenges/Chemistry Solutions, (with podcasts and a final report), Local Section Science Cafes, ACS PressPacs, and Bytesize Science (podcasts).

Global Challenges/Chemistry Solutions began as a series of twelve award-winning podcasts, including topics such as Clean Water, Climate Change, Combating Disease, Sustainable Future, Safety and Security, New Fuels, Safe and Nutritious Foods, and Public Health (*14*). The podcasts are available at the ACS website (*16*), and the final report on Global Challenges / Chemistry Solutions can be found on the Chemistry and Engineering News digital website (*15*). Additional podcasts are being continually developed, and are available at the ACS website.

**Preparing Future Chemists** is comprised of multiple initiatives that are focused on recruiting and educating the next generation of chemists to pursue sustainable chemistry solutions. Foremost in this area are the annual ACS Green Chemistry & Engineering Conferences (GC&E), sponsored by the ACS Green Chemistry Institute each summer in Washington, D.C. (*16*), and the Annual Green Chemistry Summer Schools (*17*). The GC&E include technical sessions, the Presidential Green Chemistry Challenge Awards, exhibits, and a student workshop. The Green Chemistry Summer School includes presentations by leading researchers, collaboration on problem solving projects, laboratory experiments, poster sessions, and discussions on the role of science in solving global sustainability challenges. The 15$^{th}$ Annual Green Chemistry & Engineering Conference will be held June 21-23, 2011, in Washington, DC (*18*),

ACS also offers workshops for science teachers. There are many other ACS Green Chemistry Educational Resources (*19*), including numerous books (e.g. <u>Going Green</u>, <u>Real World Cases in Green Chemistry, Volumes I and II, Introduction to Green Chemistry</u>) and other online resources, activities and experiments (by grade level), and links to other online resources.

**Policy Advocacy** involves ACS advocating for science-based policy that promotes innovation, science education and workforce, science and openness, and sustainability (*20*). ACS develops and disseminates policy statements on green chemistry, sustainability, climate change and funding for federal programs related to sustainability. ACS also advances legislation on green chemistry, sustainability, and climate change, and regularly provides congressional briefings.

**Informing Our Members** involves sharing tools to enable efforts focused on sustainability. Sustainability initiatives across ACS are coordinated through the Sustainability Stakeholders Steering Group (S3G), with representation from governance committees and staff groups that are active in sustainability. Committees that are represented include the Committee on Environmental Improvement (CEI), the Society Committee on Education (SOCED), the Committee on International Activities (AC), the Society Committee on Science (ComSci), the ACS Board Standing Committee on Professional and Member Relations (P&MR), the Committee on Meetings and Exposition (M&E), the Committee on Corporation Associates (CCA), the Local Sections Activity Committee, and the Divisional Activities Committee. Staff groups that are represented are the Green Chemistry institute (GCI), the Office of Public Affairs (OPA), and the ACS Strategy Group. Resources for Earth Day, National Chemistry Week, National Lab Day, and the UN International Year of Chemistry

2011 are available on the ACS website (www.acs.org) and the ACS Network (www.acs.org/network).

**Recognizing Best Practices** acknowledges ACS members and groups leading sustainability-focused activities. The Presidential Green Chemistry Challenge Awards recognize outstanding chemical technologies that incorporate the principles of green chemistry into chemical design, manufacture, and use. The ACS National Award for Affordable Green Chemistry, sponsored by Dow Chemical Company, recognizes outstanding scientific discoveries that lead to cost effective implementation of eco-friendly systems. The Kenneth G. Hancock Award recognizes outstanding student contributions to furthering the goals of green chemistry through research or education. The winners receive national recognition for their work. The Joseph Breen Fellowship recognizes a young green chemistry scholar to attend an international conference.

**Green Operations** establish operating procedures that contribute to the sustainability efforts of ACS. Over recent years ACS has implemented many changes in operations to improve our carbon footprint. Electronic dissemination of science content has been very successful with high impact. We now offer electronic version of Chemistry and Engineering News, journal publications, and Chemical Abstracts. We now offer electronic dissemination of National Meeting content through videos of about 14-20% of the presentations, and we our educational resources are available electronically at acs.org. We have reduced our footprint for National Meetings through reusable grocery bags for events, natural gas buses, and recycling requirements at venues. ACS has received the EPA Energy Star certification for ACS Headquarters.

## ACS Sustainability Website

ACS will launch its Sustainability Website during IYC 2011, with content organized in three key areas: ACS and Sustainability; a Learning Center; and What You Can Do. The URL is http://www.acs.org/sustainability.

This site will provide a single ACS location for information about all aspects of sustainability to interested science professionals, educators, decision-makers, and the general public. In addition to comprehensive documentation for ACS sustainability initiatives, the website also provides numerous links to external websites with sustainability content.

## ACS Sustainability Vision for the Future

Many ACS sustainability initiatives are underway, and their success will continue to be expanded into the future. They demonstrate that ACS can provide knowledge content and opportunities for interaction and can leverage its unique capability as a convener of communities to foster coordinated efforts on sustainability. The sustainability initiatives reaffirm that ACS is uniquely positioned to be catalytic in fostering needed emphasis and innovative approaches to support sustainability in the chemical enterprise, and through that, to foster needed change in the larger community.

Specific future initiatives include: a sustainability theme for the UN International Year of Chemistry 2011, which will be continued beyond 2011; extension of local section and division programs to reach larger numbers of chemists about topics in sustainability; expansion of CS3 meetings on sustainability topics to China, Japan, and the US; and global alliances with other chemical societies and other organizations interested in further progress on sustainability, education, and public awareness, and advances in policy.

These will be accomplished through the engagement of ACS members, working individually and collectively with global partners. The greatest opportunity lies in unleashing the human energy of the chemical enterprise. Through the communication networks of ACS, both formal (the ACS Sustainability website) and informal (the ACS Network, and personal contact), we may engage far greater numbers of scientists and citizens, both in the US and throughout the world, in active support of sustainable change, at local, state, national and international levels. This unleashing of human potential can lead to significant measurable progress on sustainable development. It will take all of us, working together, to create a sustainable future.

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# Chapter 2

# Is Chemistry Education Sustainable?

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Chemistry plays a major role in achieving sustainability by designing products and processes that are better for human health and the environment. Underlying advances in green and sustainable chemistry is education. Content and pedagogy, professional development, accreditations and assessments must incorporate green chemistry and sustainability concepts if we are to produce the scientists who will develop sustainable technologies and the citizens who will make informed choices. The International Year of Chemistry in 2011 offers an exceptional opportunity to increase global awareness of the transforming power of chemistry in meeting the challenges of sustainability.

## Introduction

The question "Is chemistry education sustainable?" can be addressed in two ways. One approach would be to consider if the way chemistry is currently taught – content, pedagogy, assessments – is viable in preparing our students to be successful in the 21st century. Answering this question would be the topic of an entirely different paper! The second approach in answering this question is to consider if the chemistry curriculum is adequately preparing our students to meet the challenges of sustainability. Addressing this question forms the core of this chapter.

The American Chemical Society (ACS) has a strong commitment to sustainability, defined by the Brundtland Commission as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs (*1*)." The mission of the ACS is "To advance the broader chemistry enterprise and its practitioners for the benefit of Earth and its people."

One goal in the Society's current strategic plan states that the "ACS will be a global leader in enlisting the world's scientific professionals to address, through chemistry, the challenges facing our world."

Green chemistry, the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances (*2*), is our discipline's unique contribution to sustainability. The chemical industry is big business in the U.S.: more than 96 percent of manufactured goods are touched by chemistry and more than 800,000 people work in the chemical industry (*3*). By designing chemical products and processes that benefit the environment, chemists can make significant contributions to a sustainable future.

The role of science in achieving sustainability is well recognized. In 2003, for example, the National Academies report *Beyond the Molecular Frontier* (*4*) noted that "Greater understanding of the societal implications of their work by scientists and engineers will enhance our stewardship of this planet." Furthermore, the role of sustainability education has been highlighted in various reports and by a variety of organizations. The U.S. Department of Education hosted a Sustainability Education Summit in September 2010 at which Secretary Duncan observed, "Success in the STEM fields is critical to help students build the knowledge and skills they need to succeed as consumers, workers, entrepreneurs, and innovators in the green economy (*5*)." Chemistry plays a pivotal role among the STEM (Science, Technology, Engineering, and Mathematics) disciplines in meeting the challenges of sustainability.

## The Grand Challenges

*Sustainability in the Chemical Industry – Grand Challenges and Research Needs: A Workshop Report* (*6*) identified eight grand challenges (Table I) that need to be addressed by the chemical industry in order to achieve the goals of sustainability. The final challenge focuses on education: the innovations needed to meet the first seven technological challenges will only come through world-class education of our future scientists and engineers. In addition, our citizens who do not become scientists or engineers need a basic understanding of the role of science in sustainability so that they can be informed citizens and consumers.

The report highlighted several areas for particular attention in improving sustainability science literacy: professional development for educators, managers, and corporate executives; the integration of sustainability topics across disciplines at the secondary and tertiary level; and the incorporation of sustainability concepts into accreditation, assessments, and curricular materials.

### Professional Development

Professional development is a critical need as many of the chemists currently in the classroom, laboratory, or boardroom were not trained in sustainability or green chemistry concepts. A number of professional development opportunities are highly effective, but reach a relatively small number of people. The University of Oregon, for example, runs an NSF-sponsored summer workshop to introduce


In Sustainability in the Chemistry Curriculum; Middlecamp, C., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2011.

organic chemistry faculty members to greener organic laboratory experiments. These workshops are invaluable in familiarizing faculty members with the principles and practice of green chemistry because few professors are well-versed in green chemistry and sustainability. In follow-up surveys with the participants, the University of Oregon determined that the majority of workshop participants implemented green chemistry on their home campuses, affecting approximately 30,000 students (*7*). Securing buy-in from faculty can be a labor-intensive endeavor, but one that pays big dividends in terms of the number of students impacted.

The ACS and the European Union both offer summer schools focused on green chemistry and sustainability, targeted to graduate students and postdoctoral scholars. These programs introduce advanced chemistry students to green chemistry at the start of their careers, providing them with the tools needed to implement green chemistry in their research and teaching. The summer schools are also effective in building a community of green chemistry practitioners. A 2008 survey of participants who attended the first five ACS Summer Schools indicated that 81 percent still maintained contact with people they met at the Summer School. In addition, 86 percent of respondents noted that they had used green chemistry in their career since participating in the Summer School.

The need for specialized professional development should decrease as sustainability and green chemistry concepts become part of the mainstream curriculum, but we are a long way from that ideal. Sustainability topics too often remain at the edges of the secondary and tertiary curriculum and are covered if time permits. Weaving sustainability into textbooks and other curricular resources across the disciplinary spectrum – from accounting to zoology – will deepen student awareness and understanding of the multidisciplinary nature of sustainability.

### Integrating Sustainability Topics

Sustainability is such an important topic that the United Nations (UN) declared 2005-2014 the "Decade of Education for Sustainable Development". The goal of this decade is "to integrate the principles, values, and practices of sustainable development into all aspects of education and learning, in order to address the social, economic, cultural, and environmental problems we face in the 21$^{st}$ century (*8*)." The UN recognizes that global challenges require global solutions; scientific breakthroughs are key to meeting the triple bottom line of social, economic, and environmental responsibility.

How are we doing in educating our students for a sustainable future? The Organization for Economic Cooperation and Development (OECD) published in 2009 the results of the 2006 Programme for International Student Assessment (PISA) in environmental science and geoscience. Students in 57 countries participated in the 2006 PISA, which focused on science. *Green at Fifteen* (*9*)*?* examined the knowledge and skills of 15-year-olds with regards to environmental issues; understanding environmental issues is essential to designing solutions to global challenges. This report noted strong student interest in environmental issues, with students gaining most of their knowledge about the environment through school, such as geography and science classes. Yet understanding lags behind awareness, with the United States scoring below the OECD average.

Knowing about environmental issues is not enough. Students must have more than a deep understanding of the role of science in addressing sustainability; they must be prepared to implement their creative ideas. Entrepreneurship would be a very powerful addition to the curriculum, and has seen increased emphasis, particularly at the graduate level.

A recent example of entrepreneurship in green chemistry is the launch of GreenCentre Canada, which seeks to "transform breakthroughs in Green Chemistry into green products and industrial technologies that benefit the world (*10*)." The Centre serves as a model for collaboration between academia and industry, with government support, in converting fundamental research into sustainable products and processes. The Queen's University Ionic Liquids Laboratories (QUILL) Research Centre is another example of industry/university cooperation with potential applications in green chemistry, as some ionic liquids may function as greener solvents (*11*).

ACS, with support from the U.S. Environmental Protection Agency, has developed a number of green chemistry education resources, including *Introduction to Green Chemistry* (*12*), *Real-World Cases in Green Chemistry* (*13*), and *Greener Approaches to Undergraduate Chemistry Experiments* (*14*). The new editions of the ACS textbooks *Chemistry in the Community* and *Chemistry in Context* include a much stronger focus on sustainability, and highlights of these texts are featured in separate chapters.

Students often ask are "How do you know if something is green?" or "How green is green?" These are not easy questions to answer, but metrics can help. A variety of metrics have been developed to assess greenness. Metrics like atom economy (*15*) and E-factor (*16*) can be useful, especially when comparing two processes. While focusing on a single metric may be useful in illustrating a particular concept, however, a full life cycle analysis (LCA) is needed to thoroughly evaluate the environmental impact of a process or product. Currently, LCA is more commonly found in the engineering curriculum than in the chemistry curriculum, yet LCA would be a useful tool in helping chemists evaluate their processes.

**Accreditation and Assessments**

The American Chemical Society and the Accreditation Board for Engineering and Technology (ABET) recognize the importance of sustainability in approving bachelor's degree programs in chemistry and engineering, respectively. The *ACS Guidelines and Evaluation Procedures for Bachelor's Degree Programs* (*17*) state, "Students should conduct themselves responsibly and be aware of the role of chemistry in contemporary global and societal issues." ABET's *Criteria for Accrediting Engineering Programs* (*18*) stipulate that students must attain "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context."

**Table I. Grand Challenges for Sustainability in the Chemical Industry**

| |
|---|
| 1. Discover ways to carry out fundamentally new chemical transformations utilizing green and sustainable chemistry and engineering, based on the ultimate premise that it is better to prevent waste than to clean it up after it is formed. |
| 2. Develop life cycle tools to compare the total environmental impact of products generated from different processing routes and under different operating conditions through the full life cycle. |
| 3. Understand the toxicological fate and effect of all chemical inputs and outputs of chemical bond forming steps and processes. |
| 4. Derive chemicals from biomass – including any plant derived organic matter available on a renewable basis, dedicated energy crops and trees, agricultural food and feed crops, agricultural crop wastes and residues, wood wastes and residues, aquatic plants, animal wastes, municipal wastes, and other waste materials. |
| 5. Lead the way in the development of future fuel alternatives derived from renewable sources such as biomass as well as landfill gas, wind, solar heating, and photovoltaic technology. |
| 6. Continue to develop more energy efficient technologies for current and future sources of energy used in chemical processing. |
| 7. Develop more effective technology and strategies to manage the resulting carbon dioxide ($CO_2$) from current and future human activity. |
| 8. Improve sustainability science literacy at every level of society – from informal education of consumers, citizens and future scientists, to the practitioners of the field, and the businesses that use and sell these products. |

**Table II. Science in personal and social perspectives standards**

| *K-4* | *5-8* | *9-12* |
|---|---|---|
| Personal health | Personal health | Personal and community health |
| Characteristics and changes in populations | Populations, resources, and environments | Population growth |
| Types of resources | Natural hazards | Natural resources |
| Changes in environments | Risks and benefits | Environmental quality |
| Science and technology in local challenges | Science and technology in society | Natural and human-induced hazards |
| | | Science and technology in local, national, and global challenges |


In Sustainability in the Chemistry Curriculum; Middlecamp, C., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2011.

Standards at the K-12 level vary by state, but are largely based upon the National Science Education Standards (*19*), which include elements of sustainability education. In particular, the science in personal and social perspectives standards (Table II) emphasize a number of sustainability concepts.

The draft framework for science education, released in July 2010, is more explicit in addressing sustainability (*20*). One of the core ideas in earth and space science is "Human activities are constrained by and, in turn, affect all other processes at Earth's surface." A core idea in science and technology recognizes that "People are surrounded and supported by technological systems. Effectively using and improving these systems is essential for long-term survival and prosperity." The proposed framework also identifies a cross-cutting perspective on sustainability: "Students need to develop an appreciation of how to think about both the benefits and risks offered by new science and new technologies."

## International Year of Chemistry

The International Year of Chemistry (IYC) in 2011 presents an exceptional opportunity to highlight chemistry's role in achieving a sustainable world. The goals of IYC 2011 (*21*) are to

- Increase the public appreciation of chemistry in meeting world needs;
- Increase interest of young people in chemistry;
- Generate enthusiasm for the creative future of chemistry; and
- Celebrate the 100th anniversary of the founding of the International Association of Chemical Societies and of the award of the Nobel Prize in chemistry to Mme Marie Sklodowska Curie - providing an opportunity to recognize the contributions of women to the chemical sciences.

The first goal directly addresses sustainability, with the public as the primary audience. Chemical societies around the world are engaging their members in outreach activities designed to inform our friends, neighbors, and fellow citizens of the power of chemistry in providing clean water to a thirsty planet; developing renewable sources of energy; and creating new materials to meet the needs of our growing population. IYC serves as a catalyst for ongoing interactions between chemists, young people, and the general public, which will last well beyond the International Year itself.

## Conclusion

Is chemistry education sustainable? Much progress has been made, yet data on the extent to which green chemistry and sustainability have been incorporated into the curriculum are lacking. Acquiring these data would be extremely useful in identifying needs and directing resources to areas of high need.

Pockets of excellence exist on a number of campuses (*22*, *23*), more resources focused on sustainability are available (*24*, *25*), and educators are incorporating green chemistry and sustainability topics into their teaching and research (*26*, *27*).

Multiple approaches are needed to make all chemistry green and sustainable, and these approaches all start with education.

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# Chapter 3

# Sustainability: A Vehicle for Learning How To Respond to the Challenges of the 21st Century

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The act of embracing a sustainability agenda can transform our higher education institutions and confer advantages that will allow colleges and universities to make a successful transition into the 21st century while preserving and accentuating our distinctive qualities and character. Faculty members in Departments of Chemistry or in related programs can take advantage of these institutional dynamics to advance their ideas as the boundaries across disciplines continue to blur. If we take sustainability seriously, we can position the institutional environment itself as a working laboratory for developing and deploying sustainability strategies; engage faculty, staff and students in exploring, interpreting and developing solutions for important aspects of the Big Question of sustainability; create a new and powerful context for learning through linking the institution itself in new and meaningful ways to the community; provide a supportive environment for the disciplinary transformations and connections that will be needed in a new era; demonstrate the value of multiple frames of reference that can guide the application of knowledge, skills and civic and social responsibility in new settings and in the context of complex problems; contain costs by fostering energy conservation and efficiency in the construction and maintenance of facilities, the management of a vehicle fleet and approaches to the design of greener transportation systems; streamline the management of campus operations by reducing waste and increasing recycling; support the local economy by encouraging local purchases, converting campus food systems to locally and sustainably grown food; and, provide an impetus


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ACS Symposium Series; American Chemical Society: Washington, DC, 2011.

for closer working relationships within the community and local employers to share climate expertise and to pool resources. We cannot do any of this without chemists.

## The Challenge Ahead

As we enter the 21st century and watch our familiar institutions and relationships change under the strain of a globally integrated world order, we have begun to see that our traditional ways of doing things will not suffice for a new age. The Chairman and CEO of IBM Corporation, Samuel Palmisano, spoke recently to the Council of Foreign Relations (*1*). His theme was "The Current Economic Environment in the United States." He made several points that can set the stage for thinking about the ways that sustainability captures all of the elements of a contemporary liberal education and can place the study of chemistry and its related disciplines in a context that is both very personal and, at the same time, very far-reaching. Palmisano argued that (a) We are learning more and more about how the world works as sensors embedded across entire ecosystems, supply chains, healthcare networks, and communities send back information across vastly expanding networks of communication; (b) Our world is becoming increasingly interconnected so that ideas, images, data can spread quickly from one place to another without the help or management of "experts;" and (c) Even everyday objects are becoming intelligent and can generate enormous volumes of information. If we add all the other ways in which the changing patterns of settlement and the movement of people across the landscape can alter the ways that people can affect their environment, we have the ingredients for a true rethinking of the world order. The boundaries of our traditional disciplines will not stand in the face of such sweeping changes in how we learn, what we do with the flood of information that we now can explore and the complexity of interactions of natural systems and social systems on our planet. Across the science, technology, engineering and mathematics (STEM) disciplines, scholars and textbook editors are exploring ways to connect the disciplines and to shed light on the value of each field as a critical element in understanding and managing the large social and economic challenges we face.

What we have not figured out yet is how to make the best use of this new world order and its implications for citizenship and scholarship. We know a lot more but are we actually any smarter? Palmisano makes the case that the advantage will now go to places and organizations that are smarter than their competitors. Countries, regions and communities that have a smart infrastructure will do well---smart transportation systems, modern airports, secure trade lanes, reliable energy grids, trusted financial markets and an enhanced quality of life. Underlying all of these conditions is the concept of sustainability. In sum, "the enterprises, countries and communities that provide the smartest, most connected and most open environments for [the] coming generations to grow and innovate will be the ones that win" (*2*). Palmisano predicts, as do many other futurists, that "businesses, societies and communities will soon begin to transform their systems, operations, enterprises and personal lives to take advantage of " (*2*) the interconnected world that is opening up in front of us. As these forces reshape how and where we work and live, our ability to understand the impact of our choices on the health of the larger environment will become ever more important. We can see this unfolding as elements in both natural and manmade disasters that impact our environment, affect our livelihoods and alter the ecosystems that sustain us.

These changes are affecting how we educate, how we use our educations, how we frame questions in our own areas of expertise and who we will work with in the future to explore those questions and generate knowledge that will help us design solutions to a new generation of problems.

What does this mean for chemists? As Carol Geary Schneider has made abundantly clear in her prefatory remarks to Creating Interdisciplinary Campus Cultures (*3*),

> For dozens of different but intersecting reasons—developments and tensions within established fields, creative work that cuts across fields, the deepening connections between the academy and the communities it serves, and the actual interests of contemporary scholars---both intellectual work and undergraduate teaching and learning move restlessly across the so-called disciplinary boundaries. Across all the major domains of academic work, with established fields as well as in new fields, we have broken free of anything we might think of as a disciplinary framework for pathbreaking intellectual work.

The field of chemistry is increasingly being linked to other disciplines both within science and within the social and behavioral sciences and humanities. In addition, it is increasingly clear that every college graduate needs to have some understanding of and fluency in the sciences, including chemistry. Furthermore, chemistry itself, especially at the undergraduate level is itself a vital component of the liberal arts. The impact of these trends can be understood especially clearly in the way that our concern about climate change and sustainable stewardship of the natural environment has unfolded. To set a context for what follows, consider the following definition of sustainability as a working model of the many elements that are being rewoven into the interdisciplinary study of the impact of climate change on local communities as well as on the planet as a whole. This approach is proposed by *Sustainability Measures* in West Hartford, CT. While there is no agreed upon definition of the scope and context of the concept of sustainability, it may help to approach this topic with an explicit definition in mind.

> Sustainability is related to the quality of life in a community -- whether the economic, social and environmental systems that make up the community are providing a healthy, productive, meaningful life for all community residents, present and future (*4*).

## What Does It Mean To Be Educated?

In the 107th Yearbook of the National Society for the Study of Education (*5*), David Coulter and John Wiens summarized an extraordinarily rich and insightful series of essays and conversations with business people, students, parents, teachers and administrators about education. They pointed out that across these different ages and stages of life, the vision of an educated person was the same: Educated people "attempt to make a difference in the lives of others; they use their knowledge and understanding in their engagements with other citizens, listen respectfully and thoughtfully, and act with honesty and diplomacy. In other words, they exhibit certain traits of character" (ref (*3*), p 10).

Tracking all the way back to the classical philosophers, Coulter and Wiens ground these character traits in the two principles of wisdom---*sophia* (the pursuit of deep understanding) and *phronesis* (practical wisdom, the ability to know the right thing to do in a particular situation and the propensity to act accordingly) (ref (*3*), p 13). The most fully developed and contemporary perspective on the elements that should make up a practical liberal education that combines *sophia* and *phronesis* can be found in Greater Expectations (*6*) and its successor, Liberal Education and America's Promise (LEAP) (*7*). Each of these projects addresses primarily postsecondary education but both anchor their arguments in the K-12 experience. Each includes a portfolio of related studies and reports but it will suffice, for purposes of this reflective piece, to summarize only the Essential Learning Outcomes here. What is most important to keep in mind when reading these outcomes is that these concepts were derived by a study of the professional standards set by several professional societies and by regional accrediting bodies. They rise above traditional views of liberal learning to represent a more nearly universal conception of the experiences and capabilities of a person prepared for an interconnected world. The world of today is filled with complex and rapidly changing problems, the solutions to which will require a new kind of collaboration and experimentation and a new definition of how we should educate.

## Essential Learning Outcomes

The LEAP Essential Learning Outcomes are designed to prepare students at all levels of education. As a student progresses to successively higher levels, both the intellectual complexity and the significance and importance of problems will continue to expand and performance expectations will continue to rise. Together, the complexity and importance of the questions and the realities of active involvement in the design of workable solutions will prepare students for the experiences and challenges that await them upon graduation. The basic premise behind the model is actually captured nicely in a very different document, the Brown University Task Force on Undergraduate Education Report, September 2008.

- A curriculum should be more about context than content and the basic conditions that foster learning rather than the subjects learned.
- The most important social, political, scientific and moral challenges of any era have always demanded the ability to navigate multiple points of view and the application of the tools of many disciplines.
- The curriculum has always reflected the changing landscape of American culture and the challenges of nation-building.

The components of a 21st century education as articulated by LEAP offer a powerful set of expectations for what a contemporary education should entail (see ref (*5*)).

- Knowledge of human cultures and the physical and natural world.
  - **Focused** by engagement with big questions, both contemporary and enduring

- Intellectual and practical skills
  - **Practiced** extensively across the curriculum, in the context of progressively more challenging problems, projects and standards for performance

- Personal and social responsibility
  - **Anchored** through active involvement with diverse communities and real-world challenges

- Integrative learning
  - **Demonstrated** through the application of knowledge, skills and responsibilities in new settings and complex problems.

It should be evident that this formulation of a well-balanced and purposeful education requires an especially complex set of Big Questions that provide the resources, the challenges, and the opportunities for application that can undergird a meaningful education. The sustainability agenda offers an especially important and challenging set of Big Questions. Students care about these questions. They want to become active contributors to solving environmental problems. They want to study in places that share their concern and take sustainability seriously. They themselves want to be taken seriously as well. They are embracing sustainability for all of these reasons.

Science, technology, engineering and mathematics (STEM) are an integral part of a comprehensive world view. Over a decade ago, in a prescient exploration of The Challenge of the 21st Century, Managing Technology and Ourselves in a Shrinking World, Harold Linstone (1994 (*3*)) argued that a new century demands new thinking and that today's problems must be understood through the use of three different lenses. The three different kinds of perspectives that Linstone offers are the technical or analytic, the organizational or institutional, and the personal or individual. He makes a compelling case for the importance of using these different frames whenever we face an unfamiliar and complex problem. All three ways of looking at things are informed by and in many ways shaped by STEM and its insights and ways of exploring the world and the interactions of people, places and things.

## Sustainability as a Context for a 21st Century Education

In a prospectus entitled "A Call for Climate Leadership" (*9*), the American College and Universities Presidents Climate Commitment set out an agenda for the future that would embrace a concern for the environment and for sustainability as an institution-shaping goal of the nation's colleges and universities. As ACUPCC explains it, "Colleges and universities are ideal settings to develop workable new strategies, systems, behaviors and technologies that can be scaled up to the community and state levels. By involving students, faculty and staff, these institutions can become effective models for achieving climate neutrality and sustainability. We need academia to take the lead on cutting-edge research, action and demonstration projects that will speed the path to climate neutrality across all society's sectors- catalyzing investment and driving the development of new markets."

A study of climate change and its impacts on our planet emphasizes the interconnections among the economy, society and the environment. It matches up well with Linstone's three frames of technology, organization and personal reactions and responsibility, all of which must be engaged in a comprehensive approach to integrating research, education and practice and practical solution-funding within a well-designed curriculum for all students. These ideas and actions can be approached from many directions. The ACUPCC Call for Climate leadership (ref (*7*), page 7) describes ten different ways to become climate neutral. They include fostering energy conservation and efficiency, generating or buying renewable power, designing greener transportation systems, purchasing practices (buying local, buying recycles and sustainable goods), reducing waste and increasing recycling, converting campus food systems to locally and sustainably grown food, investment in climate solutions through endowment policies, and research and development on new energy technologies, new system design, emphasizing climate science and [policy in the curriculum and educating the community about climate solutions and partnering with local communities and businesses to share climate expertise and pool resources. Students can be involved in every one of these aspects of a fully developed climate commitment agenda. The full realization of a sustainability theme as an institution-shaping strategy can address every aspect of the LEAP Essential Learning Outcomes.

## Sustainability as a Powerful Context for Learning

This reflective essay attempts to make the case that a study of the environment and sustainability offers an especially powerful context in which to promote the kind of learning that will prepare students for life and work in the 21st century. Whatever our students' plans or interests STEM must contribute to their growing understanding of the world and their personal agency within it. For those students who are planning to pursue careers in STEM fields, we must prepare them to understand and experience the new ways that the disciplines are beginning to interact and to prepare them for the fact that the nature and use of scholarship will change during their professional careers.

There is a close alignment between the way that the world is changing and our growing expectations of what can be accomplished during an undergraduate experience. Liberal Education and America's Promise offers a portrait of the core components of a 21st century education that aligns closely with the realities of a globally integrated world. The expectations and experiences associated with the study of the environment and the broad concepts of community sustainability provide an especially promising way to approach the study of STEM within the social, cultural, environmental and economic context of our institutions and our communities. This compelling societal context can engage and inform all of our students, whether they plan to become STEM academicians, professional scientists or engineers, science or math teachers or professionals in other fields. We all need to understand the questions that science can answer and the questions that science cannot resolve and how to tell one kind of question from the other. The exploration of environmental and sustainability questions can offer an especially powerful way to learn how to apply knowledge, insights and values from different disciplines and different frames of reference to the kinds of problems that now confront us all in an interconnected world where each of us can have a voice and where each of us can make a difference.

## Sustainability Offers an Excellent Vehicle for Approaching the Transformation of Higher Education for a New Era

The health of our physical environment touches people's lives in ways that are intense and personal. The opportunity to address the challenges that face our environment is equally attractive to faculty, staff, students and community members from across the entire spectrum of fields and professions. Sustainability provides a Big Question, the sort that makes sense to everyone. This Big Question can be broken down into smaller projects and questions of varying degrees of complexity that allow everyone to contribute, whatever their ages, their expertise or their experience. The Climate Commitment portfolio attracts seasoned professionals and elementary school children with equal authenticity.

A shared commitment to managing the impact of a large enterprise on the environment around it crosses every aspects of institutional organization, passing across boundaries that often are difficult to traverse, creating an atmosphere of cooperation and shared purpose that is a key requirement for transformational change. Our goal is "to bring common understanding and a common spirit of responsibility so clearly needed in a divided world." The sustainability movement that is unfolding across the country as institutions of all kinds embrace a climate commitment offers a suitably complex structure. It can be both an end in itself---to become carbon neutral for example---and a means to a larger end---to prepare a university or a college to be successful in the 21st century and to create a learning environment that supports a more intentional and integrative approach to undergraduate and graduate study.

As sustainability spreads across an institution and finds a place in both the arts and sciences and professional programs, It can serve as a remarkably successful vehicle for fostering personal, institutional and community engagement without setting up the often time-consuming debates about what engagement really means and whether people are doing it already. The impact of the work is visible and compelling and it doesn't really matter what you call it.

In short, the sustainability agenda can readily be adapted to the distinctive characteristics of a particular institution and the environment around it, avoiding the classic "not invented here" problem that often limits the spread of innovation in higher education. It is easy to match the sustainability portfolio to the unique assets and strengths of a particular institution. At WSU, for example,

- We are in a hotbed of organic farming,
- In the heart of the bluff country along the banks of the upper Mississippi,
- At an institution that has chosen as its signature themes healthy people, healthy working relationships and a healthy environment,
- And that enjoys excellent collaborations with a number of regional partners including Winona Health (a regional health center), the City of Winona and the County of Winona and Eagle Bluff Environmental Center in Lanesboro, among others.

In our hands, as is the case in many communities that have embraced this agenda, sustainability offers a wonderful set of questions and challenges and opportunities for shared effort as well as individual action that is drawn from our own local experience and resources. Pursuing a sustainability agenda is an excellent illustration of what it can mean to "think globally and act locally."

## The Study and Practice of Sustainability Also Can Be a Vehicle for Rethinking the Nature of the Professions and the Core of the Academic Disciplines

We academics are often accused of focusing too much on the task of informing our students and the public, not to mention our colleagues in other disciplines, rather than taking time first to inspire and engage them. We think of others as our audience, not our partners or collaborators.

At the American Chemical Society (ACS) annual meeting in San Francisco in 2010, I spent my time in the company of the authors of an undergraduate text for non-science majors called Chemistry in Context as well as participating in a symposium on **Sustainability in the Chemistry Curriculum: What, Why Now, and How.** There I was reminded of the Triple Bottom Line. For business, the triple bottom line refers to the financial, social and environmental effects of a firm's policies and actions that together shape its viability as a sustainable enterprise. The phrase was coined by John Elkington, co-founder of the business consultancy SustainAbility, in his 1998 book Cannibals with Forks: the Triple

Bottom Line of 21st Century Business. For higher education, there is a similar triple bottom line for all that we do as well: social responsibility, economic impact and ethical practice in the conduct of our disciplines and professions. As we rethink how we prepare our students for the $21^{st}$ century and as we consider how we, as practitioners and academics can model how educated people think and act responsibly, we are opening up new ways to educate and new expectations for ourselves and for our students.

**Students can be involved in every one of these aspects of a fully developed climate commitment agenda.** The full realization of a sustainability theme as an institution-shaping strategy can address every aspect of an intentional and meaningful undergraduate experience.

- by positioning the institutional environment itself as a working laboratory for developing and deploying sustainability strategies
- by engaging faculty, staff and students in exploring, interpreting and developing solutions for important aspects of the Big Question of sustainability
- by creating a new and powerful context for learning through linking the institution itself in new and meaningful ways to the community
- by demonstrating the value of multiple frames of reference that can guide the application of knowledge, skills and civic and social responsibility in new settings and complex problems.
- By providing a means for people to work together in new ways to address environmental challenges and to draw upon each other's experience and expertise to develop solutions to those challenges.

## A Sustainability Agenda Is Meaningful in Its Own Right but It Also Offers a Means To Prepare an Institution for the $21^{st}$ Century

As we enter the $21^{st}$ century and watch our familiar institutions and relationships change under the strain of a globally integrated world order, we have begun to see that our traditional ways of doing things will not suffice for a new age. A sustainability agenda can make our institutions smarter, more open and more connected. These are qualities that will help us be successful in a new era. In the $21^{st}$ century we must operate our institutions in new ways for many reasons. We must contain costs; protect our distinctive mission and core during times of fiscal constraint; minimize our environmental footprint; prepare our students in new ways for the demands of the global, open, connected world that so many futurists from Thomas Friedman to IBM CEO Palmisano can already see developing within our institutions and in our surrounding environments. The sustainability agenda offers an especially attractive response to Palmisano's challenge "to provide the smartest, most connected and most open environments for [the] coming generations to grow and innovate…"

## A Sustainability Agenda Requires a Productive Blend of Inspiration, Engagement and Information, and a Healthy Dose of Understanding about How People Actually Make Choices. We Can Learn This Right on Our Own Campuses and Engage Our Students in These Discoveries.

In a recent article in Science Magazine (*10*) entitled Behavior and Energy Policy, two economists, Hunt Allcott and Sendhil Mullainathan, made the case that energy efficiency depends on both the technologies we have available and an understanding about how people make choices. Smart policies consider both elements. As they put it, economic models based on price and information assume rational choices. However, we aren't all that rational, at least most of the time.

- People procrastinate.
- Our attention wanders.
- Peripheral factors subconsciously influence our perceptions and decisions.
- We often resist actions with long-term benefits if they are unpleasant in the short-run.
- Small changes in context (what they call "nudges") can affect our behavior as much as large price changes.

In reality, psychological cues typically cost very little compared with price changes. When our students work on real-world problems and have the advantage of seeing their work through the lenses of different disciplines, including behavioral economics, they will be better prepared to take on these challenges later on. The bottom line---in fact, the triple bottom line---is that colleges and universities who turn themselves into smart, connected and open environments, in their campus operations, in their physical spaces, in their approach to education and in their approach to scholarship and creative activity, will be successful. They can do this more effectively if they understand more about why people do the things they do and what it takes to inspire and engage members of their campus communities. They will attract students. they will enjoy community support. They will attract and keep the best of the new generation of scholars. What better theme to use than sustainability as a vehicle for this transformation?

## Creating a Supportive Environment for a Campus Wide Commitment to Sustainability

Each institution will have its own way of incorporating a sustainability mode into its academic programs, its campus operations and its partnerships with its broader community. The process at Winona State University (WSU) has unfolded in four stages.

**Phase One: Start with Existing Programs and Activities and Add a Sustainability Component**

At WSU, Sustainability, for the most part, was first integrated into already active campus cross-disciplinary or artistic and cultural programming. In addition, students have become involved in many aspects of the larger ACUPCC work as either student employees or as members of project teams. These work-related and co-curricular experiences offer valuable learning opportunities and can both inspire and engage and, in a simple way, draw more interest in sustainability and serve as informal recruiting opportunities.

This first stage was facilitated by a request from the Faculty Senate asking that WSU become a signatory to the American College and University Presidents Climate Commitment (ACUPCC). To support and guide the early efforts to expand our sustainability efforts, we created an all-campus Sustainability Committee and appointed a part-time Sustainability Coordinator. We took on the easy shifts in emphasis first while we were completing our campus profile and prepatring our plans to move toward becoming carbon neutral in our operations.

- Campus lecture series such as the Lyceum Series began to include environmental speakers and authors.
- The common book: The selection of the common book always has a local or regional setting and now with a focus on environmental issues
- Living/learning in residential college: Communities with environmental and sustainability themes have begun to appear along with other choices.
    - "**Whose Planet Is It Anyway?**- Actually, it's yours, and mine, and theirs and everyone's. This living and learning community will explore how we can keep this planet healthy and alive for all of us."
    - "**Mississippi River**-The Mississippi River influences all it touches. Throughout history and in the modern era this river continues to be a driving force in our society. This living and learning community will explore this rich, multi-faceted part of the American fabric."

**Phase Two. Build Additional Capacity To Support Projects and Programs Focused on a Sustainability Theme**

In the second stage, new common experiences have been designed by our Center for Engaged Research, Teaching and Scholarship (CERTS) through its connection with our Sustainability Committee that was set up to guide our ACUPCC efforts. This process has been assisted by the emergence of a self-organizing dimension to the sustainability community that has been growing on campus. The administration has funded a part-time sustainability coordinator for the past two years who had responsibility initially for working with the Sustainability Committee to prepare the initial documents required by our Climate Commitment. The coordinator also played an initial convening and recruiting role until the sustainability community began to reach critical mass and organizes itself around a portfolio of sustainability themes. We have also put some funding into an innovation fund but otherwise we have wisely allowed this community to take shape and grow through a natural process of development. Sustainability at WSU is increasingly self-organizing and is shaped by the nature of our institution, its location on the Upper Mississippi in the bluff lands and our shared philosophy and history.

As the ACUPCC effort began to take a distinctive shape at our institution, the faculty moved to the idea of a common environmental theme that would tie together discussions and classroom activities across the year. These common themes have been taken up across the institution by disciplines as diverse as Nursing , English, Graphic Arts and Chemistry. These discipline-spanning themes so far have been Water (2008-2009), Sustainable Food (2009-2010) and The Big Sky (2010-2011).

The committee that planned the Sustainable Food theme for this past academic year included representatives from the local organic farming community, the Bluff County Co-Op, the Community Gardens Project, the land Stewardship, the Winona County EDA, St. Mary's University, the WSU Center for Engaged Research, Teaching and Service (CERTS) and WSU faculty and staff. The year long program included a local sustainable foods banquet, a Farmer's Market on the campus during Homecoming Weekend, field trips to local farms and projects woven into the curriculum by faculty in disciplines ranging from art and design to English to Biology and cooking classes for students with an emphasis on local and sustainable foods. The theme was carried over into the program of the annual Frozen River Film Festival which, in addition to films, offers a number of related activities including a winter Farmer's Market and food-related events featuring locally grown produce.

### Phase Three: Weave Sustainability into the Curriculum in Ways Appropriate for Your Institution and the Students You Serve

In the third stage at WSU, distinctive curricular elements are starting to appear such as certificates, sequences of study, an honors scholar program that entails a package of change agent courses from which the participant may choose, all with an engagement or field experience. In addition, our Outreach and Continuing Education Division is developing a set of "stackable credentials" that can be used individually or put together to form a degree completion program for adults. One example of such a credential is our new Energy Resource Advisor (ERA) Certificate. The ERA was designed by a cross-functional team of WSU participants and a number of affiliated agencies and partners to accelerate public understanding of energy efficiency, clean energy, carbon emissions, resource conservation, green technologies, and green jobs. This curriculum is the *first of its kind in Minnesota*. It is a non-credit, continuing education course for adults 18 years of age and older, using online instructional technology combined with applied, hands-on experience. It is intended to foster understanding and leadership of environmental sustainability in our communities, homes and workplaces. With Innovation Grant funding from the Minnesota State Colleges and Universities, the ERA curriculum was developed through a collaborative partnership among: Winona State University, Eagle Bluff Environmental Learning Center, Clean

Energy Resource Teams (CERTs) , Winona County Environmental Services. U.S. Fish and Wildlife Service and several other state and regional organizations.

Another example of a curricular segment is the Green Cord Project. Successful participants will graduate with honors as a Sustainable Future Scholar. The proposed "Creating a Sustainable Future (CSF) Scholar program" is a set of courses, programs and opportunities designed to (1) give students the experience and education they need to contribute to our region's and our planet's current and future efforts for sustainability, and (2) develop a deeper understanding of the complexities and connectedness of the issues in this area. In particular, components in the CSF Scholar program are geared toward efforts that will empower our students to be sustainability change agents.

**Phase Four: Become a Working Sustainability Laboratory**

This phase is just beginning at WSU. It includes two core elements. First, the faculty and the climate commitment subcommittee are working on several more formal courses of study that are in planning stages such as formal minors, a major in sustainability and a Professional Masters Degree, probably offered in collaboration with one or more other institutions with complementary strengths that will prepare environmental resource professionals. This may build an advanced level exploration of various aspects of sustainable communities that also have been incorporated into our certificate program, including the theory and practice behind new approaches to both the technology and social science of climate neutrality.

