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From the Publisher

This Fall 2009 issue of *Science Education & Civic Engagement: An International Journal* is highlighted by several changes in leadership and design.

First, we would like to welcome two new members to our editorial team. Eliza Reilly joins Trace Jordan of New York University as co-editor of the journal, while Marcy Dubroff has been appointed managing editor. Eliza and Marcy are both based at Franklin & Marshall College, the new home of the journal, and boast a wealth of experience in both publications management as well as connecting science education and civic engagement.

Eliza is the director of the Phillips Museum of Art at F&M and the former director of its Center for Liberal Arts and Society. Previously she was director of programs in the Office of Science, Health, and Student Engagement at AAC&U, working on the SENCER and PHHE programs. From 1996–2001 she also served as the executive director of the American Conference of Academic Deans, a national organization of chief academic officers and other academic administrators committed to improving undergraduate liberal education. Eliza received an M.A. in art history and a Ph.D. in American history from Rutgers University and is a Senior Scholar with the SENCER project. She also serves as the general editor and coordinator of the SENCER Model Series.

Marcy has spent more than 20 years in higher education and currently serves as the director of Franklin & Marshall's Clemente Course in the Humanities. She has also worked in various capacities including sports information, public relations, and as a photographer. She was the co-founder of the groundbreaking website College Lacrosse USA, which was purchased by Street & Smith's Sport Annuals, a division of Conde Nast Publications in 2000, and is the editor of the award-winning newsletter *Liberales*, a publication of Franklin & Marshall's Center for Liberal Arts and Society. She earned her B.S. with distinction from Cornell University.

We would also like to welcome several new members to the editorial board of SECEIJ:

- *Shree Dhawale* is Associate Professor of Biology and Honors Program Director at Indiana University-Purdue University Fort Wayne. She is a broadly trained molecular geneticist with research interests in regulation of gene expression, biotechnology, molecular cloning, and use of herbal extracts for inhibiting cancer cell proliferation.
- *David Ferguson* is Distinguished Service Professor and chair of the Department of Technology and Society at Stony Brook University where he holds a joint appointment in the Department of Applied Mathematics and Statistics. His research and teaching thrusts are in the areas of problem solving, advanced technologies in the learning and teaching of mathematics and science, and socio-technological decision making.

- *Robert Franco* is Director of Planning and Institutional Effectiveness at the University of Hawaii, Kapiolani Community College. He is a recognized expert on contemporary Samoan, Polynesian, and Pacific Islander demographic, ecological, health, and cultural issues.
- *Cindy Kaus* is Associate Professor of Mathematics at Metropolitan State University in St. Paul, Minnesota. An advocate of incorporating civic issues in mathematics to reach groups of students typically underrepresented in the STEM disciplines, she has directed and co-directed various grants leading to curriculum reform in mathematics.
- *Theo Koupelis* is Associate Dean of Math and Sciences at Edison State College in Fort Myers, Florida. He has published research on the theoretical modeling of outflows from compact astrophysical objects and is the author of the introductory astronomy textbook *In Quest of the Universe*.
- *Kirk Miller* is the B.F. Fackenthal Jr. Professor of Biology at Franklin & Marshall College where he teaches biostatistics, epidemiology, vertebrate anatomy, and comparative physiology. He is a comparative physiologist and biostatistician with a principal interest in how the embryonic environment affects embryonic growth and neonatal fitness.
- *Amy Shachter* is the Associate Provost for Research Initiatives at Santa Clara University. Her research interests center on porphyrin synthesis.
- *Garon Smith* is Professor of Chemistry at the University of Montana. He is an analytical/environmental chemist with broad interests in air and water characterization.
- *Mary Tiles* is Emeritus Professor of Philosophy at the University of Hawaii and now resides in the United Kingdom. Her research interests focus on the applied uses of mathematics, measurement, and modeling in both Chinese and European contexts.

In addition, this issue debuts our new journal design, created by John Svatek of Kerning Pair Design, Lancaster, Pennsylvania. Early next year, we will augment the PDF version of SECEIJ with a new and improved website.

We invite you to download this issue of the journal and to connect with the work of colleagues both in the United States and abroad. We also hope you will send us your thoughts and comments on how we can continue to improve SECEIJ.