Second, we are also gradually turning the entire Winona campus into an sustainability studies laboratory through a combination of efforts, including placing Environmental Monitoring stations in the new residence hall complex that will provide data for class projects; involving students in our efforts to reduce the use of cars for short distance travel near campus; and encouraging the consideration of a "Green Fee" that the students would assess themselves that would provide support for expanding the role of the sustainability coordinator as well as provide funding for a competitive grant program for student sustainability projects. We were the first campus to add a ZipCar program in our system and the student environmental club put together a bike borrowing program and a bike repair and maintenance program to encourage bike use.

In sum, the act of embracing a sustainability agenda can transform our higher education institutions and confer advantages that will allow colleges and universities to make a successful transition into the 21st century while preserving and accentuating our distinctive qualities and character. If we take sustainability seriously, we can---

- position the institutional environment itself as a working laboratory for developing and deploying sustainability strategies;
- engage faculty, staff and students in exploring, interpreting and developing solutions for important aspects of the Big Question of sustainability;

- create a new and powerful context for learning through linking the institution itself in new and meaningful ways to the community;
- provide a supportive environment for the disciplinary transformations and connections that will be needed in a new era;
- demonstrate the value of multiple frames of reference that can guide the application of knowledge, skills and civic and social responsibility in new settings and in the context of complex problems;
- contain costs by fostering energy conservation and efficiency in the construction and maintenance of facilities, the management of a vehicle fleet and approaches to the design of greener transportation systems;
- streamline the management of campus operations by reducing waste and increasing recycling;
- support the local economy by encouraging local purchases, converting campus food systems to locally and sustainably grown food; and
- provide an impetus for closer working relationships within the community and local employers to share climate expertise and to pool resources.

Chemists can contribute to each of these aspects of a fully developed sustainability agenda as it plays out in an academic setting. Chemistry can provide insights into the challenges of working in an interdisciplinary mode to articulate questions of importance, to explore those questions and to apply the insights gained to advance both the theory and practice of new approaches to liberal learning in the 21$^{st}$ century. This is not someone else's job. It is everyone's job.

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## Chapter 4

# Sustainability and the Pedagogical Perspective of "Connected Science"

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If we are to connect sustainability issues to the education of chemistry majors, how might we do that? Is it a question of finding more room to hang "separate fruit" on the course tree? Or might another perspective provide possible solutions? In recent years, a group of STEM faculty in diverse disciplines and institutions have, through a set of interrelated projects in the scholarship of teaching and learning, begun to articulate a pedagogical perspective that they describe as "connected science." This chapter will look at the characteristics of "connected science", an example from my own work in this area, and the opportunities this approach may create to incorporate sustainability issues throughout the chemistry curriculum. The goal of this approach is that chemistry majors would learn science knowledge and processes in a contextualized way, often drawing the context from significant real-world issues. The hope is that learning in this contextualized context would provide opportunities for students to practice complex analysis and better position them to act in the world around them.

"The drama of our time is the coming of all men into one fate."

- Robert Duncan (American poet)


In Sustainability in the Chemistry Curriculum; Middlecamp, C., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2011.

## Why Sustainability Needs To Be in the Chemistry Curriculum

If there is one issue that crosses boundaries – national, disciplinary, social – it is the challenge of sustainability in human activities. Probably the most widely cited definition of sustainability is the one found in the Brundtland Commission's report *Our Common Future* (*1*) which stated that "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Many uses of this definition focus on environmental concerns such as resource depletion or adverse effects such as air or water pollution. The National Research Council report *Our Common Journey* (*2*) described what they called a "normative" vision of sustainability and stated "The primary goals of a transition toward sustainability over the next two generations should be to meet the needs of a much larger but stabilizing human population, to sustain the life support systems of the planet, and to substantially reduce hunger and poverty." It is this latter description that I have used as a reference point in the thinking and work described here, as the explicit emphasis on meeting the needs of the world's population and substantially reducing hunger and poverty makes clearer the positive contributions that chemistry can make to this transition towards sustainability.

There are two different but complementary perspectives that argue for the inclusion of sustainability into the undergraduate chemistry curriculum. One perspective focuses on what the broad goals of undergraduate education should be in the 21st century. One of the most widely known attempts to present these goals is the 2007 report *College Learning for the New Global Century* (*3*) produced by the Liberal Education and American's Promise Project of the American Associaton of Colleges and Universities. That report identified the following as essential learning outcomes:

- knowledge of human cultures and the physical and natural world
- intellectual and practical skills (inquiry and analysis, critical and creative thinking, written and oral communication, quantitative literacy, information literacy, teamwork and problem solving)
- personal and social responsibility (civic knowledge and engagement, intercultural knowledge and competence, ethical reasoning and action, foundations and skills for lifelong learning)
- integrative learning

A second perspective comes from within the scientific community itself and is epitomized by two examples. John Holdren's recent presidential address to the American Association for the Advancement of Science was titled "Science and Technology for Sustainable Well-Being" (*4*); after introducing the concept of "sustainable well-being", he went through a taxonomy of shortfalls in this area before focusing on five specific challenges that ranged from meeting the basic needs of the poor to mastering the energy-economy-environment dilemma to eliminating nuclear weapons. The National Research Council workhop *Sustainability in the Chemical Industry: Grand Challenges and Research Needs* (*5*) identified as one of eight grand challenges to sustainability in chemistry the need to "improve sustainability science literacy at every level of society—from informal education of consumers, citizens and future scientists, to the practitioners of the field, and the businesses that use and sell these products." In particular, the report pointed to a need for research on how to incorporate sustainability concepts across curricula: K-12, undergraduate, and graduate.

Both of these efforts – the clear articulation of broad and important learning goals for undergraduate education and the need to improve sustainability literacy through incorporation into curricula – connect to elements of professional education described by William M. Sullivan, in *Work and Integrity: The Crisis and Promise of Professionalism in America* (*6*). In that book, Sullivan put forward a model for professional education comprised of what he called three apprenticeships (*6*):

- a *cognitive apprenticeship* where the student learns to think like a member of the profession;
- a *skill apprenticeship* where the student practices the skills routinely used by members of the profession;
- an apprenticeship that "teaches the skills and traits, along with the ethical comportment, social roles, and responsibilities, that mark the professional…the novice is introduced to the meaning of an integrated practice of all dimensions of the profession, grounded in the profession's fundamental purpose."

In the context of Sullivan's model, sustainability is clearly related to the third apprenticeship that encompasses social roles and responsibilities, which perhaps can be concisely described as a moral/ethical apprenticeship.

To this point, most efforts to incorporate sustainability concepts within the undergraduate chemistry curriculum have focused on green chemistry. Green chemistry as defined by Anastas and Warner (*7*) is "the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture, and application of chemical products." While there is no question that green chemistry principles and practice will be an important part of sustainability, the definition above has an inherent limitation. Another important component of incorporating sustainability into the chemistry curriculum is the question of context. In short, context matters. Green chemistry applied to developing a better synthesis of Viagra in terms of reducing environmental waste is not the same as green chemistry applied to developing a new antimalarial drug that, along with reduced environmental waste, could save 1 million lives each year (*8*). Sustainability must address more than just low pollution processes. It must address broader social issues as well. How can we incorporate context into our chemistry courses for majors? One of the big challenges and concerns for many chemistry faculty is this sense that there is so much content that our students need to encounter and learn in our courses that there simply isn't time or space for anything else. The "content gorilla" is very much present in any discussion of how we might change undergraduate chemistry courses, and not acknowledging that reality almost certainly dooms the discussion in terms of making any real progress. Consequently, the traditional pedagogies that have been used in chemistry courses to "cover the content" are deeply entrenched. Even active learning pedagogies such as POGIL (*9*) still largely maintain the separation between content and context. At the same time, there is tremendous truth in what Larry Cuban wrote originally in the context of improving quantitative literacy (*10*), that curriculum and pedagogy are inseparable and that new learning requires new and progressive pedagogies. How might we begin to accomplish this in regards to chemistry and sustainability?

## Both/And Rather than Either/Or

One possible solution lies in the intersection of two experiences I have had in recent years. Starting in the fall of 2005, I redesigned my biochemistry course to reflect the approach advocated by the SENCER Project (*11*, *12*), a National Science Foundation funded systemic reform project in STEM education. SENCER, an acronym for "Science Education for New Civic Engagements and Responsibilities", advocates teaching through large and complex issues containing a civic dimension to the underlying science concepts. SENCER courses use issues such as global climate change, energy, diabetes, AIDS, tuberculosis, nuclear technology, and nutrition as contexts to engage students with the science at the heart of these questions. While much work within the SENCER project had been focused on courses for nonscience majors, a growing number of faculty involved in the project (including myself) were interested in exploring the potential implications of this approach for courses within STEM majors.

At the same time that I was redesigning both semesters of my biochemistry course for majors, I was part of a cohort of 22 individuals selected by the Carnegie Foundation for the Advancement of Teaching as Carnegie Scholars for 2005-2006 (*13*). The Carnegie Scholars program provided individual faculty with the opportunity to participate in several extended residencies at the Carnegie Foundation while at the same time working on a scholarship of teaching and learning project at their home institution. The theme that united the members of the 2005 cohort was integrative learning, and roughly a half dozen faculty in the cohort taught in various STEM fields. During the time spent together in residencies, conversations about both individual projects and common features and experiences led to a growing realization that our individual projects were linked by a common pedagogical perspective, what Tricia Ferrett of Carleton College (another 2005 Carnegie Scholar) named "Connected Science" (*14*). By this phrase Ferret aimed to capture what she saw as as an attempt to coherently connect content, context, and pedagogy in support of integrative learning. While a fuller presentation of the Connected Science approach to teaching and learning will have to wait for the publication of a forthcoming volume being edited by Ferret and David Geelan (University of Queensland), for the purposes of this chapter it will be sufficient to list the important characteristics of this approach. These include:

1. Data: What can it tell students (and not tell them)? Data are multidimensional and students must see all dimensions.

2. Engaging multiple perspectives (in and outside of science)
3. Attention to the cognitive, social, and emotional dimensions of learning
4. Student writing or other "non-traditional" (for science) products of student learning that "fit" the learning goals and where the students are in their journey
5. Students' prior knowledge and experiences are important to the class and the pedagogy welcomes their contributions
6. Core habits of mind and ways of knowing in science; nature of science
7. Teaching to prepare students for their future (real world problems)

How were these characteristics embedded into the biochemistry courses that I was redesigning at the same time as my Carnegie Scholar fellowship?

## Redesigning a Course To Create Opportunities for Connections

The underlying premise of the biochemistry course redesign was, using the SENCER approach, to teach through various public health issues to the underlying biochemistry that students needed to learn. Consequently, I made three major changes in the structure and organization of the courses:

1. Wherever possible, illustrative examples that were used in class would be drawn from public health topics rather than the typical examples found in textbooks that had been used for many years. These included Aβ or influenza proteins as examples of protein structure and folding, HIV protease as the central example for enzyme mechanisms, malaria and diabetes for glycolysis, and multi-drug resistant TB as an example for secondary active transport
2. At various points in the course, I would ask students to read and respond to articles that focused on the broader societal context of these public health issues.
3. Students would work in small groups to develop a presentation on the biochemistry of a public health topic of their own choosing.

These changes were implemented in the hope of provide openings or opportunities in these courses for students to make connections among the information, ideas, and perspectives in this course and those in other courses or areas outside the natural sciences.

To orient students to the public health context that would be used throughout the course, I spent part of the first day of class having students work through one of the activities found on the DVD set of the series "Rx for Survival: A Global Health Challenge" (*15*) that was broadcast on PBS television stations in 2006. The activities I used were selected so that they could be done in roughly 20 minutes, did not require any advance preparation, and incorporated aspects of public health that drew from both scientific as well as other disciplines. The readings that were used to provide the broader societal context came from a number of different sources: *The Atlantic Monthly*, *The New Yorker*, *The New York Times*, *Time*, and books that focused on specific public health issues such as Alzheimer's Disease or HIV/AIDS or depression (individuals interested in a a complete list of readings used over the years can contact me). Reflective writing assignments coupled to these readings asked for students to respond to some combination of the following prompts: what students saw as major themes in the readings, how the topic of the readings connected to other courses at Saint Vincent, what connections students saw between the readings and values central to Saint Vincent's identity and mission (community, care, hospitality, stewardship).

The combination of the primary scientific literature being available in electronic format and public databases such as the Protein Data Bank and Proteopedia made it relatively straightforward to incorporate examples from public health issues as illustrations for course concepts. To give just two examples, principles of protein structure could be examined using the influenza proteins hemaggluttinin and neuraminidase and secondary active transport could be illustrated with microbial drug resistance transporters. While I had been using take-home questions as part of my exams during the semester for almost a decade, the use of topics such as Alzheimer's Disease and viral infections as context for the course provided an excellent framework for writing new questions based on published primary literature (interested faculty can contact me for details of these questions). The public health context also created the opportunity to include, as part of the take home questions, articles from journals such as *Science* that focused more on the policy aspects of a particular issue.

The public health project, a suggestion from other faculty in my cohort of Carnegie Scholars, provided a mechanism for giving students some authority to make choices and explore what interested them as well as demonstrating the connections that they could make. The assignment utilized the KEEP (Knowledge Exchange Exhibition Presentation) Toolkit, a set of web based tools, as a way of presenting the final work of students. The KEEP Toolkit was developed by the Knowledge Media Lab at the Carnegie Foundation for the Advancement of Teaching (*16*), as a resource to help teachers and students quickly create compact and engaging knowledge representations on the Web that integrated text, images, video, and hyperlinks. Selected examples of completed public health projects can be found on the web (*17*)

To analyze and evaluate how the changes to the biochemistry courses worked out, I closely examined multiple samples of student work (reflective writing, selected assignments, public health projects). The results have been analyzed in more detail elsewhere (*18*), but the major conclusions can be summarized as follows. In term of mastery of biochemical content, the average on a cumulative final exam that remained virtually identical before and after course redesign remained unchanged; classes over the past five years continue to have a class average on that exam of 80%. To me, this supports the conclusion that students did not show any loss of content knowledge in the redesigned course. While the courses had included take-home questions as part of each exam for over a decade, the diffficulty of the take home questions in the redesigned course was noticeably higher. In both reflective writing that was part of the take home questions as well as the public health project, students demonstrated the ability to make connections at various levels. Students made reference to concepts they had learned in other courses, personal experiences, and values, and institutional values such as care, community, and hospitality (all values central to Saint Vincent College's institutional identity and mission as a Catholic, Benedictine, liberal arts college). Student comments on surveys reflected a significant level of affective engagement in the course.

How did my redesign of the biochemistry courses exemplify some of the characteristics of "Connected Science"? The use of public health topics as the context through which students encountered biochemical content provided a framework where multiple perspectives, in and outside of science, could be brought into the course. The reflective writing and public health projects were both "non-traditional" products of student learning that fit the goals of the course and provided flexibility that allowed students to communicate where they were on their journey as learners. These same assignments were structured so that students were welcome to incorporate prior knowledge and experiences that they had and thought were relevant. And since the vast majority of the students in these course were interested in careers in health professions or biomedical research, these same public health issues were clearly relevant real world problems. And although it was not something that I intentionally focused on in the initial redesign, student comments made it clear that there was an emotional dimension to their learning that was much less obvious in the old course design. As one student wrote as part of a reflective writing assignment linked to tuberculosis:

> "I think of TB as a an early 20$^{th}$ century disease, affecting people who live in crowded, poverty stricken areas…I know when you give blood you are asked about exposure to TB and when we came to school we were tested for TB, but I never gave it a second thought, thinking these general precautions just to be safe. If I were to rank the high priority diseases on the onset of this activity, I would not include tuberculosis in the top five…My personal views have changed as a result of reading the article and the information on the website. I seem to be connected to this disease on a closer level than before...I now realize that I fell into a group of people that thought TB was a dead disease, a thing of the past."

## Connected Science and Sustainability

What possibilities does the Connected Science approach offer in regards to bringing sustainability into chemistry? We need to start with the recognition that several studies, summarized by Cooper (*19*), clearly and persuasively argue that the traditional curriculum in chemistry includes too much content. The problem with an overcrowded curriculum is that it creates conditions that result in what Lee Shulman (*20*) has described as inertia – an inability to use what has been learned. Shulman writes: "A play on Plato's concept of 'innate ideas,' inert ideas are those that simply lie there, doing nothing. They are not forgotten; nor are they in some intrinsic sense wrong. They are simply not in a form that lends them to any useful purpose beyond being remembered…Inertia as pathology describes those states of mind where people come to know something but simply can't go beyond the facts, can't synthesize them, think with them, or apply them in another situation." Shulman proposes as a solution to this pathology (*21*) that teachers ensure that "the subject-matter content to be learned is *generative*, essential and pivotal to the discipline or interdiscipline under study, and can yield new understandings and/or serve as the basis for future learning of content, processes, and dispositions."

Sustainability offers a context for learning chemistry that is rich in generative possibilities, particularly when it is incorporated in ways reflective of the characteristics of Connected Science that I have described here. Sustainability also offers the advantage that it can be viewed, as Daniel Sherman has suggested (*22*), as a "big idea" that cuts across disciplinary boundaries. The term "big idea" comes from the work of Grant Wiggins and Jay McTighe (*23*), who described a big idea as "a concept, theme, or issue that gives meaning and connection to discrete facts and skills." Sherman's point that sustainability, unlike other big ideas, isn't limited to a single discipline is key because it suggests that sustainability can be a big idea that actively supports integrated learning. Does sustainability serve as a big idea for chemistry? I think the answer can be found by looking at the various chapter headings in the American Chemical Society report *Global Challenges/Chemistry Solutions* (*24*). In that report (based on a series of podcasts that still continue) we see the following listed - water (purification, desalination), climate change (reducing greenhouse gases, permanent solutions), safety and security, fighting disease, new fuels, and food (safety, nutrition). These issues clearly are related to concepts that students learn in a range of chemistry courses – general chemistry, organic chemistry, inorganic chemistry, physical chemistry, and biochemistry. At the same time, these issues offer a wide range of possibilities for helping students learn chemistry in a contextualized manner that engages multiple disciplinary perspectives, offers potential for affective engagement, helps students learn something about the nature of science and the core habits of mind and ways of knowing involved in its practice, and prepares students for their future. The biochemistry courses at Saint Vincent briefly described here, as well as other courses taught by either members of the 2005 cohort of Carnegie Scholars and faculty involved in the SENCER Project, serve as "proof of concept" examples of the potential to be found in the pedagogical approach of connected science. This approach seeks to foster student learning that encompasses both appropriate understanding of disciplinary content and an awareness of contextual connections. It is not a question of either content or context, rather it is a question of how we approach both simultaneously. The challenge of sustainability demands nothing less from chemistry education.

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In Sustainability in the Chemistry Curriculum; Middlecamp, C., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2011.

## Chapter 5

# Sustainability! What, How, and Why Now for All Our Chemistry Students

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Sustainability in the chemistry curriculum: What, how, and why now? For most chemistry instructors, the "what" of sustainability involves making changes in the curriculum to include new content. This content comes with a learning curve, one that most chemistry instructors will have to climb. The "how" of sustainability in the curriculum also has a learning curve. Instructors will have to gain expertise both in helping students master these new concepts *and* in helping students find ways to use these new concepts as future citizens and professionals. The "why now" of sustainability is the most straightforward of the three. The time is now because we and our students need this new knowledge if the 2010 San Francisco meeting theme, "*Chemistry for a Sustainable World*," is to become a reality.

## Introduction

What, how, and why now? *What* topics in sustainability fit in the undergraduate chemistry curriculum, in particular, in an introductory (*1*) chemistry course? *How* can we engage students in learning these topics? And *why* is it time – perhaps past time – for us to integrate sustainability (*2*) into our introductory courses and, more broadly, throughout the undergraduate chemistry curriculum?

While these may appear to be three routine questions, rethinking a first-year chemistry course with an eye toward sustainability is far from a routine process. In order to decide *what* changes to make, instructors first will have to grapple


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ACS Symposium Series; American Chemical Society: Washington, DC, 2011.

with a new body of content. Secondly, as previous speakers in this symposium have pointed out, this new content is contested, including that there are many definitions of sustainability currently in use. Furthermore, the content is complex, encompassing a set of ideas that relate *both* to a body of knowledge (the concepts of sustainability) *and* to a process of problem-solving (using these concepts to ask and answer questions). Thirdly, as tends to be the case with any change in the curriculum, infusing new content will involve lengthy discussions, turf battles, and value conflicts, all sprinkled with a bit of departmental politics.

Similarly, the question of *how* is non-routine. Changing the curriculum to include sustainability is not simply a matter of “add and stir.” Timing (i.e., when to introduce content), scope (i.e., how much of it to introduce), and feedback (i.e., what happened as a result) all warrant close attention. Without this attention, students are likely to experience difficulties as they attempt to learn the content. The same, of course, is true when teaching a complex chemical concept such as equilibrium or bonding. The *how* of teaching any topic, including sustainability, is truly part of the art of teaching.

The question of *why now* is the most straightforward of the three. Why now? The answer is one built of necessity. Our students are entering a 21st century world and need a curriculum to match. This need exists whether they are chemistry majors, other science majors, or non-science majors. The less straightforward question is *how to move from words to actions*. Although our world has changed, our introductory chemistry curriculum has largely maintained it its traditional form and content. It is easy to make the case that our chemistry students now need a curriculum that is better matched to the challenges they will face when they graduate; in contrast, it is not so easy to move from rhetoric to practice.

An overarching reality frames the discussion of *what*, *how*, and *why now* in the chemistry curriculum; namely, for a significant fraction of our students, introductory chemistry is the last chemistry course, possibly even the last science course, that they may ever take. This holds true both for our nonscience majors as well as for those in science and engineering. For the former, upwards of 90% will never take another chemistry course; for the latter, it is not usual for 25% to drop out during or after the first semester of an introductory chemistry course, with a similar attrition occurring after the second semester.

The discussion on *what*, *how*, and *why now* that follows is based on the experiences of the author in teaching, learning, and writing about concepts relating to sustainability. For the past 15 years, she has been teaching a one-semester introductory chemistry course for non-science majors (*3*). This course engages students in learning chemistry through real-world societal issues such as air quality, climate change, nuclear energy, and food production. Over the same period, she served on the author team of *Chemistry in Context* and currently is the editor-in-chief (*4*). This textbook, a project of the American Chemical Society (ACS), is now in its 7th edition and currently is used by over 20,000 students at 700 colleges and universities in the United States (*5*). With the approval (and strong urging) of the Education Division of the ACS, this edition contains a new chapter on sustainability for which she was the lead author (*6*).

## The Question of "What"

In preparing to teach an introductory chemistry course that includes sustainability, it is useful to think of sustainability both as a topic worth studying *and* as a problem worth solving. As a topic, sustainability provides a new body of content for students to master; as a problem, it generates new questions for students to ask – ones that help us imagine and achieve a sustainable future. Thus the introductory chemistry instructor may be faced with climbing not one, but two learning curves, one for answers and a second for questions.

Many concepts are associated with the topic of sustainability (see Table 1). At first glance, these concepts may not appear to have much in common with those typically taught in an introductory chemistry course, such as stoichiometry, states of matter, atomic structure, bonding, thermodynamics, equilibrium, or kinetics (*7*). However, it is possible to organize the content of an introductory chemistry course around societal issues that involve chemistry, as was done in 1989 by the original authors of the *Chemistry in Context* project (see Table 2). If a course centers around topics such as energy, food, polymers, and air quality, the match with sustainability becomes much more obvious. Even if instructors do not organize their entire course around real-world societal themes, they still can include concepts relating to sustainability by infusing examples of real-world issues.

For example, consider the real-world topic of air quality, one of interest to health professionals in particular and more generally to all who live in a congested urban area or downwind of one. The words "Humans have a special responsibility to guard the quality of the air on our planet" are the point of departure for Chapter 1 of *Chemistry in Context*. The narrative continues, pointing out that living out this special responsibility has proven to be no easy task. Maintaining and improving air quality requires that at least some of our citizens, if not a majority, be armed both with good answers and good questions about air quality, many of which will require a knowledge of chemistry. Chapter 1 describes what is in the air we breathe, how it got there, and how the concentrations of substances in air – large and small – affect our health. The chemical concepts of atoms, molecules, compounds, and elements naturally arise as part of the discussion. So do the chemical combustion reactions that release $CO_2$, CO, NO, $SO_2$, hydrocarbon fragments, unburned fuel, soot, and particulate matter into the air. How is outdoor air different from indoor air? Are some people more susceptible to air pollution than others? Questions such as these can engage our students, perhaps together with their families and friends, in learning topics that are part of our introductory chemistry courses.

With a topic such as air quality, it is easy to make a good match between our chemistry curriculum and our planet. Homework and test questions can assess student knowledge of both. For example, here is an end-of-chapter question that relates to ultra-low sulfur diesel fuel, now readily available in the United States (*8*). Note that it gives students practice in basic chemistry skills as well as connects to wider issues.

**Table 1. Example of Concepts Related to Sustainability***

| | |
|---|---|
| **cradle-to-cradle** | a term coined in the 1970s that refers to a regenerative approach to the use of things in which the end of the life cycle of one item dovetails with the beginning of the life cycle of another, so that everything is reused rather than disposed of as waste |
| **external costs** | costs that are not reflected in the price of a commodity, such as the price of a gallon of gasoline or a ton of coal, but nonetheless take a toll on the environment |
| **ecological footprint** | a means of estimating the amount of biologically productive space (land and water) necessary to support a particular standard of living or lifestyle. |
| **shifting baselines** | the idea that what people expect as "normal" on our planet has changed over time, especially with regard to ecosystems |
| **tragedy of the commons** | the situation in which a resource is common to all and used by many, but has no one in particular responsible for it. As a result, the resource may be destroyed by overuse to the detriment of all that use it |
| **Triple Bottom Line (TBL)** | a three-way measure of the success of a business based on its benefits to the economy, to society, and to the environment |

* definitions from glossary, *Chemistry in Context*, 7th edition, 2012.

**Table 2. Table of Contents for *Chemistry in Context*, 7th Edition**

Chapter 0 – Chemistry for a Sustainable Future

Chapter 1– The Air We Breathe

Chapter 2 – Protecting the Ozone Layer

Chapter 3 – The Chemistry of Global Climate Change

Chapter 4 – Energy, Chemistry and Society

Chapter 5 – Water for Life

Chapter 6 – Neutralizing the Threat of Acid Rain

Chapter 7 – The Fires of Nuclear Fission

Chapter 8 – Energy from Electron Transfer

Chapter 9 – The World of Plastics and Polymers

Chapter 10 – Manipulating Molecules and Designing Drugs

Chapter 11 – Nutrition: Food for Thought

Chapter 12 – Genetic Engineering and the Molecules of Life


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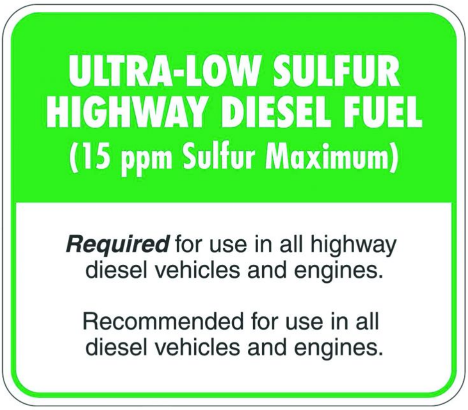
ACS Symposium Series; American Chemical Society: Washington, DC, 2011.




*Prior to 1990, diesel fuel could contain as much as 2% sulfur. New regulations have changed this, and most diesel fuel today is ultra-low sulfur diesel (ULSD) containing a maximum of 15 ppm sulfur.*

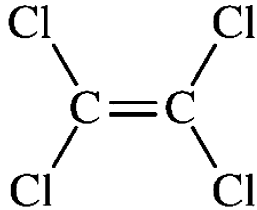
- **a.** *Express 15 ppm as a percent. Likewise, express 2% in terms of ppm. How many times lower is the ULSD than the older formulation of diesel fuel?*
- **b.** *Write a chemical equation that shows how burning diesel fuel containing sulfur contributes to air pollution.*
- **c.** *Diesel fuel contains the hydrocarbon $C_{12}H_{26}$. Write a chemical equation that shows how burning diesel adds carbon dioxide to the atmosphere.*
- **d.** *Comment on burning diesel fuel as a sustainable practice, both in terms of how things have improved and in terms of where they still need to go.*

Here is another example, this time from an in-chapter activity, that helps students consider the question: "How do I not get something dirty (such as the air) in the first place?"

**The Logic of Prevention (*9*)**

It makes sense to take off muddy shoes at the door rather than cleaning up the carpet later. Prevention! List three "common sense" examples of things to do that prevent air pollution so that it doesn't have to be cleaned up after the fact.

This third example relates to solubility, taken from Chapter 5, "Water for Life." It is an in-chapter activity that is part of a larger discussion of why some organic solvents (in contrast to water) are good solvents for grease and oil. Some of these, such as tetrachloroethylene, are used for commercial dry cleaning because they are nonflammable, stable, and relatively inexpensive. However, for large and long term use, they have undesirable environmental effects.



tetrachloroethylene ("perc")

**Liquid $CO_2$ as a Solvent (*10*)**

- **a.** *Which of the six principles of Green Chemistry are met by the use of liquid carbon dioxide as a solvent to replace organic solvents? Explain.*
- **b.** *Comment on this statement: "Using $CO_2$ as a replacement for organic solvents simply replaces one set of environmental problems with another."*
- **c.** *If a local dry cleaning business switched from "perc" to liquid $CO_2$, how might this business report a different Triple Bottom Line?*

Here are some key points that might be helpful to keep in mind when teaching a course that infuses the concepts of chemistry with those of sustainability. First, teaching "in context" is a pedagogical strategy backed by the research on how people learn (*11*). Second, it is not a choice between teaching content *or* teaching in context. Rather, one can do both. The idea is to find the "sweet spot" in which students engage most fully in the learning process. Third, engaging students in learning chemistry can have a high pay-off over time. The primary goal of any chemistry course is, of course, that students learn chemistry. However, a goal of equal importance is that students leave their chemistry course with both curiosity and a desire to learn more. The last thing that should happen in a course is to end a conversation about chemistry rather than to start one. "Do no harm."


In Sustainability in the Chemistry Curriculum; Middlecamp, C., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2011.

## The Question of "How"

The "how" of teaching sustainability also presents instructors with a learning curve. This is true, of course, with any new domain of knowledge. Just as instructors have learned to guide their students through chemical concepts that students find confusing (*e.g.*, isomers and entropy), they will need to guide students through concepts relating to sustainability. Fortunately, excellent resources exist to help instructors. Although none are specifically tailored for an undergraduate chemistry course, nonetheless they are helpful points of departure (*12*, *13*).

One of the concepts of sustainability that the author team of *Chemistry in Context* found particularly difficult to illustrate was the Triple Bottom Line, or TBL (see Table 1). In part, difficulties arise because this concept has multiple levels of meaning. On one level, the TBL is a metaphor that challenges corporations to consider more than simply the profit margin. On another level, it is a concept, one that makes sense to both businesses and their investors. On a third and more technical level, it is a reporting tool; that is, a numerical measure of outcomes. The Triple Bottom Line can be represented in different ways, and Figure 1 shows two that convey slightly different meanings. In the first, the three components are of equal weight; in the second, the environment plays an overarching role.

What should chemistry students know about the TBL? First, note that students may already be familiar with the term, having encountered it elsewhere in their studies. Some students actually may be quite sophisticated in their knowledge; others may simply be able to state the TBL in general terms, such as "Profits, People, Planet." Secondly, like many concepts in sustainability, the TBL does not fall in the category of simply something to know and recite on an exam. Rather, it is a tool to be used for analysis. For example, the nuclear chapter in *Chemistry in Context* cites the Triple Bottom Line as a means of examining the benefits and risks of nuclear energy:

> "Clearly, one of the desired benefits of nuclear power is electricity. Along with this, we desire minimal risks, including those to local, regional, and global economies, those to workers in all parts of the nuclear fuel cycle, and those to the environment. This should sound reminiscent of the Triple Bottom Line: the nuclear power industry should promote health for our economy, for our communities, and for our ecosystems (*15*).

Thirdly, the Triple Bottom Line illustrates the connected way of thinking that we want to encourage in our students. Actions are no longer conceptualized in isolation from each other; what one does here affects something else over there. Connectedness is not something that most instructors typically point out in doing a titration or in synthesizing a compound in a laboratory experiment. But with a topic such as nuclear energy, the Triple Bottom Line offers a tool that connects ideas and helps frame the arguments.

Difficulties in learning a particular concept of sustainability also may unexpectedly arise, just as they do in teaching chemical concepts. Consider, for example, the film *An Inconvenient Truth* on global warming. Al Gore, in narrating the film, refers to the Arctic region as "the canary in the coal mine." He is trying to convey the idea that the Arctic can give us early warning as to the dangers that we all may someday face elsewhere on the planet.

For several years, I have shown this film and repeated this metaphor as I have described the melting of land and sea ice in the polar regions. This past year, I went one step further and more carefully explained canaries, coal mines, and the related issues of air quality. I even included the metaphor in a list of concepts that students were told they would need to explain. Finally, I asked this question on a quiz: "When it comes to global climate change, why are the Arctic and the Antarctic referred to as the canaries in the coal mine?" About 80% of the class correctly answered the question. Table 3 includes some of the more telling – and even amusing – incorrect responses. Clearly some students either did not recognize the word *canary* or did not have a clue as to the practice of using them as air quality detectors.

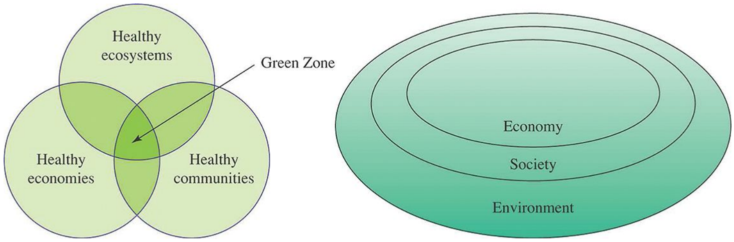



*Figure 1. Two Representations of the Triple Bottom Line (14).*

**Table 3. Student Explanations of the Metaphor "Like a Canary in a Coal Mine"**

• Canaries give warning when a mine is about to collapse.

• Canaries hold up the mine, so when they break they cause the mine to collapse.

• The Antarctic & Arctic are the "problem causers" in global warming, like canaries would be in a mine.

• If the canaries get sick, you put them in a mine or more or less hide them, so the problem isn't in your face, which means you don't have to deal with it.

• Canaries are rare, so the metaphor is saying the Arctic and Antarctic are less seen and talked about.

The point here is not to laugh at my students. If the joke was on anybody, it was on me, their instructor. Rather, the point is that teaching sustainability is just like teaching any other topic. It can be done well or badly. It can connect to students or miss the mark. It can be paced appropriately or inappropriately. It can be well-organized or muddled.

This example also points to the use of feedback to make mid-course corrections. Low stakes quiz questions are one form of feedback. Puzzled looks in class are another. For example, I remember seeing puzzled looks when I once brought up the topic of "engine knocking" in the context of gasoline additives. As it turned out, most of my students have never heard an engine knock. Similarly, I noted puzzled looks when I discussed Chernobyl in the context of nuclear energy. A brief written survey later revealed to me that one third of my students did not recognize the word, one third had at least heard of Chernobyl, and one third knew the story of the reactor explosion and release of radioactive materials. In hindsight, then, it is not surprising that students today would fail to understand a metaphor that refers to canaries and miners. If the Arctic region is cast in these terms, the meaning easily can be lost.

Excellent resources exist to point out the trouble spots. A good example is *The Psychology of Climate Change Communication* (*16*). For example, a cartoon in this publication shows a man reading the newspaper and asking his wife "Shouldn't we make the hole in the ozone bigger to let out all the greenhouse gases?" In fact, students *do* confuse the concepts relating to the ozone hole with those relating to climate change. This is understandable, just as they confuse enthalpy with entropy, and fission with fusion. Again, part of the "how" of teaching sustainability is to gain experience in spotting the conceptual trouble spots. This experience comes through multiple pathways, including getting feedback from students and consulting colleagues who are climbing the same learning curve.

In summary, the "how" of teaching sustainability is a question that chemistry instructors are only at the early stages of answering. At its heart, sustainability involves envisioning solutions to complex problems that are difficult both to describe and remedy. The answers are not in the back of the book; in fact, the questions may not yet even be written.

## The Question of "Why Now"

Admittedly, this is the easiest question of the three to address. As others in this symposium have pointed out, the time is now because our students need it, welcome it, and ask us for it. Our professional society, the *American Chemical Society*, also has spoken to the question of "why now." The theme of this national meeting in San Francisco, "Chemistry for a Sustainable World" is a case in point.

The ACS Committee on Environmental Improvement has issued a powerful statement that perhaps best frames our endeavors in infusing sustainability into the undergraduate curriculum:

> "Sustaining the habitability of the Earth and its ability to provide the resources required for the well-being of future generations is a profound human obligation. Achieving this goal in the face of a rapidly expanding global population, widespread substandard living conditions, diminishing conventional energy sources, and widely documented strains on the planet's biological, chemical and physical systems is a daunting challenge. Meeting this challenge will require myriad insightful and innovative technological, economic and organizational advances from the combined efforts of our best scientific, engineering, managerial, and political talents. As the world's largest scientific society, ACS has both an opportunity and an obligation to energize and empower its more than 160,000 members to engage their knowledge and skills to help meet the challenges of a sustainable human society. The time for focused ACS leader-ship in this critical endeavor has arrived." (*17*)

In closing, I would like to express my gratitude to my many students and colleagues who are taking this obligation seriously. Much is at stake as we explore the questions of what, how, and why we teach about sustainability now in our chemistry classrooms.

## Acknowledgments

The author gratefully acknowledges those who have contributed to the *Chemistry in Context* project, including previous editors-in-chief Truman Schwartz, Conrad Stanitski, and Lucy Pryde Eubanks. The support of those in the ACS Education Division is also acknowledged, including Directors Mary Kirchhoff and Sylvia Ware. Matt Fisher, a member of the ACS Committee on Environmental Improvement, has been a clear voice in pointing out that it is not context or content; rather it can and should be both.

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## Chapter 6

# Bridging Disciplinary Boundaries: Sustainability Discussions in the Chemistry Classroom

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Sustainable environmental solutions are complex and rarely the result of science alone. The dynamic equilibrium of technical, economic, and social forces necessary to find solutions to environmental challenges is sometimes referred to as the *triple bottom line* of sustainable development. This view of sustainability can be a useful part of the learning framework for many chemistry courses.

Using examples from a 100 level environmental chemistry course, this learning framework will be discussed in the context of specific assignments and lecture topics. Example units focusing on clean coal technology, utilization of biofuels and the role of hydrogen in our energy future will be discussed. This approach allows the instructor to maintain the basic pedagogy of the chemical curriculum, while challenging the students to think about the broader implications of chemical technologies in formulating sustainable solutions to environmental challenges.

## Introduction

Any discussion of sustainability has to begin with a discussion about the meaning of the term. In a career that has spanned both industry and academia, I have yet to find one definition of sustainability that satisfies all. I teach at Pacific Lutheran University, a suburban liberal arts school with about 3000 students. When I ask PLU students what they believe sustainability means, I routinely get a range of answers from pragmatic discussions of recycling to detailed questions


In Sustainability in the Chemistry Curriculum; Middlecamp, C., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2011.

about carbon footprinting techniques. I have watched our students implement many exciting projects in the past few years that are all uniquely sustainability related in their own domain. A few examples include a major habitat restoration project, a drive to limit the use of bottled water on campus ("Take Back the Tap"), an effort to increase our campus recycling rate by encouraging people to eliminate their office trash cans ("Can the Can"), a successful and productive community garden, and a student fee increase that was voted in by the students to purchase energy offsets and fund student led energy reduction projects. These are wonderful examples of the diversity of sustainability projects that can occur around a university community. Sustainability questions and challenges exist all around us in the university environment: in our academic function, in our built environment and in our community and culture.

At Pacific Lutheran University, the mission of the Chemistry Department is *"to provide high quality educational programs for all students who study chemistry at PLU. Faculty strive to teach chemistry in ways that help students become life-long learners, effective written and oral communicators, and explorers of the relationship of chemistry to other fields."* This mission encourages us to extend our pedagogy in ways that allow students to ground the chemistry they are learning in interdisciplinary ways. This is exceptionally true for students that are not chemistry majors or minors: For these students who are only taking one or two chemistry classes, their ability to contextualize and utilize chemistry must be linked to issues and ideas that will stay with them long after the chemistry final examination is over.

The challenge for many of us in chemistry departments around the country is to find ways to integrate the varied notions of sustainability in our chemistry courses. We can all give a great lecture on using the 1$^{st}$ and 2$^{nd}$ laws of thermodynamics to evaluate ideas about alternative energy, or teach the synthesis of biodiesel as a reaction example. A bigger hurdle is to find broader themes that allow course discussions to build around a theme of sustainability in its interdisciplinary entirety, without giving up on our core chemistry learning objectives. I propose using the *triple bottom line* of the balance of economic, social and environmental forces as one way to approach this issue in the chemistry classroom.

## Course Description

This discussion will focus on some of the techniques I use to encourage this interdisciplinary perspective in our 100 level Environmental Chemistry course. This course, Chemistry 104, is designed to investigate several topics of environmental concern. Each chapter involves a chemical explanation of the topic, analysis of the causes and potential solutions, and discussions of the social and/or political factors that promote or impede efforts to improve the environmental problem. I view this as a stealth approach to teaching the basic chemistry: the material is covered, but in the context of issues the students are invested in learning about.

The students taking this course have quite varied interests and academic backgrounds. As our one entry level chemistry course at PLU, this is the only course we teach that is truly designed for students that have no high school chemistry background, or a weak (or forgotten) one. As such, it is taken by some students to prepare for our General, Organic, Biochemistry (GOB) introductory course or our traditional freshman chemistry course. It is also a popular course with students in our Environmental Studies Program: It may be the only chemistry course taken by students in this program if they focus on disciplines other than the natural sciences. Finally, this course satisfies the general university requirement for a laboratory based natural science course. As a result, there is a smattering of students from a variety of other disciplines taking this course as the one laboratory science class of their undergraduate program.

Due to this diverse spectrum of student groups, the course must cover the "usual suspects" of disciplinary topics including nomenclature, bonding, molecular geometry, moles and balanced reactions, basic thermochemistry, aqueous chemistry and an introduction to oxidation reduction chemistry. Thanks to the authors of *Chemistry in Context* (*1*), an excellent text exists to outline the desired matrix of environmental issues and chemistry fundamentals. This textbook provides a great disciplinary introduction while using many current and topical issues as the focal points for its chapters.

## Sustainability Defined for Discussion Purposes

### Environmental, Social, and Economic Dimensions

*Chemistry in Context* does a good job of introducing the student to the real-life complexities of the issues at hand. To expand upon this I begin the class with a more detailed discussion of sustainability as an intrinsically interdisciplinary concept, and introduce the Brundtland Commissions' definition of sustainable development (*2*). This United Nations report is frequently referenced and defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This report discusses in detail the need for understanding the limits imposed by technologies, population growth, social organizations and economic reality.

I expand on this by presenting a concept introduced by Munasinghe (*3*, *4*). He added the framework of the *sustainable development triangle* as an explicit representation of the environmental, social and economic dimensions contributing to sustainable solutions. This idea was featured in the 2001 Intergovernmental Panel on Climate Change (IPCC) summary report (*5*). The phrase *triple bottom line* was introduced by Elkington (*6*) in his book focusing on 21st century business.

Teaching that a sustainable solution to an environmental challenge can be viewed as the intersection of economic, social and environmental forces is a model that I have found resonates with college students. Students quickly accept this working definition of sustainability as the balancing of forces looking for an overlapping solution.

## Scale-Determination of Time and Place Scope

Another introductory syllabus unit, before the chemistry begins, is the concept that a sustainable solution for a challenge, or even a discussion about the sustainable merits of a given development or technology, must be framed in time and place. That is, any issue will provide a different set of questions and answers when looked at on a global scale vs. a national or local scale. As a starting point, try asking your freshman students where the electricity comes from to power your laptop. I guarantee that at least 20% will answer "from the outlet in the wall". College students sometime need help in expanding their sense of the boundaries around them. Once students are challenged to specify their problem boundaries they tend to become very good at focusing in on the intricacies of an issue. As a bonus, many are very interested in local issues that allow them to engage in specific inquiry that does not come quite as easily when talking about global challenges.

Part of the definition of scale and place that needs to occur for many students is a simple high level snapshot of the world around them. Two inputs that I have found that resonate and set the stage for future discussions are a quick review of world population growth and energy use patterns.

Review of population growth in the context of the student's individual perception is especially helpful. I remind them that there were about 3 billion people in the world when I was born, about 4.5 billion when most of them were born, and we are closing in on 7 billion at the moment. This growth rate is surprising to many of the freshman. This provides a great discussion opening to talk about the importance of scale when discussing an issue like climate change. The consequences of projected climate change for the population of northwest Washington State are completely different than those in sub Saharan Africa.

Energy is a theme that provides an ongoing foundation for most of our environmental discussions in class. Scale and place are critical when discussing energy solutions. We start off simply: "Where does the energy come from to power the needs of this rapidly expanding population?" A discussion of wood, coal, petroleum, natural gas, hydropower and nuclear electric power helps introduce the traditional major fuel sources. Clearly, different regions and countries have different potentials for utilizing these energy sources.

To cement the notion of scale, the discussion of energy helps students begin to take in a very complicated issue at the national scale. The U.S. Energy Information Administration (*7*) provides a yearly detailed overview of energy inputs and expenditures in the U.S. economy which is summarized annually by Lawrence Livermore National Laboratory (LLNL). The resulting summary graph of estimated U.S. energy use can be found at the LLNL web site (https://flowcharts.llnl.gov/content/energy/energy_archive/energy_flow_2008/2008StateEnergy.pdf ).This is an extraordinarily complicated picture of energy inputs (by sources), energy outputs (to use sector) and associated waste streams.

This complicated picture provides an opening for endless specific discussions of substance. As a scale example, the class can discover exactly what it would take to replace coal with solar power on an energy basis. It can provide numerous energy balance discussions to reinforce thermodynamic basics. It encourages us to take a look at major waste streams and talk about technical, social and economic potentials associated with them. This data set has many uses to show the correlation between our natural science view of energy and the major technical, economic and social consequences associated with managing energy supply and use.

## Term Paper

Once the groundwork is set, one of the ways that I implement the *triple bottom line* view of sustainability is to build into the syllabus a term paper that uses the IPCC *sustainable development triangle* (*5*) as a tool. This assignment, worth roughly the equivalent of a midterm examination, is fairly straightforward. It has been described in detail previously as a learning activity example developed as part of the Curriculum for the Bioregion program at the Washington Center at Evergreen University (*8*). Students are asked to write a term paper on an environmental topic of their choice. The paper must include a discussion of the pertinent chemistry surrounding the issue, as well as the broad environmental, social and economic factors that contribute to the complexity of the problem. Most importantly, the paper needs to present the student's proposal as to how these sometimes competing driving forces can be best managed into a sustainable solution to the problem. I grade for appropriate reference materials, writing style, and grammar as well as the content and argument. The chemistry detail section is weighted heavily, but still only contributes about 35% to total paper grade.

The papers have covered a wide range of issues, local to global in scope, and short term to very long term in time scale. A few of the recent topics are listed here:

Saving the Bristol Bay Watershed
Is it Worth Developing Biodiesel?
Is Solar Power a Viable Energy Source in the Pacific Northwest?
Management of Nuclear Waste through Reprocessing
The Decline of Plants due to Deforestation in Brazil
Domestic Wind Power in the Northwest
Pharmaceutical Metabolites in Wastewater
Exploring the Pros and Cons of Farmed Fish
Global Warming and Its Effects on the Grinnell Glacier
Diesel in America
Should We Drill in ANWR?
Nuclear Power: The Debate
Waving Hello to Ocean Power
What Does the Melting Ice Cap Mean for the Sami People of NW Norway?
Are Genetically Modified Foods Better or Worse for the People and the Environment?
Clean Coal: Myth or Possibility?
Geothermal Energy
Iron Fertilization for Growth of Phytoplankton

This assignment becomes a core activity throughout the duration of the course. Students develop topics, refine them, change scope and time scale and usually have fun with this assignment. Each time I teach this class I am impressed with the scope of the issues that the students focus on and the creativity and insight that many of their solutions hold. Reading a term paper from a freshman chemistry student that includes a thoughtful interdisciplinary discussion of a topic is a great break from most of our news sources!

## Learning Units as Interdisciplinary Examples

In the next section I will give three examples of units that are used in the course to teach the appropriate chemistry in the context of the environmental, economic and social dimensions of the issue at hand.

### Coal as an Energy Source

The first example is the use of coal as an energy source. Many PLU students come from the northwest region of our country. They know that Washington State is a major producer of hydroelectric power; they do not realize the role of coal power in our state. In reality, our reliance on hydropower is limited and as electrical loads grow, coal has been one of the sources used to fill the demand that hydropower cannot meet. Hydropower is currently supplying about 65% of the Washington's electrical power (*9*).

The chemistry component of the coal unit is rich. In addition to the basic combustion reactions there are many opportunities to balance equations that are pertinent to the topic at hand. I spend a significant amount of time focusing on the various combustion chemistries of carbon, nitrogen and sulfur. As developed in *Chemistry in Context,* this is also a good time to introduce efficiencies, talk about power plant design basics, and the issues associated with energy loss in combustion chemistry as an energy source. If desired, a discussion introducing acids and bases can be worked in at this point using the S and N acids as examples.

Once this core chemistry is established, extensions beyond the disciplinary edges really help develop this issue for the students. We start with carbon dioxide sequestration: a discussion of the technical challenges, the proposed solutions, and their cost. This is a very lively way to follow a section on balancing combustion reactions. A discussion of the coal supply chain starting from mountain top removal and ending with coal combustion residue is a great way to reinforce the notion of the social consequences of the extraction industries and of the reaction waste products.

Any discussion of coal will probably include a discussion of the sulfur cap and trade system. One activity that works well to reinforce this concept is a lecture period devoted to turning the class into an emissions credit trading floor. The class is divided into teams that need to balance the output of their power plants. They can choose to buy low sulfur coal at a premium; invest in sulfur removal technology; or buy emissions credits from those that have made these investments. Each team needs to actively balance these decisions to make sure that their power plant has the emissions credits needed at the end of the day. The trading floor gets quite energized at times!

## Corn-Based Ethanol or Other Biofuels

A second example that takes a specific chemistry topic and puts it into a broader sustainability context is the area of biofuels. Examples are numerous and may include corn ethanol, biodiesel, algal sourced fuels, and cellulosic sourced fuels. I use corn ethanol in a general discussion to introduce thermodynamics and the 1st law. I do not spend a great deal of time on the chemistry of fermentation, but rather focus on the use of ethanol in a combustion reaction. Bond energy calculations help clarify exactly how much energy comes out of the combustion of a gallon of ethanol.

Once the class is comfortable that they can calculate how much energy a gallon of ethanol contains, we spend an entire lecture trying to figure out together how much energy goes into it, from the corn seed to the gas tank. This is an excellent way to introduce other forms of embodied energy into the classroom discussion: examples include the energy needed to pump water, make fertilizer, run combines, or transport ethanol. It highlights the key variables that are involved in the controversy around the energy balance estimates for ethanol, and it provides a forum to discuss the role of government subsidies for ethanol, and their key role in the economics. An extension of this activity is the food vs. fuel debate. This is couched in energy terms and highlights the potential ethical arguments around using food sources as inputs into our energy supply system.

## Hydrogen as an Energy Storage Device

A third example is my personal favorite: the introduction of hydrogen as an energy storage mechanism. I use this example as an introduction into the section on oxidation and reduction. I again start with bond energy calculations to establish that the thermodynamics inform us how much energy is stored in the hydrogen molecule. Then the endothermic reaction from water to hydrogen gas is highlighted. Most college students have a vague awareness of hydrogen as a fuel, but would say that it is easily made from water, unaware of the needed energy inputs and their consequences. "Where does the hydrogen come from?" quickly becomes a discussion pattern for this chemistry section. The environmental chemistry context for hydrogen is rich, including the various chemical synthetic routes, then the option for synthesis from water via electrolysis. This leads directly to a discussion of fuel cells and batteries. Once again *Chemistry in Context* provides a nice framework to compare the use of hydrogen as a combustion fuel vs. a reactant for an oxidation reduction in a fuel cell. This discussion reinforces the role of efficiencies in determining the best use of our energy inputs.

The broader issues around hydrogen are also a fertile discussion ground. Students will want to talk about safety and hydrogen storage, which clearly has technical, economic and social elements. They will want to discuss the consequences of distributed generation of electricity vs. centralized production; a real option for fuel cells. Each year a lively discussions centers around the need for the development of a hydrogen infrastructure, and who should pay for its development.

Hydrogen is a particularly good example of an energy source that is very scalable. There are many applications that allow a broad discussion of scale, timing, economics, governance as well as the science at hand. A few examples include the use of hydrogen for electrical generation via fuel cells, the use of fuel cells in the transportation section to increase efficiencies, and the potential for distributed generation of electricity rather than centralized production.

## Sustainability in the Chemistry Curriculum

What I have offered is a simple framework based on the common *triple bottom line* notion of sustainability to introduce sustainability and sustainable development in the context of traditional chemistry learning objectives.

There are many efforts underway to develop sustainability educational principles, goals and learning objectives with concepts and language that is interdisciplinary, general, and adaptable to disciplinary nuance. While it is beyond the scope of this effort to review them all, I will point out one that I find useful. This is a collaborative effort to develop a Sustainability Education Framework (*10*). Representative student learning outcomes from this effort include:

1. Recognize the interdependence of species and the dynamic interrelationships with social and ecological systems.
2. Comprehend systemic limits such as carrying capacity and the ways in which human systems can and do threaten ecological systems.
3. Synthesize the complexity of proposed solutions to environmental issues such as climate change.
4. Predict how human activities affect issues such as climate change, air and water quality, and environmental health.

As I look at these outcomes from a chemistry disciplinary perspective, I feel our basic courses can have a lot of input towards achieving these learning objectives. Chemical education will play a strong role in making sure that our graduates have the ability to discern real solutions to environmental challenges and, importantly, confidently reject proposals that don't meet the standards set by the Brundtland Report. Developing the skills to apply basic chemical concepts to actual interdisciplinary problems is a powerful tool to energize the chemistry classroom. While this is a straightforward outcome for an environmental chemistry course, the same ideas have been woven into portions of general chemistry, organic, analytical and physical chemistry courses here at PLU. The hurdles are a bit higher, but the interest level of the students remains quite high when the learning is put into the context of their decision making outside of the classroom.

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## Chapter 7

# Sustainability, Not Just Another Addition to Our Syllabus

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Changing college science curricula is a challenge that many choose to avoid whenever possible. But the limitations and consequences of the present instructional practices of chemistry force us to take up this challenge in the area of sustainability. This paper presents ideas on how sustainability can be introduced into college chemistry courses using a lens approach instead of a replacement for existing topics. Suggestions on this topic that have been posted on the American Chemical Society's Network are included. Specific methods of applying a sustainability lens in introductory courses for non-science and science majors are presented. Also described are the means of personalizing aspects of sustainability to encourage student interest.

## Introduction

What topic could be more important to students than their future and the world that they will inhabit? Imagine a clicker question that asks:

Who is in favor of living in a manner so that you can have a better future?

A) Yes – I want a great future!
B) No – I don't care about the future.

Our challenge is to make the connection between the topics presented in our chemistry courses and the issues that have sustainability considerations. Many have observed that the self-perceived "immortality" of young people is an impediment to convincing students that they should be thinking about their


In Sustainability in the Chemistry Curriculum; Middlecamp, C., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2011.

current lives in the context of future consequences, from personal habits to collective action.

We can increase student interest by personalizing the topics of sustainability in ways that makes it immediate and relevant. This can be something as specific as the amount they pay for gasoline, or, one step removed, the limitations on their future choices in life. This personalization of sustainability is one feature that will be explored in this paper.

It is useful to consider how some courses have evolved over the years. For general chemistry, we have witnessed a stress on qualitative chemistry give way to the "baby pchem" mode. For organic chemistry we have seen an increased emphasis on mechanisms and the analysis of spectroscopic data to help students understand the ways that the natural and human-influenced world uses carbon-containing compounds.

If we propose to include sustainability in the curriculum as simply another chapter of the book or as end-of-chapter boxes, we will be met with resistance to the former and irrelevance for the latter.

Instead we should introduce sustainability as a lens, to use a term coined by others. For this application, a lens allows the viewer to see some parts of a picture invisible without the lens. The lens does not change the reality of the image – or the chemistry in this case – but instead reveals important information that might be missed. It is straightforward to view almost any subtopic in chemistry through the lens of sustainability and thereby add to the educational experience in a practical way that can benefit society. For example, energy, natural resources, environmental quality, chemical synthesis and many other concepts have sustainability considerations at their core.

So how does one focus this lens in a chemistry class for science or for non-science majors? Instructors for non-science major courses must keep the mathematical knowledge base appropriate for the audience. But those courses are not required and not part of a sequence, so curricular limitations are less restrictive than for the traditional science major sequences. And because students typically select the class from an array of other such general education offerings, they may have an inherent interest in the topic. This combination of factors suggests that using the sustainability lens to focus the course material can be quite successful.

In the introductory chemistry course for science majors, typically titled general chemistry, the syllabus is more restrictive, but a deeper analysis is possible and a wider range of subtopics are included, so there are more opportunities for connecting sustainability to course material. For general chemistry, one must also provide sufficient coverage of traditional topics to permit students to succeed in successive courses. So there are factors to consider in teaching both majors and non-science majors.

## Contributed Ideas

In preparation for this symposium, I posted a request for sustainability curriculum ideas on the American Chemical Society (ACS) Network (*1*). Almost four dozen replies were received, and the discussion was viewed over 7,000 times by network members. ACS's Green Chemistry Institute Director Bob Peoples stated that our current business models are not sustainable: given our growing population and its concomitant need for limited food, shelter and other amenities, combined with the limitations that we already see, the only conclusion is that we must change. He stated that the training of scientists must, therefore, include principles of green chemistry and mechanistic toxicology. Although his conclusion is addressed to the curriculum of science majors, his promotion of green chemistry as a dimension of sustainability also applies to non-science majors. These students can readily understand several of the Principles of Green Chemistry (*2*), such as using safer solvents and increasing energy efficiency.

Here are ideas excerpted from posts by ACS members. The first two were selected for this paper because they stated central considerations for this topic. The remaining ones are representative of ideas of three individuals who offered a number of related postings. All of these are available on the ACS Network under the discussion heading Sustainability in the Curriculum (*1*). Online discussion between some of these authors is of added interest.

A) Thomas Burns (Novozymes North America) noted the importance of helping individuals understand their own environmental impact, especially how their personal decisions contribute to this impact. He also proposed an ambitious set of educational goals spanning primary schools through college. He believes that even young students can comprehend the effect that humans have on the environment. More mature students are able to recognize that their actions and preferences have consequences both for the present and the future. At the highest academic levels, students can consider their responsibility to have a positive influence. He notes the importance of including ethical considerations along with the scientific principles.

B) Cathy Middlecamp (University of Wisconsin-Madison) stressed that there are multiple answers to sustainability-based questions. This makes the topic different from much of what is taught in chemistry and therefore provides opportunities to teach critical-thinking skills. She also predicts that our children and grandchildren will want to know how we as chemistry educators dealt with these challenges.

C) Allen Doyle (Sustainability Manager, University of California at Davis) saw sustainability as a lens and encouraged teachers to start by changing one laboratory experiment to better reflect the Principles of Green Chemistry (*2*). He also raised the issue of workplace actions that can be a model for students. Doyle proposed going beyond the Principles of Green Chemistry with a set of criteria that included: "Don't deplete limited elements." For example, copper and lithium would be in this category. His posts included suggestions for the classroom, such as a campus adopting an element and tracking its use and other aspects of the element. This exercise in an inorganic chemistry course would surely be of value to our students.

D) Paul Comet (independent consultant) suggested several experiments, some appropriate for non-science majors. One example was the creation of a simple solar oven. Another was the reaction of bones with sulfuric acid to extract phosphorus, an element which is somewhat limited in availability. He also proposed a series of analysis experiments to determine the chemical composition of certain types of waste, as well as the conversion of waste. He noted the truism that nature does recycle, an appropriate idea to introduce to students.

E) Radoslav Bozov (independent consultant) offered several thought-provoking ideas that caused an intense discussion among posters. One was to substitute computer simulations for physical labs to reduce waste. ACS does have a statement (*3*) on the use of virtual labs in instruction that recognizes the value of such a format, but cautions about extensive reliance on non-physical means of teaching topics. Another idea was to mimic nature using biological macromolecules because sustainable systems will resemble biological systems more than the traditional educational experiments which use harsh reagents.

## Chemistry and Society

I have taught our department's liberal arts major class Chemistry and Society using the ACS text Chemistry in Context (*4*) for the distance learning version of the class. The textbook provides links to online resources on many topics. Although teaching chemistry without direct classroom contact limits what can be done, the online format is amenable to some features, such as web searches and class discussions. The lens of sustainability can be readily applied to many of the topics in this book, including the ozone layer, climate change and water.

The discovery of the causes of ozone depletion in the stratospheric, and the response of the scientific and political community to this depletion present an ideal case study. This topic, like others in the text, uses such issues as the basis of standard chemistry instruction. In chapter two of Chemistry in Context, "Protecting the Ozone Layer," the concepts of atomic structure, periodicity and interaction of radiation and matter are introduced in order for students to understand key aspects of ozone depletion (*5*). The text website has a link to the stratospheric ozone database at NASA (*6*). Students can enter a date, the latitude and the longitude to obtain stratospheric ozone concentrations. By doing so, students can study seasonal, annual and geographic variation in stratospheric ozone concentrations. For example, one exercise asks students to compare the ozone concentration above their particular location with those over Antarctica, acquiring data values over a period of time. The temporal data for Antarctica readily reveals seasonal variation and the yearly dramatic decrease in ozone concentration. These data point to the need to control chlorofluorocarbon use because of the connection between these chlorine-containing species and ozone depletion. In addition, analyzing data over the current location of the student personalizes the connection to the phenomenon of stratospheric ozone depletion. The text's inclusion of the diplomacy required to develop the Montreal Protocol, an international agreement about ozone-depleting substances, allows students to see the relationship between science and a societal decision.

Frequent news stories on climate change sensitize students to the importance of the issue. Chapter three of Chemistry in Context on global warming capitalizes on this interest to draw students to the science behind the greenhouse effect (*7*). In addition to discussing molecular vibrations and the related infrared radiation absorption and transmission, the text introduces Lewis structures and the mole concept. The text website provides a link to the Carbon Dioxide Information Analysis Center, a database at Oak Ridge National Lab (*8*). Students can review details about carbon dioxide emissions for many countries over several decades, and in some cases, over a century. The database also includes the origin of major sources of these emissions, such as solid, liquid and gaseous carbon compounds. A typical assignment is to compare absolute and relative changes in carbon dioxide emissions for several countries over time because these two analyses provide different perspectives.

Chapter five of Chemistry in Context, "The Water We Drink," not only discusses the solubility of ions in water, but also the rules of nomenclature and concentration units (*9*). A direct connection for the students is an assignment to research their community's annual drinking water quality report. Students can determine if the water they drink meets federal standards for various pollutants. This assignment personalizes the topic since they may discover they ingest substances which cause them some concern. Fortunately, most reports indicate the high quality of water in the US. This fact can lead to a discussion about why tap water is just as good, or even better, than non-sustainable bottled water, a point emphasized in the text. Instructors can use this lesson to raise questions about ethical behavior and one's responsibilities to others on the earth to make wise choices.

## General Chemistry

Our department's general chemistry curriculum for science and engineering majors uses a general chemistry text (*10*) that includes some consideration of sustainability issues, such as the recycling of aluminum and the use of nuclear power (*11*). In this course, I include a focus on climate change because students have probably read little on the science behind the phenomenon, and because I believe it has the potential for greater impact on society than many other issues. One place to have this discussion is in the textbook's chapter on nuclear chemistry, because electrical power generation from nuclear fission results in a lower level of carbon dioxide emissions than burning fossil fuels.

Most general chemistry textbooks have a chapter on atmospheric chemistry which includes a discussion of air quality, acid rain and the greenhouse effect (*12*). My course highlights this last topic and uses one of the online resources from Chemistry and Context (*7*). Figure 1 shows the average carbon dioxide emissions per person for several countries. To bring the point of global disparity to their attention, after giving the first data point, I reveal the next three points in succession, but only after inviting the students to estimate these values. Although many students know that China's total emissions are now the largest of any country, most are quite surprised that China's per capita emission value is only slightly above the global average. Similarly, few students guess that per capita emissions for the United States are four times the global average. Finally, the last three bars indicate that modern commerce as it exists in Japan, Germany and Russia is possible with emissions approximately half those of the United States. This class activity stimulates students to think about carbon dioxide emissions and their role in the problem.

The other side of the emission coin is the actual atmospheric concentration of carbon dioxide. First, I show a figure with concentration data from 10,000 to 2,500 years ago which indicates a pre-human effect carbon dioxide concentration range of 260-280 ppm. I attempt to personalize recent data by inviting students to view the rapidly increasing concentration of this molecule in the life span of those currently living. For a particular example, I use Figure 2 to indicate concentration values at the time of the birth of my mother (1922, 302 ppm), myself (1948, 310 ppm), my son (1978, 335 ppm) and my granddaughter (2008, 385 ppm). This dramatic increase in the change per generation that has occurred in a single life span showing an increase in the atmospheric concentration of carbon dioxide equal to approximately 30% in less than one century gets their attention. Next, I show ice core data from the last 800,000 years during which time the concentration never exceeded even 300 ppm.

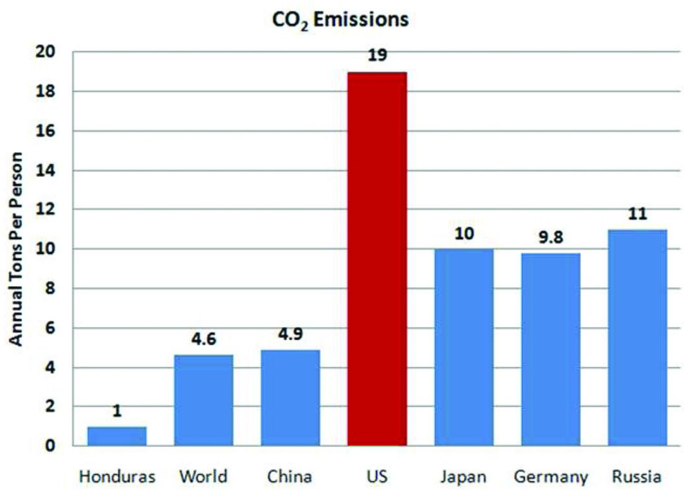


*Figure 1. Average Carbon Dioxide Emissions Per Capita in 2007. Source: Carbon Dioxide Information Analysis Center, Oak Ridge National Lab (8).*

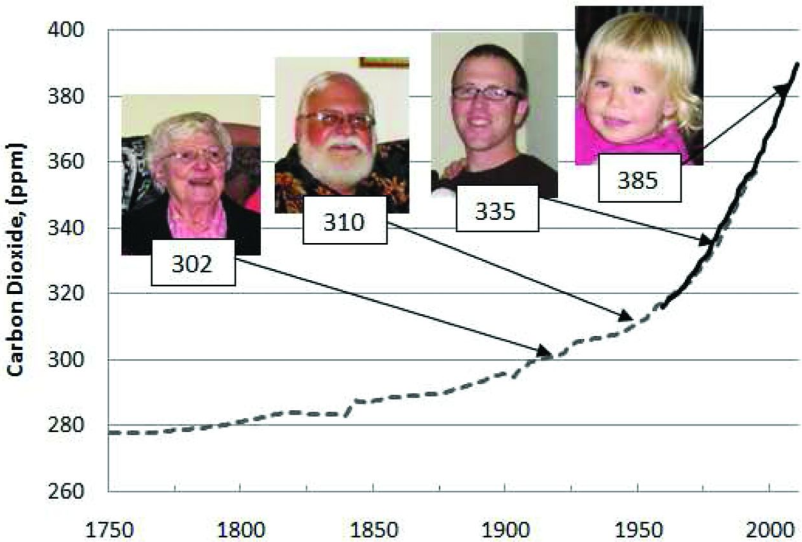


*Figure 2. Atmospheric Carbon Dioxide Concentrations. Solid line data from reference (13); dashed line data from reference (14). Approximate values at the birth of the indicated individuals are marked.*

We then look at projections from the Intergovernmental Panel for Climate Change (IPCC) for future atmospheric $CO_2$ concentrations and global average temperatures compared to historical variations. It is important to carefully present the facts and reasonable projections, so as not to add to the frenzy of predicted catastrophe that students might read in the popular media. The IPCC prediction for carbon dioxide concentrations in the benchmark year of 2100 ranges from 550 to 900 ppm (*15*). Some students resist taking such predictions seriously because the date seems so far into the future. I counter this by showing projections for the year 2050 when they are likely to be alive, and to reference the youngest person shown in Figure 2, who might well live to 2100 given the lifespan of her great grandmother.

Analogies to comparable situations can be useful to put the science into context. The average surface temperature rise of 0.8°C (1.5°F) during the approximately 130 years for which precise measurements are available may not register as significant to the students (*16*). The analogy I use is a fever of this level for a child. Such a small temperature increase does not indicate a crisis for either the child or the earth. But the projections for 2050 and 2100 are increases of approximately 2°C (3.6°F) for the former and 3°C (5.4°F) for the latter (*15*). These values usually convince students that while the present situation is perhaps not too serious, the problem has the potential to change their lives and perhaps the lives of their children. This is another opportunity to discuss ethical concerns related to our actions.

We use personal response devices to poll students to determine the degree to which the science of climate change is understood. Their responses also engage students in the topic, particularly when they see the distribution of responses across the whole class. As part of a project funded by NASA, we also pose questions to students regarding their knowledge and attitude about climate change using an online survey (*17*, *18*).

A major thrust of the climate change education resources produced in the NASA-funded project and related activities being carried out under the auspices of the National Council for Science and the Environment, is the idea of enacting solutions to climate change using mitigation and adaptation. The former means reducing the problem by limiting greenhouse gas (GHG) emissions, while the latter refers to accommodations that will need to be done in response to climate change in order to limit or prevent unwanted consequences. Mitigation is more apropos to teach in a chemistry class.

In this vein, examining the major sources of GHG's can lead to a valuable discussion. Many students think that transportation is the source of most GHG emissions. However, the IPCC data (*15*) shows that this category is only responsible for 13.1% of anthropogenic GHG emissions. Producing energy is the largest source (at 25.9%), and industrial activity ranks next at 19.4%. These facts can help students make prudent personal decisions, such as reducing the use of electricity and recycling manufactured materials like aluminum and plastics. To make this point, I use slides with photos depicting the amounts of carbon dioxide produced in one hour of use for several types of light bulbs, as well as the volume of this gas produced in making one aluminum can from aluminum oxide.

Another chemical aspect of GHG's is the variable of different gases. Because of its chemical formula and molecular geometry, methane has an global warming impact that is many times that of carbon dioxide (on a molar basis). This fact can lead to a discussion of the sources of atmospheric methane and ways to reduce its emissions.

My presentations about climate change end with an inquiry about whether or not the facts and predictions have motivated listeners to change behaviors, such as to do more recycling, reduce driving, or change dietary habits, among others. The immediate replies determined through personal response devices allow a discussion on the collective views of the group, which can be a useful dimension of the lesson.

Many other topics in general chemistry could be applied to sustainability, but the ideas in this paper provide suggestions for where to begin or expand, one's consideration of sustainability.

## Conclusion

As Robert Peoples noted, our current business models are not sustainable (*1*). If we are preparing our majors to be professionals in scientific fields that are pursuing sustainable practices, , and our both our majors and non-science majors to be voters, parents, and citizens, clearly we cannot ignore this aspect of their education. Mark McCaffrey of the Cooperative Institute for Research on Environmental Sciences at the University of Colorado at Boulder blogs on the topic of climate change. In his March 2010 post entitled "Painting the Deck Chairs Green," (*19*) he proposes that we replace the word "sustainability" with the word "survivability." Although that idea may seem extreme, most would agree that operating in the present manner is not acceptable. Our legacy as teachers must be to educate our students about sustainability, especially since they will outlive us and their actions will almost certainly have even greater consequences for the planet's future.

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## Chapter 8

# Critical Evaluation of New Ideas in Sustainability: We Can, But Should We?

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The current emphasis on sustainability has inspired the development of a wide variety of technological solutions, but the creation of a new product or process is not enough—wise evaluation of this technology must precede its implementation. Wise evaluation of any new technology answers the question "We can (utilize this product or process) but should we?" In my chemistry course for nonscience majors, we tackle the different factors that must be considered in the critical analysis of a proposed solution. In the process of considering whether the benefits outweigh the risks associated with using a specific product or process, we use case studies to explore topics including the relative importance and likelihood of each benefit and risk, the need to strengthen these assertions of benefit and risk using evidence from authoritative sources, and the importance of specifying the group of people involved.

There's a warning printed on the plastic bag that covers my husband's shirts when they come back from the dry cleaners. It states (in capital letters) "WARNING: TO AVOID DANGER OF SUFFOCATION KEEP AWAY FROM BABIES AND CHILDREN. DO NOT USE IN CRIBS, BEDS, CARRIAGES OR PLAYPENS. THIS BAG IS NOT A TOY." The capital letters, as well as the words, communicate the high level of importance attached to this warning. This sounds reasonable enough: parents of small children tirelessly protect their little ones from plastic grocery bags, torn balloons, and other plastic sheets that could block breathing either by covering theirs noses/mouths or by blocking their airways. Even a swallowed piece of cellophane can be a danger. Like other


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parents, my husband and I vigilantly patrolled the surroundings of our children to keep them safe from this and other dangers.

So imagine my surprise when I heard a radio interview with a proponent of recycling who suggested that people recycle plastic bags from the dry cleaners by using them to cover their infants' crib mattresses! Somehow, I thought, the good intentions behind recycling had been disconnected from common sense. Crib mattresses do need protection to avoid the growth of microorganisms; covering the mattresses with dry cleaner bags is, indeed, one possible technological solution to this problem. However, this man probably had not asked the question that I want all of my chemistry students to ask when they consider any proposed technological solution: "We can, but should we?"

The Environmental Protection Agency website describes sustainability as a worldview involving "recognition of the need to support a growing economy while reducing the social and economic costs of economic growth. Sustainable development can foster policies that integrate environmental, economic, and social values in decision-making" (*1*). This description makes sustainability a powerful countercultural perspective. In the face of generations characterized by "I'll Do It My Way" (Frank Sinatra, 1969) (*2*), "Have It Your Way®" (Burger King advertising campaign, 1976) (*3*), and "What Have You Done for Me Lately?" (Janet Jackson, 1986) (*4*), sustainability says that there is good reason for me to look out for the interests of others, in addition to looking out for my own interests. There is a large measure of responsibility, community, and altruism that can come from such a mindset.

The current emphasis on sustainability has inspired the development of a wide variety of technological solutions: alternative energy sources, new recycling strategies, more efficient engine designs. Creative and resourceful scientists routinely discover or invent new products or processes that are then offered as solutions to existing problems, and it's a good thing that they do! This is one way that problems get solved: basic research leads to possible applications. However, the use of a new product or process to solve a particular problem is not enough—wise evaluation of this technology must precede its implementation. Failure to evaluate a technological solution before its implementation can result in unintended (but often foreseeable) consequences that cause more problems than they solve.

The use of thalidomide to treat the morning sickness of pregnant women in Europe in the late 1950s and early 1960s epitomizes the essence of what is at stake. No one has ever suggested that anyone involved in the production or the prescription of thalidomide anticipated the harm that would come to over 10,000 babies. Perhaps the risk of those horrific birth defects was, in fact, unforeseeable. When the connection between taking thalidomide during the first trimester and its teratogenic effects was discovered, thalidomide was removed from the European market; it was never marketed in the United States (*5*). We should keep this piece of history in the forefront as a reminder of why it is so important to investigate thoroughly the risks as well as the benefits of a proposed technological solution to a current problem.

The more pressing the problem is, the greater the temptation to launch a technological solution without a proper investigation. The introduction of the nonsteroidal anti-inflammatory drug Vioxx® provides a good example. Who would argue that it is important to get relief to the people who suffer from the pain of osteoarthritis? The 2004 recall, based on the startling discovery that Merck failed to disclose serious heart-related side effects, has generated much litigation as well as discussion about the balancing of profit margin and social responsibility (*6*, *7*). When medications such as Vioxx® are marketed, it can also be argued that the manufacturer reaps most of the benefits (in the form of financial profits) while the consumer assumes most of the risks (in the form of serious side effects). Whether the risks are unforeseen (as with thalidomide) or foreseen and undisclosed (as with Vioxx®), both are examples of technological solutions that caused more problems than they solved.

Wise evaluation of any technology answers the question: "We can (utilize this product or process), but should we?" What are the benefits, and what are the risks? Do the benefits outweigh the risks, and how do you know? Is this just your opinion (based solely on your own feelings), or do you have evidence from authoritative sources to support your assertions? While it is true that not all consequences of a given choice can be foreseen (that's the whole Law of Unintended Consequences), many can at least be reasonably anticipated with careful consideration of the possible consequences of applying a specific technological solution to a specific problem with a particular group of people (*8*, *9*).

Unless we are intentional about training our chemistry students to ask these questions, it may not occur to them to do so. In my chemistry course for nonscience majors at Converse College, we use fictional and nonfictional case studies to investigate the different factors that must be considered in the critical analysis of a proposed solution to a current problem. Long the province of law and medical courses, case studies are now used in a wide variety of courses because they so easily connect students' imaginations with the concepts under investigation (*10*, *11*). Case studies give students a reason to learn: in any endeavor, past a certain level of ability, motivation is everything. This course is an easy place to incorporate this type of analysis because we consider a series of environmental issues that they have heard about in the news (air pollution, deterioration of the ozone layer, global warming, etc.). In addition, because many of these students are from majors such as English and history, they are often much more comfortable in the world of words than they are in the chemical world dominated by numbers and symbols.

Similar conversations and training for chemistry majors are often sorely missing because the critical evaluation of proposed solutions (and even the awareness that these analyses should be done prior to implementation) have to be intentionally inserted into most existing courses. We may be so busy helping our chemistry majors master the details of organic, analytical, inorganic, physical, and biochemistry that we forget to carve out the time to help them explore the different facets of this question as well. Our chemistry majors are among the students who may well be the most able to comprehend and assess the benefits and risks of particular technologies, and they certainly are more likely to be the ones who could be developing and implementing them. Therefore, it is even more critical that this analytical skill be part of their formal training. As their mentors, we would be wise to walk through the stages of this analysis with them. If we don't, then who will?

In order to thoughtfully consider the different pieces of this puzzle and then assemble them into a coherent argument about whether a particular technology can be wisely applied to a particular problem or need, I developed a pattern for my students to follow. This is by no means the only one, but it does work for my nonscience majors class.

**We begin with a problem**. An easy one to use in the beginning is a familiar dietary concern: adults need 1000 milligrams of calcium daily.

**The class proposes several solutions**. Not surprisingly, the most common solution offered is to drink three 8-ounce glasses of milk daily, since 8 ounces of milk supplies 300 milligrams of calcium.

**We define the terms benefit and risk**. Most people have a general idea of the definition of the words "benefit" and "risk", so we take some time to list the outcomes that they would classify as "benefit" or "risk." Benefits are things that you would like to see: better health; protection from disease, danger, and psychological harm; economic gain; protection and nurturing of the environment. Risks are things that you prefer would not happen: death, disease, terror, environmental harm.

**In small groups (and then as one large group), we consider the benefits and the risks of this proposed solution**. The benefits that we list for drinking three 8-ounce glasses of milk daily in order to meet this dietary need for calcium usually include strong bones and teeth and healthy skin. Because most people in the United States have adequate refrigeration and do not have lactose digestion problems, they often have more trouble coming up with risks. Usually someone in the group is (or has a relative who is) either lactose intolerant or allergic to dairy products. That opens the door for talking about how lactose intolerance is a common characteristic for people whose ancestors are not from Northern Europe. What if the problem that we are trying to solve involves the malnutrition of children in a country in central Africa? Our well-meaning shipment of milk could completely miss the mark of solving the problem of adequate calcium intake for them. What if the problem that we are trying to solve involves malnutrition in an area without electricity? The lack of adequate refrigeration would derail our proposed solution. While this issue is not environmental, it does get us thinking about how a proposed solution will not necessarily be an effective solution. You have to do your homework.

**When the issue is more complex, then we take a look at the relative importance and the relative likelihood of occurrence of each benefit and risk of a proposed solution**. Using a scale of 1-3, they can quickly rate a particular benefit (or risk) as shown in Table 1.


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**Table 1**

| *Relative Importance* | *Relative Likelihood of Occurrence* |
|---|---|
| 1 = Very Important<br>2 = Moderately Important<br>3 = Unimportant | 1 = Very Likely<br>2 = Moderately Likely<br>3 = Unlikely |

**Table 2**

| *Risks* | | | *Benefits* | | |
|---|---|---|---|---|---|
| *ID* | *Importance* | *Likelihood* | *ID* | *Importance* | *Likelihood* |
| Core Meltdown | | | Relatively low operating costs | | |
| High-Level Waste Disposal | | | Low emission of $SO_x$, $NO_x$. and $CO_2$ | | |

Consider the problem of providing electricity for a community. One possible solution is to produce it using nuclear power. A risk/benefit chart for analyzing this possible solution might look like the one shown in Table 2. Once the risks and benefits are identified, students rate the relative importance and likelihood of occurrence with this scale of 1-3.

**Find authoritative support for your assertions**. At this point, whether the benefits outweigh the risks depends on the evidence that can be presented to support these assessments of relative importance and relative likelihood. Do the benefits outweigh the risks for your particular community? Make your case! Very often, my students do not know how to distinguish authoritative sources (particularly Internet sites) from those that are not (*12*). They generally need help not only with identifying authoritative sources of information but also with understanding why they should bother to do this research. Assertions are strengthened with evidence from authoritative sources; and the more authoritative evidence they bring to the table, the stronger the argument for their case.

So who are these "others", and what do they need? How might they be harmed by the next good idea to roll out of a research lab? There are several points to consider.

## 1. Define whom you're talking about.

One of the pitfalls of risk/benefit analysis is making it too general. When we consider the question: "Should Americans meet their energy needs by using petroleum?" we always come down to the place where you can't effectively evaluate the risks without defining the group of people. Americans in Louisiana assumed a very different set of risks than those in Ohio, as they learned after the BP oil spill in the Gulf of Mexico in the summer of 2010 (*13*). When they were in the middle of this environmental catastrophe, the citizens who live and work along the Gulf Coast might have reconsidered whether they REALLY needed petroleum-based energy in their lives. Were the benefits of this low cost, readily available energy source really worth all that they lost (and could lose again) in a similar event?

While the citizens of Ohio were undoubtedly sympathetic, they had no personal impact from this catastrophic event. They weigh similar benefits against some very different risks. Instead, they live with chronic air-quality issues causes by emissions from coal-based power plants (*14*). In addition, the high population density of Ohio generates large electricity needs, which require large amounts of inexpensive fuel to make the process cost-effective. Their experience with the Davis-Besse nuclear power plant in 2002, in which a football-sized crater in the wall of the nuclear reactor head was caused by a boric acid leak, has made the possibility of nuclear energy in Ohio a very unpopular option (*15*).

## 2. The people who assume most of the risks can be a completely different group from those who reap most of the benefits. They could be separated by commercial transactions.

This is the case when a product is sold to solve a problem. The most obvious example of this is when a pharmaceutical company markets a medication to treat a particular disease or condition. The company, which reaps the benefit of profits and financial stability, does assume the risks of financial and legal liability if something goes wrong. If they have done their assessments of efficacy and safety correctly and disclosed all necessary warnings, this risk is arguably minimal. The patient, who reaps the benefit of better health, accepts the risks associated with companies that either have not done their testing properly or who willfully failed to disclose what they knew to be likely risks. Are the health benefits associated with this medication worth the risk that a company may be more concerned with profit/loss calculations than they are with the health of particular individuals?

## 3. The people who assume the risks can be a completely different group from those who benefit. They could be separated by geography.

People sometimes unwillingly assume a risk that they don't even know exists. When my class considers the fictional scenario "Should the citizens of Metrotown dump their sewage into the Podunk River?" they acknowledge the very real need of the Metrotown City Council to come up with a way to protect their citizens from the diseases that would be spread by NOT disposing of the town's sewage in some way. They can easily see the benefits of this "technological" solution: it's inexpensive, easy to implement, fast, and effective. Without question, it would solve the problem. My students also quickly chime in "But what about the people who live downstream?" which is exactly the point. For one thing, they will very likely suffer harm to their aquatic ecosystem, which could affect not only the health of the animals and plants living in and near the waterway but also the health and recreation of its residents. If the town relies on tourism, there could be a negative economic impact as well. The part that my students consider most outrageous is that the citizens of Downstream City had absolutely no voice in this process. And, of course, it would be. Those who will assume the risks need to be informed and have their concerns addressed, particularly if they reap none of the benefits.