—*Wm. David Burns*
Publisher

POINT
OF VIEW

Citizen Science and Our Democracy

The theme for the National Center for Science and Civic Engagement's 2009 Washington Symposium and Capitol Hill Poster Session was "citizen science." The term usually describes the observation and data gathering activities of ordinary people, often working from or near home, and assisting a research scientist or team in a project. We were interested in a slightly different meaning of the term, however—one that would invoke scientific literacy and numeracy as essential capacities for citizens conscientiously engaged in a modern democracy.

We asked: What do we really need beyond a basic understanding of the scientific method, or discrete mathematics, or elementary statistics, to make sense of the complex civic questions we face today and will face in the future? More fundamentally, though, we wanted to explore what scientific practices and democratic practices have in common. How are the two "projects" related? And what should we do to encourage each to reinforce and strengthen the other?

For help in thinking about this, we turned to one of the handful of citizen scientists currently serving as a member of Congress, Representative Rush Holt of New Jersey. A thoughtful public servant who formerly worked in the Plasma Physics Laboratory at Princeton University, Holt graced our meeting with an original, nuanced, and encouraging address. He reminded us of the common roots of science and democracy in the Enlightenment. He reviewed the critical role that science played in what I have elsewhere called "the making of our democracy." Echoing C.P. Snow's critique of more than 50 years ago, he lamented the separation of the scientific and non-scientific communities into "two cultures." Lastly, he suggested how we might begin to bridge these gaps.

We asked Mr. Holt for permission to transcribe his remarks and to include them in this issue. The man whose campaign bumper stickers playfully assert, "My Congressman IS a Rocket Scientist," kindly assented and we are pleased to present his thoughts to you.

—*Wm. David Burns*
Executive Director, NCSCE

Representative Holt's Remarks

I'm really pleased to recognize the role of Rutgers in sowing the seeds for this SENCER program. It is, I think, tremendously important.

I'm delighted to see you, and to see your posters, and to hear about the programs at the various universities, and to run into some old friends like Will Dorland from Maryland, who was at the Plasma Physics Laboratory when I was assistant director there at Princeton.

This is almost to the day the 50th anniversary of C.P. Snow's address on "The Two Cultures." Snow's was an interesting observation at that time, but the cultural divide Snow described has turned into, at least in this country—and I would venture to say in other countries—a critical problem that, I think, puts us at risk in a number of ways as a society.

C.P. Snow, a chemist, government advisor, novelist, and otherwise diversely-oriented person was talking about England 50 years ago. But his analysis applied equally well to the United States, because at the same time we launched—and "launched" is the right word following the launch of Sputnik—into an education program in the United States that really did divide our society into the two cultures of scientists and non-scientists. This divide persists to this day.

Following Sputnik, we set in place an educational system that was intended to produce a generation of scientists and engineers the likes of whom the world had never seen. Our initial motivation was fear and our justification was national defense. And indeed, we have produced generation after generation of the world's best scientists and engineers.

However, we have relegated them, or allowed them to relegate themselves, to a compartment of our society, of our economy, and of our political world, and we have relegated everyone else to the extra-scientific area. That's dangerous. So it was music to my ears, really, when President Obama, in his inaugural address this year said, "We will restore science to its rightful place."

Now, he made this promise in a section of his address dealing with the economy. And of course, the theme of his inaugural address was, "We're in deep trouble, economically." The President was making the point that investment in science is important for us to be able to grow out of our economic problems.

But that statement—that we will restore science to its rightful place—is much richer than to say that science produces jobs. Of course, science does produce jobs, which it does, even in the short term. That is why it's great that there is a lot of money for science in the economic stimulus bill that was passed by Congress and signed by the president. It provides $22 billion of new research money.

But the president was saying a lot more than that science creates jobs in the short term. He was also saying that science creates jobs, productivity, and economic sustenance in the long-term. And he was saying quite a bit more than that, when he said we will restore science to its rightful place.

He said that we will do away with the kinds of censorship and stifling of science—ideological stifling of science—that has undermined a basic principal of the United States. The United States has had, over the centuries, really until roughly fifty years ago, a very scientific bend. It was not a coincidence that the guys—and they were guys, sorry to say—who wrote the Constitution called themselves in many cases, "natural philosophers." Back then, that was the equivalent of our word scientist today.