While the Podunk River scenario is a simplistic story, it's not too far removed from the acidification of some Canadian lakes involving the $SO_x$ ($SO_2$ and $SO_3$) and $NO_x$ (NO and $NO_2$) produced by coal-fired power plants in the Great Lakes region of the United States. Certainly there was no intention to harm the Canadian ecosystem. Still, once the risk is known, those who are involuntarily assuming the risk (and reaping none of the benefits) must have a voice in this decision-making process (*16*). It's one thing for the residents of the Great Lakes states to decide that the risks to their own health and air quality are worth the benefits of the electricity that is produced; it's quite another to dump the risks into someone else's lap (or lakes) without their consent. The maintenance of healthy international relations between countries is one of the benefits that result from an attitude of responsibility toward neighbor countries.

## 4. The people who assume the risks can be a completely different group from those who benefit. They could be separated by time.

What if the people who will assume the risk cannot be informed and considered because they have not yet been born? Consider the problem of the permanent disposal of high-level nuclear waste and the possible solution of storing this waste under Yucca Mountain, Nevada (*17*, *18*). High-level nuclear waste is currently stored at the site where it was produced; as a nation, we need a permanent disposal site that is more secure than our present solution to this problem. Clearly, most of the people who assume the short-term risks of this technological solution currently reside in Nevada; some live along the routes that would be used to transport the high-level waste by rail or by truck. But since this high-level nuclear waste will likely remain radioactive for thousands of years after it is stored underground, the people who will assume the long-term risks of groundwater contamination and/or release of radioactivity at the surface have no say because they just cannot be consulted. In a very real sense, they depend on us to act responsibly on their behalf.

The separation by time need not be several generations. Consider the transaction that took place in 1953, when Hooker Chemicals and Plastics Corporation sold their 15-acre site to the Board of Education (City of Niagara

Falls, New York) for $1. The deed included a "disclaimer of responsibility for future damages due to the presence of buried chemicals (*19*)." And, in that instant, the disaster that we now know as Love Canal was set in motion. The Board of Education built a school on this site and sold the rest of the land to residential developers. Communication of the enormous risks to life, human health, and environmental health seems to have stopped with this disclaimer. The failure to disclose the presence of thousands of barrels of chemicals stored underground in Love Canal, New York created an enormous, unknown set of risks for the people who would one day live and work in the community built on this site. The people who made the decision to bury all of those drums of chemicals at what was to have been William T. Love's "Model City" could not have been thinking clearly. Perhaps they weren't thinking at all. Or maybe they were looking for the least expensive, most expedient way to remove a problem from their sight. They reaped all of the benefits. They also heaped the assumption of the horrible risks of miscarriage and childhood cancers on unsuspecting young families they had never met: residents of Love Canal who had no idea that they were building houses and sending their children to school atop what has been called "a witch's brew of noxious chemicals (*19*)." Part of the response to the environmental disaster at Love Canal was the passage of CERCLA (Comprehensive Environmental Response, Compensation, and Liability Act) and the creation of the Superfund in 1980. The mindless self-centeredness that created the disaster at Love Canal is the antithesis of sustainability. Perhaps, after more than 30 years of cleaning up Superfund sites, the citizens of the United States were ready to do things differently—perhaps this was part of the motivation for the concept of sustainability. Perhaps they thought, "If Love Canal (and other Superfund sites) is what self-centeredness has gotten us, it's time to change our focus."

Choices have consequences—everybody knows that, even if they don't like it. Just because we don't identify the risks of a proposed solution doesn't mean they don't exist. (In fact, if there are enough risks, or if one of those risks is important enough, the proposed solution isn't actually a solution at all.) Even if we decide that the benefits outweigh these risks, we would be wise to acknowledge that the risks are still there, warn those who must decide whether to accept these risks, and think through how to handle them if they do happen. Part of wise mentoring is to incorporate this type of analysis into the curriculum of both the nonscience majors chemistry course (where it fits easily with the consideration of current environmental issues) and in the curriculum for chemistry majors. With the exception of environmental chemistry courses, the big challenge with helping chemistry majors think through these issues is finding places to insert them alongside traditional chemistry topics.

I want my students to be fully aware of this responsibility to look out for their neighbors, those in their own community and those downstream, those in the present and those who will inherit this world from them in years to come. Certainly they will have to decide whether they want to live that way, but at least those with the technical capacity to understand the possible technological solutions to whatever problems come their way will also have the awareness and the skills to consider the ethical questions that accompany any new technology. We all know that perfect solutions (*i.e.* those having benefits without risks) don't exist. The question is still this: "Do the benefits outweigh the risks, and how do you know?"

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# Chapter 9

# Sustainability in the Undergraduate Chemistry Curriculum

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Since late 1980's, there has been a major emphasis on sustainability in all sectors of society. Education has been recognized as a major tool for fostering the ideals of sustainability. Possible approaches for integrating sustainability in the chemistry curriculum are discussed.

## Introduction

In order to understand the need for an emphasis of sustainability in the chemistry curriculum, it is helpful to look at the historical roots of the term. The World Commission on Environment and Development (WCED) is generally credited with popularizing the term sustainable development. The commission, which was established in 1983 to examine the link between development and the environment was chaired by Gro Brundtland. It was established in response to concerns that development was depleting planetary resources and creating new environmental problems while at the same time poverty, which the development was supposed to alleviate, was on the increase. In 1987, the commission produced a report titled "Our common future" (*1*). Prior to the report, population growth was seen as the source of many environmental problems around the world. However, the commission asserted that uncontrolled exploitation of resources was the most significant threat to the planet. Indeed, they observed that the population problem was more an effect of unsustainable uses of resources rather than its cause. The commission defined sustainable development as one in which humanity meets the needs of the present without compromising the ability of future generations to meet their own needs. This has come to be the commonly used definition of sustainability. In addition, the report observed that there


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is a limit to how much the biosphere can absorb the effects of development. However, this limit is not absolute, but defined by the state of technology. Social re-organization and management of technology can preserve the environment while realizing the economic growth needed for its exploitation.

Subsequent conferences on sustainable development have emphasized the crucial role of education. In 2002, the United Nations declared 2005-2014 as the decade of Education for Sustainable Development (*2*). The goal is "to integrate the principles, values, and practices of sustainable development into all aspects of education and learning, in order to address the social, economic, cultural and environmental problems of the 21st century".

## Chemistry and Sustainability

Chemistry as a science is central to many fields of human endeavor. For example, the agricultural sector requires chemical products such as fertilizers, pesticides and food preservatives, while the pharmaceutical industry uses chemical products in the design and manufacture of drugs. For a long time, the chemical industry gave little or no consideration to the effects of chemical products on the environment. The goal of many of industries was simply to maximize profits. However, in recent years, there has been a paradigm shift. It is now recognized that successful enterprises should not only maximize profits, but also score highly on environmental and societal returns. This constitutes the so called triple bottom line.

One of the ways in which the chemical industry has responded to concerns about the effect of chemical products on the environment is through the practice of green chemistry. This is defined as the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances (*3*). The guiding philosophy of green chemistry is to reduce or eliminate waste, minimize hazards, and lower energy requirements of chemical production processes.

Chemical enterprises can improve their sustainability by applying the principles of green chemistry. However, the concept of sustainable chemistry is much broader than the practice of green chemistry. Sustainable chemistry also embraces the issue of positive returns to society. This distinction between green chemistry and sustainable chemistry can be illustrated by considering the use of corn based ethanol as an additive to gasoline. Ethanol is more environmentally friendly than methyl *tert*-butyl ether (MTBE) or other fossil fuel based octane boosters. Since ethanol is an oxygenate, ethanol blended gasoline burns more efficiently and emits less volatile organic compounds (VOCs) compared to gasoline containing MTBE as an octane booster. Furthermore, the use of corn, a renewable feedstock, and yeast, a biocatalyst to produce ethanol is consistent with the principles of green chemistry. Ethanol blended gasoline also competes favorably in price compared to gasoline blended with other octane boosters.

There are however some limitations to the use of corn based ethanol as an additive to gasoline that impact the sustainability of the process. The use of corn as feedstock in ethanol production leads to higher prices of the produce due to increased demand. This increase in price hurts the poor who may not be able to afford corn yet it is a common staple food around the world. In addition, using arable land to support fuel production when a large population in the world is going hungry can not be viewed positively from a social benefits perspective. Thus, while production of ethanol from corn for blending with gasoline demonstrates sound principles of green chemistry and is profitable, it may not be sustainable due to limitations on societal returns.

## Engaging Students on Sustainability Issues

Most college students have some knowledge about current environmental concerns. Concepts like carbon footprint, climate change, renewable energy, recycling and living green are not new to them. This knowledge can be useful in the classroom for teaching sustainability. However, there is an accompanying risk. If technologies are presented as sustainable or green when they are not, students may not have the scientific background needed to critically evaluate such claims. Thus, an attuned curriculum can be a tool to correct misinformation and provide the knowledge, skills and critical application necessary to challenge incorrect assertions (*4*).

Students can influence decision making through participation in interest groups, civic activities and conversations with those within their sphere of influence. Students are also consumers. If equipped with the correct information, they can make personal choices that are supportive of good environmental practices. For example, they can choose to purchase products that are manufactured in an environmentally responsible manner.

## Integrating Sustainability in the Curriculum

Approaches that can be used to integrate sustainability in the undergraduate curriculum will vary depending on the level of the courses. Quite often, there is little room to incorporate a new chapter on a topic such as sustainability in existing courses. However, discussions related to sustainability can be woven into many content areas so as to provide enrichment without replacing core content.

One of the motivations for the practice of sustainable chemistry is to prevent environmental problems. It seems logical therefore, that discussion of sustainable chemistry should be preceded with creating understanding of the environmental problems that need to be solved or that can result from non sustainable practices. Thus, introducing a discussion of environmental issues in any content area provides a good starting point for incorporating sustainability in the curriculum. At the upper division level, special topics courses that address environmental and sustainability issues are more appealing. Examples of these two approaches will now be discussed.

## Introducing Sustainability in Introductory and Lower Division Courses

The first example demonstrates application of this approach in lower level laboratory courses. A review of several commercial laboratory manuals and published experiments reveals a strong emphasis on safety of experimental procedures and handling of hazardous chemicals, but limited or no mention of the environmental aspects of generated waste. In one laboratory experiment that involves qualitative analysis of inorganic ions for example, students are directed to empty waste into a beaker during experiments then transfer it into designated containers at the end of the laboratory period. The waste generated in the experiment contains species such as $Cu^{2+}$, $Hg^{2+}$, $Sn^{4+}$, $Bi^{3+}$, $Pb^{2+}$, $Ni^{2+}$and $CrO_4^{2-}$. Other experiments generate waste containing complexing agents such as EDTA and o-phenathroline, and reducing agents such as $Na_2S_2O_3$. It should be possible to add a brief discussion on the fate of properly and improperly disposed waste during the pre-lab period without sacrificing much class time. The instructor can point out that if poured down the sink, this waste would end up in a waste water treatment plant that is not equipped to remove these chemical species. The chemicals may then be released into surface or ground water, providing a pathway to human consumption and harm to health. A discussion of the fate of the collected waste can cover treatment options such as precipitation and the recovery of metals by electrolysis. Additional discussion can include waste minimization and microscale experiments, getting the message closer to the principles of sustainability.

Cann and Dickneider give excellent examples of using laboratory experiments to introduce green chemistry concepts in organic chemistry courses (*5*). In synthesis reactions, achieving a high percent yield (Y) is always a desirable goal. However, in green chemistry, an important measure of how environmentally friendly reactions are is the % atom economy (AE), defined as the mass of desired product as a percent of the total mass of all the starting materials. Cann and colleagues combine these two measures to arrive at a new metric, the percent efficiency (RE) defined as:

$$\%\ RE = \%\ Y \times \%\ AE$$

Students learn that a high percent yield is not the only important consideration and that reactions with high reaction efficiency would be more environmentally friendly. To incorporate the concept successfully, it is necessary to teach about atom economy first.

A third example demonstrates how a topic that seems unrelated to sustainability can be linked to the issue by incorporating environmental aspects. Many general chemistry textbooks have problems on calculating volume or mass of a liquid using density as a conversion factor. Students are asked to calculate the volume of a liquid given the mass and density, or to calculate mass given density and volume. Additional manipulations involve converting units from metric to English systems of measurement. Conversions involving mercury are popular since it is a liquid at room temperature and it has unusually high density.

Mentioning the environmental problems related to mercury using the example of mercury thermometers and their replacement with alcohol thermometers can get students thinking about broader issues that are relevant to sustainability.

## Upper Division Topic Courses

In order to fully equip chemistry students with the knowledge needed to authoritatively discuss sustainability, it is important to offer at least one course that delves into environmental and sustainability issues in depth. Indeed, given the current emphasis on sustainability, it is almost imperative that all chemistry students should take such a course. Similar sentiments have been expressed by the ACS Committee on Environmental Improvement (*6*).

I now discuss incorporation of sustainability in two special topics courses that I have taught. Students in both courses are usually chemistry, biology, industrial health and hygiene or earth science majors. The first course, Environmental Chemistry I, is populated mostly by juniors but some sophomores and seniors also take the class. Students in the second course, Environmental Chemistry II, are usually a mix of seniors and juniors and will have taken the first course.

One portion of the first course deals with traditional environmental chemistry topics such as toxic heavy metals and water treatment, toxic organics (pesticides, dioxins, furans and PCBs), air pollution and atmospheric processes (stratospheric ozone, ground level air pollution) and, energy sources and greenhouse effect (global warming and renewable energy). These topics provide an important background about environmental issues.

Students are also given assignments to research on sustainable chemistry practices and make presentations to the class. In one approach, students are assigned case study topics. Examples include supercritical $CO_2$, GM crops, recyclable carpeting, pressure-treated wood, replacement of CFCs, ionic liquids, antiscalant and dispersing agent, recyclable carpeting, biodegradable polymers, biodiesel, and targeted insecticide delivery. These topics are outlined in the course textbook (*7*) but students are required to do additional research.

A second approach that has been used is to ask students to pick an issue of interest to them which they then present to the class as an opener prior to the bigger presentation. This takes no more than 2-3 minutes. They are required to have one graphic that will depict the issue and possible solutions. Short video clips from the web are allowed. Examples of topics have included compact fluorescent lights, green roofing, bottled water, water from sewage, biodegradable chelating agents, lead paint replacements, disposable diapers, green toothbrush, chlorine free bleaching, green shower curtains, phytoremediation, biosand water filters and lifestraw water purifier. There is always an amazing variety of topics. Students seem very interested in the presentations.

In another type of assignment, students are asked to explore environmental and sustainability issues from around the world and identify how they can personally get involved. They are required to give a geographical and cultural context to the issue. This includes displaying a map of the region and highlighting interesting cultural, historical or other facts. The exercise promotes an appreciation of the global aspects of environmental problems and that environmental problems transcend geographical barriers. Topics have included fate of electronic-waste, recycling of graphite in dry cell batteries, impact of river damming, cyanide fishing, coal mining and clean coal technology.

The laboratory portion of the course covers topics such as water quality analysis (hardness, alkalinity, dissolved oxygen, chromium, nitrate and phosphorous) some instrumental techniques (GC-MS, AAS, UV-Vis) and box model analysis of waste accumulation in lakes. Experiments that relate directly to sustainability include microemulsions as green solvents, analysis of sunscreens at the microscale and synthesis of biodiesel (*8–10*).

Additional topics on sustainability such as industrial ecology, green chemistry, hazardous waste minimization, regulation and treatment are discussed in the second course. More information about the content covered in that course can be found in the main textbook used in the class (*11*).

## Conclusion

Despite a crowded curriculum, there are some ways to include sustainability in the chemistry curriculum. A desirable outcome is practical application of the knowledge and skills acquired. Thus, students should be able to make sustainability an important consideration in decisions they make in their professional roles in the future. Since sustainability transcends all disciplines and economic sectors, what they learn should serve them well in their chosen careers.

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## Chapter 10

# Sustainability and Chemistry: Key Concepts in an Arctic-Focused Interdisciplinary Course

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Sustainable development is an interdisciplinary topic of great debate. In the north, this issue involves renewable resources and the impact of energy development and mining. Current issues of climate change, water rights and food security involve sustainability, which when discussed using chemistry concepts engages students by guiding them to the realization that their lives and homes, i.e., the local environment, is vulnerable to global environmental pressures. Sustainability, a holistic context, integrates local concerns, world views, and traditional knowledge. In an interdisciplinary course, the inclusion of culture and society engages students in an active learning process of asking questions about science as applied to their local land and environment. The capacious place-based issues relating to sustainability can be adapted to demonstrate the connections between chemical principles and societal understanding of technological options. The local landscape can be a central focus point in interdisciplinary science courses and demonstrate real life examples of chemistry familiar to the students. In the UARCTIC course, *Land and Environment*, we connected chemical concepts to current issues such as mining and food security in terms of risks and benefits for the local Arctic communities.


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## Introduction

The importance of understanding the science that underlies policy issues for the circumpolar north residents needs no emphasis, especially in the present era of climate change. Humans are influencing the biogeochemical cycles of the North by increasing resource and energy development projects that impact the marine food web. As a unique component of the global environment, the circumpolar north, with large seasonal changes in light and temperature, is pivotal. As a region, it is sensitive to change and is an effector of change in other parts of the planet.

The connections between global and Arctic systems may put circumpolar peoples at greater risk. Recent experience shows that the Arctic has a predisposition to deliver environmental surprises, including abrupt changes. Complex environmental system theories suggest that new properties are generated by multiple feedback systems. In the Arctic, these emergent properties exhibit some differences from those seen in ecosystems at lower latitudes. Scaling and temporal history are also different at higher latitudes and only recently have begun being studied.

Any educational approach to the problem of sustainability in the Arctic requires an interdisciplinary component that focuses on both local and global biogeochemical systems. The goal of this approach should be to widely disseminate useful information so as to lessen vulnerability and improve resilience. This component should reach across disciplines enabling students in *all* degree programs to become leaders in their industries and communities by developing a holistic perspective associated with the issue of sustainability.

Because of the higher percentage of rural populations in the North who live subsistence or resource development lifestyles, changes in the environment are more readily evident. Students can observe the “shifting baselines” (the idea that what people have come to expect as normal on our planet has shifted as time has passed, especially with regard to ecosystems) in their land and water as well as in the socio-economic environment. They are affected by the legacy of resource development, where turning a huge profit was the primary objective. Students should learn about the need for a new “normal” with a cradle-to-cradle approach to the use of manufactured items in which the end of the life cycle of one item dovetails with the beginning of the life cycle of another.

To accomplish this, interdisciplinary chemistry and engineering courses must introduce students to the Triple Bottom Line, a three-way measure of the success of a business rather than solely profit: benefits to the economy, benefits to society, and benefits to the environment (“Planet, People and Profits”). For example, in our course, *Land and Environment*, an argument could be made that nuclear power in rural villages could reduce dependency on oil. In fact, Alaskan rural villages are currently considering the new, small pellet nuclear technology for power plants as an energy option. Russia is proposing floating nuclear reactors in the Arctic Ocean. What do Arctic students of today and citizens of tomorrow need to know to make informed choices about this issue and others? Relating issues of sustainable development to decisions in public policy and scientific research foci is of critical importance in developing an educated workforce. Other complex questions arise across the Arctic today, such as the long-lasting effects of earlier development and resource extraction (*1*, *2*).

While global warming is altering land and seascapes in the North, the Arctic is also a sink for contaminants (*3*, *4*). Global atmospheric and ocean patterns tend to carry pollution toward the poles, but there is no mechanism to transport them back out again. Consequently, they accumulate in the food web. Food security is an issue for thousands of communities in the circumpolar north. The hidden danger to wildlife and human health from long-term low-dose exposure and the cumulative effects on the human body are of great concern to Native leaders (*5*). Such issues are not well covered by common disciplinary approaches, but, on the other hand, key concepts of different disciplines can be included in interdisciplinary courses. In developing *Land and Environment*, a course for the circumpolar studies program of the UARCTIC (University of the Arctic, a cooperative network of universities, colleges, and other organizations committed to higher education and research in the North), this was our approach (*6*). The theme of sustainability enabled us to use a place-based focus on "knowledge needed to live in a northern community" to engage students in the underlying relevant science concepts

## Land and Environment

The UARCTIC course, *Land and Environment,* is interdisciplinary and provides students with a greater understanding of the complexity and relevance of Arctic issues. *Land and Environment* also was designed as a forum to promote integrative thinking. The students in the UARCTIC network are highly diverse in experience, education, and geography. Cross cultural communication is therefore an intrinsic part of the course. In-class discussions were generated by asking students to relate the assigned readings to their own experience.

*Land and Environment* was developed both for the UARCTIC place-based Baccalaureate of Circumpolar Studies curriculum (*7*) and for the University of Alaska Fairbanks (UAF) Liberal Arts and Sciences elective. It is web-based delivery and consists of twelve modules; each comprised of a "lecture," additional suggested readings, student activities, and study questions (Table 1). Although the course is taught in several countries, English is the primary language, with consideration and assistance for those whose first language is not English. This course is part of the "science core" for the UARCTIC baccalaureate of Circumpolar Studies.

### Background to *Land and Environment*

The concept of knowledge related to living in the North is not new. Northern educators, who interact with diverse cultures, have been exposed to using local knowledge about the land, often called traditional ecological knowledge (TEK), to engage students in their course topics. The concept of sustainable development was common knowledge in the Arctic since Gro Brundtland, lead author of *Our Common Future*, the report of the World Commission on Environment and Development of, was from an Arctic nation. Meeting the needs of future


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generations is a central value of indigenous northern people. The context of the themes "climate change and complexity (environment), natural resource development (economics) and health (society) turned out to be a good fit both for sustainability and for interdisciplinarity (Table 1). It becomes obvious that the phrase "living well" is essentially sustainability, and community health meant resilience and adaptability.

The approach to teaching chemistry "in context" was pioneered by the American Chemical Society through its two textbooks, *Chemistry in the Community* (high school) and *Chemistry in Context* (college). The first edition of *Chemistry in Context* appeared in 1993, and the text is currently in its seventh edition (*8–10*). This college-level textbook not only introduced the idea of teaching chemical concepts through topics such as climate change, water, and air quality, but also more recently has framed these topics using the larger issues of sustainability.

SENCER (Science Education for New Civic Engagements and Responsibilities), a national curriculum reform project in higher education, also provided a robust intellectual framework for *Land and Environment*. The SENCER project is aimed at improving undergraduate learning outcomes by teaching "through" complex, unresolved issues of civic consequence to fundamentally important concepts in science. Chapters in *Chemistry in Context* also served as the basis *Energy and the Environment*, one of the SENCER model courses (*11–15*). In addition, the *Vision and Change* report laid the intellectual groundwork for our course (*16*). Capacious issues and problems, with inextricably social and technical origins, will dominate the 21st century. For example, industrial ecology should replace industrial chemistry in many chemistry and engineering curricula.

Using teaching and learning approaches both from *Chemistry and Context* and from SENCER, we were ready to deliver *Land and Environment*, an interdisciplinary course dealing with the impacts of natural and physical change on northern peoples and the complexity of the circumpolar North. We concentrated on three major areas of inquiry: (1) climate change and complexity; (2) natural resources and (3) health and environment. Emphasis was given to the challenges of resilience and sustainability in the North and to the need for proper, long-term stewardship.

## Course Goals

Clearly, the development of science-based knowledge is the foundation of long-term stewardship to insure the future for generations of Northerners. A major goal of this Arctic science course is to demonstrate how legacy activities can lead to stewardship and how a sustainability focus can advance public policy.

The goals and learning outcomes of *Land and Environment* were influenced by SENCER and its model courses (Reilly, 2010). These outcomes include that students acquire:

1. A more in-depth chemical and biological knowledge of the general concepts underlying selected natural resources of immediate interest to the students.
2. An appreciation of how scientific methods contribute to the understanding of resource management and human health.
3. An insight into the complexity of environmental and human systems, and the connections to the effects of change on northern ecosystems.
4. An interdisciplinary understanding of relationships between cultures of the North, stewardship values, and scientific knowledge.

While *Land and Environment* is not a SENCER model course, student course evaluations have shown it increased awareness of the complexity of environmental and human systems as well as an increased appreciation of the connections between science concepts and natural resource management. The students particularly noted the importance of diverse cultural values in stewardship, and the inherent value of traditional ecological knowledge found in indigenous cultures.

## Themes and Course Modules

We used the question "What do we need to know to live in the North?" as our underlying theme in developing *Land and Environment* to engage the students. In this approach, the student moves inward from an issue to the chemical principles underlying the issue and then back outward to unresolved solutions. Using three interdisciplinary themes (Climate Change, Natural Resources Development, Health and Environment, see Table 1), the course organizers hoped to relate to the issues central to the ongoing sustainability debates in the North. In response to current questions, discoveries and societal issues, the chemical content changes each year.

The twelve course modules are interdisciplinary and connect science and the social sciences, including economics. The real world is not separated in an arbitrary way, and sustainability as a field should not be separated into disciplines. While the course topics are not comprehensive, they span the issues of concern to many communities in the North and at the same time touch on the three dimensions of sustainability. These modules illustrate how place-based issues are important to discussions of sustainability and provide opportunities to teach basic concepts in chemistry.

For each module, students participate in online discussion groups and in an activity such as "Where does your water come from?" or "Identify a risk imposed on your community by resource development that you/they do not see as acceptable." For example, the nuclear chemistry module (Module 11) is based on recent broad-based discussions throughout the circumpolar North that reveal growing concern over chronic exposure of food to radioisotopes and the transmission of these radioisotopes up through the food web (*17*). In 1986, after the accident at Chernobyl, radioisotopes were similarly transported in the food chain from lichens to caribou, eventually impacting wolves and subsistence food users. This module also poses the question "What can the experiences of the Arctic people teach our students about energy sustainability today?"

Questions about industrial development of natural resources also are relevant to people in all societies (Module 7). These questions are not usually addressed in disciplinary approaches because of their complexity, but many students are eager for applied, place-based thinking in the context of their community's health and sustainability.

**Table 1. Topics in *Land and Environment***

| | |
|---|---|
| ***Part I*** | ***Climate Change and Complexity*** |
| **Week 1** | **Module 1:** Frameworks for Analysis of *Land and Environment* in the Arctic |
| **Week 2** | **Module 2:** Biocomplexity in the North |
| **Week 3** | **Module 3:** Fisheries |
| **Week 4** | **Module 4:** Marine Mammals and Fisheries |
| | |
| ***Part II*** | ***Natural Resources Development*** |
| **Week 5** | **Module 5:** Natural Resources: Chemistry and Environmental Sustainability |
| **Week 6** | **Module 6:** Water Supply and Waste Treatment in the Arctic |
| **Week 7** | **Module 7:** Observations, sustainability and the Impacts of Change |
| **Week 8** | **Module 8:** Food Chemistry, Subsistence Webs, and Nutrition |
| | |
| ***Part III*** | ***Health and Environment*** |
| **Week 9** | **Module 9:** Diet and Mental Health of Circumpolar Peoples |
| **Week 10** | **Module 10:** Food Traditions and Food Systems in Rural Alaska |
| **Week 11** | **Module 11:** Nuclear Chemistry, Radioecology, and Stewardship |
| **Week 12** | **Module 12:** Cancer and Biomarkers of Health |

Since many populations in the North are exposed to elevated concentrations of contaminants through traditional food and many of these contaminants come from regions outside the Arctic (*3*, *4*, *7*, *18*, *19*), the connection to basic global system science was made. Global contaminant pathways include the atmosphere, ocean currents, river outflow, and animal migration, all of which are affected by climate. In addition to these pathways, precipitation, animal availability and human industrial activities in the North are also affected by climate change. As an upper division elective, *Land and Environment's* interdisciplinary approach to an issue also covers topics related to indigenous studies, sociology, biology and chemistry.

The sections that follow illustrate how the underlying chemical topics are approached as well as the interdisciplinary nature of the content.

## Natural Resources: Chemistry and Environmental Sustainability (Module 5)

The production of a metal from an ore is an ideal topic for integrating chemical concepts with how humans produce materials as they re-engineer the planet. Students learn how pollution by industrial gases impact the sustainability of the planet's life support system – the atmosphere. Exercises at the end of this module connect the chemical language (balanced chemical equations) to sustainability issues such as waste products. Examples from these exercises include:

- What metal ores are extracted from the land nearest your community?
- How are these ores extracted from the Earth?
- What are the pollution problems associated with their extraction?
- How are these metals used in the world?

The production of iron for steel can engage the student from the "Iron Age" to the "Iron Man" and our current use of materials. Iron, the fourth most abundant element in the Earth's crust, is the metal used in greatest quantity by industrialized nations. It has been associated with human activities since 1000 B.C. The majority of the iron extracted from ores is used to manufacture steel, an alloy of iron, which contain a small amount of carbon. The percentage of carbon determines the properties of steel. Low-carbon steel (less than 0.25% carbon) is relatively soft and suitable for making cans and wire. High-carbon steel (up to 1.5% carbon) is very hard and strong and is used for making tools and surgical instruments.

World reserves of iron are still large, and the Arctic has an abundant supply, but steel is imported from lower latitudes to the North. The carbon reduction method is commonly used for steel making. Hematite ($Fe_2O_3$), magnetite ($Fe_3O_4$) and limonite (hydrated $Fe_2O_3$) and siderite ($FeCO_3$) are the principal iron ores. Since most of these contain relatively high concentrations of the metal, little preliminary treatment is required, and reduction by carbon in a blast furnace is the first major step. The modern blast furnace is based on techniques discovered in the fourteenth century; except for vast increases in scale and some substitutions of materials, it has not changed greatly.

A mixture consisting of iron, limestone and coke (coal residue left after destructive distillation) enters the top of the furnace, while preheated (~1,000 °C) air is simultaneously forced through blowpipes at the bottom of the furnace. The blast of air from the iron, limestone and coke mixture passes up the shaft and reacts with some of the carbon in the coke to form CO and $CO_2$. The exhaust gases, which contain a high concentration of CO, carbon monoxide, can be trapped above the furnace and, after cleaning, may be burned to run the preheaters. This is an early example of using a process waste. Liquid iron, and a layer of slag that floats on top of it, collect at the bottom of the furnace. About 90% of the iron content of the ore is recovered as molten iron.

Most ore in the lower portion of the furnace shaft is reduced by direct reaction with carbon:

$$FeO + C \longrightarrow Fe + CO$$

Higher in the shaft, where the air is cooler, indirect reduction of iron by CO instead of C occurs:

$$FeO + CO \longrightarrow Fe + CO_2$$

The high temperature of the furnace changes limestone to lime:

$$CaCO_3 \longrightarrow CaO + CO_2$$

Lime (CaO) lowers the melting points of the silicon and aluminum oxide impurities. As a base, CaO neutralizes the acid slag of $SiO_2$ and $Al_2O_3$ as well as removing sulfur from iron sulfide:

$$FeS + CaO + C \rightleftharpoons Fe + CaS + CO$$

This reaction may reverse when large concentrations of CaS build up in the slag. Most low-sulfur coal available has been allocated to metallurgical use – hence, the past incentive to use "dirtier" coal for electric power-plant supply. This leads to $SO_2$ being released in the atmosphere.

The pollution associated with blast furnaces is primarily solid wastes (slag) and particles suspended in the air blast. Older blast furnaces were extremely bad air polluters, and some regions are still dotted with old slag heaps that support little or no plant life. Production of coke also generates $H_2S$ and $SO_2$. Slags are sometimes used as aggregate for cement, and air pollution can be controlled by bag houses, wet scrubbers and electronic precipitators. Water is required to quench coke and slag and for scrubbing particulates, so water pollution is a secondary problem unless effluents are treated in sedimentation ponds.

The mining of ores has become more regulated in regard to affects on air and water quality. The United States Environmental Protection Agency (EPA) is now also regulating mercury emissions. However, as demand increases with population growth, the release of toxic chemicals and metals is also increasing in the North. For example, the release of toxic chemicals in Alaska increased 23% to about 700 million pounds in waste crushed rocks (*20*). The presence of toxic material needs community monitoring in order to preserve the sustainability of future generations in the north. This section describing the process technology of iron ores includes the principles of chemical reactivity and the conservation of matter. The transport of matter as elements is illustrated now as waste products like CO are burned to provide heat to the blast furnace. The production of steel is an example of applied science which provides a context in story form that assists long term learning. The inclusion of waste products like the gases points out the connections among complex processes that must be considered in economic or policy decisions related to sustainability.

### Food Chemistry, Subsistence Webs, and Nutrition (Module 8)

The topics of food chemistry and nutrition can be used to integrate biochemical concepts with how human food systems are organized. Students learn concepts such as proteins and fats and how catalysts are used in a living system. Chemical cycles and energy flow are traced through trophic levels as illustrated in human food systems leading to polluted, non-sustainable food supplies.

Sustainability and stewardship directly relate to maintaining life. Life comes in a variety of forms, from bacteria to plants and fish and mammals. But there is a unity within these variations; these different organisms are made up of the same basic biomolecules: proteins, carbohydrates and fats. All organisms also use and need vitamins, salts and minerals. These molecules are acquired from food and provide the organism with energy and raw materials to grow or renew their own molecular structures; for example, proteins supply the biological catalysts, that is, enzymes that control the chemical reactions of the cell.

Foods are the source of these molecules; and the way an organism uses food is known as *nutrition*. For humans, a nutritional diet should supply a balance of carbohydrates, fats, proteins, vitamins, minerals and water. These nutrients provide energy for the performance of essential metabolic processes and supply materials for building cellular structures and body tissues. Nutrients also can provide the molecules or their precursors needed for regulation of metabolic and physiological process.

### Subsistence Food Webs

People in traditional societies typically recognize the fact that everything in nature is connected as part of a web of life. Arctic people realize that many events are either directly or indirectly connected to human activity (Gaia Hypothesis). The subsistence food web or chain has been damaged by excessive harvest, when managers overestimate the sustainable harvest (catch) from an ecosystem. A sustainable food supply, an ecosystem service, can be continued if the "take" is below the maximum harvest – an application of the precautionary principle. Subsistence food was the most important way Arctic people received energy and bodybuilding material – and, unfortunately, now, become exposed to toxins and contaminants. All northern plants and animals are exposed to contaminants that accumulate after transport to the high latitudes. Global air and water currents bring these pollutants to the Arctic. The pollutants travel in clouds, fog, rain and dust, and they settle on tundra, mountains, lakes, rivers, streams, ice and oceans. From soil and water, these molecules and elements move into plants and from there into animals.

Plants and animals may accumulate contaminants – that is, they take them in faster than they can get rid of them. Some of these contaminants can build up "through the food chain" as one animal eats another, becoming more concentrated and dangerous at each step. This is called biomagnification, and while not all contaminants biomagnify, Arctic peoples are concerned (*20*).

The contaminants that biomagnify include metals (e.g., mercury) and persistent organic pollutants such as dioxin that is released from incinerators. The buildup of toxins in an animal depends on the "trophic level," that is, where the animal eats on the food chain. For instance, mercury can concentrate as it moves up trophic levels (see Table 2).

**Table 2. Trophic Levels**

| | | |
|---|---|---|
| Algae is eaten by a duck, which is eaten by a man | → | 2 steps |
| Plant is eaten by a reindeer which is eaten by a man | → | 2 steps |
| Phytoplankton eaten by small fish eaten by large fish eaten by seal eaten by man | → | 4 steps |
| Phytoplankton eaten by small fish eaten by large fish eaten by seal, eaten by bear, eaten by man (or man eaten by bear) | → | 5 steps |

Plants are considered producers and are the lowest of all on the food chain. Plants and plant-eating animals such as ducks and reindeer generally have low levels of global contaminants, but they may still have high levels of contaminants if they are located where local spills of oil, metals and other chemicals have occurred. Polar bears tend to have a high level of contaminants because they eat higher on the food chain.

## Organochlorides in the Arctic Environment

Polychlorinated biphenyls (PCBs) are chemicals that are no longer produced in the United States but were commonly used as lubricants in hydraulic fluid, transmission oil, and in electrical transformers during the Cold War period of 1950-1980. PCBs are one of the persistent organic pollutants, chemicals that stay in the environment for a long time and travel long distances. Because they move, we cannot always tell whether the PCBs that we find in soil, water, plants, animals and people originated from somewhere close by or from far away. Congener analysis helps determine this. Congeners refer to structurally different forms of a chemical; there are 209 different PCB congeners, all with slightly different structures.

PCBs are of great concern because they biomagnify. With high exposure such as in industrial accidents, PCBs can discolor nails and skin, cause a rash (chloracne), cause chronic bronchitis, and may cause a host of other symptoms including jaundice, nausea, fatigue, and abdominal pain. At low levels of exposure from food, they affect the reproductive system and thyroid function as well as damage the immune and nervous system. Some PCBs are suspected of causing cancers in the liver, skin and intestines. By doing specific chemical analysis, we can see how much of each congener is in a sample of soil, water, blood, plant tissue, muscle and so on. This pattern is called a "fingerprint." If we find congeners that indicate several industrial congeners, this might indicate more than just a local source.

Organochlorides also include pesticides, which in the Arctic usually are transported by air currents from southern agricultural sources. All countries around the world use pesticides when they are growing crops. In the United States, crop-dusting planes are often used to apply pesticides to huge agricultural farms. When the chemical is released from the plane, much of it travels into the air and gets into streams and lakes near the farm; but many of these chemicals rise up into the air and travel on prevailing winds to the Arctic.

Pesticides such as DDT, aldrin, dieldrin, chlordane, and heptachlor are banned or severely restricted in many nations, including the United States. However, they continue to be employed in some nations. For example, DDT is used in Africa to control malaria. Because wind and water carry DDT to the Arctic, the compound continues to be detectable in Arctic marine mammals. DDT and the toxic chemicals it breaks down into (DDE) are also found in humans throughout the world and in the breast milk of women worldwide. The use of chemicals to help one community may inadvertently injure and even inflict damage on future generations of another. When air, water or food are impacted elsewhere around the globe, issues of environmental justice arise (*3*).

**Nuclear Chemistry, Radioecology, and Stewardship (Module 11)**

The topic of nuclear chemistry is used to illustrate the importance of energy in the North and the risks and benefits of choices. From another course module, students learned that the North depends on burning fossil fuels to meet its energy needs. Another option to meet these needs is to use nuclear power. To understand the risks and benefits, students need to understand concepts relating to nuclear fission, how energy is generated in a nuclear power plant, and the potential health risks of radioactive fission products.

The first controlled release of the energy locked in the nuclei of atoms was surely one of the major events in the history of the planet. In 1945, the subsequent explosion of two atomic bombs demonstrated the military use of this enormous energy. Not only was it a giant step in understanding and manipulating nature, but also the sheer magnitude of the explosion meant that all of humankind shared and will continue to share the dangers and benefits. The unveiling of nuclear energy as well as the devastation of Hiroshima and Nagasaki pointed to the dangers arising from the fallout of radioactive fission products, which have the potential to affect all life on the planet. The future use or non-use of nuclear power in the Arctic depends on a collective wisdom. For example, Amchitka is one of the Aleutian Islands and was the site of three nuclear weapons tests: Longshot (1965), Milrow (1969), and Cannikan (1971). These tests, similar to the reactor accident at Chernobyl, left a legacy that the circumpolar north has to deal with. At the same time, nuclear energy may be part of a sustainable solution necessary to achieve a secure energy future for the peoples of the North.

In both nuclear weapons and nuclear power plants, the process of fission produces radioisotopes. These radioisotopes are deliberately released when an atomic bomb explodes ("fallout") and accidentally released if something goes wrong at an atomic power plant. Distribution and ecological relationships of these fission products have been extensively documented in several research studies. In addition, two books have discussed issues relating to nuclear weapons testing in the North: *The Firecracker Boys*, by Dan O'Neill (1994) and *Amchitka and* *the Bomb*, by Dean W. Kohlhoff (2002). Continuing studies in both areas have resulted in many other reports. Seasonal injection of past stratospheric fallout occurs in the upper boundary of the troposphere at about 40° - 50° N latitude. Regions with high rainfall accelerate deposition; because of this, northern regions, such as southeast Alaska and southern Canada have received most of the fallout on the North American continent. For Alaska, the highest fallout, cesium-137 was observed in caribou samples from southern high rainfall areas (57° - 59° N latitude, 120 cm annual rainfall); median values in caribou from central areas (64° - 66° N latitude, 57 cm rainfall); and lowest values were in northern areas (67° - 70° N latitude, 30 cm rainfall). Changes in rainfall patterns caused by climate change will impact potential fallout distribution patterns. (D. Dasher, personal communication)

Because organisms have a high percentage of water, a sequence of reactions occurs when water is irradiated. The initial step is to produce H· and ·OH, the hydroxyl radical. These free radicals are encountered as transitory intermediates in a variety of reactions. This radical is an oxidizing agent, sometimes called a reactive oxygen species (ROS).

A mammal can repair the damage from the inevitable "background" radiation of normal living circumstances (cosmic rays and the presence of natural radioactivity); but, additional radiation may cause irreparable changes in cell metabolism. Two of the greatest health hazards of radioactive waste are the isotopes strontium-90 and cesium-137. Strontium-90 is an energetic beta emitter with a half life of 28.8 years. The periodic table shows that the element strontium is in Group 2A along with calcium. Because of their chemical similarity, bodily processes will carry both strontium and calcium atoms into bone. The proximity of the emitted beta particles causes deleterious effects on the production of red blood cells by the bone marrow. Cesium-137, also an energetic beta emitter, has a half life of 30 years. Since cesium is chemically related to sodium and potassium in Group 1A of the periodic table, it would be expected to interfere with sodium and potassium in a variety of physiological functions. The legacy of past nuclear weapons development requires continued monitoring (*21*). The context of radiation moving north and south can be expanded by showing students films such as Nevil Shute's *On the Beach*, a classic of the Cold War. On-line discussions can direct the students through the chemical concepts related to ionizing radiation, isotopes and mechanisms of tissue damage. Then these discussions lead to the "pros" and "cons" about the future of a safe nuclear energy industry in the North. These discussions then return to the "What is the sustainable energy future in the North?"

## Discussion

"What do we need to know in order to live well in this vast region?" This was the critical question discussed during the design process of the Land and Environment course.

The need for a place-based interdisciplinary science course in both the science and non-science curricula is critical in light of climate change and the

North's vulnerability. The importance of understanding the science and related sustainability issues for the circumpolar north increases at a time when humans are influencing biogeochemical cycles of the north through increased resource development and extraction. At the same time, aggressive harvesting from the marine food web impacts subsistence activities and cultural values (*22*, *23*). Given the vulnerability of high-latitude ecosystems, students need to acquire an understanding of chemistry in order to appreciate the implications of "business" decisions and their potential effects on the Arctic landscape. This knowledge of underlying issues will enable the student/citizen to more fully participate in debates at the local and even national levels on sustainability issues.

The unique fragility of the Arctic underscores the impact of human activities. Past and emerging problems in the North require solutions and social action that in turn serve as models for future stewardship (*21*). Since the biocomplexity of the Arctic is linked to the entire global ecosystem, no discussion of our planet's sustainability is complete without including the Arctic, its people and the cultures that were developed in a place of extremes. Raising student awareness of the holistic nature of their environment was intended to be the significant feature of the course using topics related to sustainability in the north. Molecules are connected to ecosystems which are connected to human social and political systems.

Discussion on the different issues reinforced to the students that the concept of sustainability is fundamental to how individuals view change. Students gained a perspective that people of the north, i.e. themselves, need to protect and conserve Earth's ecological and biogeochemical systems for the long run. Since local environment shapes culture, so like biodiversity, cultural diversity must also be valued. The triple bottom line — protecting the planet, people and jobs — gained prominence in these difficult discussions of resource development in the north. One student stated that her impression of the North had changed so that she feels the need to do whatever she can to ensure that the fragile habitats are protected for the future generations, so that they will also enjoy the benefits of the natural resources. Thus, sustainability creates a forum for integrative thinking.

*Land and Environment*'s objective was also to discuss interactions between chemicals and organisms and their effect on social and political aspects of sustainability policies. This knowledge is basic for the evaluation of the bioavailable forms of toxins and transmission routes to humans. The course approach engaged students in learning needed chemical concepts, but not every detail of the vast field of chemistry was covered (*9–11*).

In order for students to think about their responsibilities to respect the land and sustain the environment, the student must be exposed to complex systems and observe the feedback mechanisms in their lives. Developing a place-shaped knowledge requires both experimental theory and practical experience. This is the notion of "place based education" which involves respect for material and the life-forms in their environment. Respect for the unique places which some people call home should be part of a sustainability ethic (*22*, *23*) and embedded in the *Land and Environment* course. While not explicitly written in our goals and objectives, another learning outcome was an awareness by students that ecosystems in the Arctic are home to people whose culture was shaped by their environment, and should be valued.

The issue of sustainability leading to respect for place and people is a learning outcome that can be best captured by one of the southern students in this distance delivery course which was also offered as part of UARCTIC network science curriculum (*6*).

> "…during this course I have really enjoyed putting names and facts to the body of Arctic information I have learned previously. My impression of the North, since I was a lot younger has been of a mystical and magical place, and every class I take specifically on the Arctic serves to both strengthen and broaden that view. Robert McGhee says the North is "the Last Imaginary Place", and as a southerner I'm still trying to (and am not sure I ever will) fully grasp the true sense of it being a 'Home'. This course has, however, taught me that it is home, to not just people and plants, but an array of natural wonders seen nowhere else on earth."

Sustainability is an evolving topic because the planet is changing. Thus, in order to bring sustainability into classroom discussion, science courses must become more "active" and must be prepared to change as the local and global contexts related to sustainability change. It is time for chemistry curriculum to move from the past perfect to the uncertain active.

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## Chapter 11

# The Imperative for Infusing Sustainability into the Chemistry Curriculum

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Sustainability is the challenge of the century. The issues of sustainability are rapidly moving to center stage in our societies across the world. As chemistry begins to play a major role in shaping technology in the transition to a more sustainable world, our chemistry curriculum must reflect this. We must blend green chemistry and sustainability into all our courses.

## Sustainability

Sustainability is rapidly moving from the wings to center stage all across the globe. A recent article in the *Harvard Business Review* named sustainability as the latest "business megatrend." Sustainability was ranked on the same level with other megatrends such as "information technology" and Demming's "drive for quality (*1*)." Both of these have had far reaching, and in-depth affects on how businesses operate. Sustainability is not just a nice thing to consider, but a necessity if we are all to enjoy a reasonable quality of life on this planet. It is the challenge of the century.

Sustainability is largely focused on the environmental impact of anthropogenic activities that consume natural resources and produce waste. In the 1970s, an equation that expressed environmental impact (I) as a function of population (P), affluence (A) and technology (T) was developed (*2*). Over the past several decades, all three factors have coalesced to deliver the "perfect environmental storm."

$$I = P x A x T$$

The global human population (P) was 1 billion in 1800 and it doubled by 1927. By 2010, it had mushroomed to 6.9 billion, and estimates indicate that by


In Sustainability in the Chemistry Curriculum; Middlecamp, C., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2011.

mid-century 9 billion people will inhabit the earth (*3*). Each year, the needs of an additional 80 million people must be met.

Technology (T) has no doubt allowed us to live longer more comfortable lives, but at a cost. For example, mechanization of the logging business in the 1950s, brought about by the chainsaw, allowed us to cut trees 100 times faster than with a bucksaw or axe, thus accelerating the deforestation of vast areas of land. The automobile has certainly increased our mobility allowing us to get from point A to point B in a fraction of the time on foot. Yet, each year the 600 million motor vehicles on the planet emit about 5 billion tons of carbon dioxide while burning 600 million gallons of gasoline. The green revolution that allowed farmers to keep up with needs of the burgeoning population was brought about by factors such as fertilizers, pesticides, mechanization, irrigation, and hybrid plants. This has been accompanied by eutrophication, soil degradation, desertification, loss of plant diversity, and depletion of aquifers.

Rising affluence (A) is often measured by GDP growth rate. Over the last several years, both China and India have experienced an unprecedented growth in their GDPs with rates near 10% (*4*). Combined, these countries have about a third of the world's population and their pathways to affluence are largely based upon the consumption/waste paradigm of the West. The problem lies in the size of the ecological footprint of those in the West, particularly those of us who live in the U.S. If everyone lived so resource and waste intensive, like the typical American, it would require several Earths. Currently, our total world ecological footprint is in overshoot requiring about 1.4 Earths (*5*). In short, we are consuming "natural capital," while to be sustainable we should only be consuming "ecological interest." We are devouring natural resources (both renewable and non-renewable) and creating waste faster than nature can take our wastes and convert them back into resources.

Individuals, corporations, and governments are finally beginning to take action to create a more sustainable society. Most every day, we see an advertisement or two in the popular media about how green a product or company is, and how we can help save the planet by such actions as changing our light bulbs, using reusable bags, turning down our thermostats, converting to renewable energy sources, and driving fuel efficient vehicles. What role can chemistry play?

## Sustainability and Chemistry

Although scientists and engineers may be able to influence population growth (P) and rising affluence (A), our clearest path to reducing the environmental impact (I) of society is through the development of technology (T). As indicated previously, technology (chemistry included) in most instances has been part of the problem.

As chemists, we design compounds to have certain chemical and physical properties to meet the end use of a material. Perhaps we are making a polymer that will be used to produce a plastic bag. We might consider such properties as glass transition temperature, molecular weight, tear resistance, permeability, and stability to air and light. Until recently, many technologies were developed with little attention to their environmental footprint and to systems thinking. Did we consider all the resources and energy that was utilized, and all the waste that was generated to produce this bag? The bag may have performed brilliantly during its use, but what about at the end of its useful life? Does it decompose to innocuous substances, or better yet, does it become the raw material for the production of a useful item? This cradle-to-grave and cradle-to-cradle life cycle assessment approach is now being applied to the creation of many products. As a result, green chemistry is now taking its rightful place in the practice of chemistry.

We are witnessing the rise of green chemistry/sustainability not only in industry (*8*), but also as a prominent theme at our national meetings (*6*) and in our professional publications (*7*). Forward thinking companies are developing sustainability plans, and hiring individuals to implement these plans and to change the corporate culture. Companies are responding to this megatrend and are likely to continue to do so for decades (*1*).

## Sustainability and Chemical Education

With very few exceptions, the materials that we use to educate our students, especially our chemistry textbooks, are blind to this revolution. For example, looking back through the organic textbooks that many of us learned from decades ago and comparing them with those of today, there are fewer changes than one might expect. Yes, today's textbooks are adorned with colorful illustrations and have a plethora of supplemental resources. In addition, they have vignettes of interesting chemistry applications that are set off in boxes. Nonetheless, one could take an organic textbook from four decades ago and, with only a few tweaks here and there, still be able to teach with it today.

Had we been students of business decades ago, would the same thing hold true for our business textbooks? Clearly the answer is no. One could argue that chemistry is based on the laws of nature which are constant, while business is based upon the fluctuating theories of management, and the winds of society, politics, economics, culture, environmental issues and sustainability. However, one might well raise the question of when our science majors, in particular our chemistry majors, would have the opportunity to study how chemistry influences and is influenced by these same types of issues.

There has been a significant change in the way we teach college chemistry for non-science majors. These courses used to repeat the high school chemistry course that drove many of these same students out of the sciences. They see no relevance of chemistry to their lives, and this only serves to reinforce their distaste for science in general and chemistry in particular. The year 1990 saw the beginnings of a revolution in chemistry textbooks for non-science majors with the publication of the first edition of *Chemistry in Context*. To quote the publisher's website for the 6$^{th}$ edition of this book

> "Following in the tradition of the first five editions, the goal of this market leading textbook, *Chemistry in Context*, sixth edition, is to establish chemical principles on a need-to-know basis within a contextual

> framework of significant social, political, economic and ethical issues. The non traditional approach of *Chemistry in Context* reflect today's technological issues and the chemistry principles imbedded within them. Global warming, alternate fuels, nutrition, and genetic engineering are examples of issues that are covered in CIC (*9*)."

If this is the market leader, then this approach has been embraced by many instructors and hopefully by the students that use it. When students see how a knowledge of chemistry can help them understand everyday issues, they can appreciate the value of chemistry. Chemistry becomes germane to their lives.

The 7th edition (2011) will continue this same tradition, but an overarching theme of sustainability and a greater emphasis on green chemistry will be added. To quote Cathy Middlecamp, Editor-in-Chief of this new edition: "*Chemistry in Context* was groundbreaking in its approach to teaching chemistry; it will be groundbreaking again by infusion of the issues of sustainability (*10*)." The beginning chapter is an introduction to sustainability and the topic is woven throughout the rest of the book. Sustainability related concepts such as cradle-to-cradle, shifting baselines, the tragedy of the commons, the triple bottom line, and ecological footprints are blended into issues that confront society. Yes, chemistry within the context of societal issues, and now the megatrend sustainability is changing the way we teach chemistry to our non-science majors.

Middlecamp also indicated that some of her chemistry graduate students asked "why do non-science majors get all the good stuff (*10*)?" *Why isn't the chemistry that science majors learn taught within the context of real-world issues?*

What progress have we made in at bringing green chemistry, not to mention sustainability, into the chemistry curriculum for our science majors? If we judge this by taking a look at the textbooks we use for these courses, a recent survey (*11*) would indicate not very well. This survey showed that only 33/144 textbooks mentioned green chemistry, and most of the references were cursory and were often contained in a vignette set off in a box. Furthermore, 7 of the 33 were chemistry textbooks for non-science majors. Although this survey was focused on green chemistry, this author's experience has been that, aside from textbooks for environmental chemistry and for non-science majors, one would be hard pressed to find the topic of sustainability in any college chemistry textbook. While we do a poor job of blending green chemistry into the curriculum, we do a dismal job with the broader issues of sustainability. As this megatrend is bursting onto the world scene, many chemistry academicians and chemistry textbook authors have not changed the basic content of their courses and textbooks for decades.

The following is from the 2008 ACS Guidelines and Evaluation Procedures for Bachelor's Degree Programs:

> "Ethics should be an intentional part of the instruction in a chemistry program. Students should conduct themselves responsibly and be aware of the role of chemistry in contemporary societal and global issues (*12*)."

ACS accredited programs should be surveyed to assess how each program is fostering an awareness of the role of chemistry in contemporary societal and global issues, issues that include sustainability.

In content driven courses, a major challenge for instructors is to cover the required material in the allotted time. How can we possibly add any new material when covering the bulk of the required material is a challenge? Yet, it is imperative that we teach green chemistry and the broader issues of sustainability to our future scientists as well as to our non-scientists. One answer is to blend these subjects into mainstream topics that are already covered in a chemistry course, thus requiring the addition of little new material. At the University of Scranton, we have infused green chemistry into nine courses (*13*). As students move through the curriculum, they experience how green chemistry applies to all fields of chemistry and is not a field in itself. Although these examples blend green chemistry into only a topic or two in each course, it is not hard to imagine how green chemistry can be infused into additional topics. The blending of the broader concepts (*e.g.* cradle-to-cradle, shifting baselines, the tragedy of the commons, the triple bottom line, ecological footprints) of sustainability is a greater challenge, but one that we can't afford to ignore.

Perhaps we need to take a good look at what determines the content of a chemistry course. Clearly, there are many answers including the ACS guidelines (*12*), the way the professor learned it, the textbook, perhaps a blend of these, and more. To assess what should be taught, for example, in an organic chemistry course, one might assemble a broad ranging group of chemists that practice organic chemistry. This group would largely be taken from industry, but would also include academics, government employees, and representatives from NGOs. They would be asked to peruse a typical organic chemistry textbook and rate which topics are important, and which ones can be removed. Whatever the results, they should be interesting! If we find that this leads to the elimination of a number of topics, this further opens the way to teach the remaining topics in context, while blending in green chemistry and the broader issues of sustainability.

In addition to educating our students within the context of the real-world, the added benefit of greening our courses is the improvement of the image of chemistry and attracting additional people to the field. The vast majority of students in our lower level courses do not go on to practice chemistry. These future politicians, business leaders, citizens, and scientists will see how science and technology can contribute to a sustainable world. They will understand how chemistry is essential to solving the world's science and technology problems. It will illustrate that chemistry is certainly the central science, but not just central to the other sciences, but central to the issues of this megatrend.

A decade or two from now what will a typical chemistry textbook contain? Will its contents still be virtually the same as today's textbook, or will there have been a revolution in the way we teach chemistry to our science majors?

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## Chapter 12

# Science and Global Sustainability as a Course Context for Non-Science Majors

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We have developed a course on Global Sustainability which is offered to non-science majors. Our approach is to use sustainability as the set of interconnected "real world" issues that we teach through to the underlying science content. Students are guided through basic chemistry and the role of energy in global warming before looking at how global warming could affect biosystems and food supplies. From food supplies we lead students into the effects of malnutrition and the emergence of disease across the world. Students are introduced to chemistry, earth science, biology and the interconnections of a number of scientific disciplines within the overarching context of sustainability. Student response to the first four offerings of the course and ongoing revisions to course structure and student work will also be described.

What should general education accomplish, especially in regards to science at the undergraduate level? *Greater Expectations* (*1*), a report published by the Association of American Colleges and Universities (AACU), outlined the goals of general education as acquiring intellectual skills and capacities, understanding multiple modes of inquiry and approaches to knowledge, and developing societal/civic/global knowledge. The report described liberal education, which is at the heart of AACU's perspective on general education, as a "philosophy of education that empowers individuals, liberates the mind from ignorance, and cultivates social responsibility …characterized by challenging encounters with important issues, and more a way of studying than specific content." If we narrow our focus a little more to science education and science literacy, then *Science for All Americans*


In Sustainability in the Chemistry Curriculum; Middlecamp, C., et al.;
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(*2*) – published by the American Association for the Advancement of Science – presents a natural extension of the philosophy found in *Greater Expectations*:

> "Science literacy—which encompasses mathematics and technology as well as the natural and social sciences—has many facets. These include being familiar with the natural world and respecting its unity; being aware of some of the important ways in which mathematics, technology, and the sciences depend upon one another; understanding some of the key concepts and principles of science; having a capacity for scientific ways of thinking; knowing that science, mathematics, and technology are human enterprises, and knowing what that implies about their strengths and limitations; and being able to use scientific knowledge and ways of thinking for personal and social purposes."

## Revising the Natural Sciences Component of the Saint Vincent Core Curriculum

In the fall of 1999, Saint Vincent College began a process to consider if any changes should be made in the College's core curriculum. Natural sciences faculty, who had been meeting on a regular basis for two years to discuss common concerns, asked themselves what understanding of science every Saint Vincent student should have at graduation. Underlying this work was a shared sense that the natural sciences component of the core curriculum as it was then configured was not accomplishing what faculty wanted. Faculty focused their discussions on four questions. With respect to the natural sciences, what should all graduates of Saint Vincent College know and be able to do? Did the statement of the natural science core curriculum goal need to be modified? If so, how? What curricular approach(es) would most effectively address the stated goal and learning outcomes?

Over a period of several months, faculty members worked together to identify over 50 specific learning objectives that wee grouped under five broader goals. These objectives covered a wide range of aspects of science literacy including critical thinking, quantitative reasoning, fundamental concepts in various disciplines, the process of scientific discovery, and the impact of science on society and the human condition. The natural science goal within the core curriculum was revised (additions shown in **bold**) to read:

> "Science is a creative endeavor that contributes to our knowledge of the natural world. An educated person should be familiar with the process by which scientific knowledge is obtained through objective observation, the formulation of questions, the testing and verification of hypotheses and the development of explanatory theories. Also of importance is a familiarity with some of the major observations and theoretical models in science that guide scientific developments. **Finally, one should understand the impact science has had on daily life and the human condition.**

Scientific literacy is demonstrated when a person can

- **describe the nature of scientific knowledge, use the scientific method and comprehend, present and critique scientific work.**
- explain the most fundamental observations and models developed in the process of scientific inquiry.
- **evaluate the impact science has had on the human condition.**"

The explicit emphasis on helping students better understand the impact of science on their lives represented a major addition to the natural sciences component of the core curriculum. These revisions were approved by the entire faculty at Saint Vincent in 2001. As part of the implementation, students were required to take two courses, one from a group that was broad in scope and often focused on interdisciplinary themes (tier 1 courses) and the second from a group that were designed to provide more depth in one area of science (tier 2 courses).

## Science Education for New Civic Engagements and Responsibilities (SENCER)

At the same time that work on revision of the natural sciences goal and objectives in the core curriculum was coming to an end, science faculty at Saint Vincent became aware of the NSF-funded SENCER Project. SENCER, an acronym for "Science Education for New Civic Engagements and Responsibilities," aimed at improving undergraduate science education and foster civic engagement by teaching the basic canonical science concepts "through" complex, capacious, and unsolved public issues (*3–5*). The project also hoped to foster civic engagement by connecting basic science content to unsolved public problems. SENCER 's learning goals were:

- teaching science in ways that were consistent with the nature of scientific inquiry
- engaging an educated citizenry with complex issues related to science
- encouraging students to make connections across the disciplines
- ensuring a level of scientific competency that justified calling someone generally educated

SENCER courses used issues such as AIDS, the environment, catastrophes, tuberculosis, and global warming as the context through which faculty led students to explore the scientific concepts important to understanding the civic issue. Several Saint Vincent faculty found what SENCER advocated particularly attractive as an approach for the proposed tier 1 courses. They felt that the SENCER approach would provide them with a framework that allowed coverage of foundational principles in several scientific disciplines while making very clear the relationship between science and real world issues. Such an integrated approach was viewed as fully consonant with both the revised natural science goal articulated by the faculty and the mission of Saint Vincent College, which sought to "provide quality undergraduate education for men and women to enable them to integrate their professional aims with the broader purposes of human life." The College applied to participate in the SENCER Project, was accepted, and was able to send an advance representative to the 2002 SENCER Summer Institute and a full team – a biologist, a physicist, an economist, and the Academic Dean – to the 2003 Summer Institute.

As we became more familiar with the approach advocated by SENCER and thought about the multidisciplinary nature of the content goals identified by science faculty as important in tier 1 courses, we began to see that the broader question of global sustainability might make an appropriate complex, capacious, and unsolved civic issue to structure a new course around. By sustainability, we were not thinking just of environmental issues but more along the lines of the National Research Council report *Our Common Journey* (*6*) which framed sustainability as a challenge "to meet the needs of a much larger but stabilizing human population, to sustain the life support systems of the planet, and to substantially reduce hunger and poverty." We saw the explicit reference to meeting human needs and reducing both hunger and poverty as providing a broader, more inclusive framework for science concepts from different disciplines than a global warming course we initially proposed.

## Science and Global Sustainability: The Initial Course Design

David Burns has described six elements that function as key components in the design of an effective SENCER course (*7*):

- interests and motives
- complex, capacious, civic issue (context)
- canonical STEM elements (content)
- pedagogies
- action
- assessment

Sustainability was a topic that more and more students were interested in, even if they didn't know much about the topic. As a context for the course, we saw sustainability as the quintessential complex civic issue with the capacity to contain a great deal of content, particularly science content, within it. And the work done by Saint Vincent faculty to develop goals and objectives for the natural science component of the core curriculum meant that the canonical elements of science content had already been identified. Action and assessment will be examined later in this chapter.

Science and Global Sustainability was developed as a new tier 1 course and piloted as an Honors course during the Fall 2003 semester, after which the hope was to offer the course on a regular basis to all interested students. The overall student learning objective was that by the end of the course each student would be able to evaluate and examine scientific component of specific issues related to global sustainability and how these scientific concepts influenced other perspectives. This overall objective was broken down into six more specific learning objectives:

1. To introduce concept of global sustainability and identify some challenges that must be met to accomplish that goal
2. To examine basic concepts of structure of matter, energy and its manipulation, physical history of universe, and life on earth
3. To examine how these concepts are applicable to specific sustainability concerns of global climate change, feeding the world's population, and threats to world health
4. To explore relationship between science important in concerns listed above and other perspectives (e.g. economic, ethical, religious) on the same issues
5. To develop students' abilities to assess risks and benefits as part of making reasoned decision regarding issues involving science and technology
6. To help students further develop problem solving and critical thinking skills

The course was organized around three major themes: global climate change, feeding the world's population, and threats to world health. Student understanding of course concepts was assessed through a combination of periodic exams (four total throughout the semester) and a final group presentation used in place of a traditional final examination. For the presentations, students worked in groups of 3-5 people on a topic chosen by them that they saw as related to sustainability. That could be a topic covered in class that had caught their attention and that they wanted to explore further, or it could be a topic that the course had not examined.

The first two class periods were spent discussing the general idea of sustainability using the introductory chapter from the National Research Council report *Our Common Journey* (*6*), Peter Raven's article "Science, Sustainability, and the Human Prospect" (*8*), and Aldo Leopold's essay on the land ethic (*9*). At that point the course shifted to a focus on global climate change. After examing the concepts of energy and heat, we looked at principles of chemical bonding to understand what made some molecules greenhouse gases. Then we used the topics of how planets form and earth cycles to explore what contributed to climate over a long period of time. Finally, we used ecosystems and the environment to explore the potential impacts of climate change. The capstone activities were class discussions on "what should we do"and a short paper on what information would be most important to use if a student were to explain global climate change to a friend or family member.

We then transitioned to the second theme of the course, feeding the world's population. After examining the characteristics that distinguished living from nonliving systems, we revisited chemical bonding and structure but with an emphasis on organic and biological molecules. Once students understood the structural difference between carbohydrates, fats, and proteins we examined how cells could use each type of macromolecule for energy. As part of this, we also looked at the second law of thermodynamics, oxidation/reduction reactions, and some general principles of how metabolic pathways have evolved. The capstone activity for this section asked students to monitor and record the food they consumed for a week. At the end of the week, each student wrote a 2-3 page memo that presented an analysis of the food consumed including:

1. amount of protein, carbs, fats and other substances consumed in the week;
2. amount of saturated fat consumed that was saturated during the week ;
3. estimate of how much food was "wasted" (e.g. not eaten) during the week;
4. any changes to diet the student would recommend based on concepts from the class.

The final theme of the course was threats to world health with an emphasis on combating infectious diseases such as AIDS and malaria. This section started with our examing more closely one of the most important characteristics of living organisms, inherited characteristics and the ability to replicate. Students learned about inheritance, genes (dominant and recessive), mitosis, meiosis, chromosomes, and the central dogma of molecular biology (replication, transcription, translation). Basic ideas underlying cloing and genetic engineering were also introduced, often in the context of identifying viruses and developing new drugs. At the same time that students were encountering a significant amount of biology, they were also encountering chemistry concepts such as the structure of DNA and RNA as well as drug development. The capstone activity for this section involved a discussion where the class was asked to make recommendations to a hypothetical private foundation on spending $5 million to fund one of three proposals to combat infectious diseases (AIDS, measles, and vancomycin resistant Staphylococcus aureus). The activity came from a curriculum module on emerging infectious diseases developed by BSCS for the National Institutes of Health and available on the NIH website (*10*).

The course was interdisciplinary in a variety of ways. Student encountered concepts from chemistry, biology, physics, earth sciences and astronomy within the same course. Topics chosen by students for the final presentations included ocean related issues (pollution, overfishing, coral health), tuberculosis, and energy sources; all of these were topics where students could (and did) incorporate aspects from more than one discipline both within and outside the sciences. Disciplines such as philosophy, sociology, theology, and economics were incorporated into the course through class discussions and informal student interviews of faculty from these disciplines. At several points, the instructor pointed out connections between the various units in an attempt to help students see the relatedness of the three themes. Global climate change influenced the types of crops being grown around the world. Because of this influence, people's diets were changing in a way that could potentially be linked to hunger and malnutrition. The effects of malnutrition adversely affected the ability of the human body to fight infectious diseases through the immune system. Finally, there was growing concern in the global public health community that certain infectious diseases could be observed in new areas of the planet because of travel and global climate change.

## Student Response to Course and Revisions That Resulted

At the end of the first offering, students completed both the Student Assessment of Learning Gains (SALG) and the normal student course evaluation form used by Saint Vincent. The SALG (*11*, *12*), originally developed by Elaine Seymour in 1997 in support of two NSF funded curriculum reform projects in chemistry, asked students to assess and report on their own learning, and on the degree to which specific aspects of the course contributed to that learning. The responses on the SALG showed that half of the students felt highly or extremely confident that they could discuss scientific concepts with friends and family. Most felt that they were able to think critically about scientific findings they read in the media. Two-thirds of the students felt that they could now make an argument using scientific evidence. From the student course evaluation form, 70% strongly agreed that this was both a successful and intellectually fulfilling course. Student comments included the following:

> "Developing a broadened scientific perspective and applying it to real life." (in response to a question about skills gained)
> "I can now understand the real-life implications of scientific concepts like energy extraction by mitochondria and put them together with the big picture." (in response to a question about skills gained)
> "I really enjoy incorporating science knowledge into my field and discussing new topics with people who are willing to do so."

The course was offered again during Fall 2004 semester. This time the course was open to any student who wanted to use the course to fulfill the natural sciences component of the core curriculum. During this second offering it became clear to the instructor that while Honors students were highly motivated and easily saw connections between topics, the larger student population was very different from Honors students in regards to motivation and the ability to make connections between topics. As one student wrote in response to an open-ended question on the SALG in the Fall 2004 semester, "Try to have more of a related flow regarding the material covered. One day we are talking carbon structures, then the next day we were discussing world hunger. I did not feel that there was a obvious direction in class." The instructor also came to the conclusion that the text being used at the time for the course, *The Sciences: An Integrated Approach* (*13*), was arranged in a fragmented way that did not encourage students to make connections between topics. For these reasons and others, the decision was made at the end of the Fall 2004 semester that the course would not offered for several years to allow time for instructors to rework problematic parts of the course.

Fall 2008 was the next time Science and Global Sustainability was offered. During this time period several ideas as to how to change the course were implemented. While we were unsuccessful in finding a text to replace the one by Trefil and Hazen and so continue to use that as the course textbook, assignments were altered to stay more focused on the course itself. Outside readings, written assignments and other work was changed to keep the focus on the particular topic under discussion. The instructor intentionally took a more explicit approach to pointing out connections between topics rather than assuming that students would make these connections on their own. Wherever possible, classroom discussions of applications were centered on each student's major. Examples from the popular media were incorporated into the course; in Fall 2008 one laboratory period was devoted to watching "An Inconvenient Truth" with discussion afterwards. In Fall 2009 the film "The Day After Tomorrow" was shown and students were asked to separate the scientific facts from the science fiction. Fall 2009 semester also saw the incorporation of additional readings excerpted from books such as *Hot, Flat, and Crowded: Why We Need a Green Revolution and How It Can Renew America* (*14*), *Half the Sky: Turning Oppression Into Opportunity for Women Worldwide* (*15*), and *28: Stories of AIDS in Africa* (*16*). Finally, in the Fall 2010 offering students will be asked to interview foreign students at Saint Vincent and ask what these students believed about America before coming here. The hope is that this activity will provide class participants with first-hand experience of different perceptions of American society, perceptions that Friedman has argued are connected to the challenge of sustainability and developing "green" economies.

Based on responses to the course evaluation instrument used at Saint Vincent, student reaction to the revised course was more positive at the end of both the Fall 2008 and Fall 2009 semesters. 46% very strongly or strongly agreed that the course was "intellectually fulfilling for me"; only 8% disagreed with this statement. The same percentage (46%) very strongly or strongly agreed that they felt challenged and motivated to learn; again only 8% disagreed with this statement. Student comments on the course evaluation form often centered on the idea of learning a lot about real world applications of the science content included in the course. One particular response was very encouraging - "Why hasn't anyone else told us about all of this? I'm mad! I'm going to change my major so that I can do policy work."

We continue to revise Science and Global Sustainability so that students encounter a learning environment that is relevant, challenging, rewarding, and directly linked to the goals of the Saint Vincent core curriculum that include but are not limited to the natural sciences. One possibility that we hope to explore in the near future is the incorporation of service learning, through either on-campus or local community opportunities. But the evidence gathered to date suggests that the challenge of sustainability has provided a framework for student learning that accomplishes what Saint Vincent faculty initially envisioned for our proposed "integrated science" course, but in a way that students see as clearly connected to an important real world issue.

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## Chapter 13

# Science, Society, and Sustainability:

## A Certificate Program

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Many academic disciplines have adopted and integrated the term "sustainability" as a "new and improved" addendum for 21st century curricula. Students are often exposed to a wide range of explanations without cohesion of content leading to a vague concept of their applications. This critical issue transcends individual disciplines but is rarely offered as a bridge between them. Herein, we describe a multidisciplinary approach integrating science, society, and sustainability into a coherent program of study and civic engagement. Students completing this program enhance their academic majors by developing their ability to make thoughtful life choices and address problems from a global perspective.

## Introduction

We have developed an academic certificate titled Science, Society and Sustainability. In this chapter, we will discuss 1) the process of how we brought our idea to reality; 2) what motivated us to do this; 3) the obstacles that presented themselves and how we overcame them; and, finally, 4) a description of the program itself. We are confident that this program can serve as a model that others can adapt to meet the curricular needs of their students.


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ACS Symposium Series; American Chemical Society: Washington, DC, 2011.

## The Process

In the summer of 2007, six members of the Texas Woman's University (TWU) faculty and administration attended their first SENCER Summer Institute (SSI 2007). SENCER (Science Education for New Civic Engagements and Responsibilities) is a faculty and curriculum development program funded by the National Science Foundation (NSF) whose mission is the improvement of science education at all levels. This is achieved by organizing science learning around important civic questions that are already important to students (such as climate change, HIV, etc.) and by using civic engagement activities to let students put their knowledge to work immediately in the local community. Hence, students are more likely to learn the science. For more information, visit www.sencer.net. It was following this meeting that we started to think about revising our science courses to include a civic engagement component.

That year, we offered *Introduction to Environmental Chemistry* for the first time. For the civic engagement component of the course, students interviewed students, faculty and staff about their attitudes and practices concerning recycling on campus. A report was written and submitted to TWU Facilities Management. As a result of this action, TWU has an improved recycling program. The continuing success of that course started us thinking about developing other courses dealing with environmental issues.

In 2009, we offered for the first time a SENCER course titled *Climate Change: A Human Perspective*. The civic engagement component of that course has students considering the effect of humankind on the climate and vice versa, and students participate as citizen scientists observing the response of local plant species to global warming. In the summer of 2009, faculty members from TWU attended the Green Chemistry and Engineering Conference to present a talk about our SENCER program in a chemistry education session. It was after that meeting that we really started to really focus on teaching about sustainability issues.

Due to the complex nature of sustainability, we soon realized that a single course would be insufficient to teach our students about sustainable issues and practices. That is when the idea of a minor in sustainability was first considered. We envisioned a multidisciplinary program that would involve as many other departments in the College of Arts and Sciences (CAS) as possible. At TWU, a minor is 18 credits with 6 of those coming from upper division courses. For the core requirement, TWU requires all students to take at least one course with a "global perspective" as well as two courses in natural science. In order for any course to fulfill the global perspectives or natural science core requirements, it must meet several criteria. These criteria are designated as Exemplary Educational Objectives.

Under the global perspectives objectives are two criteria that are particularly relevant to sustainability. Upon completion of a global perspectives course, students will be able to: 1) Demonstrate an understanding of prevailing world conditions, developments and trends associated with world issues such as population growth, economic conditions, international conflicts; and 2) Demonstrate the knowledge, values and skills needed to participate in decisions about the way we do things individually and collectively, both locally and


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globally, that will improve the quality of life now without damaging the planet for the future. The natural science core designation also has two critical criteria relevant to sustainability. Upon completion of a natural science course, students should be able to: 1) Demonstrate knowledge of the major issues and problems facing modern science, including issues that touch upon ethics, values, and public policies; and 2) Demonstrate knowledge of the interdependence of science and technology and their influence on, and contribution to, modern culture (*1*). Since sustainability is both a global and natural science issue, we felt that we could easily develop a minor related to sustainability using the courses we already have.

Upon presentation of our initial ideas to the Associate Provost for Undergraduate Studies, the concept of a certificate was brought forth. A certificate is 12 to 18 credits, all of which must be upper division courses. The advantages of a certificate over a minor are numerous. First, the student actually gets a certificate indicating the achievement. Second, the certificate can stand alone in the absence of a baccalaureate degree. Third, the certificate would require students to take upper division courses in disciplines that they may not normally take. Thus, not only are students expanding their horizons, but we also expect to populate normally sparsely enrolled upper division courses within the college. Hence, we decided to develop a certificate related to sustainability.

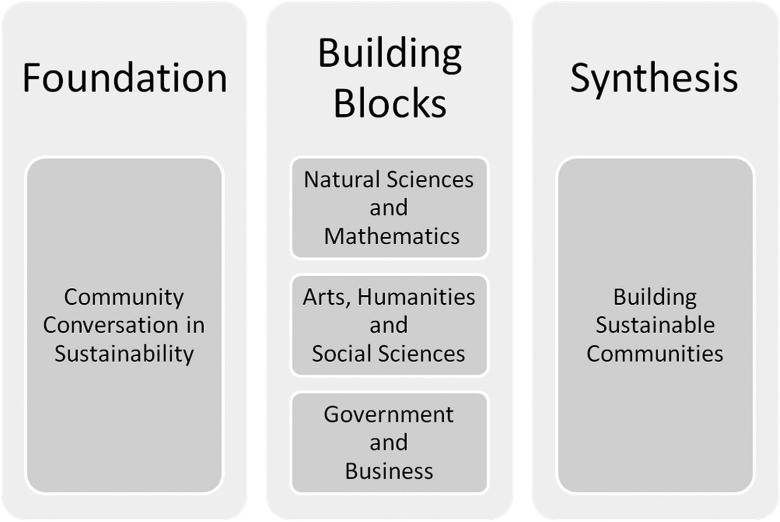


*Figure 1. A schematic of the certificate in Science, Society and Sustainability. Students would start off with a Foundations course which would introduce them to sustainability from scientific, sociological and economic points of view. They would then take at least one course from each of the focus areas designated as building blocks. Departments from the College of Arts and Sciences would contribute eligible upper division courses. Finally, students would put it all together during the synthesis course through involvement in a community sustainability issue. More detail is given below.*

Finally, in the spring of 2010, faculty members from the college met and hammered out a program. The faculty members at the meeting included representatives from the departments of Chemistry & Physics and Biology, the School of Management and the School of the Arts. What came out of that meeting was a basic plan which consisted of a multidisciplinary foundation course, building block courses from around the College of Arts and Sciences and a capstone synthesis course with a significant civic engagement component dealing with sustainability issues in the community. This plan is schematically outlined in Figure 1.

## The Motivation

The primary goal for any program development is to benefit the educational needs of our students. Sustainability is in the news but individuals' concepts of sustainability vary widely. We wanted to develop a program that would address sustainability from several points of view: scientific, sociopolitical and economic. Our own experience, and that of others in the SENCER community of practioners, is that students learn more about sustainability, retain it longer, and are able to apply it more effectively than in similar non-SENCER courses (see Reference (*2*)). The design of a variety of related SENCER courses are also available at no charge online (*3*). Many students, including chemistry majors, have approached us with a desire to take courses in sustainability. Our chemistry curriculum has been traditional in that it did not emphasize concerns about environmental impacts of the chemical enterprise. This certificate program will allow our chemistry majors an opportunity to explore the context in which their chemical education applies to the greater good for the community. We are currently implementing green chemistry practices in our undergraduate teaching laboratories. Because of this, chemistry majors will give this certificate program serious consideration in their academic plan. In fact, we expect students from all majors to consider this program.

In addition, such a program would populate upper division courses so all departments within the College of Arts and Sciences have expressed interest in this certificate. We expect this program to enhance our students' ability to understand how their formal education is related to other knowledge, and to their future careers. Further, it is the right thing to do. Sustainability is relevant to life on our planet. There is no Planet B! Finally, the certificate program will allow us to incorporate SENCER ideals in a substantial way into our curriculum and give us a vehicle to teach civic engagement skills.

With these thoughts in mind, we developed the learning objectives shown in Table 1. These objectives will enable our students to develop critical thinking, problem-solving and written/oral communication skills that will serve them well in their professional careers.


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**Table 1. Certificate Program Objectives**

| |
|---|
| 1. Define scientific, sociological and economic sustainability. |
| 2. Evaluate a variety of sustainability issues, along with their risks and benefits. |
| 3. Predict impacts of modern lifestyles on earth's material and energy resources. |
| 4. Relate knowledge of scientific, sociopolitical and economic aspects of sustainability to a civic issue within the community. |
| 5. Synthesize sustainable solutions to complex civic issues. |
| 6. Communicate civic issues and sustainable solutions to the general public and policymakers. |

## The Obstacles

The development of any new program faces obstacles. One major obstacle is to get others, particularly significant others, on board. At TWU, this was not a problem. The CAS Dean as well as the Chairs of the various departments within CAS have all been supportive of the concept. We planted the seed about two years ago and have presented our ideas about the certificate at: 1) the monthly CAS chairs meetings; 2) the fall CAS faculty meeting, 3) numerous faculty forums throughout the academic year, and 4) at our Civic Engagment Learning Community which is comprised of faculty members from different disciplines.

Of course, the biggest obstacle for any program development is budgetary. Not unlike so many institutions around the country, TWU has been faced with financial cutbacks during the last few years. The idea to create a certificate program is not an expensive one, however, and we have been able to pursue it in spite of a series of budget cuts. Costs associated with this program are minimal. Although the proposed program will use existing courses, it still requires the creation of new courses. Times demanding financial efficiency do not bode well for new course development. Nonetheless, we have created three new courses relevant to the certificate program and they have been approved. We plan to offer the initial foundation course during the fall 2011 term.

## Program Description

Sustainability can be defined as using resources to meet the needs of today without jeopardizing future generations from being able to do the same. However, different disciplines have different perceptions with regard to sustainable practices. The goal of the Certificate in Science, Society and Sustainability is to integrate the principles and values of sustainable practices into all aspects of education and learning to enable our students to address the social, economic, cultural and environmental problems facing humanity in the new millennium.

## Program Requirements

The certificate requires 15 to 18 credits of upper division courses (i.e., 3000 and 4000 level) in an organized and integrated course of study. Students will be responsible for any prerequisites for courses required for the certificate. A capstone course involving a civic engagement project to address a local sustainability issue is also required.

### Coursework

The first course serves as a foundation for the certificate. All students pursuing the certificate will be required to take this course. *Community Conversations in Sustainability* is a multidisciplinary, team-taught course discussing all aspects of sustainability from scientific, sociological and economic points of view. Topics include the impacts of energy production, food production, industry and our modern lifestyle on our local and global community with an emphasis on systems and possible solutions. The course is formatted as a three credit seminar. There is a course prerequisite of a lower division SENCER science course.

Table 2 lists the learning objectives for the foundation course. Student learning will be evaluated through in class examinations, participation in group discussions and a formal presentation of a sustainability project.

The building block courses will examine sustainability within specific disciplines in the College of Arts and Sciences. Students will be required to take at least one 3000 or 4000 level course (3 credits each) in each of the three areas of focus (Natural Sciences and Mathematics; Arts, Humanities and Social Sciences; Government and Business) from courses proposed by appropriate departments (see below). This will total a minimum of nine credits. Students are responsible for course prerequisites, if any exist, for these courses.

The Science, Society and Sustainability certificate resides within the department of Chemistry and Physics. Certificate programs in Texas institutions of higher education must consist of upper division courses. Potential courses are reviewed by a small multidisciplinary committee, chaired by the Chemistry and Physics department chair, which is tasked with the selection of building block courses. Syllabi for proposed courses should describe how the course addresses a minimum of three certificate learning objectives.

**Table 2. Foundation Course Learning Objectives**

| |
|---|
| 1. Define scientific, sociological and economic sustainability. |
| 2. Discuss the impacts of technology on earth's material and energy resources. |
| 3. Evaluate a variety of sustainability issues, along with their risks and benefits. |
| 4. Illustrate scientific, sociological and economic concepts and their applications to sustainable solutions. |
| 5. Make predictions about the impact of modern lifestyles on sustainability. |

*Building Sustainable Communities* is a three credit seminar course which requires synthesis of sustainable solutions for a selected complex civic issue, followed by public presentation to the appropriate decision-making body. The synthesis course will be a capstone in which students use knowledge from all previous coursework to investigate and propose a solution to a selected sustainability issue. All students pursuing the certificate will be required to take this course.

Table 3 lists the learning objectives for the capstone course. Student outcomes will be evaluated through participation in, and leadership of, class discussions of aspects of the selected civic issue; a written report giving the synthesized solutions for the issue; and successful delivery of a formal public presentation to the appropriate decisionmakers. We envision these decisionmakers might include the TWU Board of Regents, the county commissioners court, Texas Commission on Environmental Quality, or similar agencies.

## Assessment

A variety of traditional and innovative assessment tools will be used to evaluate student learning in the certificate program. Table 4 displays how these assessments relate to the learning objectives for the program. Traditional assessments include exams, papers and class discussions. Innovative tools are pre/post surveys, projects and civic engagements.

Pre and post surveys will allow students an opportunity to make their own assessment of personal learning gains. This feedback will be used by program faculty to refine the program over time. In both the foundation and capstone courses, projects will be used as a vehicle for students to learn and communicate new knowledge of course content materials and/or synthesis of new ideas. These may include individual and small group assignments on various topics related to sustainability issues. Presentations will be made to class members and to various decisionmakers as appropriate for the particular project.

**Table 3. Capstone Course Learning Objectives**

| |
|---|
| 1. Apply knowledge of scientific, sociological and economic aspects of sustainability to a civic issue within the community. |
| 2. Debate their understanding of the impacts of technology on earth's material and energy resources in order to synthesize sustainable solutions to complex civic issues. |
| 3. Evaluate the risks and benefits of a variety of possible solutions to civic issues. |
| 4. Use scientific, sociological and economic concepts to propose sustainable solutions for the selected civic issue. |
| 5. Construct a presentation that provides sustainable solutions for the selected complex civic issue and deliver it to an appropriate community agency. |

**Table 4. Assessment of Certificate Program Objectives**

| | Exams | Pre/Post surveys | Papers | Class Discussions | Projects | Civic Engagement |
|---|---|---|---|---|---|---|
| 1. Define scientific, sociological and economic sustainability. | X | | X | X | | |
| 2. Evaluate a variety of sustainability issues, along with their risks and benefits. | X | X | X | X | X | X |
| 3. Predict impacts of modern lifestyles on earth's material and energy resources. | X | X | X | X | X | |
| 4. Relate knowledge of scientific, sociopolitical and economic aspects of sustainability to a civic issue within the community. | X | | X | X | X | X |
| 5. Synthesize sustainable solutions to complex civic issues. | X | | X | X | X | X |
| 6. Communicate civic issues and sustainable solutions to the general public and policymakers. | | X | X | X | X | X |

## Benefits to Students

Upon completion of this program, students are equipped to analyze sustainability problems from different disciplinary points of view. Further, they can extrapolate their knowledge and experience to global issues and perspectives. These foundations assist in making educated decisions concerning their careers and lifestyles. Moreover, it develops critical thinking, communication, and leadership skills enhancing their chosen careers.