The founders were thinking like scientists; they were asking questions so they could be answered empirically and verifiably. That's what science is. It is a system for asking questions so you can answer those questions empirically and in a way that others can verify your empirical tests for those answers.

Every shopkeeper, every farmer, every factory owner throughout American history has had this scientific tradition. It was common for Americans to think about how things work and how they could be made better and made to work better.

We're at a time now where, if I talk to most of my colleagues in Congress, most of your colleagues at the college or university, or any American on the street, however well educated, however able, however smart, they will likely say, "Oh, science, oh no, I'm not a scientist. I can't understand that, that's not for me."

And thus we are deprived of the scientific way of thinking. The scientific way of thinking is important not just for developing new technologies, but for creating the kind of self-critical, self-correcting, evolving society we need to create. The whole balance of powers in our constitution, the whole idea of openness that we embrace as a democracy, these are very scientific in nature.

It is so important that we try to bridge this chasm, merge these two cultures, so that no educated person in America would ever say, "Oh, that's science, I can't think about that."

Your courses are so good because you work at from both directions. Much of my career has been as a teacher, and any teacher will tell you, the first challenge is motivation. You know, there is nothing you can teach. That's the dirty little secret that faculty members sometimes learn. You can only help students learn.

Students have to have some reason to do the work, a purpose for learning the material. You provide that purpose in many cases by reminding them that learning has to do with the quality of their life in areas that they may never have thought had anything to do with science. You have shown them that they don't have to wear lab coats or do equations in order to bring a scientific understanding, and more important, a scientific frame of mind, a kind of questioning attitude, to their lives, their work, and their roles as citizens.

Looking for empirical answers and independent verifications is essential to help find the answers to the important questions in daily life, whether it's trying to decide what kind of soap to buy, or what kind of college to attend, or what kind of candidate to vote for. In what you do in your courses I see an attempt to provide for students that very kind of motivation.

But you also are working at it from the other end, nudging the scientists to move out of their culture. You are helping scientists understand that non-science students at the university—and the 80 percent of the American population who say science is not for them—are not just a necessary nuisance in their lives, but really the whole reason that we practice science.

Why do we practice science? So that we can have a better quality of life, so that we can understand how the world works, get along with each other, and provide for the needs, and not just material needs, the needs of the people and society.

You know, I'd like to say that President Obama thinks like a scientist. He might dispute that, but I see it in how he conducts meetings. I see how he asks questions in a way that they can be answered empirically with evidence. He asks questions with an open mind, recognizing that the answer to the question must necessarily be regarded as provisional. You know every scientist—every physicist anyway—has somewhere in the back of his mind or her mind that whatever it is you think about how the world works, how this subject works, what is known about plasma physics or planetary science, is provisional. There might just be a patent clerk in Switzerland who has a little different idea or maybe even a very different idea. And empirically, some day that patent clerk's ideas might supersede everything you thought you knew.

It is this kind of thinking that has made science so successful. Science gives a kind of reliable knowledge, provisional though it may be, that allows people to improve their lives.

It is this kind of thinking that allows citizens to improve their government. It is why we are the oldest surviving constitutional government in the world, because the authors were thinking like scientists, and they set up a system that allowed us to keep thinking like scientists.

Every business major and English composition major that you bring in to your classes is not just someone who can have the beauties of science unlocked for them in a small way. It may be that this student will be the citizen who will help move our society along through scientific thinking.

You are doing a favor for each faculty member you nudge out of her or his narrow specialty to be exposed to the great unwashed non-science student body. You are doing a great favor by reminding them their science is all about. They're not doing science for their own esoteric entertainment. A few might be, but that is not why the National Science Foundation puts out billions of dollars a year. That is not why this Congress is interested in science. We are interested and making investments because of what this means for our society and the welfare of all of these people who are in this nation conceived in liberty and dedicated the proposition, that all, not just those who did differential equations, or you know, spectrophotometry. are equal, and deserve the benefits of our society.

So what you are doing is the missing link between things that the NSF, and the NIH, and NIST and others have funded for years. And what all the rest, the 80 percent non-scientific society have not only been deprived of, but have ignored for all these half-century, roughly speaking.

So thanks for doing what you do. I hope you understand the importance of what you are doing. I certainly do. And I thank you very much.