## Appendix 1

A survey of the courses offered by the various departments throughout the College of Arts and Sciences reveals several courses that can be used as building block courses within the three focal points. Below are just some of the courses that could be considered with their respective catalogue description (*4*).

**Natural Sciences and Mathematics**

***Department of Biology***

*Ecology*: Introduction to relationships between organisms and their environment, limiting factors, food chains and pyramids, and population dynamics.

*Science in the Secondary Classroom:* Professional development in strategies for teaching high school and middle school science using science inquiry and active learning techniques.

*Scientific Communication:* This course is designed to improve the written and verbal communication skills involved in gathering, analyzing, and distributing scientific and technical information efficiently and accurately for specific scientific audiences.

***Department of Chemistry and Physics***

*Climate Change*: A study of climate change with a synthesis of meteorology, geology, oceanography, astronomy and anthropology in context of man's impact on climate and climate's impact on man.

*History of Modern Science*: An exploration of the development of the sciences in their social and political context; science from Newtonian revolution to present.

*Water in a Changing Environment:* An investigation of the sustainability issues of water from an American southwestern to global perspective. Study combines the science, sociology, and economics of water quality and availability of transboundary water systems in a changing environment.

**Humanities, Arts and Social Sciences**

***Department of Dance***

*Dance, Gender and Culture*: Dance expression and how it inscribes markers of identity such as gender, race, ethnicity, social class, ableness and sexuality on the body in performance.

***Department of Music***

*Music and World Cultures*: A study of the elements and functions of music with an emphasis on the anthropology of music and multi-cultural awareness.

***Department of Visual Arts***

*Global Perspectives in Art*: Develops understanding and appreciation of various cultural values while increasing skills in creative arts techniques.

***Department of Psychology and Philosophy***

*Global Perspectives in Psychology*: Intercultural/international perspectives in psychology; psychology's relevance to the understanding of global problems and how psychology itself is affected by global events/cultures.

*Bioethics*: Centers upon problems with respect to biomedical technology, genetics, ecology, abortion, euthanasia, human experimentation, prolongation of life, psychosurgery, ethical and social issues in biomedicine.

***Department of Sociology and Social Work***

*Population Dynamics*: Population theories, the use and interpretation of demographic data, population change and policy, relationships between population and socioeconomic factors.

*Principles of Geography*: Review of the major concepts of human geography with an emphasis on the relationships of human population dynamics, culture, and physical environment.

**Government and Business**

***School of Management***

*Business Principles of Community Service*: Preparation for community service including management functions, principles of marketing economics, entrepreneurship, financial success skills and business ethics.

***Department of History and Government***

*Global Issues and Trends*: A general survey of nations, regions and cultures.

*Environmental Science, Economics and Law:* Interdisciplinary introduction to the challenge of environmental protection.

*International Relationships:* The interaction of countries and non state actors in the area of diplomacy, international law, international economics, international organization, and war.

## References


1. http://www.twu.edu/academic-affairs/core-curriculum.asp.
2. *Science Education and Civic Engagement: the SENCER Approach*; Sheardy, R. D., Ed.; ACS Symposium Books: Washington, DC, 2010.
3. http://www.sencer.net/Resources/models.cfm.
4. General Catalog, 2009-2011, Texas Woman's University.

## Chapter 14

# Water for a Thirsty World: A Liberal Arts Seminar Course Designed for First-Year Non-Science Students

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A key principle inherent in sustainability issues is the idea of utilizing current resources wisely so as to not jeopardize their use by future generations. Water is one such resource whose demand is in danger of outstripping its supply. Efficient water use and re-use provides chemists with enormous opportunities to develop green alternatives in manufacturing practices, and to create systems that maintain and perhaps even improve the quality of our current supply. However, before we can chart a path to water sustainability, we must first understand the *complexity* of the resource under study. This chapter describes a course on water that can serve as a pedagogical model for incorporating sustainability ideas into the liberal arts curriculum, while simultaneously introducing students to chemistry. As more and more educators seek to incorporate sustainability concepts into their courses, the seminar described here may serve as a model to implement similar courses at other institutions.

## Introduction

Many liberal arts colleges require entering students to enroll in a seminar course early in their academic programs, and often in their very first semester of college. This chapter describes a seminar course developed for entering first-year students entitled *Water for a Thirsty World* and taught at Dickinson College in Carlisle, PA in Fall 2003.


In Sustainability in the Chemistry Curriculum; Middlecamp, C., et al.;
ACS Symposium Series; American Chemical Society: Washington, DC, 2011.

The course was created as an offering in our First-Year Seminar Program. This program is similar in format to those offered at many other liberal arts institutions under various titles such as *Great Ideas of the 20th Century*, or *Great Books*. A commonly stated purpose for all of these courses is to introduce students to the standards and expectations of academic life, especially as they make the transition from high school to college. The audience for the course was 16 newly entering students from widely divergent backgrounds whose academic interests at this point were mostly undefined.

Because the audience was diverse and not necessarily science-focused, the seminar was purposely designed to explore the topic of water from scientific, historical, economic, and international perspectives. This would be accomplished mainly through reading journal articles and books, watching films, and then having students discuss and write about their understanding of the topics.

When the course was conceived, sustainability was a word whose meaning few people understood, and even fewer people actively incorporated as an objective into their courses. Although the Brundtland Commission of the United Nations had earlier defined sustainability based in development terms, it has taken on a much broader definition in intervening years. The definition that I used in the course can be simply defined as "making sure that the resources we depend on today are available in the same good condition for future generations."

A course on water sustainability also lends itself naturally to introducing students to ideas relevant in the field of green chemistry. For instance, the growing realization that we will be facing water shortages in upcoming decades necessitates water pollution prevention at the source. New manufacturing processes such as those acknowledged in the Presidential Green Chemistry Challenge and nascent technologies that utilize water more efficiently or in a less polluting manner could be explored within the realm of a course of this type.

At Dickinson, I had been teaching environmental chemistry to a non-chemistry audience, so a seminar course devoted to water seemed a good extension of ideas relevant within the field of environmental chemistry. One large component of my environmental chemistry course focused on water, and it seemed reasonable to use that as a starting point for talking to non-science majors about natural resources. Also, the year 2003 proved to be auspicious because the media were just beginning to heavily delve into water-related issues, and there were multiple media sources relating to water from which to choose. In the intervening years, this reference list has grown enormously, and I have provided an annotated bibliography at the end of this chapter including materials that were not available when the course was originally taught.

## Water for a Thirsty World Overview

The First-Year Seminar Program at Dickinson is directed by an Associate Dean, who confers with faculty on their seminar content in the fall semester a year before the course is offered. Approximately 40 seminars are offered each fall, and the class size is purposely limited to 16 students total. Each faculty member teaching a seminar has wide discretion as to the content of the course (e.g. how many writing assignments will be required, how many books will be read, what days they want to teach it, and whether they want to join a "learning community" where students in the seminar live together for the entire semester and plan outside events to enhance student learning in the course).

Once their seminar topic is approved, faculty are tasked with creating a course description meant to pique the interest of an eighteen year-old high school student. The seminar description for the *Water for a Thirsty World* course is shown below:

> Water is a vital resource for the survival of life on this planet. We rely on it for food production, electricity generation, for bathing, drinking, and recreation. It shapes where and how we live. Access to clean water leads to economic prosperity, while lack of water can lead to poverty, disease, and war. In recent years, the demand for fresh water outweighs the supply, raising questions about how we will cope with this shortage. This seminar explores the subject of water from scientific, historical, economic, and international perspectives. We will begin by asking the question: What is water and where does it come from? What are some of the ways that humans have an impact on their water supply, and what are the results? The historical and economic impacts of water will be examined by looking at how water shaped the development of the American West, through readings such as *Cadillac Desert* by Marc Reisner, and its documentary counterpart, and *Encounters with the Archdruid* by John McPhee. We will also examine recent concerns about national security and the public water supply, in light of events surrounding September 11$^{th}$, 2001. In the international realm, the impact of water (or lack thereof) in the politics of the Euphrates River Valley and the Yangtze River Basin will also be examined. Throughout the seminar students will be challenged to consider who gets water, and why? What would life be without water?

A booklet listing the 40 potential seminar choices is sent to students in the summer before their arrival at Dickinson, and they are asked to choose six seminars of interest to them. From this list, the Associate Dean distributes these students into one of the seminars, which carries one course credit and meets one of the distribution requirements for the Dickinson degree.

Once students are assigned to a seminar, they are encouraged to make email contact with their seminar professor, who serves as their academic advisor until they choose a major by the end of their sophomore year. When they choose a major, the first-year seminar professor essentially turns over student advising to a new advisor chosen by the student in their designated major.

In order to break the ice with the students, I initiated email contact with students before they entered, by writing a short description of what we would be doing in the fall, something about myself, and I encouraged them to contact me if they had any questions or concerns before the semester began. Some students responded to my email, but few questions were raised at that point. It should be noted that some seminar faculty were vehemently opposed to making themselves available to students in the summer, as this is the primary time they engage in scholarship, and so they chose not to initiate prior contact with their advisees.

First-year students arrive on campus in the fall three days earlier than upper-class students. While classes for all students begin on a Monday in late August or early September, first-year students meet as a group exclusively with their seminar advisors during those three days before all classes start. The purpose is to begin to initiate a model for how their days will be structured prior to all students being present on campus. They learn where their classes will be located, they take language placement exams, and they begin to work on assignments that are given in their first-year seminar course. During these first three days, they also attend mandatory sessions that introduce them to the college library, show them how to retrieve information, and how to cite references. These library sessions continue and the expectations deepen throughout the course of the semester. Many seminar instructors have students work on an assignment collaboratively to begin to instill in them the "habits of the mind" they hope to develop throughout the coming semester, and which will evolve and expand throughout their college career.

## The Nuts and Bolts of the *Water for a Thirsty World* Seminar

### College-Wide Learning Objectives for First-Year Seminars

When the seminar was originally taught in 2003, the concept of student assessment was not as imperative as it is today, and the learning objectives for first-year seminars were fairly amorphous. In looking at the handbook that faculty were given at that time, the following goals were listed:

- To cultivate habits of mind essential to sustained critical inquiry;
- To introduce new students to the standards and expectations of academic life;
- To nurture information literacy as a life-long learning process;

Over time, and with a deeper appreciation for assessment, the learning objectives for the program have evolved into the following:

The First-Year Seminar (FYS) introduces students to Dickinson as a "community of inquiry" by developing habits of mind essential to liberal learning. Through the study of a compelling issue or broad topic chosen by their faculty member, students will:

- Critically analyze information and ideas;
- Examine issues from multiple perspectives;
- Discuss, debate and defend ideas, including one's own views, with clarity and reason;
- Develop discernment, facility and ethical responsibility in using information; and
- Create clear academic writing

## Sample of the *Water for a Thirsty World* Course Syllabus

### *Introduction*

Water is a vital resource for the survival of life on this planet. We rely on it for food production, electricity generation, for bathing, drinking, and recreation. It shapes how and where we live. Access to clean water leads to economic prosperity, while lack of water can lead to poverty, war, and disease. In recent years, the demand for freshwater outweighs the supply, raising questions about how we will remedy this shortfall.

### *Course Content*

This seminar will examine the subject of water from scientific, historical, economic, and international perspectives. We will begin by asking the question: What is water and where does it come from? What are some of the ways that humans have an impact on their water supply, and what are the results? Should we trust that water from our tap is "clean"? How would we know? The historical and economic impacts of water will be examined by looking at how water shaped the development of the American West, through readings such as *Cadillac Desert* by Marc Reisner, and its documentary counterpart. In the international realm, the impact of water (or lack thereof) in the politics of the Euphrates River Valley and the Yangtze River Basin will also be examined. Throughout the seminar students will be challenged to consider who gets water, and why? What would life be without water?

### *Grading*

Grading in the course was based on three areas: clear writing (60%), discussion and debate (30%) and library and other assignments (10%). The way I described each of these in the syllabus for the students was as follows:

### *Clear Writing (60%)*

Knowing how to write and communicate effectively is a skill you will need to master during your college career. No matter which career path you choose after you leave Dickinson, it will inevitably involve some form of communication and writing. As such, you will need to demonstrate that you are skilled in this area. In order to help you practice this skill, you will be asked to draft six writing assignments during the semester. The topics and formats for these assignments will be designated throughout the course. Each paper will be handed in as a draft after peer-review, and after revision in final form. In between each draft and final there will be ample time to discuss the assignment with me or to consult with the

Writing Center. Grades assigned for drafts will be recorded and averaged together with the final grades to make up this portion of your grade.

*Discussion and Debate (30%)*

Logical thinking and the ability to clearly express your ideas are forms of communication that will be exercised during this course. As such, you will need to be present (both mentally and physically) in order to participate. All classes will require that you have completed the assigned reading ahead of time, in order to be prepared to discuss the topic of the day. I will occasionally test this requirement by giving short, unannounced quizzes on various aspects of the reading. The quizzes, in addition to your contributions to the discussion, will allow me to assess your knowledge and familiarity with the material.

*Library and Other Assignments (10%)*

Learning to use the library effectively is one of the stated goals of the first-year seminar program, and a skill that will serve you well throughout your college career. As such, you should become familiar not only with the building, but with the library staff as well. Throughout the semester we will have several library assignments that will be collected and graded.

## Representative Seminar Assignments

*Reading Assignments*

Students were expected to come to class having read the material for that class and to be able to answer questions on the material if asked. The general expectation for each lecture was to have had the students read one or two book chapters or several articles and to be ready to discuss these. I purposely chose books and articles that covered a spectrum of reading levels and a variety of sources (e.g. newspaper articles, popular magazine articles, scholarly journal articles) in order to introduce them to different types of information. This also led us to see how scholars utilize a variety of source material in their work: for background, opinion, and fact.

*Writing Assignments*

Dickinson is fortunate to have a campus Writing Center available to help guide students in their scholarship. The Writing Center staff were available to serve as a guide for students and faculty alike. Each seminar had a Writing Center tutor assigned to it who was an upper-class student who was available in the evenings to help students work on drafts. After each visit, the Writing Center tutor would submit to the professor a report on what they had covered with the student during their session. In addition to the tutors, we also employed peer editing in the classroom where students would be expected to read and critique other students' work. In order to make this process more formal, I would collect the comments and suggestions that they made on peers drafts and tell them that giving good feedback to others would reflect positively in their own grade. Examples of topics for four of the writing assignments are listed below.

1. In the article *Priceless: A Survey of Water* the authors argue that there are common problems associated with water throughout the world. What are these problems and what evidence do the authors cite in support of their argument? What conclusion do the authors want to leave you with, and are you convinced?
2. In the reading *Managing Water for People and Nature* the authors suggest that water policies fail to protect aquatic ecosystems and lead to water scarcity. What do the authors believe is the cause, and what are three ways the problem might be alleviated?
3. In the article *Environmental Change and Violent Conflict* the authors propose that resource scarcity can and does lead to violent conflict, and they provide evidence to support their hypothesis. They provide three conditions that may be present to explain how conflict arises. Your assignment is to apply their theory to a novel example of your choosing. That is, pick a conflict in the world at large and apply their criteria. Be sure to answer the questions: Are their criteria met in the example you have chosen? If not, are there other factors not identified by the authors that may play a role?
4. Write a two page editorial-opinion piece on one of the topics we've discussed this semester in class pertaining to water. Some examples are listed below. In order to write an editorial, you need to peruse the editorials section of a major newspaper and use it as a guide to style. The purpose of an editorial is to convince the reader of your argument through reasoned evidence. Possible topics:

    a. The pros/cons of building dams;
    b. The pros/cons of removing dams;
    c. Subsidizing (or not subsidizing) water for agricultural purposes (i.e. Should taxpayers pay to grow crops where it may not be economically sound?)
    d. Controlling (or not controlling) nature for human purposes (Do humans have the right to divert rivers for their own use?)
    e. How water gets allocated amongst individuals (Should there be control by a few stakeholders or equitable disbursement among individuals?)
    f. How water gets allocated amongst states or countries (Should California have priority to the Colorado River instead of Arizona? New Mexico? Utah?)
    g. Any other water-related issue that has both a pro and con side to the topic.

*Library Assignments*

Each seminar had a library liaison that was assigned to the seminar. The liaison served as a point person for the students to contact with questions, and the liaison facilitated three discussions with the students throughout the seminar on topics that were chosen by the advisor. These might include citing references properly, how to search for reference materials, or even an in-class assignment for helping them find relevant journal or secondary source materials. In our seminar, the library sessions were geared at finding suitable source materials and references, proper citations for formal writing, and understanding the layout of the College's library.

## Course Layout

The seminar was held for three 50-minute periods per week. Other time formats were available (such as two 75-minute periods per week, or one three hour time slot), but I felt that students lack the attention span to sit for that long. I required three texts for the course, and there were additional readings (journal articles, popular articles) available on the Blackboard site created for this course (references are listed at the end of the syllabus). The seminar consisted of three modules that were divided along the lines of the chosen texts. The first third of the course was devoted to the topic of "Water in the World" and was deliberately chosen to introduce students to some of the ways that people in other countries or in different fields might think about water. Because new seminar instructors were counseled by older, more seasoned instructors to choose materials that lent themselves to controversy and discussion of different points of view, I geared the second third of the course around the topic of "Water and Public Health," and the readings in this section reflected that subject. Finally, the final third of the course was meant to cover some historic and economic aspects of water through careful reading of *Cadillac Desert: The American West and its Disappearing Water*. In each module, student teams were tasked ahead of time with leading the discussions for that day based on the assigned readings. There was a general progression throughout the course to turn the daily discussions over to the student teams each day. In the first section, I led many of the discussions to model how the discussions might occur. By the second and third sections of the course, the students were responsible for leading the class discussions. A preview for the general layout of the course (based on a 15-week semester) is shown in Table I.

**Table I. Class Schedule from *Water for a Thirsty World* Seminar**

*Section 1: Water in the World*
*Water: The Fate of our Most Precious Resource, by De Villiers*

| ***Date*** | ***Topic*** | ***Reading Assignment*** |
|---|---|---|
| M | Water and the Human Condition | Water Pressure<br>Priceless: A Survey of Water |
| W | The Hydrologic Cycle (video) | Managing Water for People and Nature |
| F | What is "Good" Writing and How Do You Accomplish It? | Writing Assignment 1 Due |
| M | Where Does Water Come From, and Where Does It Go? | De Villiers, Ch. 1-3<br>The Origins of Water on Earth |
| W | Where Does Water Come From, and Where Does It Go? | Revised Assn. 1 Due<br>The Oceans and Weather<br>Chaotic Climate<br>Threat of Localized Cooling Flows From Global Warming |
| F | No class – out of town | |
| M | Tampering with Nature | De Villiers, Ch. 4-10<br>Under the Weather<br>Growing More Food with Less Water<br>Irrigating Crops with Seawater |
| W | Tampering with Nature | Environmental Change and Violent Conflict |
| F | Learning to Use Your Library Effectively | - |
| M | Tampering with Nature | Writing Assignment 2 Due<br>Mighty Monolith<br>The Power of Gravity<br>Chinese Will Move Waters to Quench Thirsty of Cities |
| W | The Politics of Water | De Villiers, Ch. 11-15 |
| F | The Politics of Water | Frankly, My Dear, I Don't Want a Dam |
| M | The Politics of Water | Revised Assn. 2 Due |
| W | The Politics of Water | Diseased Passage<br>Drinking Without Harm |
| F | What is To Be Done? | De Villiers, Ch. 16<br>Sweating the Small Stuff |

*Section 2: Water and Public Health*
*Our Stolen Future: Are We Threatening Our Fertility, Intelligence and Survival – A Scientific Detective Story, by Colburn, Dumanowski, and Meyers*

*Continued on next page.*

**Table I. (Continued). Class Schedule from *Water for a Thirsty World* Seminar**

| | | |
|---|---|---|
| M | The Estrogen Effect (video) | Malignant Mimicry<br>Can Environmental Estrogens Cause Breast Cancer? |
| W | Water Quality/ Water Perils | Understanding Microcontaminants in Recycled Water. |
| F | Advanced Library Research | Writing Assignment 3 Due |
| M | No class- Mid-term Pause | |
| W | Hormone-mimicking chemicals | Colburn *et al.,* Ch. 1-2 |
| F | Our Stolen Future | Revised Assn. 3 Due<br>Colburn *et al.,* Ch. 3 |
| M | Our Stolen Future | Colburn *et al.,* Ch. 4<br>Evaluating Impacts of Hormonally Active Agents in the Environment |
| W | Our Stolen Future | Colburn *et al.,* Ch. 5<br>Re-engineering the toilet for sustainable wastewater management |
| F | Our Stolen Future | Colburn *et al.,* Ch. 6 |
| M | Our Stolen Future | Writing Assignment 4 Due<br>Colburn *et al.,* Ch. 7-8 |
| W | Our Stolen Future | Colburn *et al.,* Ch. 9 |
| F | Our Stolen Future | Colburn *et al.,* Ch. 10 |
| M | Our Stolen Future | Revised Assn. 4 Due<br>Colburn *et al.,* Ch. 11-12 |
| W | Our Stolen Future | Colburn *et al.,* Ch. 13-14 |
| | *Section 3: Water and the American West*<br>*Cadillac Desert: The American West and its Disappearing Water, Revised Edition, by Reisner* | |
| F | Cadillac Desert: An American Nile (video) | - |
| M | Cadillac Desert | Reisner Introduction and Ch. 1 |
| W | Cadillac Desert | Reisner, Ch. 2 |
| F | Cadillac Desert | Reisner, Ch. 3 |
| M | Cadillac Desert | Writing Assignment 5 Due<br>Reisner, Ch. 4 |
| W | Cadillac Desert | Reisner, Ch. 5 |
| F | Cadillac Desert | Reisner, Ch. 6 |
| M | Cadillac Desert | Revised Assn. 5 Due<br>Reisner, Ch. 7 |

*Continued on next page.*

**Table I. (Continued). Class Schedule from *Water for a Thirsty World* Seminar**

| | | |
|---|---|---|
| W | No class | |
| F | Thanksgiving Break | |
| M | Cadillac Desert | Reisner, Ch. 8 |
| W | Cadillac Desert | Sustaining Life on Earth<br>Reisner, Ch. 9 |
| F | Cadillac Desert | Writing Assignment 6 Due<br>Reisner, Ch. 10 |
| M | Cadillac Desert | Reisner, Ch. 11 |
| W | Cadillac Desert | Reisner, Ch. 12 |
| F | Cadillac Desert | Revised Assn. 6 Due<br>Reisner, Epilogue |

**Required Texts:**

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De Villiers, M. Water: The Fate of our Most Precious Resource, Mariner Books: New York, 2001.

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**Additional Readings: (These Were Made Available on the Course Blackboard Site and Are Listed in Order of Their Appearance in the Syllabus)**

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Johnson, N.; Revenga, C.; Echeverria, J. Managing Water for People and Nature. *Science*. **2001**, *292*, 1071-1072.

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Kasting, J.F. The Origins of Water on Earth. *Sci. Am. Presents.,* **1998**, 16-22.

Webster, P.J.; Curry, J.A. The Oceans and Weather. *Sci. Am. Presents,* **1998,** 38-43.

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Suplee, C. "Threat of Localized Cooling Flows From Global Warming." The Washington Post (1 Dec 1997. 25 Aug 2010) (<http://pqasb.pqarchiver.com/washingtonpost/access/23340047.html?FMT=ABS&FMTS=ABS:FT&date=Dec+1%2C+1997&author=Curt+Suplee&desc=Threat+of+Localized+Cooling+Flows+From+Global+Warming>.).

Baron-Faust, R. Under the Weather, *Sci. Am. Presents*, **2000**, 90-96.

Postel, S. Growing More Food with Less Water. *Sci. Am.,* **2001**, *284*, 46-51.

Glenn, E.P.; Brown, J.J.; O'Leary, J.W. Irrigating Crops with Seawater. *Sci. Am.*, **1998**, *279*, 76-81.

Homer-Dixon, T.F.; Boutwell, J.H.; Rathjens, G.W. Environmental Change and Violent Conflict. *Sci. Am.,* **1993**, *268*, 38-45.

Kosowatz, J.J. Mighty Monolith. *Sci. Am. Presents,* **1999**, 14-16.

Gibbs, W.W. The Power of Gravity. *Sci. Am.,* **2002**, *287*, 88-91.

Eckholm, E. "Chinese Will Move Waters to Quench Thirst of Cities." New York Times (27 Aug 2002. 25 Aug 2010) (<http://www.nytimes.com/2002/08/27/world/chinese-will-move-waters-to-quench-thirst-of-cities.html?scp=24&sq=Eckholm&st=nyt>.).

Nemecek, S. Frankly, My Dear, I Don't Want a Dam. *Sci. Am.,* **1997**, *277*, 20-22.

Niiler, E. Diseased Passage, *Sci. Am.,* **2000**, *283*, 23-24.

Masibay, K. Drinking Without Harm. *Sci. Am.,* **2000**, *283*, 22.

Martindale, D. Sweating the Small Stuff. *Sci. Am.,* **2001**, *284*, 52-55.

Rennie, J. Malignant Mimicry. *Sci. Am.,* **1993**, *269*, 34-38.

Davis, D.L.; Bradlow, H.L. Can Environmental Estrogens Cause Breast Cancer? *Sci. Am.,* **1995,** *273*, 166-172.

Sedlak, D.L.; Gray, J.L.; Pinkston, K.E. Understanding Microcontaminants in Recycled Water. *Environ. Sci. Technol.,* **2000**, *34*, 508A-515A.

Maczka, C.; Pang, S.; Policansky, D.; Wedge, R. Evaluating Impacts of Hormonally Active Agents in the Environment. *Environ. Sci. Technol.*, **2000**, *34*, 136A-141A.

Larsen, T.A.; Peters, I.; Alder, A.; Eggen, R.; Maurer, M.; Muncke, J. Re-engineering the toilet for sustainable wastewater management. *Environ. Sci. Technol.*, **2001**, *35*, 192A-197A.

Kates, R.W. Sustaining Life on Earth. *Sci. Am.,* **1994**, *271*, 114-122.

**Additional Videos:**

Water, water everywhere. Dir. David Chamberlain. Narr. Suzanne Grew Ellis. 2001. Videorecording. Films for the Humanities and Sciences.

The estrogen effect: assault on the male. Prod. Deborah Cadbury. Perf: Hugh Quarshie. Videorecording. Films for the Humanities and Sciences, 1997, 1998.

Cadillac desert: an American Nile. Dir. Jon Else. Narr. Alfe Woodard. Videocassette. PBS Video, 1997.

## Course Assessment

### Student Assessment

Dickinson students assessed all 40 seminars using a 23 question survey based on a 4-point numerical rating system where: 1 = very dissatisfied; 2 = dissatisfied; 3 = satisfied; 4 = highly satisfied. An assessment of my course (*n* = 15, 1 student


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absent) compared to a compilation of all student answers from all seminars ($n$ = 572) is given in Table II.

**Table II. Student Assessment Questionnaire for *Water for a Thirsty World* Seminar**

| *No.* | *Question* | *College Mean* | *Seminar Mean* |
|---|---|---|---|
| 1 | Overall, how satisfied are you with the quality of this seminar? | 3.3 | 2.8 |
| 2 | Compared to the courses you took in high school: | | |
| | How intellectually challenging was this seminar? | 3.7 | 2.8 |
| | How much work was required of you? | 3.6 | 3.3 |
| | How much writing was required of you? | 3.6 | 3.6 |
| | How much library research was required of you? | 3.6 | 3.7 |
| | How much oral presentation was required of you? | 2.8 | 3.0 |
| | How much reading was required of you? | 4.1 | 3.9 |
| 3 | Compared to other courses you've taken this semester at Dickinson: | | |
| | How intellectually challenging was this seminar? | 3.2 | 2.8 |
| | How much work was required of you? | 3.2 | 3.2 |
| | How much writing was required of you? | 3.9 | 4.0 |
| | How much library research was required of you? | 3.6 | 3.7 |
| | How much oral presentation was required of you? | 3.1 | 3.9 |
| | How much reading was required of you? | 3.8 | 4.1 |
| 4 | Did you receive satisfactory roll-call grades in your courses this semester? | NA | Yes in 4 (73%) Yes in 3 (24%) |
| 5 | Approximately how many hours per week did you spend studying and working for this seminar? | NA | 5.5 |
| 6 | If you were to start the semester over again would you have taken this seminar? | 3.1 | 2.2 |
| 7 | How much did you improve in the following areas: | | |
| | Thinking critically and analytically | 2.9 | 2.4 |
| | Formulating your own arguments based on evidence | 2.9 | 2.9 |
| | Recognizing and critiquing arguments | 2.9 | 2.6 |

*Continued on next page.*

**Table II. (Continued). Student Assessment Questionnaire for *Water for a Thirsty World* Seminar**

| *No.* | *Question* | *College Mean* | *Seminar Mean* |
|---|---|---|---|
| | Accepting constructive criticism from others | 2.8 | 2.4 |
| | Giving constructive criticism to others | 2.6 | 2.3 |
| | Conducting research | 2.8 | 2.9 |
| | Reporting your research findings to others | 2.7 | 3.0 |
| | Contributing to in-class discussions | 2.8 | 2.4 |
| 8 | To what extent have the following aspects of your writing ability improved as a result of this semester? | | |
| | The content of your writing | 2.9 | 2.9 |
| | The organization of your writing | 2.9 | 2.9 |
| | The style of your writing | 2.7 | 2.4 |
| | The mechanics of your writing | 2.6 | 2.3 |
| | Proper citation style | 2.7 | 3.1 |
| 9 | How much of your work for the semester involved the revision of your writing assignments? | 2.9 | 3.5 |
| 10 | On average, how many pages did you write per week for this seminar? | 2.4 | 2.0 |
| 11 | Did you have to complete a final project for this seminar? | NA | Yes |
| 12 | If your final project was a paper, how many pages was it? | NA | 9.0 |
| 13 | How many drafts/revisions of the final project did you submit for review? | NA | 1.3 |
| 14 | Did you conduct research using primary sources for this seminar? | NA | Yes |
| 15 | Did you visit the Writing Center for this seminar? | NA | Yes (54%)<br>No (46%) |
| 16 | How many times did you consult the Writing Center for help? | 2.4 | 3.5 |
| 17 | How useful was the help you received? | 2.4 | 2.4 |
| 18 | To what extent did the library sessions help you improve in the following areas: | | |
| | Use of print versus electronic indices | 2.4 | 2.5 |
| | Discipline- or subject-specific resources | 2.5 | 2.9 |

*Continued on next page.*

**Table II. (Continued). Student Assessment Questionnaire for *Water for a Thirsty World* Seminar**

| *No.* | *Question* | *College Mean* | *Seminar Mean* |
|---|---|---|---|
| | How to get started on a research project | 2.5 | 2.7 |
| | Different between popular and scholarly articles | 2.6 | 2.6 |
| | Difference between primary and secondary sources | 2.4 | 2.4 |
| 19 | Please indicate your level of agreement with the following questions regarding your freshman seminar professor: | | |
| | She communicated a joy for learning | 3.5 | 2.9 |
| | She opened my mind to new ideas | 3.4 | 3.1 |
| | She was always prepared for class | 3.5 | 3.3 |
| | She facilitated class discussions | 3.6 | 2.9 |
| | She provided a syllabus that accurately reflected the course content, assignments, and expectations | 3.5 | 3.6 |
| | She made the evaluation standards clear | 3.2 | 3.3 |
| 20 | Would you take another course taught by this professor if the subject interested you? | 3.3 | 3.1 |
| 21 | Would you recommend the professor to other students looking for a good teacher? | 3.3 | 3.3 |
| 22 | Overall, how satisfied are you with the quality of the instruction you received in this seminar? | 3.4 | 3.2 |
| 23 | Overall, how satisfied are you with the advising you've received this semester from your freshman seminar professor? | 3.2 | 3.3 |

## Instructor Assessment

I was satisfied with the first iteration of the course. Like any course that we teach, I discovered aspects that I would keep and improve, and also material that I would change or discard. Based on written comments, and in conjunction with the quality of the discussions, the more media-friendly book written by Colbourn *et al.* was the class favorite. The students cited it as easy to read and understand, and also as interesting. On the other hand, they strongly disliked *Cadillac Desert*, which surprised me at first. They described it as dry and boring, although I would describe it as the best written of the three texts. Many of the students had never been to California or lived in a state that had water rationing, so the subject matter of the book was foreign to them. I would likely not use that text again for this audience. The students liked the variety of readings from the magazines and newspapers, and were satisfied with the films.


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The single largest change I would make to the course is to restructure the course to make it more relevant to each *individual* student. By this, I mean I would have students do more work towards understanding how *they* use water in their own lives. For this, some of the new references and websites that I list below in the annotated bibliography would be useful. As most college students carry around plastic water bottles or aluminum water bottles between classes, I would begin a class asking for reasons the students carry one type (plastic) versus another (aluminum) instead of utilizing tap water for drinking. Another activity could involve tracking their water usage for one week in a journal. Or they could determine the water footprint of a favorite product using the water footprint calculator below. Instead of relying so heavily on student-led discussions, which were useful as long as the students had prepared good questions (but tended to be passive for the audience), I would actively engage the students in activities that would help them to understand water through personal use. In retrospect, field trips such as to the local water treatment facility would have been a good idea, although the original 50-minute lecture format didn't lend itself particularly well to this goal. With the wealth of new water materials freely available on the internet, educators can create a course that uniquely meets the needs of students at their own institutions.

## An Annotated Bibliography for Water Sustainability Curriculum Materials

When the original course was offered, many materials that are particularly relevant today were not yet available. Below I list other potential sources that could be incorporated into a course of this type depending on personal interest. There are many water-related references available on-line and this list is not meant to be exhaustive.

### Books

Royte, E. Bottlemania: Big Business, Local Springs, and the Battle Over American's Drinking Water. Bloomsbury: New York, 2009.

Royte, E. Bottlemania (How water went on sale & why we bought it). Bloomsbury: New York, 2008.

Steingraber, S. Living Downstream: An Ecologist's Personal Investigation of Cancer and the Environment, 2nd edition. De Capo Press: New York, 2010.

Gleick, P.H. Bottled and Sold: The Story Behind Our Obsession with Bottled Water. Island Press: New York, 2010.

### Textbooks

A number of chemistry texts have chapters devoted to the topic of water. Two of the more useful are:

Eubanks, L.P., Middlecamp, C.H., Heltzel, C.E., and Keller, S.E., *Chemistry in Context: Applying Chemistry to Society, 6th ed.* McGraw-Hill Higher

Education: New York: 2009. Ch. 5. A new edition of the text should soon be available.

*Chemistry: A General Chemistry Project of the American Chemical Society.* McGraw-Hill Higher Education: New York: 2004. Ch. 1.

## Magazines

*National Geographic* has two issues that are particularly relevant to water-related issues. The first is the September 2002 issue on The State of the Planet, which focuses on fresh water. The more recent April 2010 special issue entitled *Water•Our Thirsty World: A Special Issue* is entirely devoted to the subject of water and is particularly useful at the undergraduate level.

## Newspapers

Many national newspapers (*The Washington Post, the New York Times*) have run in-depth stories concerning both domestic and international water-related issues. These are accessible through a search of individual databases, or through composite search engines such as Lexis-Nexus or Proquest that indexes many national and international newspapers.

## Films

Websites containing information about DVDs pertaining to water issues:

http://www.flowthefilm.com - a documentary examining water privatization

http://liquidassets.psu.edu - a documentary examining US water infrastructure

http://www.waterfortheages.org/water-films - a website showing YouTube clips from a number of documentaries about water

## Ideas for Student Experiential Learning

- Visit to the local drinking water treatment works;
- Visit to the local sewage treatment works;
- Visit to a power plant;
- Visit to a paper mill;
- River-rafting trip;
- Visit to a local farm to see how water is used in agriculture

## Internet-Based Resources

IBM has an interesting website devoted to water issues and accessible at: (http://www.ibm.com/smarterplanet/)

The Water Footprint Network has an interactive calculator that allows the user to calculate their "water footprint." The site is accessible at: (http://www.waterfootprint.org/)


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A neat introductory chemistry lesson about water (geared towards the non-scientist) written by Professor B.Z. Shakhashiri is accessible online at: (http://www.scifun.org)

The Knight Center for International Media at the University of Miami School of Communication oversees http://www.onewater.org which is a useful collection of images and information about water issues from around the world.

## Conclusion

This model for constructing a course pertaining to water and water-related issues is meant to serve as a starting point for others who may be interested in teaching a similar course at their institution. While the references cited herein are not meant to be comprehensive, they do provide an overview of some of the more useful types of information available currently that can be utilized to engage students in a course on water and sustainability. The approach of studying water from a diversity of perspectives including: historical, economic, scientific, international, and environmental, is a particularly well suited topic for entering college students with diverse academic interests.

## Chapter 15

# Following the Phosphorus: The Case for Learning Chemistry through Great Lakes Ecosystem Stewardship

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Making connections between basic chemistry topics and "real life" issues and phenomena is now a standard feature of most high school and college introductory chemistry textbooks. These examples are often isolated, however, and do not offer students the opportunity to see the connections among the many principles in the undergraduate chemistry curriculum that are inherent to complex and potentially contentious environmental issues which affect the personal lives of the students themselves. By identifying and following the pathways of phosphorus runoff from farm fields in Northwest Ohio to Lake Erie, where it promotes the growth of Harmful Algal Blooms, undergraduates can see new relationships among key chemistry principles and deepen their understanding of these principles through science-based service-learning projects of benefit to environmental stewardship organizations.

## The "P" in Pea Soup

During a recent general education seminar at Case Western Reserve University, I asked my students to characterize their relationship with a major water resource in their lives. One of them wrote about jet-skiing through what looked like pea soup in the Western Basin of Lake Erie (Figure 1). As repulsed as he was by his spoiled recreational experience, he seemed resigned to the problem being too big and complicated to solve, and the efforts of one individual being useless.

*Figure 1. A glass of Western Lake Erie basin water full of toxic algae. Photo credit: Thomas Bridgeman, Department of Environmental Sciences, University of Toledo.*

Headlines such as “Toxic algae blooms choking Lake Erie” and “Scientists say the toxic blue-green algae will only get worse on Ohio lakes” in the Toledo Blade and the Cleveland Plain Dealer during the summer of 2010 were reminiscent of those heralding the “death” of Lake Erie forty years ago (*1*).

*Figure 2. Skin irritation caused by toxic algae. Photo credit: Wisconsin Department of Natural Resources staff photo.*

Accompanying the headline, The Blade's article chronicled cases of poisoning by microcystin, a hepa- and neurotoxin as well as skin irritant produced by microcystis (Figure 2), the most prevalent harmful blue-green alga in western Lake Erie: "Dogs lapping up water along infested shorelines have died of it."

In the 1960's, unsustainable loading of the lake with nutrients such as phosphorus (P) in bioavailable forms (*2*) contained in detergents, untreated human waste, and chemical fertilizers resulted in anthropogenic eutrophication of the lake, producing harmful algal blooms (HABs) (Figure 3) associated with foul-smelling drinking water, beach closings, and massive fishkills.

During the 1970s and 1980s, remarkable progress was made in reversing these effects. As effluent from municipal wastewater treatment plants and other "point sources" of nutrient loading was drastically reduced, water quality increased dramatically and algal blooms all but disappeared. Although the arrival of invasive quagga and zebra mussels clogged water treatment plant intake pipes and smothered recreational boat hulls, the increasing clarity of Lake Erie accompanying their spread was welcomed by swimmers. Yet by the mid 1990's, despite the elimination of phosphorus from most detergents and strict regulation of discharges from point sources of pollution, HABs had begun to re-occur in the western Lake Erie basin, at times increasing dramatically in frequency and mass . At the same time, an anerobic "dead zone" began to appear each summer in the central basin.

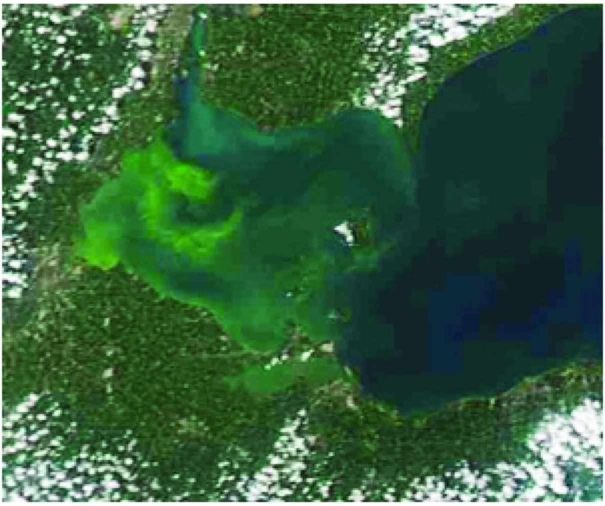

*Figure 3. Satellite image of a Harmful Algal Bloom (HAB) in the Western Lake Erie Basin. Photo credit: NASA/GSFC, MODIS Rapid Response.*

The cause-effect story of how excess nutrients generate HABs is now told in chemistry and biology textbooks both at the high school and college level. Since phosphorus is a key limiting factor in the growth of algae in freshwater systems, as well as a major component of fertilizers in its phosphate forms, it has been identified as the most likely culprit in the Western Basin of Lake Erie. It is here that the largest watershed in the Great Lakes ecosystem – the Maumee River and its tributaries – joins the lake, and the majority of the land in that watershed is still dedicated to farming. The solution to the problem would appear to be straightforward: reduce the loading and transport of such nutrients to tributaries of Lake Erie.

The principal message of a recent television broadcast sponsored by the Ohio Farm Bureau was that farmers now have the technology to do so: the latest fertilizer and pesticide spreaders incorporate GPS technology, enabling farmers to make nearly instantaneous application adjustments based on known changes in residual nutrient levels from one section of a field to another (*3*). So, with the availability of such precision agriculture technology, farmers should now be able to apply fertilizer in carefully calculated quantities that will prevent it from running off into headwater tributaries of Lake Erie.

This would be a simple (though costly, short-term) solution to the problem, assuming that the mere quantity of nutrients entering these waterways was the true culprit. But total phosphorus inputs to Lake Erie have been at or near regulatory limits in recent years; the Ohio Lake Erie Phosphorus Task Force has reported that "pollutant loading data for the Lake's major U.S. tributaries suggests that the problem stems not from any increase in the total amount of phosphorus entering the lake, but instead from changes in the forms of phosphorus entering the lake from its large agricultural watersheds" (*4*). As a percent of total phosphorus reaching the lake, the bioavailable type appears to be on the rise.


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## Where the Chemistry Is

Clearly there is a chemistry-based process at work here. Yet what collegiate general chemistry textbook presents the process of phosphate transport from the soil to a complex freshwater system and ultimate plant metabolization and decomposition *in toto* and as a *chemical* one? And why would this approach be relevant to chemistry students unless they planned to become farmers, soil scientists, or fertilizer vendors?

To explore this question further, let's take a short detour to review the typical sequence of some key chemistry topics taught at the undergraduate level. Usually, the topics listed below are covered in an introductory chemistry text, often in the same order:

Atoms
Elements
Molecules and bonds – ionic, covalent, hydrogen, etc.
Compounds (inorganic, organic)
Aqueous solutions (concentration, precipitation/mineralization, equilibrium)
Acids and bases (pH)
Photosynthesis and plant metabolism (ADP, ATP)

Despite the fact that the order of these topics constitutes a logical disciplinary progression in order of relative complexity, in the words of J. Dudley Herron, often

> …students cannot see where this information is leading, and it does not seem logical at all to them….We see the need for what we are asking them to learn, but the beginning students do not. In fact, they cannot (*5*).

To address this concern, many textbooks now provide "real life" applications of these individual topics to everyday problems and phenomena, including the relationship between excess nutrients in freshwater systems and the growth of toxic algae. Such examples illuminate the chemically-based manifestations of the problem, the most dramatic part of the story at the tail end of the "phosphoric journey." What is missed is the opportunity to apply chemical principles to the sources of the problem many miles upstream in the headwaters of rivers like the Maumee.

## Tracking the Chemistry to the Source

From the perspective of farmers, yield is the key driver of fertilizer application practices. Yet since the 1970s, farmers have become increasingly responsive to the need for more ecologically sustainable agricultural practices to control soil erosion and water pollution; many have begun to employ conservation tillage, which involves minimal if any disturbance to the soil surface. While this practice has significantly reduced soil erosion, it has had the unintended consequence of causing stratification of phosphorus concentrations in the soil, with much higher levels in the first two inches than at the depth normally analyzed to determine fertilizer application for optimal yield, six to eight inches (Figure 4). The result has been significantly increased levels of phosphorus runoff during major precipitation events of the kind expected to become more frequent in Northwest Ohio due to climate change.

Farmers could, of course, do more testing at the two-inch level, and test ever smaller grids of land to develop a detailed nutrient saturation map. They could then upload such maps to the GPS systems in their new high-tech spreaders, and program them to apply fertilizer judiciously to maximize yield while controlling or eliminating phosphorus-laden runoff entirely. But the current soil analysis protocols of commercial soil testing laboratories do not routinely provide data on phosphorus content at this level, where "P loss" is most likely to occur, and farmers would incur an additional expense for such tests. Ideally, farmers would develop nutrient management plans for their entire croplands, but such plans would entail testing at a level that some small independent farmers would find prohibitively costly.

*Figure 4. Soil sampling in an Iowa field. Photo credit: Iowa State University.*

Farmers will need to do more than simple soil testing, however, to develop such plans. As a Pennsylvania State University guidebook on phosphorus use points out,

> Most soil scientists agree that it is not likely that there will be a simple critical soil test level for P loss potential. It is more likely that an integrated approach, including many other site specific factors, will be necessary for interpreting the environmental pollution potential of a field…. More data of this type are needed for different soil types, crop covers, surface runoff volumes, and erosion potentials, so that scientists can develop recommendations for fertilizer and manure use that will be effective for crop production and farm management, yet flexible enough to be workable and economical for farmers (*6*).

While there are agencies equipped to assist farmers in the process of taking such an integrated approach, including agricultural cooperative extension and/or soil and water conservation services, they often lack the human resources to assist all the farmers who need help in pursuing such an integrated approach, which involves not only testing of nutrient levels, but incorporating factors such as soil type, land slope, and tillage practices to determine optimal land management practices.

## Focusing the Chemistry Curriculum on Links in the Nutrient Chain

On the surface, then, "following the phosphorus" may seem to be too hopelessly complex a process to link with the undergraduate chemistry curriculum. But for some undergraduate science faculty in Northwest Ohio, this process promises to create a unique opportunity for undergraduates to understand their chemistry better.

How, exactly? In terms of the chemistry topics listed earlier, an inquiry-based approach could promote students' learning of the "standard" list of general chemistry topics by engaging them in seeking answers to the phosphorus-related questions in Table 1.

The effort to weave these topics together into an inter-institutional and interdisciplinary curriculum has already begun in some Ohio colleges located within the Western Lake Erie watershed, for in addition to consisting of vast amounts of farmland, the Western Lake Erie Basin contains a significant number of higher education institutions for such a rural area. As illustrated in Figure 5, most are located in cities and towns on one of the region's major rivers or tributaries; in some cases, these waterways bisect their campuses.

**Table 1. The relationship of harmful algal blooms (HABs) to introductory chemistry topics at the undergraduate level**

| | |
|---|---|
| Atoms/elements | What are the properties of pure phosphorus?<br>Why would pure phosphorus be fatal to plants?<br>What are the most common natural sources of phosphorus, and what forms do they take?<br>Which of these forms spur plant growth? |
| Molecules and bonds – ionic, covalent, hydrogen, etc. | What types of chemical bonds are found in the forms of phosphorus contained in organic and commercial fertilizers?<br>How does the bonding of phosphorus to elements in various soil types affect its availability to plants?<br>How does the chemical composition of these soil types determine the type of bonding that takes place? |
| Compounds (inorganic, organic) | How do organic and inorganic phosphorus differ from each other?<br>What are the conditions for each becoming bioavailable? |
| Aqueous solutions (concentration, precipitation/ mineralization, equilibrium) | What is the saturation point of an aqueous solution containing the phosphates present in soil?<br>What happens when the water contained in soil becomes saturated with phosphorus, and how is this process similar to or different from what happens in a test tube in the laboratory? |
| | What factors determine whether the phosphorus will remain in the soil once the saturation point has been reached?<br>Do phosphates promote algal growth in salt solutions like ocean water to the same degree as they do in fresh water? |
| Acids and bases (pH) | What happens to the water solubility and bioavailability of phosphorus to plants as pH increases? As it decreases? |
| Photosynthesis and plant metabolism (ADP, ATP) | How is phosphorus metabolized by algae? What happens chemically during this process?<br>Are there chemically-based trigger mechanisms for growth of toxic vs. non-toxic species of fresh water algae? If so, how do they function? |
| Plant mortality and decomposition | What is the chemical composition of microsystin, and how are its composition and effects similar to or different from that of other hepatoxins?<br>What are the conditions (e.g., light, water temperature and depth) that promote or retard its production in and emission from HABs? |


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*Figure 5. Ohio colleges and universities in Western Lake Erie Basin watersheds.*

## Promoting Deeper Learning Through Civic Engagement

Specifically, science faculty at Lourdes College, Defiance College, and the University of Findlay are beginning to take a holistic look at watershed processes in their communities, one that encompasses both the biology and chemistry of water and soil interactions. Their efforts are an expression of, and have evolved with the support of, complementary programs of the National Center for Science and Civic Engagement at the Harrisburg University of Science and Technology: SENCER (Science Education for New Civic Engagements and Responsibilities) and GLISTEN (the Great Lakes Innovative Stewardship Through Education Network).

SENCER is a 10-year-old NSF-funded faculty development program that promotes teaching "to" basic, science and mathematics principles "through" complex, capacious, often unsolved problems of civic consequence. Civic engagement in courses taught by SENCER-affiliated faculty may take many forms, from issue-focused case studies discussed in the classroom to "on-the-ground" actions that help students learn science and mathematics by applying their skills directly to addressing unmet needs in the local community (*7*).

The GLISTEN project, an outgrowth of SENCER funded by the Learn and Serve America program of the Corporation for National and Community Service, takes the SENCER approach to civic engagement a step further, by promoting the incorporation of environmental service-learning components into undergraduate coursework in the STEM disciplines and focusing students' service-learning activities on stewardship of the largest source of available fresh water on earth, the Great Lakes (*8*). A Great-Lakes-wide project, its focus is nonetheless on coordinated local action. Therefore, GLISTEN is organized into "collaborative clusters" of higher educational institutions committed to enhancing their undergraduate STEM curricula through collaboratively addressing Great Lakes ecosystem challenges in their regions of that ecosystem; the locations of these clusters appear in Figure 6. Each cluster incorporates community-based public and private non-profit environmental agencies and organizations focused on stewardship of the Great Lakes, including venues of informal science education for public dissemination of project activities and outcomes.

In each Cluster, science and engineering faculty form mutually-beneficial partnerships with the community-based organizations to align undergraduate course goals and learning outcomes with activities that address "beneficial use impairments" affecting Areas of Concern identified in the bi-national Great Lakes Water Quality Agreement, such as the Maumee River watershed. Among these impairments are eutrophication or undesirable algae, resulting in others such as beach closings and restrictions on fish consumption, with the potential for added costs to agricultural enterprises in order to address all of them. Through course-based projects involving water quality testing, soil testing, and control of erosion, stormwater and the spread of invasive species, students in courses taught by GLISTEN-affiliated faculty are motivated to learn science more deeply, because they see the direct relevance of disciplines such as chemistry and biology to the world around them through active engagement in stewardship of that world.


*Figure 6. Location of GLISTEN Collaborative Clusters as of February, 2011.*

The goals of GLISTEN also include helping students as well as other residents of Great Lakes communities to become enlightened stakeholders who practice active stewardship behaviors in their private and civic lives. While most undergraduates do not plan to be farmers, they will probably be homeowners, and many will be suburban homeowners whose role in the management of nutrient-laden stormwater runoff is equally significant. Indeed, as private citizens with a science-based understanding of the causes of lake eutrophication, they will be well-positioned to support development of the Lake Erie Nutrient Binational Management Strategy called for in a recent report by the Lake Erie Nutrient Science Task Group. This strategy, says the report, will require "the consensus of key Lake Erie resource managers on the goals, objectives, targets, indicators, priority watersheds, monitoring and research needed to improve current conditions and to prevent further eutrophication of the lake." Key to the success of that strategy will be "the commitment from various stakeholders (e.g., government officials, members of the agricultural community, land use planners, homeowners, etc.) to join forces and to change how nutrients are currently used, applied, transported, and discharged" (*9*). Successful students in GLISTEN-affiliated courses, therefore, will be uniquely positioned to help forge consensus among very diverse stakeholders by promoting science-based practices to non-technical constituencies such as farmers and homeowners, whose collaboration will be critical to the success of the strategy.

## Coordinating the Curriculum and Community Outreach

In terms of student learning and impact in the context of their coursework, although the efforts of faculty and students at these colleges and universities are in their nascent stages, these efforts represent a new approach to interdisciplinary


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and inter-institutional collaboration. Such an approach could provide the human resource pool needed by state agricultural cooperative extension and soil and water conservation services to help farmers develop detailed science-based nutrient management plans for farmlands at the greatest risk of contributing phosphorus run-off to Lake Erie tributaries.

Critical to the success of this effort will be

- explicit linking of topics throughout the undergraduate chemistry and biology curricula to HAB-related applications
- forging of ongoing alliances between college faculty and community-based environmental practitioners, particularly those already engaged in assisting farmers with maximizing crop yield while limiting environmental impact on the tributaries of Lake Erie
- engagement of college and university laboratories in testing soil samples gathered from the stratum most likely to leach phosphorus into these tributaries, one that current standardized soil testing protocols do not typically analyze
- the aggregation and sharing of chemical and biological data in compatible and actionable formats that will facilitate enlightened decision making in both public and private arenas
- coordination of chemistry and biology curricula on and among collaborating campuses to ensure that service to farmers and other community-based stakeholders is provided consistently and continuously and
- engagement of undergraduates at various levels in increasingly complex projects addressing the HAB issue, from water quality and soil testing in lower level classes to "deliverable projects," such as fully-developed nutrient management plans, in capstone classes.

This approach is being driven in large part by student interest. An exemplary case is Kyle Snyder, a Lourdes College senior, farmer's son, and agricultural landowner himself. Convinced that agricultural run-off is the principal contributor of toxic-algae-generating phosphorus to the western Lake Erie basin, he has been actively engaged in conversations with his rural neighbors about the types and amounts of fertilizer they are using on their fields. Associated with these communications has been the development of a senior research project on nutrient runoff and transport through sub-surface drainage systems – ubiquitous in Northwest Ohio since most farmland there contains soil that once formed part of the Great Black Swamp. It is here that he confronts the interface between environment and economics. Two of his findings are laying the groundwork for further engagement of faculty and undergraduates in addressing the phosphorus runoff problem. First, most farmers have a very keen sense of environmental stewardship, and would be open to education about the issue provided it is communicated in a manner respectful of their detailed knowledge of their land and its productivity crop challenges. Second, they are not averse to making modest financial investments in addressing the phosphorus runoff problem. Thus, they are likely to respond positively to voluntary development of nutrient management plans for their land, provided they receive needed support in doing so (*10*).

As of the publication of this monograph, plans are progressing to create such a synergistic campus-community network that will enable Kyle and others farmers to make land management decisions based on science generated by his peers in undergraduate science classes taught throughout Northwest Ohio. A future monograph will address the effectiveness of this approach, from both the curricular and environmental perspectives, in terms of learning gains for the undergraduates and land management practices in the agricultural community (*11*). The hope is that by "following the phosphorus," college and university students in the Western Lake Erie Basin – majors and non-majors alike – will not only have a much clearer understanding of how science relates to their everyday experiences, but be empowered to inform and lead others in the effort to apply that understanding in their professional and private lives for the long term.

## Glossary (*12*)

**ADP, ATP**: Adenosine diphosphate and Adenosine triphosphate. The conversion of ATP to ADP, resulting in the loss of a phosphate molecule, is the basis of metabolism in plants and animals.

**Anerobic dead zone**: a layer of lake water that has little or no dissolved oxygen in it, resulting in the disappearance of fish and other aquatic wildlife.

**Conservation tillage**: Tillage that involves breaking up the top layer of the soil but leaving at least 30% of crop residue from the previous year on the soil surface.

**Dissolved reactive phosphorus**: That part of the total quantity of phosphorus found in water which can be used by plants.

**Eutrophication**: Fertilization by nutrients of an aquatic ecosystem, causing high biological productivity and biomass in that ecosystem. Eutrophication can be a natural process that occurs over an extended length of time; as used in this monograph, it is a process accelerated by an increase of nutrient loading to a lake by human activity, including farming.

**Harmful Algal Blooms (HABs)**: In fresh water ecosystems, rapidly-growing blue-green algae resulting from high nutrient and light levels. HABs can produce neurotoxins (which affect the nervous system) and hepatotoxins (which affect the liver).

**Microcystin**: A hepa- and neurotoxin as well as skin irritant produced by microcystis.

**Microsystis**: A type of blue-green algae which produces microcystin.

**Quagga and zebra mussels**: Invasive species of mussels native to parts of northern and southeastern Europe. Since invading the Great Lakes in the late 1980s, they have significantly reduced the amount of food available to native mussels and fish.

**pH**: Measure of the degree of acidity or alkalinity in a solution. Differences in pH determine how much of the total phosphorus in soil and water is in the form of dissolved reactive phosphorus and therefore available to plants.

**Soluble reactive phosphorus**: see **Dissolved reactive phosphorus**
**STEM disciplines**: science, technology, engineering, and mathematics

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8. A detailed overview of the GLISTEN project can be accessed at http://www.greatlakesed.net.
9. Lake Erie Lakewide Area Mangament Plan Lake Erie Nutrient Science Task Group; *Status of Nutrients in the Lake Erie Basin*, December 2009, pp iii–iv.
10. Summary of electronic communication from Kyle Snyder, Nov 1, 2010.

11. In addition, information on the following will be accessible at http://www.greatlakesed.net: campus and community partners involved, service-learning activities conducted, curricula developed and implemented, and student learning gains assessed.
12. Definitions in the glossary are based on information from the following resources: http://www.epa.gov/glnpo/atlas/glat-app.html#Glossary; http://www.epa.state.oh.us/portals/35/lakeerie/ptaskforce/Task_Force_Final_Report_April_2010.pdf; http://www.odh.ohio.gov/features/odhfeatures/algalblooms.aspx; http://www.glerl.noaa.gov/res/Centers/HumanHealth/docs/bluegreenalgae_factsheet.pdf; http://www.epa.gov/glnpo/lakeerie/glossary.html; http://www.glerl.noaa.gov/pubs/brochures/20ZMresearch.pdf.

# Chapter 16

# Your Water Footprint Is Next

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Most students growing up in the developed world have not had to confront the availability or cost of water. In their experience, water is readily available at a nominal (often invisible) cost. Lifestyle choices are not made on the basis of water cost or availability. Alas, this fortunate circumstance may not always persist. Throughout the world, changes in water availability are becoming more frequent. Even in the United States, some areas are facing water shortage; this typically affects agriculture first, but then the problem spreads more generally into the economy of a region. Our attention has been called to this as a consequence of climate change, but other factors are also important: population growth (increasing demand), water pollution (decreasing supply), increasing affluence (increasing demand) and other factors. These changes will gradually increase our consciousness of water issues and generate a re-examination of the choices we make about water. Much of the water that we "consume" is a largely-invisible part of the cost of producing the food we eat and the consumer goods we purchase. The water-footprint concept, analogous to the carbon-footprint concept, can provide a useful framework for understanding this complex role of water and for informing our water choices.

## Carbon Dioxide and Climate Change

The concentration of carbon dioxide in the atmosphere has been increasing since early in the Industrial Revolution, and at present is about 50% higher than its pre-industrial level. The Intergovernmental Panel on Climate Change (IPCC), as


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well as scientific organizations and academies of sciences in many countries have concluded that the Earth's climate is warming as a result of the increasing presence of carbon dioxide and other greenhouse gases in the atmosphere (*1*, *2*).

The principal cause of the increasing concentration of carbon dioxide is the combustion of fossil fuels. In turn, fossil fuel combustion is linked to energy production, which in turn is linked to economic activity. As world population has increased, and as economic activity has increased, atmospheric concentrations of carbon dioxide have increased, and consequently, global temperatures are increasing. Indeed, our every action seems linked directly or indirectly to the release of a certain amount carbon dioxide to the atmosphere, from the cars we drive to the newspapers we read to the food and drink we consume.

## Carbon Footprints

The rising environmental consciousness around carbon dioxide emissions over the last couple of decades has led to an awareness that choices we make as consumers can have a significant effect on carbon dioxide emissions—not only the energy we use to power our vehicles and heat our homes, but the energy used to produce our food, clothing, and consumables. These personal choices can be quantified as a "carbon footprint" – a statement of the carbon dioxide emission associated with a particular object or activity (e.g., a printed book, or a trip to the store) or even for a person or household (*3*).

There are many websites that offer online calculators, and the landscape is changing rapidly. The website CO2List.org lists a lot of carbon calculators and compares them. A few of the good ones as of this writing are Cool California (*4*), the Global Footprint Network (*5*), $CO_2$List (*6*), and the Nature Conservancy (*7*).

A perusal of such sites, using one's own situation as a starting point for a carbon footprint calculation, soon reveals that different programs give quite different answers because of the assumptions embedded in the calculation methods. For example, the program may ask you how many miles you drive your personal auto per year, but different programs take different approaches to calculating your gasoline consumption based on that information (recall that not only does gas mileage vary with vehicle, but also with driving habits and driving environment). Thus, the serious student of this is advised to look at several calculators and make thoughtful comparisons.

The complexity does not end there. How should we include your share of the carbon footprint associated with the manufacture of your car? How would we include a farmer's travel in calculating the carbon footprint associated with a loaf of bread or a pound of meat? The message here is that the absolute numbers are less important than what they tell us about the personal choices we are making; choices we make which lower our carbon footprints are more important than the question of whether that footprint reduction is 10% or 20%.

The average American has a footprint of about 20 tons of $CO_2$ per year, and this is the highest in the world (*3*). For many of us in the sciences, travel is an important part of that footprint—depending on length, less than a dozen trips per year may double your carbon footprint (*7*).


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Recently, the business community has begun to take an active interest in corporate carbon footprints and also in the carbon footprints of the products they manufacture (*3*, *8*). This is driven partly by good citizenship and partly by good economics—carbon emissions cost money, because they represent energy. Wal-Mart has been particularly public and aggressive in trying to provide carbon footprints for its products; they have taken steps not only to reduce their own carbon footprint, but they have also encouraged consumers to buy energy-efficient products (e.g., compact fluorescents in place of incandescent light bulbs). There are now a number of companies in the business of calculating carbon footprints for manufactured products. Although this field is not yet mature, it is getting there rapidly. Discussions of a possible carbon tax in the U.S. has led companies to want to know about their carbon footprints.

## Water – A Limited Resource

Besides energy (and therefore carbon dioxide), mankind's other major consumption problem is with water. Like energy, water consumption is linked to just about every human activity: food production, sanitation, transportation, manufacturing, and so on. Even more than in the case of embedded energy, we aren't necessarily aware of the water costs embedded in the products we consume and the activities we undertake.

But the comparison of water to carbon dioxide is imprecise. The difference is that water is in some sense renewable (yes, some forms of energy, e.g., solar, are renewable, but they do not at this moment constitute a significant fraction of the world's energy portfolio). Water, in the form of rain, comes to us much as manna from heaven, but the extent to which this rain provides for our water needs varies with where we are. Compare New England, whose water needs are largely supplied by rainwater, with southern California, which imports large amounts of water from the Colorado River, northern California, and elsewhere. Insofar as we use only the amount of water that we can derive from rain, water becomes an indefinitely renewable resource. Indeed, traditionally it was accepted that access to water, like access to air, was free, and unlimited (*9*, *10*). Alas, this fortunate situation applies only for a small fraction of the Earth's population.

### The Water Cycle

The water cycle (Figure 1) tries in a finite space to summarize the very complex story of how water circulates from the Earth (via evaporation) to the atmosphere and back to the Earth (via precipitation). Reservoirs of water (e.g. lakes, streams, groundwater) may turn over in hours, days, years, or even centuries. Water runs downhill, much of it entering the oceans before evaporation begins the cycle again. A more complete description of the water cycle is given in (*11*, *12*).

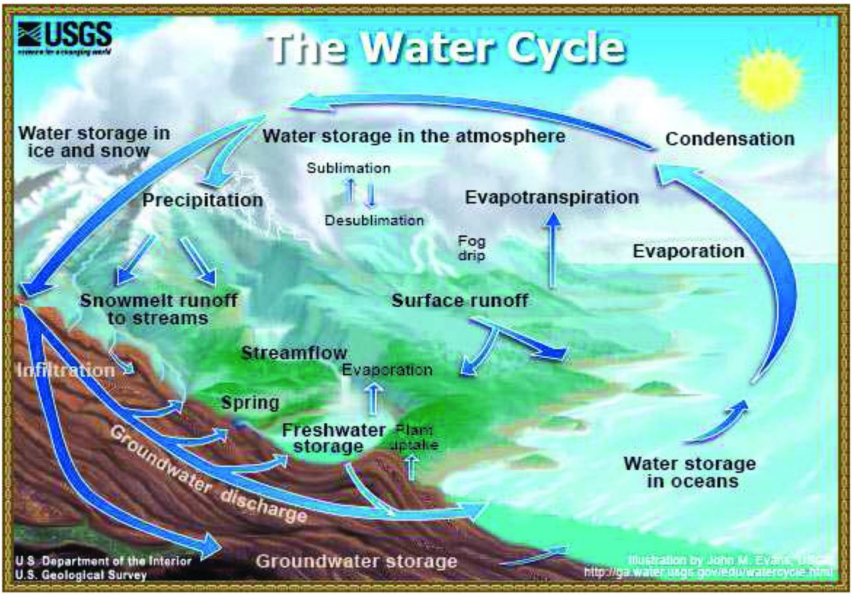


*Figure 1. The water cycle. (courtesy U.S. Geological Survey).*

Earth is often called the blue planet; Seen from space, much of the Earth is covered with water, and in fact, worldwide there is a large amount of water. But more than 97% of the Earth's water is saline, and in the oceans. Of the remaining 3%, about 2/3 is tied up in icecaps or glaciers, and only the remaining 1% is available for human use, and only about a third of that is in rivers and lakes (*13*, *14*). (Figure 2).

**Uses of Fresh Water in the U.S.**

By world standards, the United States has a seemingly generous supply of water. Per capita U.S. withdrawal of fresh water in 2000 was 5413 l per day. As is the case throughout the world, the majority of that water (roughly 70%) is used for agricultural purposes. Of the 30% that is nonagricultural, about half is used for domestic purposes and the other half for industrial purposes (*13*, *15*).

By world standards, this is a generous rate of use. Worldwide, water use, like energy use, tends to track with standard of living. Water conservation is starting to happen in the United States; per capita withdrawals have decreased in the last 20 years. Unfortunately, U.S. water resources are already over-allocated. To cite one well-known example, allocation of Colorado River water was based on data from the wettest period in 400 years. The Intergovernmental Panel on Climate Change has pointed out that as warming accelerates, changes can be anticipated in the timing, volume, quality and spatial distribution of available freshwater (*16*).

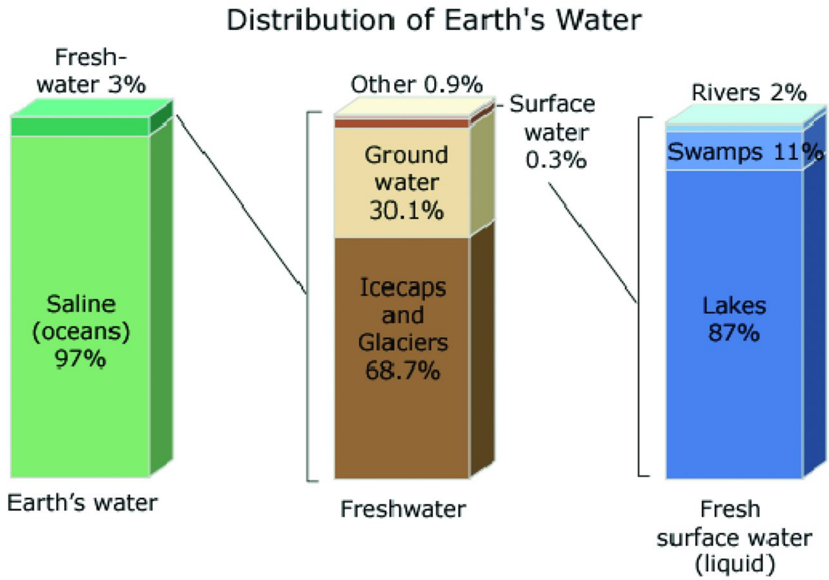


*Figure 2. Distribution of the Earth's water resources. (courtesy U.S. Geological Survey).*

**Human Use of Water**

Access to water is considered a basic human right, and traditionally no price has been put on water. This works fine when water is plentiful and when population densities are modest, but it can become problematic in arid or highly-populated environments. The human need for water takes several forms: most immediate is the water we drink and the water used to prepare our food. Immediately beyond that is the need for water for sanitation. So-called "domestic" uses of water also include other household uses such as bathing, laundry, etc.; all these together only account for about a quarter of total water consumption. According to the American Water Works Association, indoor domestic water consumption in the U.S. is currently 242 l per person per day (*17*). The remaining water consumption is largely the water cost of supplying the food we eat—the agricultural uses of water (*9*, *10*, *16–18*).

Globally, an area is considered water stressed if the per capita availability of water (for all uses, including agriculture) is below 1,000 m$^3$ per year. Worldwide, 17% of the population lack access to water, according to the World Health Organization standard for accessibility of water, which requires access to 20 l per day from an improved water source within a distance of 1 km.; The World Health Organization estimates that the total burden of disease due to inadequate water supply and poor sanitation is 1.7 million deaths per year. Water scarcity is expected to increase in several parts of the world in coming decades; IPCC estimates of the number of people affected by water scarcity are 0.4 to 1.7 billion by the 2020s, and some other estimates are even higher (*16*, *19*).


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## The Water Footprint Concept

With the recognition that we needed to pay more attention to the use and management of water, a number of groups have started to put water consumption on a more quantitative basis. The general pattern of this effort has been modeled after the carbon footprint concept, acknowledging that the two aren't entirely parallel.

The most widely-recognized effort to develop a formal water-footprint paradigm originated in 2002 with Arjen Hoekstra, at the University of Twente, in The Netherlands. This has now become the most widely accepted approach. It is supported by UNESCO and is now formalized in the Water Footprint Network (*20*). An excellent Water Footprint Manual is now available (*21*), along with a variety of other materials, including a variety of examples of water-footprint calculations.

According to Hoekstra, "the water footprint of a product is defined as the total volume of fresh water that is used directly or indirectly to produce the product" (*20*). Thus, the water footprint concept is broader than traditional estimates of water withdrawal but instead offers a more comprehensive view of how a consumer uses water.

As is the case with carbon footprints, there is room for differences in how water footprints are calculated, and the same final product may have a quite different footprint depending on its source and the cost of transportation to bring the object to its point of use. Hoekstra also points out that you will get somewhat different answers depending on your goal—information to an individual consumer, regional information supplied to a river basin authority, or aggregated information supplied to a national government (*21*).

A particularly instructive example of how a water footprint is developed can be found in the Twente group's report on the water footprint of a 0.5 l PET bottle of sugar-containing carbonated soft drink (*22*). Calculations were made for the water cost using sugar from a number of countries and from a number of sources (cane sugar, beet sugar, or high-fructose corn syrup). Calculations included the water cost of manufacturing the bottle, the water cost for operation of the soft-drink factory, the cost of transportation, and other factors. Ultimately, more than 99% of the water cost was in the production of the goods and services that form the input to the actual manufacturing process; that is, the "overhead" cost (the general cost of running the business) was less than 1% of the total cost. Surprisingly, the total water footprint for a 0.5 l bottle of beverage was between 169 and 309 l of water, depending on the source of the sugar. The least costly was beverage made using sugar beets or high-fructose corn syrup produced in the Netherlands or France. The most costly was beverage made from high-fructose corn syrup from India or from sugar cane from Cuba. A major contribution to the water footprint comes from two minor ingredients—caffeine and vanilla—which together account for about 130 l.

In collaboration with the Water Footprint Network and the World Wildlife Fund, the brewer SABMiller has calculated quite different water footprints for 1 l of the same beer brewed in South Africa (155 l) or in the Czech Republic (45 l). (*23*). Much of the difference reflects the water cost of irrigation.

## Water and Consumer Products

The Water Footprint Network has provided typical numbers for a variety of foods and other consumer materials (*20*). For example, the water footprint of a single apple is 70 l, principally because of the water used to maintain the apple tree. A single kilogram of beef has a water footprint of 15,500 l; this includes the water cost of the 1300 kg of grains the animal has consumed, 7200 kg of roughage, 24 $m^3$ of water for drinking, and a number of other components. A glass of wine typically has a water footprint of 120 l. A single slice of wheat bread requires 40 l of water, mostly for growing the wheat. A single egg requires about 200 l of water, and a hamburger sandwich about 2400 l.

What becomes clear from the numbers in the preceding paragraph is the tremendous water cost of growing plants—whether those plants are used for making a cotton shirt, for feeding us fruits and vegetables, or (most extreme) for feeding the livestock that provide us with meat and dairy products. Plant scientists have long known that a plant requires about 500 times as much water as the biomass the plant produces; that is, roughly 500 g of water is required to produce 1 g of plant dry weight (*24*). This figure only includes the water actually taken up by the plant, not water that runs off the field. If the calculation is done only for the grain or fruit of the plant (which typically constitutes less than half of the weight of the plant), this ratio increases by an additional factor of two or more.

Worldwide, about 70% of total freshwater use is for agriculture. Water efficiency can be managed somewhat by careful irrigation practices, or by growing plants in regions where irrigation is not required, but the improvements that can be attained in this way are limited. Genetic engineering may have some limited role in future improvements.

## Personal Water Footprint Calculators

Contributions to a personal water footprint can conveniently be divided into three categories:

1. Food. This includes the water cost of growing, processing, transporting, and preparing various foods.
2. Other household water uses. This includes sanitation, bathing, laundry, dishwashing, and the like. It also includes as a separate subcategory yard irrigation and maintenance.
3. Water costs of manufactured goods. This is the most difficult to deal with, because of the large number of components in the production, transportation, and marketing cycles.

Just as the concept of personal carbon footprints has become imprinted in the minds of environmentally-conscious consumers, personal water footprints are increasingly recognized as a reality of living in an environmentally-responsible manner. There is not yet the variety of calculators for water on the Internet that there is for carbon dioxide, but the number is rapidly increasing. Four widely-used ones are described below; all are available on the Web.

It is educational to compare the results of your water footprint for several different calculators. Because of differences in assumptions, the results may be quite different (the author got results that differed by more than a factor of ten); the most useful comparison is your own water footprint with the average for your own state or country.

*Facebook*

This widely-used water footprint calculator was developed by the Siemens company and is available on Facebook (*25*). It is the simplest and most accessible of the calculators described here, but it is also the least detailed. It includes only food and other household contributions; no account is taken of the water cost of manufactured goods. There are several good questions about household water consumption (use of low-flush toilets, for example). Beyond a general question about eating habits, (vegan vs. vegetarian vs. meat eater) there is no accounting for personal variations in dietary habits.

*$H_2O$ Conserve*

$H_2O$ Conserve is a program of ICCR, GRACE, Food & Water Watch, and the Johns Hopkins University Center for a Livable Future (*26*). The calculator asks you about a variety of details of your lifestyle and then combines those with statistical data about water consumption patterns in the United States. It is particularly good on household water use (toilets, laundry, etc.); this is the only calculator that asks about the use of bottled water, or the consumption of gasoline or recycling or rainwater collection. It has less details about the water footprint of food than the Water Footprint Network or Kemira calculators. It does not account for the water cost of manufactured goods.

*Water Footprint Network*

As noted above, the Water Footprint Network has been a leader in developing the water footprint concept and in implementing a set of norms for doing both personal and business calculations of water footprints (*20*). The calculator is particularly useful because it considers a variety of details about diet that are absent from other calculators (e.g., consumption of cereal products, meat products, dairy products, etc.). It also tries to individualize other household uses of water (dishwashing, laundry, garden, swimming pool, etc.). It is the only calculator that attempts to assess the water cost of manufactured goods you use (for an affluent consumer, this is more than 75% of the total water footprint). This is done on the basis of personal income (admittedly, an inexact measure, but it is the best thing available at present).

*Kemira*

Kemira is a Finnish chemical company with a particular focus on water. Their water footprint calculator does a good job on individual food and household issues, but then takes an average for the water cost of manufactured goods (with no accounting for income or lifestyle) (*27*).

**Corporate Water Footprints**

As with carbon footprints, many corporations are starting to pay attention to their water footprints. This is happening for a variety of reasons—increased water scarcity (and cost) in some areas, corporate social responsibility, and as insurance against future water shortages. For manufactured goods, the direct water cost of the manufacturing process is generally a modest fraction of the overall water footprint. Most of the water cost is in obtaining the original raw materials and bringing them to the manufacturing site.

On average, it takes 80 l of water to make $1 worth of an industrial product (*28*).

## Water and Climate Change

Climate change in coming years is expected to influence not only local temperatures, but local water availability as well. A number of important interactions between water and climate are worth noting (*16*, *19*, *29–31*):

- Changes in precipitation are particularly hard to predict.
- Extreme weather events are likely to become more common and more extreme.
- More irrigation will be needed in many areas. There are likely to be more wet years and more dry years, but less "average" years.
- Arid regions will become more arid.
- Water storage needs will increase, particularly in the U.S. west; less water will be stored as snow and gradually released over the spring and early summer.
- More people will be exposed to water stress.
- Demand for water will increase, as people in a particular country become more affluent.
- Extracting fresh water from sea water is still a major problem. Costs are still near $1 per $m^3$, and this is unlikely to decrease significantly.
- Finally, history is a poor guide for our future management of water.

## Water and Sustainability in the Chemistry Curriculum

The goal of including a discussion of water footprints in the chemistry curriculum is to sensitize students to the fact that water is neither free nor infinite. Instead, it is a finite resource that must be managed and minded. Further, it is a resource that in many environments will become increasingly costly in coming decades. This discussion is also an ideal vehicle for introducing the concept of sustainability.

Discussions of water consumption can proceed from pure chemistry in a variety of directions: how this will be affected by climate change, the sociology surrounding choices that we make as individuals, the economics of water, the water cycle, and many more. Here are some examples of student activities focused on water and water footprints:

- Have each student calculate his/her own water footprint. Use this as a starting point for getting students to think about the whole process of estimating based on incomplete data (something that we scientists often do, even without recognizing it).
- Ask students to compare their own water footprint using the various calculators that are available online and then talk about the reasons for the variations.
- Have individual students or groups of students determine the water footprint of their home, their family (note that these two are different), their chemistry lab, their chemistry department, their church, or some other entity. Ask them to identify ways that the footprint might be reduced.
- Ask students to obtain information about the water footprints of residents of various countries and use this as a starting point for talking about water consumption and lifestyle.
- Beverages provide a particularly useful comparison of the water footprints of various products. Ask students to develop a comparison of the water footprints of a single serving of a variety of beverages: tap water, bottled water, milk, orange juice, soft drink, tea, coffee, beer, wine, etc.
- Ask students to develop a simple water-footprint calculator that would be appropriate for middle-school students.
- Ask students to develop a water-footprint calculator for their chemistry course that would be appropriate to distribute to all students enrolled in their chemistry laboratory, as a way of sensitizing students to the water consumption associated with the laboratory.
- Among substances in the environment, water is unusual because it occurs naturally in all three phases. This in turn is related to the high heats of fusion and vaporization of water. Ask students to consider how the Earth would be different if the heat of fusion and/or vaporization were only half of its actual value.
- Ask students to choose a food item that they frequently consume (soft drink, hamburger sandwich, chips) and estimate its water footprint.
- Ask students to find out how their local water utility is encouraging water conservation.

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## Chapter 17

# Chemistry and Society Courses Can Address Global Issues

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Climate change and sustainability are not discipline-specific issues. As the central science, however, chemistry offers students in non-science-major "chemistry and society" courses a unique opportunity to explore these global issues in an appropriately global context. We journey around planet Earth, stopping at specific locations to explore fundamental topics from the natural sciences. Our journey investigates species extinction in the cloud forests of Costa Rica, receding alpine glaciers in New Zealand and Switzerland, carbon dioxide spewing from the smokestacks of industrial China, terrestrial carbon trapped in the frozen Arctic tundra, polarized ideologies in the committee rooms of Washington DC, and more. At each location, we connect the science with significant social, political, ethical, and economic issues in that region. Our global analysis incorporates interviews with scientists, policy makers, community leaders, and others as we weave scientific climate-change principles within the contextual framework of social issues and ecosystems. This global analysis allows each student to personally assess the momentous challenge and urgency of addressing climate change, as well as the stewardship required of us—the planet's trustees—to provide a habitable world for future generations.


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## Authors' Note

*Please note* that the following content is taken in part from an upcoming undergraduate chemistry text from Pearson Education—written by the co-authors of this article—with climate change and sustainability topics/issues. The title for this text will be *Concepts in Chemistry: A Global Narrative on Climate Change and Sustainability*, and the anticipated date of publication is January 1, 2014.

## Introduction

Non-science-major chemistry and society courses can address the complex multidisciplinary and interdisciplinary issues associated with climate change and sustainability. These global issues, though, require a global analysis. Even though time in the classroom is limited, it is nevertheless possible to achieve that balanced, global analysis by keeping each classroom topic focused, fundamental, and personal.

I take my students on a journey around the planet—physically through field trips and vicariously through interviews, web links, and stories from my own experiences. Together, we weave the threads of the climate change and sustainability story from far-flung locations into a global fabric that connects chemistry with significant social, political, and ethical issues.

Please join me as we travel to some of these locations. I will briefly illustrate how I try to accomplish this challenging task with a few representative examples. We will begin our journey as I did with my "Chemistry and Society" students who entered the classroom on the first day of the 2010 spring semester.

## Bonn, Germany (United Nations Climate Negotiator Speaks)

Just prior to the 9:00 a.m. start of class, I encouraged the students to "…Please quickly find a seat. We are going to watch a live webcast from Bonn, Germany." The live image of Yvo de Boer, the chief UN climate negotiator, was already projected on a screen at the front of the classroom. I stated that "This will be the first press briefing since the close of the Copenhagen climate conference last month. His comments will be of direct concern to every single one of you in this room and they will be fundamental to this course. I will explain later."

Almost immediately, Mr. de Boer began speaking. "It is fair to say that Copenhagen didn't deliver the full agreement the world needs to address the collective climate challenge," he said. "That just actually makes the task at hand more urgent. The window of opportunity we have to come to grips with this issue is closing …COP15 was not a success but did produce three key things." Mr. de Boer listed these:

- It raised climate change to the highest level of government, which is ultimately the only level at which it can be resolved.
- The Copenhagen Accord reflects a necessary, political consensus on the long-term, global response to climate change.


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- Closed-door negotiations very nearly brought a full set of decisions to implement rapid climate action.

"So, in a way you could say that Copenhagen didn't produce the final cake, but it left countries with the right ingredients to bake a new one in Mexico." (*1*)

## Copenhagen (Hopenhagen)

The live briefing from Bonn lasted less than ten minutes. We disconnected from the webcast without listening to the follow-up question-and-answer period. I told my students we would be investigating the "ingredients" that Mr. de Boer spoke of, the raw materials that would hopefully lead to a successful outcome at the next Conference of Parties (COP16), to be held in Cancún this December (*2*).

This prompted a classroom question-and-answer period directed at me, the course instructor. "What is the UNFCCC?" "What are COP15 and COP16?" "What's the big deal with Copenhagen?"

This was a great way to begin a semester: inquiry-based learning. The first order of course business, though, before answering questions, was to address first-day-of-the-semester issues such as the class roster, course syllabus, and course mechanics. I explained that "this is an issues-oriented chemistry literacy course. We will broadly apply chemistry concepts to the study of our atmosphere, water, and energy, within the contextual framework of social issues and ecosystems. We will focus our discussion on the most compelling dynamic issues of our time—climate change and sustainability."

Copenhagen is the perfect starting point for this discussion.

Copenhagen fashions itself as an eco-metropolis; it is rated as the greenest major city in Europe and aims to become the world's first carbon-neutral capital city by 2025 (*3*, *4*). As such, Copenhagen was a fitting host for the 15$^{th}$ Conference of Parties (COP15) to the United Nations Framework Convention on Climate Change (UNFCCC) from Dec. 7-18, 2009 (*5*).