POINT
OF VIEW

Science and Civic Engagement in the Developing Democracy of Georgia

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Mzia Zhvania
Ilia Chavchavadze State University

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Science opens the mind.
— Robert Lawrence Kuhn

Introduction

The situation concerning science and education in the former Soviet Union has been described in articles by experts from the former soviet republics and by foreign researchers (Dezhina, Graham, 1999; Khitarishvili, 2007; Kuchukeeva, O'Loughlin, 2003; Kuhn, 2003; Saluveer, Khlebovich, 2007). It is obvious that science had an exceptionally favored position in the former Soviet Union. Together with education, science was linked to ideology as an important part of national politics. Pure science and applied technology were highly developed in many fields. Soviet scientists were at the cutting edge of mathematics and in several branches of physical science, especially nuclear physics, chemistry, and astronomy. At the same time, Soviet scientists were almost completely isolated from the international scientific community. Only a few selected scientists were free of restrictions and could collaborate with research institutions in Western countries.

The core of fundamental science was the Academy of Sciences of the USSR and the various national academies of science in Soviet republics, which received their budget directly from the government. Financial support for research was distributed according to political priorities and political decisions, without any peer review. Much of the research was carried out outside the academy system—most of this research was of an applied nature, related to weapons systems. Science served the power and strength of the state.

The development and advancement of science was a national priority for the Soviet government and top scientists were held in high respect. To be a scientist was very prestigious and large numbers of students graduated in STEM fields every year. Science was emphasized at all levels of education.

The Soviet education was free, highly specialized, and didn't have a tradition of liberal education. Division between scientific research and teaching was quite strict. Except for a few, the universities were not as strong in basic research compared to the academy institutes.

Current State of Science and Education

The collapse of the Soviet Union, the end of centralized planning and financing of science and education, the financial crisis, and the brain drain had a particularly damaging effect on science and education within small, newly independent countries such as Georgia. Scientists and educators had to face a new reality. Because governmental financing was now very low, it was impossible to maintain excellence in research and higher education. Faculty and students had to look for their own research funding via joint research projects in private schools, educational projects, or by studying abroad. Going abroad to study was difficult for students because of financial cost and major differences in the structure of higher education between Georgian and foreign universities. The consequences of long-time isolation, lack of skills, lack of knowledge of foreign languages, and lack of information channels associated with severe financial problems inhibits the ability of Georgian scientists and educators to get financing even within programs that are prioritized and specially targeted for Georgia (e.g. INCO, INTAS etc.). The need for reforms within Georgian science and education was obvious.

Reforms in science and education were initiated in 2000. The Georgian Academy of Sciences lost its function and all research institutes were placed at the disposal of the Ministry of Education and Science. The most significant source of research funding became the Georgian National Science Foundation (GNSF), created within the Ministry of Science and Education of Georgia, whose funding process is based on competition and peer review. An optimization of universities and research institutes was also conducted. Georgian universities along with universities from Armenia, Azerbaijan, Moldova and Ukraine have declared their willingness to introduce the Bologna measures in their higher education systems. (Documentation regarding the Bologna process is available at the Georgia Ministry of Education and Science [2009].) This commitment includes Georgian participation in establishing the European Higher Education Area (EHEA) by 2010, coordinating degree requirements, promoting international cooperation, and facilitating the mobility of scientists between institutions. The introduction of structural changes and improvements in the quality of teaching should strengthen research and innovation in Georgia. The Government claims that the concepts of "continuing education" and "education oriented society" are the priorities of new educational policy. New curricula, along with new teaching and learning methodologies, were introduced to the universities. Despite these changes, our understanding of Georgian science development is still not defined.

Introduction of SENCER

To compensate for a deficiency in knowledge and skills of Georgian scientists and educators, training and workshops were conducted in Tbilisi for those interested in continuing their professional work. International conferences, workshops, seminars have been designed to highlight the new ways that Georgian scientists are successfully pursuing their research. In June 2003, our group organized one such conference: "Gaining Knowledge and Skills Needed for Scientific Communication and Collaboration." This conference was sponsored by Sigma Xi, the U.S. National Academy of Science, UNESCO, Iowa State University, IWISE, the International Network for Successful Scientific Publications, CRDF, GRDF, the Georgian Academy of Science, I, Beritashvili Institute of Physiology, Georgian Technical University, the Armenian National Science Foundation and other international and national organizations.

The conference program offered a selection of topics that were designed to address the interests of working scientific researchers. The program included information about Sigma Xi, scientific book/journal donation programs, research resources used by Iowa State University and other American universities, gateways/directories, other online publication resources, scientific databases and specialized search engines, scientific equipment donation or refurbishing, research, and study opportunities abroad. There were also some special interactive sessions on distance communication in science, including electronic journals, electronic conferences, electronic lectures, preparing manuscripts for international publications. Reports on innovative scientific work in Georgian universities and research institutes were also organized. During this conference, scientists and science educators from Georgia and Armenia had their first introduction to the ideals, philosophy and goals of the SENCER project. The presentation was made by a special guest of the conference and co-principal investigator of SENCER project, Professor Karen Oates.

The SENCER approach and the issue of civic engagement are very relevant for the Georgian educational system. Civic engagement takes many forms and can be measured by various indices. One of the most comprehensive definitions of civic engagement belongs to Thomas Ehrlich (2009, vi, xxvi), former president of Indiana University:

> Civic engagement means working to make a difference in the civic life of our communities and developing the combination of knowledge, skills, values, and motivation to make that difference. It means promoting the quality of life in a community, through both political and nonpolitical processes. . . . A morally and civically responsible individual recognizes himself or herself as a member of a larger social fabric and therefore considers social problems to be at least partly his or her own; such an individual is willing to see the moral and civic dimensions of issues, to make and justify informed moral and civic judgments, and to take action when appropriate.

Today, Georgia is struggling to achieve democratization and sustainable economic development, and to alleviate poverty. Like other former Soviet countries (*Economic Development*, 2003), science and research are still less popular among young Georgians than other more prestigious subjects—management, law, economics, etc. We believe that Georgian universities should contribute to national goals by educating students for active, civically engaged citizenship. In order to develop the essential knowledge needed to achieve these goals, science education should be strengthened and promoted. It is important that scientifically literate people become actively involved in social and political processes within Georgia.

Despite the pressing circumstances, the issue of how science and democracy interact—How does science engender democracy? How does science and science education change the way people think? How can science stimulate new civic engagement and responsibility of citizens?—is not part of the political, pedagogical or scientific literature in Georgia, in contrast to foreign countries and especially the United States (Burns, 2003; Jordan, 2006; Kuchukeeva, O'Loughlin, 2003; Kuhn, 2003). The need for discussions and debates on these issues are critical in Georgia and provide a promising way to create the national perception of science.

SENCER in Georgia

In 2003 we participated in the SENCER Summer Institute for the first time based on invitations from Karen Oates and IWISE co-director Ardith Maney. We were impressed by SENCER topics, which demonstrated the possibilities of teaching science in a civic context. Later we read the article by Robert L. Kuhn (2003), "Science as Democratizer," and were inspired by his very interesting suggestion that "science engenders democracy by changing the way people think and by altering the interaction among those who make up the society." Kuhn also proposed that a "key to changing the way people think is critical thinking" and provided the following comments on science education:

> Basic and applied science and science education are all needed to nourish critical thinking. Science, to be science, cannot stagnate. If scientific education enforces the scientific way of thinking, scientific discovery energizes it, so that both education and discovery nourish and sustain our democracy. And science needs democracy as much as democracy needs science. Vigorous scientific research reflects democratic principles in action, and free and open scientific inquiry cannot take place without the protective support of a robust democracy (Kuhn, 2003).

Confirmation of our interest in the SENCER program was achieved by the outcomes of a two-year SENCER-Georgia pilot project that started in September 2004 in three major universities within Georgia: I. Javakhishvili State University, Technical University, and Medical State University. This project provided a wonderful possibility to begin restoring the prestige of science and stimulating an interest in science among Georgia's youth. With support from the university administration, teaching and learning centers were established in all three universities. Many important activities were performed through these centers and the central component of all activities was "civic engagement." This theme was used in all eight courses that were newly introduced in Georgian universities.

- Environment and Health,
- Social Environment and Human Behavior,
- Global Ecological Disaster and Georgia,
- Chance,
- Chemistry and the Environment,

- The Coming Energy Crisis and Then What? Apocalypse or Sustainable Development,
- Some Steps Away from Death, and
- HIV in Georgia.