I was able to provide my students with a first-person account of the Copenhagen Climate Conference, as I had traveled there barely a month before as an official correspondent for my local newspaper, the *York Daily Record/Sunday News* (*6*). The United Nations had granted me press credentials to blog for the York newspaper, and these press credentials turned out to be the 'golden ticket' in Copenhagen. The UN had accredited more than 40,000 delegates, NGO representatives, and correspondents for admission to the Bella Center, where official negotiations were taking place. Capacity at the Bella Center, though, was just 15,000, so thousands of individuals seeking entrance were left—quite literally—out in the cold. Everyone with press credentials was admitted (*7*).

The UNFCCC gathering in Copenhagen in December 2009 was unprecedented. Heads of state from more than 100 nations converged on the city for the express purpose of acting on climate change and mitigation (*8*). Each of these leaders declared a climate emergency, stressing that our planet needed to be "fixed" if we want to leave a sustainable Earth for our children, grandchildren, and as-yet-unborn generations. Copenhagen had been dubbed "Hopenhagen," a play on the city's name, to underscore the fervent hope that this climate conference would help build a better future for our planet and a more sustainable way of life (*9*).

The students in my 2010 spring semester class were hardly the only ones to experience a Copenhagen connection. I had witnessed a significant college- and community connection while blogging from Copenhagen the previous semester. In December 2009, I even taught two of my senior-level inorganic chemistry classes and my general chemistry class via Skype, live from the Bella Center (*10*). I also held a video conference with a York Suburban High School AP Biology class, and the *York Sunday News* ran three consecutive feature articles based on my blog (*11–13*).

The anticipated outcome from Copenhagen was to be a new post-Kyoto protocol. Political wrangling over emissions-reduction targets, wealthy nations' willingness (or lack thereof) to offer financial assistance for developing nations, and transparency (independent verification of each country's emissions cuts) could not be resolved. In the end, high-level representatives ceded negotiating authority to their respective heads-of-state. President Obama helped to forge a "Copenhagen Accord," but the Accord did not include specific emissions reduction targets, and the parties involved could only agree to "take note" of its provisions (*14*, *15*).

In the end, the accord's appendices for "targets"—the part of the document in which participating nations were to indicate their emissions targets—were left blank. Those countries willing to do so were required to submit their emissions targets by January 31, 2010. My students and I would have real-time access to the process, observing the dynamic events and assessing the "ingredients" proposed by each nation for "baking a new cake" to solve the climate crisis.

## China (Leading National Greenhouse Gas Producer)

What emerged from the accord was a widely varied list of promises. China, for example, returned a one-page statement that it would "endeavor" to cut emissions *intensity* by 40-45% of 2005 levels by 2020 (*16*).

The introduction of the *emissions intensity* metric deserves some explanation. China's emissions *intensity* statement, in fact, was not a pledge to lower actual greenhouse gas *emissions*. As we see in Figure 1, greenhouse gas emissions intensity is the ratio of greenhouse gas emissions to economic output.

In other words, China's pledge to cut *emissions intensity* would allow its *actual emissions* to increase as long as its economy continues to grow. This equation is a superb public policy tool.

$$\frac{\text{Greenhouse Gas Emission}}{\text{Economic Output}} = \text{Greenhouse Gas Intensity}$$

*Figure 1*


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In 2007, China surpassed the United States as the leading national greenhouse gas emitter (*17*, *18*). Countries seeking to reduce *actual greenhouse gas emissions* will see China's metric for what it is: a measure of just how *efficiently* it can make greenhouse gases, rather than a useful tool for minimizing emissions. China is, in the process, becoming a leader in energy efficiency. China's pledge to lower its *emissions intensity* as opposed to *actual emissions* opens many areas for class discussion: public policy, accounting metrics, ethics (e.g. is this just clever economics or environmental suicide?), and more.

## Costa Rica (An Ideal Natural Laboratory)

In its pledge to the Copenhagen Accord, on the other hand, the tiny central American nation of Costa Rica promised to start "immediate action. . . to implement a long term, economy-wide transformational effort to enable carbon-neutrality" [sic] by 2021 (*16*). This was a reaffirmation of its earlier pledge to become the first carbon-neutral country (*19*).

During the 2010 spring semester, I taught two sections of our Chemistry and Society course. The lecture sections of each course were equivalent; only the laboratory activities differed. One laboratory section met each week for three-hour laboratory sessions. The other traveled to Costa Rica for a ten-day ecological field trip to investigate sustainability issues associated with impacts and adaptation to climate change. This was my fourth consecutive year for this international laboratory experience.

The purpose of the Costa Rica laboratory is to provide field experiences that help us better understand fundamental principles underlying the science of climate change, present case studies of species adaptation to global warming, and show attempts to mitigate the impacts of climate change (*20*).

Costa Rica is an ideal natural laboratory for investigating issues related to climate change and sustainability for several reasons:

- The first documented species-level extinction linked to climate change—the golden toad—was reported here (*21*).
- Its national development strategy promotes education, conservation, and ecotourism (*22*).
- It meets 99% of its electrical needs through renewable resources, including wind, hydroelectric, and geothermal.
- More than 28% of Costa Rica's land is held in private or public protected reserves (*23*).
- As stated previously, it has a stated goal to become the first carbon-neutral country by 2021.
- Recently, Christiana Figueres, a member of Costa Rica's climate negotiating team since 1995, was chosen to replace Yvo de Boer as the United Nations chief climate change negotiator (*24*).

Our Costa Rica field laboratory activities investigate impacts and adaptation in three different climate/ecological zones: Arenal Volcano rain forest, Monteverde cloud forest, and Cabo Blanco dry coastal zones. Two vivid examples of impacts and adaptation related to climate change can be found in the cloud forest.

- *Species redistribution*
  Taking advantage of drier conditions, Keel-Billed Toucans are moving from the foothills into the mountains. Toucans have recently started extending their nesting zone into the cloud forest, and now they exist side-by-side with the Resplendent Quetzal. As a result, the Quetzal—symbol of the cloud forest—is now threatened with extinction as a result of climate change (*25*).
- *Species extinction*
  A seminal publication in *Nature* documented the first direct correlation between global warming and mass species extinction (*26*). An estimated two-thirds of Central- and South America's 110 brightly colored harlequin frog species have vanished in the past 20 years. Lead author Dr. Alan Pounds provides a lecture for my students in which he reiterates his bold claim: "The basic message is that global warming is already causing species extinctions, and a lot of them. In this case, lethal disease may be the bullet, but climate change is pulling the trigger." The *bullet* in this case is the chytrid fungus. The *trigger*, though, is higher temperatures.

These experiences provide a 'real-world' understanding of the science of climate change and sustainability.

Students were able to share these and other learning experiences with peers, family members, and the York community through my newspaper blog. Each student reported on a specific activity as a guest blogger. This way, students expanded their world views by investigating and reporting on these global issues.

The Costa Rica trip aims to put students into situations where they feel compelled to ask important questions. For most of my students, this is their first trip abroad and an eye-opening exposure to the developing world. Some students become passionately involved in the "why" discussions. This allows us to address issues such as "why did the U.S. refuse to ratify the Kyoto Protocol?", "why must the EPA regulate greenhouse gas emissions in order to circumvent the quagmire of climate legislation?", and "why don't we have a similar approach to energy and conservation the U.S.?"

## Washington, DC (U.S. Senate Environment and Public Works Committee)

With the Copenhagen Accord, the United States has pledged a reduction "in the range of 17%, in conformity with anticipated U.S. energy and climate legislation, recognizing that the final target will be reported to the Secretariat in light of enacted legislation. The pathway set forth in pending legislation would entail a 30% reduction in 2025 and a 42% reduction in 2030, in line with the goal to reduce emissions 83% by 2050." (*27*)

In other words, the U.S. has pledged actual reductions, but these cuts depend on our ability to push forth climate change legislation. At the time this publication was submitted, climate change legislation remained stalled in our U.S. Senate; obviously, this casts a certain degree of uncertainty on the pledges made following COP 15.

Students enrolled in my Chemistry and Society course with weekly laboratories experience a mix of traditional in-laboratory experiments and field trips. I have found that field trips significantly enhance student learning and contribute to an understanding of the interrelationship of chemistry and societal issues (*28*). One of our field trips is an all-day excursion to our nation's capitol.

The primary purpose of the Washington D.C. field trip is to connect classroom discussions with our political process. We take this field trip late in the semester, as students are beginning to see chemistry in the context of broader political issues. We visit a different legislator each semester in order to maintain a political balance in the course. In the spring of 2010, we visited the office of Republican Louisiana Senator James Vitter, meeting with Bryan Zumwalt, his legislative council on the Environment and Public Works Committee (EPW).

The House of Representatives passed the Waxman-Markey Climate Bill in June 2009 (*29*). The Senate, however, is stuck. Currently, the national political debate on climate change takes center stage in the Environment and Public Works Committee, which serves as an incubator and clearing house for climate change legislation coming out of the Senate. There is a contentious political divide over climate change on this committee.

The Washington, D.C. field trip directly connects students with the source of federal acts and legislative decisions—like the climate bills—as well as decisions to sign or not sign international protocols like Kyoto. For the students, learning about our political process on-location clearly establishes the relationship between science and public policy.

Politicians debate issues related to climate change, but our approach is apolitical. Since the beginning of the industrial revolution, the atmospheric concentration of greenhouse gases has been increasing; this is fact, objectively measured and documented.

## Boulder, Colorado (Earth System Research Laboratory)

The Keeling Curve (see Figure 2 below) has become symbolic of the global warming story and serves as the cornerstone of global warming science today (*30*, *31*). Working with the Scripps Institution of Oceanography, David Keeling began collecting $CO_2$ data at Mauna Loa Observatory in Hawaii in 1957 (*32*). The saw tooth, upward-sweeping curve that bears his name documents seasonal "breathing" and the relentless rise of $CO_2$ due to the burning of fossil fuels.

The Keeling curve is beautiful in its form, but ominous in its statement, much like the magnificent, dark funnel cloud of a tornado with your village directly in its path.

In the summer of 2009, I traveled to Boulder to visit with Pieter Tans, a senior research scientist with the National Oceanic and Atmospheric Administration

(NOAA) Earth System Research Laboratory (ESRL). Due in part to the involvement of Dr. Tans—who spent a 1978 post-doc year at Scripps working for Dave Keeling—NOAA/ESRL is a world leader in $CO_2$ monitoring and research (*33*).

NOAA started its own atmospheric $CO_2$ measurements at Mauna Lau in 1973, and Dr. Tans explains that the NOAA facility is actually next to the Scripps facility that collects the Keeling data.

"We have different buildings," he says, "but we collect from the same 40 m tower." Thus, two independent scientific research organizations obtain air samples from a common source and analyze them separately. "If you over-plot the NOAA record with the Keeling Curve," Tans adds, "they appear identical." He maintains NOAA's web page displaying the plot of month-to-month atmospheric $CO_2$ data (*30*).

With NOAA and Scripps working side-by-side to collect decades of continuous data, Mauna Loa has become the world's premier long-term atmospheric monitoring facility.

The outcome of this analysis is staggering in both its alignment and its import: both organizations reveal a breathing planet with ever-increasing concentrations of global atmospheric carbon dioxide.

Carbon dioxide produced from the combustion of fossil fuels is not our only concern for increasing concentrations of greenhouse gases in our atmosphere. Atmospheric methane is a concern as well.

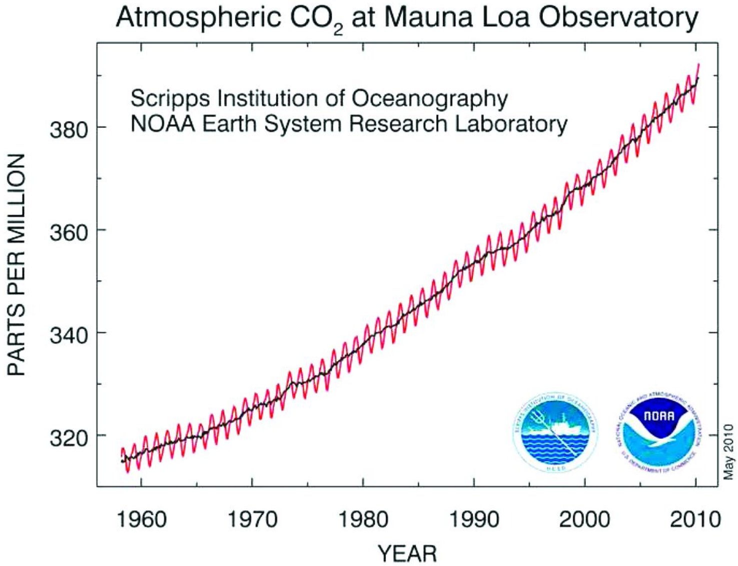


*Figure 2*

## Churchill, Canada (Climate Change at the Arctic's Edge)

Nowhere is the impact of global warming felt more dramatically than at the Arctic's edge, where the world's peatlands encircle the earth in a broad band of frozen soil. If increasing global temperatures thaw the permafrost, there is real potential for a subsequent greenhouse gas release. The permafrost region, an "arctic freezer" of sorts, contains as much as 50% of all terrestrial carbon, in the form of methane and carbon dioxide (*34*). In addition to well-documented ice- and snow albedo feedback, these ice-locked gases are another tremendous concern; a warming arctic could lead to a catastrophic feedback loop, as the release of more gasses results in even greater warming, with the end result being a dramatically different ecology across the entire planet (*35*).

The Arctic is already experiencing some of the most rapid and severe climate change of anyplace on earth (*36*). For this reason, it is imperative that we more clearly understand the impacts associated with these changing conditions.

I can't realistically take an entire class to each location around the globe, but through my travels I can investigate, document, and report on what I observe. It was for this purpose that I joined the Earthwatch research expedition *Climate Change at the Arctic's Edge,* headed by Dr. Peter Kershaw. Peter, a University of Alberta professor of earth and atmospheric sciences, led the expedition to a site near Churchill, Canada, the polar bear capital of the world (*37*).

Students can experience these research activities through my personal photos, first-hand accounts, and anecdotes. The photos in particular are a chance to display the challenges that face research scientists collecting data under extreme conditions on the frozen arctic tundra—a beautiful, but forbidding, barren landscape.

For more than a decade, Peter and his Earthwatch volunteers have collected massive amounts of data from measurements of snowpack characteristics in randomly selected sampling sites. The studies are labor intensive. Peter shares that "the Earthwatch team provides the people-power that makes it possible to collect high amounts of quality data in relatively small windows of time."

In the field, Peter and his team measure snow depth, crystal type, crystal size, layer thickness, hardness, and temperature. The samples are then returned to the laboratory for pH and conductivity measurements.

Churchill is near the edge of the northern boreal forest, a massive circumpolar woodland of mostly conifer species. Thus, Peter's data is collected from varied sites: on the wind-swept tundra; on peat bogs; and from deep snow packs within the forest. The wealth of data collected on these sites will be used to help quantify environmental responses associated with climate change. Analysis of the data further provides a benchmark of current conditions against which to evaluate predicted future changes.

Our planet's response to increasing concentrations of greenhouse gases is measurable and unequivocal. Perhaps the most visible signal of this response is melting glaciers.


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## Switzerland (Rhône Glacier)

Mountain glaciers all over the world are melting (*38*). Perhaps the best historical documentation for glacial retreat comes from the European Alps, where the Rhône Glacier serves as one of the most dramatic examples (*39*). In June 2009, I strapped crampons onto my boots and set out to explore the Rhône Glacier with local guide Charly Imoberdorf.

Speaking in a thick Swiss-German accent, Charly provided me with a detailed glaciology lesson, encompassing distant ice ages and contemporary crevasses and moulins. Standing atop the glacier, I gazed at the jagged mountains, the serrations of their gray summits in sharp contrast with soft white clouds above and the flat, verdant valley below. Charly told me that the wide, U-shaped valley was cut by a massive glacier dating to the last ice age, more than 100,000 years ago (*40*). At one point, the glacier extended all the way to Lyon, France. Then, about 15,000 years ago, the Earth's climate warmed and the Rhône retreated, like all other glaciers around the world. What remained was the glacier's signature: an erosion boundary with splintered, jagged mountains above and smooth granite walls below. In the bottom of the larger valley, I could see a smaller "U" shape. Charly told me this was cut by a more recent advance of the Rhône Glacier (*41*, *42*).

A few hours later, I trekked down into the valley to stand at the point where the glacier's snout reached in 1859. I snapped a photo from this same vantage point for comparison with an 1859 etching of the glacier. I was aware that the etching dated to approximately the beginning of the industrial revolution, the point at which mankind launched the upswing in global $CO_2$ emissions that continues to this day. The comparison showed a striking dissimilarity. Gone was the imposing mound from 1859; the glacier has retreated 5 kilometers up the valley. Its snout is now above the lip of the rock ledge half way up the mountain. The glacier's melt waters pour over the granite face as a raging waterfall. The comparison of these two images left no doubt as to just how glaciers can so clearly and dramatically confirm the climate change signal.

Since 1850, glaciers throughout the European Alps have lost more than one-third of their surface area and nearly one-half of their volume. Over that same span, glaciers in New Zealand's Southern Alps have lost *one-half* of their surface area and almost *two-thirds* of their volume (*43*). Here in the U.S., the national park named for these massive flows lost *two-thirds* of its glaciers between 1850 and 1980. Models show that in the next 20 years, those that remain could disappear completely (*44*, *45*).

Glacial retreat in the European Alps, New Zealand, and Glacier National Park coincides with an observed world-wide pattern of glacial retreat. We can now state with reasonable certainty that this retreat corresponds to the increase in anthropogenic greenhouse gases. The IPCC states that late 20$^{th}$ century glacier wastage likely has been in response to post 1970 warming (*46*). As easy-to-understand, natural indicators of climate change, glaciers stand alone in both their importance and their message.

## Geneva (IPCC Secretariat)

Meltwaters from the Rhône Glacier spill over a granite lip at 2,300 m in a spectacular waterfall several hundred feet to the valley below, forming the headwaters of the Rhône River as it tacks toward Geneva. Here the newborn river churns mightily as it rushes forward. Streamlets and waterfalls feed the river, looking like threads draped down the steep alpine slopes.

A steep winding road follows the river as it grows in size, distinguishing itself from other mountain tributaries. The turquoise-grey river, turbid from its heavy load of suspended solids, eventually flows into the western end of Lake Geneva. The Lake is a narrow, 70 km-long, crescent-shaped freshwater catchment basin lying in the path of the Rhône River. The nearly colloidal dispersion of solids in the milky feed waters that dump into the lake's eastern end precipitate as sediment; lake sediment records can provide an archival record of shifts in past environmental conditions, adding to our understanding of the evolution of climate change (*47*).

The river exits the extreme western end of the lake and meanders its way through France to the Mediterranean Sea. The city of Geneva, situated at this end of the lake, is an international meeting place for numerous governmental- and non-governmental organizations.

The Intergovernmental Panel on Climate Change (IPCC) occupies an upper level in the World Meteorological Organization (WMO) headquarters. The WMO building is a stylish, solid-looking structure of aqua-colored glass, aluminum, and steel. A double façade of protective glass membrane envelops the building's core, its elongated oval structure giving the appearance of a futuristic ocean liner run aground in a city park.

In Geneva, I introduce my students to the IPCC Secretariat. The IPCC was established in 1988 by the World Meteorological Organization (WMO) and the United Nations Environmental Program (UNEP) to provide independent analysis of the existing climate change consensus within the scientific community.

I explain that like the IPCC, our Chemistry and Society course is loosely organized into three working groups.

- Working Group I - The Physical Science Basis: Classroom lectures focus on fundamentals of chemistry, providing the basis for the scientific consensus of climate change (*48*).
- Working Group II - Impacts, Adaptation and Vulnerabilities: A primary objective of our laboratory activities, including field trips, is to investigate real-world impacts related to our changing global climatic conditions (*49*).
- Working Group III – Mitigation: In the concluding weeks of the course, we address mitigation. That is, *what do we do about it?* Students must each write a mitigation paper, as well as a brief editorial derived from their paper. They present these as mitigation PowerPoint presentations to their classmates, enabling everyone to learn about mitigation strategies from one another (*50*).

## Summary

It is a daunting challenge to address climate change and sustainability in global context. However, by making use of place-based learning through real-world field experiences, web resources, interviews, and sharing of personal experiences, it is possible to address these complex *multi*disciplinary, *inter*disciplinary issues in liberal arts chemistry and society courses.

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## Chapter 18

# Introducing Global Climate Change and Renewable Energy with Media Sources and a Simple Demonstration

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A goal in teaching chemistry to non-science majors is to enhance their understanding of socially-relevant topics in science. Meeting this objective, however, is challenging when discussing interdisciplinary subjects such as global climate change and renewable energy platforms. In Indiana University's *The World of Chemistry* course, media sources and a simple demonstration are used to introduce these topics. 1: A media project is used to engage students in the scientific discourse surrounding global climate change. By collectively analyzing the science presented in media sources, students can then independently analyze further sources on this and other complex scientific topics. The project culminates with students preparing their own general-audience news article on a chemical topic. 2: A simple classroom demonstration based on photocatalysis is coupled with the discussion on global climate change to illustrate both the promise of and challenges associated with renewable energy sources.

## Introduction

According to the AAAS report *Science for All Americans*, "…science education… should equip them [students] to participate thoughtfully with fellow citizens in building and protecting society that is open, decent, and vital. …What the future holds in store for individual human beings, the nation, and the world depends largely on the wisdom with which humans use science and technology.

And that, in turn, depends on the character, distribution, and effectiveness of the education people receive" (*1*). Yet, a report on US STEM education from the National Science Board indicates that US students are at or near the bottom with regards to science comprehension when compared to other countries with high-income economies (*2*). To address the challenges associated with STEM education, the board compiled recommendations that included providing "education that increases the public's knowledge of, and appreciation for, the importance of science and technology in the context of quality of life, economic prosperity, and national security" (*2*). Thus, what is needed can be broadly defined as *scientific literacy* (*3*). Given that television and the internet are currently the main sources for information about science and technology (*2*), it is also important that the public be able to extract and analyze the accuracy of scientific content routinely incorporated into media sources to support policy positions. This need is even more evident when considering the presentation of global climate change and energy science in media sources, wherein the same scientific content is often used to promote vastly differing policies, with potentially great impact on society.

Terminal introductory chemistry courses (i.e., for non-science major students fulfilling general education requirements) can provide a platform for discussing the underlying science of these important social issues. At Indiana University – Bloomington, this course is entitled *The World of Chemistry* and has the general objective to teach students about the chemistry that surrounds them. A diverse student population, consisting of freshman through seniors as well as nontraditional students, typically enrolls in the course. Enrollment is moderate (~80 students), and students come from all undergraduate sections of the university. The class syllabus loosely follows the table of contents for the ACS textbook *Chemistry in Context* (*4*), with a unifying theme of energy. How is energy obtained from combustion and nuclear processes? What are the chemical and environmental consequences of our energy choices? How are chemical commodities such as plastics and drugs related to our energy selections? What viable alternatives are there to energy obtained from petrochemicals? Discussed herein are examples of how media sources and a simple demonstration can be used within a diverse classroom to illustrate the chemistry and complexity of global climate change and solar energy as a future energy platform.

## Gauging Students' Perceptions

To begin discussing the chemistry of global climate change, the following *Discussion Prompt* is first administered to the class:

> *It is nearly impossible to open any major newspaper or magazine without finding an article discussing some aspect of global warming. Please tell me* ***one idea*** *that you have heard or read about global warming. If you remember where you heard it, please include that information as well.*

The objectives of this prompt are to gauge the students' perceptions of global climate change and to establish a classroom environment suitable for discussing


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a “hot button” topic. The response is diverse. Representative replies include that global warming:

- is related to burning gasoline or driving a car,
- has to do with carbon emissions,
- is a hoax,
- is different from weather,
- is political,
- and is associated with former Vice President Al Gore.

As this quick and informal survey illustrates, many of the students’ first responses have little to do with the chemical basis for global climate change. While it is feasible to teach the chemistry that underlies the process of global warming without discussing social context, completely ignoring this framework misses a great opportunity to connect the science to the students’ lives.

## An Inconvenient Truth

While it is generally easy to find current media sources discussing all the scientific topics outlined in the table of contents of *Chemistry in Context*, energy platforms and global warming are some of the most prevalent. Arguably, Davis Guggenheim’s 2006 documentary *An Inconvenient Truth* is the most widely disseminated media source dealing with global warming and energy policy (*5*). The film centers on former Vice President Al Gore’s comprehensive slide show campaign to educate citizens about global warming. Since its release, *An Inconvenient Truth* has been accredited with bringing widespread attention to the topic of global warming (*6*). Yet, many viewers wonder whether or not the science presented in it is accurate (*7–9*). Owing to the unabashed political content of *An Inconvenient Truth*, addressing this question is an appropriate and responsible reaction for educators to adopt (*10*). Moreover, the approach used to answer this question (as outlined below) is generally applicable to any media source dealing with scientific content, as the students find when working on their *Media Project* later in the semester.

Before even mentioning *An Inconvenient Truth*, students in *The World of Chemistry* receive instruction on the chemical principles relevant to understanding global warming (e.g., reaction stoichiometry and the chemistry of combustion, electromagnetic radiation and molecular shape, and the greenhouse effect). They then view *An Inconvenient Truth* over two class periods. As they are watching the documentary, they are asked to consider two questions:

(1) What is the thesis of *An Inconvenient Truth*?
(2) What evidence is presented to support this thesis?

After viewing the film, students work in small groups to answer these questions. The groups then join together to create a master answer for the class.

While there are slight variations in the responses from one year to the next, the general consensus has been the following:

(1) Thesis: global warming is occurring, potentially devastating, and caused by human activity.
(2) Presented evidence:

- $CO_2$ record from Mauna Loa Observatory (Keeling curve),
- analysis of ice core data ($CO_2$ concentration and inferred temperature),
- environmental observations (e.g., glacier retreat, ecosystem changes, extreme weather patterns, etc.),
- survey of peer reviewed literature,
- chemistry of combustion,
- the greenhouse effect (molecular vibrations).

Students are then asked to link which evidence is meant to support each part of the thesis (Figure 1). After this organization, the class can begin to evaluate the strength of each piece of evidence within the context it is meant to be critiqued. This exercise also prepares them for analysis of future media sources and their *Media Project*, described later in this chapter.

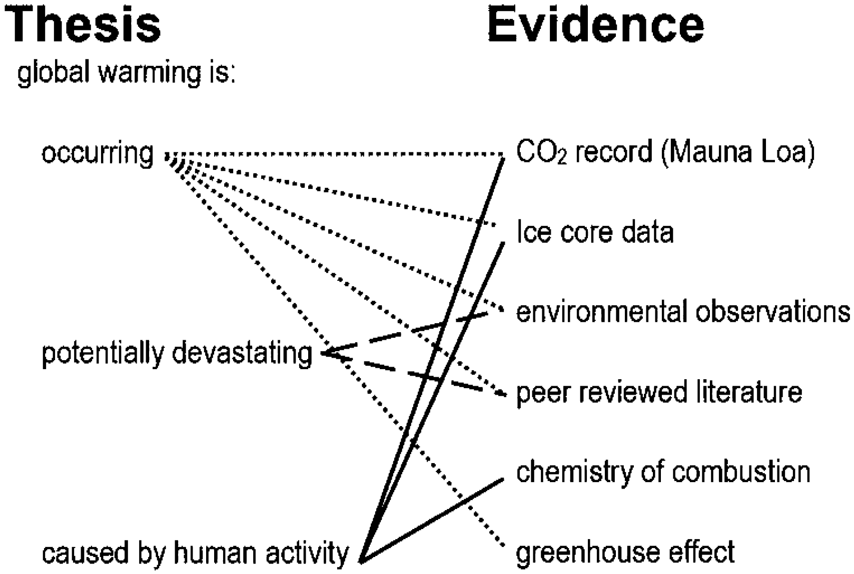


*Figure 1. A representation of how students organize or "link" the evidence presented in An Inconvenient Truth to its multi-part thesis. Note: many variations are possible.*

## Evaluating the Evidence

As evidenced by the thesis of *An Inconvenient Truth*, the debate surrounding global warming usually centers around three issues: whether or not global warming is *i)* occurring, *ii)* potentially devastating, and *iii)* caused by human activity. The taxonomy presented in Figure 1 clearly illustrates that when removed from the cause and implications, answering whether or not global warming is occurring becomes a simple exercise in applying chemical principles. The answers to whether or not global warming is the result of human behavior and potentially devastating can have huge implications in terms of policy and human conduct. By adopting this organizational strategy, the students can readily see how chemical principles can be used to reach differing conclusions. Yet, with their chemical instruction, they can weigh the evidence to formulate their own informed answers or identify what questions they still have, which would need to be addressed in order for them to respond. Thus, grouping the evidence as in Figure 1 helps students understand global warming as a scientific debate separately from a public policy debate.

## The Media Project

Using the analytical approach employed with *An Inconvenient Truth*, students then analyze other media sources for scientific accuracy. These additional sources are initially selected by the instructor and used in activities during discussion sections. Students then begin to select sources independently for analysis and incorporation into what is called their *Media Project*. The general guidelines are as follows:

(1) Select a chemistry topic to follow in print media, and read media reports (newspapers, magazines, blogs, etc.) discussing your chosen topic.
(2) Select your 3 favorite articles from the past year.
(3) Provide a summary of each article, clearly identifying the objective(s) of each source.
(4) Provide an analysis paragraph for each article; identify the chemical evidence presented to support the objective(s) of the article and evaluate the accuracy with which it is presented.
(5) Write your own news article geared toward informing your friends and family about your chemical topic, including why it is relevant to their lives.

As the guidelines illustrate, the students are free to select any chemical topic they are interested in learning more about. Approximately, 25% of the students select some aspect of global warming, while an additional 25% select an energy-related topic (e.g., carbon capture technology, nuclear fission, hybrid car platforms). Topics must be pre-approved by the instructor. This rule was established to limit the number of the last minute projects and also to encourage students to look outside the immediate class content for their topic. Students selecting global warming as their topic for the media project are directed to focus their project on one aspect so their selected articles are thematically similar.

*The World of Chemistry* is typically held in the fall semester and students are allowed to use articles from the entire year for the project. This period provides students with enough resources to select from and directs them to focus on a current topic or a current point of interest within a chemistry topic. This restriction also has practical implications for the instructor – it reduces the likelihood of plagiarism from one academic year to the next as the resources selected by previously enrolled students would be marked unsuitable.

To prepare their summaries and analyses, students are encouraged to follow the method used to evaluate *An Inconvenient Truth*. First, identify the objective or thesis of the article and summarize the evidence presented to support it. Central to this portion of the assignment is identifying whether or not the article is meant to be strictly informative or to promote a particular point of view. Second, the students are to critique the evidence. This process begins with identifying which evidence is chemical in nature and which is not. The student is then directed to focus on the chemical evidence and use course content to evaluate the accuracy of the presentation. Often, students find that minimal chemical evidence is used within an article even though it is discussing policy arising from chemical processes. In these cases, students are encouraged to outline the chemical principles that could have been incorporated into the article to aid in meeting its objective. With their chemical knowledge from class, evaluations of real news articles, and their ideas of what could strengthen such articles, students then prepare their own news article aimed to inform their family about their chemistry topic. The grading rubric shown in Table I is used to evaluate the entire project. It is not given to the students beforehand so as not to stifle creativity. The project is worth 100 points, in a class with a compiled 600 – 700 point total. A traditional grading scale (90 – 100% $A^-$ to $A^+$, 80 – 90% $B^-$ to $B^+$) is used for all class assignments, with the average grade on this assignment is roughly a B.

## Introducing New Energy Platforms

Within the context of discussing global climate change, it is also important to discuss energy sources beyond petroleum. Due to the increasing cost and geopolitical consequences of the United States' reliance on oil, a particular focus is placed on the chemistry behind energy resources such as cleaner coal, biofuels, nuclear power, and solar power. The benefits, drawbacks, and overall potential energy production of each method are discussed, with the objective of increasing the students' understanding of the underlying science of each of these platforms. This background will aid the students in future dialogues regarding energy and energy policy as they enter their formal careers (e.g., as politicians, lobbyists, solar panel installers, and voters).

Given that the sun provides the Earth with 120,000 trillion watts (TW) of energy, solar energy conversion represents a viable means of producing a sustainable energy economy (*11*, *12*). The discussion of solar energy can begin by discussing ways that students know how to utilize the energy of the sun.

Typically, this prompt leads to answers about using the thermal energy of the sun to heat (e.g., as in solar water heaters or cookers used when camping). Many students are unaware of the ways in which the energy from the sun can be also used to drive chemical reactions.

**Table I. Media Project Grading Rubric**

| *Bibliography (30 pts)* | *Analysis (30 pts)* | *Report (40 pts)* |
|---|---|---|
| A bibliography and summary provided for each article; 10 pts each.<br>**3 pts:** Provided *citation information* for source. Otherwise 0/3 pts.<br>**3 pts:** Source from the current academic year. Otherwise 0/3 pts.<br>**4 pts:** Summary provided with *primary objective* of the article identified. Reduce points if only secondary or no objectives are identified. | Analysis provided for each article; 10 pts each.<br>**2 pts:** The *chemical evidence* presented in the article is *clearly identified*. Reduce points if key chemical evidence is overlooked.<br>**6 pts:** The *chemical evidence* is *evaluated for scientific accuracy,* with support from course content and external sources. Reduce points for not identifying scientific flaws or discussing appropriate course content.<br>**2 pts:** Unanswered chemical questions are identified. Otherwise, reduce points. | **10 pts:** Report defines a focused chemical topic and its social relevance. Reduce points if unfocused or significance of topic is not highlighted.<br>**5 pts:** Chemical terminology is used accurately to describe topic. Reduce points if chemical terminology is poorly used. 0/5 pts for completely avoiding chemical content.<br>**5 pts:** Chemical terminology and concepts described in own words. Reduce points if paraphrased from class or textbook.<br>**10 pts:** Report is supported with *specific examples* from class and external sources, including selected articles.<br>**10 pts:** style – the report is well-written and organized (minimal typos, grammatical problems) with appropriate references provided. |
| **Article 1: /10 pts**<br>**Article 2: /10 pts**<br>**Article 3: /10 pts** | **Article 1: /10 pts**<br>**Article 2: /10 pts**<br>**Article 3: /10 pts** | **Report: /40 pts** |

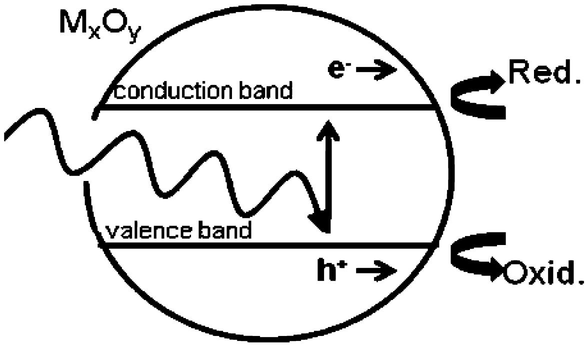


*Figure 2. Schematic illustrating how a simple photocatalyst enables surface reduction and oxidation reactions upon illumination.*

As illustrated in Figure 2, the energy of the sun can be harnessed through the use of a photocatalyst. In particular, photocatalysts facilitate surface oxidation and reduction reactions when illuminated with light of a suitable wavelength; the absorbed energy generates an electron-hole pair within the photocatalyst which can perform reduction and oxidation chemistry with molecules adsorbed on its surface. One important chemical reaction that occurs via photocatalysts is light driven water splitting, which can provide $H_2$ as a fuel source ($H_2O \rightarrow H_2 + ½ O_2$). Photocatalytic water splitting represents one way of using solar energy to convert a low value, abundant reactant (water) into useable fuel with minimized political and environmental consequences (combustion of $H_2$ yields only water).

## A Solar Energy Classroom Demonstration

To introduce the concept of solar energy, a simple demonstration based on rhodamine B degradation was developed to explore the value of using light as a form of energy to drive chemical reactions. Because dye degradation can be observed with the naked eye, it helps students understand the power of using light as an energy source. Rhodamine B forms a brightly colored pink solution when dissolved in water. It is commonly used in the textile industry and is a stream pollutant that can be decolorized in the presence of a photocatalyst (*13*). Titanium dioxide ($TiO_2$) is the most commonly studied material for photocatalytic applications and can be obtained commercially in a high surface area, highly active form suitable for dye degradation (*13*). The idea for the demonstration is based on a commonly employed research method used to screen materials for photocatalytic applications in which a colorful dye is degraded in the presence of a photocatalyst and light. In a research setting, this experiment is conducted in a temperature-controlled environment with a high power lamp (e.g., 450 W Hg or Xe lamps). There are several reports in the chemical education literature of undergraduate laboratory experiments using a desk lamp or natural sunlight to conduct photocatalytic dye degradation (*14–16*). Unfortunately, these experiments are unsuitable for a lecture setting because they require 2-4 hours and the decreases in dye intensity are unobservable to the naked eye.

Our demonstration makes use of an inexpensive 300 W work (halogen) lamp found in hardware stores and is designed to be completed during a 50 minute lecture period in a large lecture hall. The following items are used in the demonstration, although some substitutions can be made:

- Utilitech 300 W work (halogen) lamp (*17*)
- Deionized water
- Rhodamine B
- P25 $TiO_2$ (Evonik Corporation)
- 3x 150 mL beakers and 1x 1000 mL beaker
- 2x stir plates and 3x stir bars

Prior to the lecture, a 5 ppm aqueous solution of rhodamine B is prepared; a minimum volume of 300 mL of the solution is required. The solution is then distributed evenly between the three 150 mL beakers to which stir bars have been added. At this point, a brief description of the demonstration is given to the students and 200 mg of P25 $TiO_2$ is added to one of the beakers containing the dye solution, which will be irradiated with the lamp. The students should then be able to propose the different control experiments required to elucidate the necessary components for solar dye degradation (the photocatalyst + light), thus reinforcing the scientific method. The first control experiment involves irradiation of the rhodamine B solution *in the absence of the $TiO_2$ photocatalyst*. The second control experiment consists of rhodamine B and the $TiO_2$ photocatalyst *with no illumination*.

To perform the demonstration, the 1000 mL beaker is placed on top of one of the stir plates to serve as a support; the two solutions to be illuminated are placed inside the 1000 mL beaker and stirred. The lamp is placed lamp end down on top of the 1000 mL beaker so the light shines directly into the smaller beakers (as shown in Figure 3A). The lamp is then turned on to begin the experiment. The unilluminated control experiment is placed and stirred on the second stir plate, situated in a dark location or with the beaker containing the dye/$TiO_2$ slurry wrapped in foil to block stray light. Under these conditions, the rhodamine B solution is completely bleached within 30 minutes when exposed to both the catalyst and light (Figure 3B). This result is contrasted with those obtained from the control experiments, also depicted in Figure 3B. In its current form, this demonstration is suitable for a moderate-sized classroom where the colors of the beakers containing the dye/catalyst solution will be visible to all of the students. For larger classrooms, this reaction can be scaled up in size employing higher wattage work lamps (e.g., 500 W), or the catalyst can be separated from the liquid with a filter syringe and the colors of the samples projected to the entire class by placing Petri dishes containing the solutions on an overhead projector.

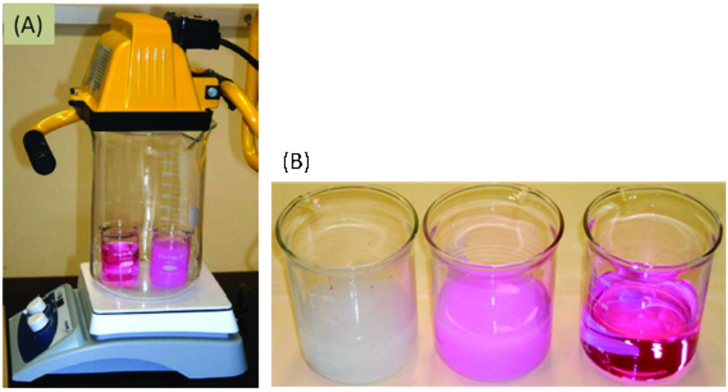


*Figure 3. (A) Setup for dye degradation. (B) From left to right: catalyst/dye solution after illumination, catalyst/dye solution without illumination, and only dye solution after illumination. Dye = rhodamine B*

This demonstration helps students understand that light is a form of energy that can be employed with an appropriate platform. The students also learn that not only dyes can be oxidized and reduced, but that water can be split to yield $H_2$, a feasible fuel that "stores" solar energy in its bonds. The demonstration prompts questions as to how photocatalysts may be applied to harvest solar energy. What is happening on the molecular level to bleach the dye? How does the dye degradation translate into an actual form of useful energy? What happens when it is dark (and subsequently, how can the energy be stored)? How efficient are the best photocatalysts? These questions can lead to fruitful discussions about the current state of materials used for solar energy applications and how chemistry can be used to modify materials to increase efficiency and storage. Also, the chemistry underlying photocatalysis is model redox reactions, which leads to a review of the of the fundamental background chemistry. In addition, as one major drawback to even the most efficient photocatalysts is their inability to absorb visible light, discussions can review the energy spectrum and the relationship between wavelength of light and energy.

The objectives of this demonstration are diverse and should promote classroom discussion about a range of topics, not only about solar energy but also a review of fundamental chemistry topics, the scientific method, and the importance of using controls during an experiment. Most importantly, students should understand that light is a form of energy that can be captured by materials to drive chemical reactions.

## Concluding Thoughts

Teaching interdisciplinary topics such as global warming and future energy platforms is challenging; however, general education courses provide an exciting opportunity to teach the underlying science of these important social issues. By integrating media sources into such courses and providing guidance on how to effectively critique content, scientific literacy can be increased while also connecting the science to the students' lives. In addition, simple demonstrations can provide memorable illustrations of chemical concepts, while illuminating and connecting seemingly disparate topics.

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17. Note that other lamps may be used; however, the support glassware may need to be changed. Also, decreasing the wattage of the lamp will increase the time necessary for complete bleaching of the dye and visa versa.

# Editors' Biographies

## Catherine H. Middlecamp

Cathy Middlecamp holds a joint appointment in the Nelson Institute for Environmental Studies and the Integrated Liberal Studies Program at the University of Wisconsin−Madison. She currently serves as the Editor-in-Chief of Chemistry in Context, a project of the American Chemical Society and has been the lead author for the chapters on nuclear energy, air quality, ozone depletion, acid rain, and polymers. She was elected a fellow of the ACS in 2009 and AAAS in 2003. Middlecamp graduated from Cornell University in 1972 with distinction in all subjects, was awarded a Danforth Fellowship for graduate study, and earned her doctorate in chemistry in 1976 from UW−Madison.

## Andrew D. Jorgensen

Andy Jorgensen is Associate Professor of Chemistry and Director of General Chemistry at the University of Toledo. He is also a Senior Fellow at the National Council for Science and the Environment and was previously the Washington Fellow at the Council of Scientific Society Presidents. He earned a Ph.D. from the University of Illinois at Chicago and a B.S. from Quincy University. He completed a postdoctoral appointment in chemical education at the University of Illinois at Urbana-Champaign. He is a member of the American Chemical Society's Committee on Education and is councilor of the Toledo Local Section. He has received a University of Toledo Outstanding Teaching Award and has been a Master Teacher in the College of Arts and Sciences.

# Subject Index




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**T**



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