Major sections of each subject were prepared in close collaboration with scientists from American universities that participated in the SENCER program, which were then adapted to the context of Georgia.

One good example of stimulating students' curiosity and problem-solving actions via science education is provided by the results of the SENCER-based presentation of "Environment and Health," which was introduced into secondary school (mainly in tenth, eleventh grades) and high school curricula. Students prepared projects and demonstrated their abilities to determine and solve problems.

The SENCER faculty team from Georgia attended the SENCER Summer Institute four times. Within the framework of the SENCER-Georgia project, we organized one-month internships in Georgian campuses for six U.S. students during May 2005, together with meetings and seminars for U.S. faculty members from partner universities. We also established contacts with Armenian scientists and educators.

The Future: Dreams and Aspirations

The SENCER-Georgia project finished in 2006 but we continue to follow our goals: to strengthen science in Georgia and to stimulate our youth's interests to science via strong collaboration with U.S. educators and scientists. For these reasons the Teaching and Learning Centers continue their work. We are still developing new SENCER subjects in collaboration with American and Armenian colleagues, such as:

- Nanotechnology,
- Drug abuse and behavior,
- Science ethics,
- Integrated neurophysiology,
- Statistical nature of traffic (telecommunication),
- Dynamic stability of power systems,
- Sustainability in hydro-engineering,
- Hydrology for civil engineering, and
- Artificial intelligence.

Each of these courses will include features of civic engagement and will use innovative teaching methods.

Together with the Georgian Chapters of Sigma Xi, we plan to begin discussions and debates on the concept of Georgian science. We are also working to promote further integration of Georgian scientists into the international scientific community. For this purpose we are going to organize electronic meetings, conferences, lectures, workshops and symposia with U.S. universities. Our other activities will include the creation of the "Center of Innovation, Eurasia" in collaboration with U.S. and Armenian colleagues, joint scientific research, and organizing a series of scientific lectures for Georgian high school teachers and students. Because the philosophy and ideals of the SENCER approach have stimulated special interest among Georgian scientists, educators and teachers of high schools and colleges, the SENCER-Georgia group is planning to establish a Georgian-American SENCER High School in Tbilisi.

In conclusion, we say that "This is not a time to be timorous. . . . Science needs democracy as much as democracy needs science." (Kuhn 2003)

About the Authors

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PROJECT REPORT

Preparing Future Teachers

Using a SENCER Approach to Positively Affect Dispositions Toward Science

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Abstract

Pre-service and in-service elementary teachers tend to have poor attitudes and beliefs about science that stem from their own early science-related experiences. The development of positive dispositions toward science among pre-service teachers is problematic but essential if we are to improve science education. Attitudes will affect behavior and positive attitudes among pre-service teachers will lead to good learning and subsequently to good science teaching. Previous studies suggest college science courses that contain elements of inquiry-based learning, practical application to teaching, and engagement with broader real-world issues can affect positive change in these dispositions. Here, I report on the efficacy of a new biology course at Longwood University in improving science dispositions among pre-service teachers. The course, modeled on a SENCER (Science Education for New Civic Engagements and Responsibilities) approach, engages students in biological concepts using focal topics that involve timely, complex, and biologically relevant issues confronting society. Four semesters of assessment data demonstrate a favorable change in students' attitudes toward science, science teaching, and engagement in broader civic issues after completing the course.

Introduction

> *Wanted: College and university science teachers wishing to become engaged in a comprehensive, important, and potentially transforming educational movement. Those who accept the challenge will join with K–12 teachers in a quest to give every American an essential understanding of the physical and biological processes that characterize our world, and to nurture curiosity and scientific habits of mind. In the process, all participants will experience change and renewal.*

This opening paragraph of "College Pathways to the Science Education Standards" (Siebert and McIntosh, 2001), both highlights the critical need for systematic consideration of science education in higher education but also identifies one of the greatest obstacles to holistic change: the cyclic nature of our educational systems. Teachers often teach as they were taught (Watters and Ginns, 2000), and thus meaningful and positive change is required not only to improve scientific understanding of all citizens but also to affect the "pipeline" that develops future K–12 teachers.

Pre-service and in-service elementary teachers, in general, tend to have poor attitudes and beliefs about science and their capacities to be effective teachers of science (Stevens and Wenner, 1996), and many experienced teachers report feeling uncomfortable and unqualified to teach science (Kahle, Anderson, and Damjanovic, 1991). Research suggests that these attitudes develop as a result of their own science-related experiences in elementary and high schools (deLaat and Watters, 1995) and support the teacher preparation pipeline problem: a student's interest in pursuing science is shaped by experiences at a young age and his/her most frequent exposure to science is through those teachers. While these pre-service and in-service teachers often have a love for the profession of teaching, they may lack a passion for or real connection to the science content. Given this situation, the development of positive dispositions towards science and science teaching among pre-service teachers is problematic (Watters and Ginns, 2000).

If we seek to change this cycle by impacting the preparation of our future K–8 teachers in their science courses in higher education, we must accept some of the constraints of our own systems. In most college and university science departments, courses are taught by disciplinary experts who may have little or no formal training in teaching or science education. As such, at the college level we have the same issues as at the K–8 levels but in reverse: faculty with a love for the content but who may not be prepared to or comfortable with modeling and teaching pedagogical approaches for these teacher candidates. How then can we seek meaningful change in the preparation of K–8 teachers while working within the higher education systems, neither overwhelming faculty with proposed changes nor selling short our future teachers on the content and context they need to successfully teach their own students?

My research in this area supports the utility of the SENCER approach (Science Education for New Civic Engagements and Responsibilities) as a way to reform science courses in higher education and positively impact teachers. SENCER (2009), a national initiative funded by the National Science Foundation and housed at the National Center for Science and Civic Engagement at Harrisburg University of Science and Technology, seeks to improve learning and stimulate civic engagement by teaching science through complex, largely unsolved civic issues that interest large numbers of students. In this paper I present survey data collected in a SENCER-styled course for pre-service teachers at Longwood University. The survey was designed to assess the efficacy of this course in improving dispositions that lead to increased student learning of science concepts, greater confidence in teaching science, and enhanced engagement in broader civic issues. The underlying idea of this study is that attitudes will affect behavior and that positive attitudes among pre-service teachers will lead to good learning and subsequently to good science teaching.

Methods

Institutional context

Longwood University has a long tradition of developing teachers, and until 1975 was an all-female institution with a predominant focus on teacher education. Today, pre-service teachers continue to make up the largest major program on campus (approximately 750 of 3900 undergraduates). The home for these pre-service teachers is the Liberal Studies program in the Cook-Cole College of Arts and Sciences. This program seeks to provide a strong Liberal Arts content background to pre-service teachers before they begin their formal training in education. In addition to their required General Education science course, students within the Liberal Studies program who are seeking elementary licensure (grades K–6) are required to take four science courses: one two-hour physics course, one two-hour chemistry course, one three-hour earth science course, and one four-hour biology course. Students electing to obtain certification to teach science at the middle school level (grades 6–8) have the additional requirement of selecting General Chemistry 101 as their general education science requirement.

Course context

The Fundamentals of Life Science, Biology 114, is a required science course for all of Longwood's Liberal Studies majors and is the only life science course they are required to complete in preparation for their teaching careers. As a four-credit hour course, students participate in three hours of lecture and two hours of laboratory each week. The course was first offered in the fall of 2004 following a curriculum change to science requirements in the major; prior to this term, students seeking K–8 teaching licensure were required to complete four-credit courses in zoology and botany. These courses were taught using a traditional lecture-lab format. As the primary instructor for the new course, I had the opportunity to design a new course model.

Building on student feedback from previous courses, relevant pedagogical research on the effectiveness of topic-focused and inquiry-based approaches (Korb, Sirola and Climack, 2005; Crowther and Bonnstetter, 1997), and my department's involvement in the SENCER program, I structured Biology 114 around a number of focal topics. These topics involve timely, complex, and biologically relevant issues confronting society. Students are engaged in these topics from the start and are required to reflect on and inquire about these issues throughout the course. For example, we spend several weeks engaging the topic of cancer, a subject that most students consider interesting and important and one with a rich civic context. To build student interest in the topic, they are assigned context readings beforehand. These may be cancer survivor stories or articles on new treatment technologies. Along with discussions and reflective writing assignments over these readings, students analyze recent trends in cancer rates and are asked to generate hypotheses explaining them. Students then test their hypotheses, in effect, by writing a brief research paper that explores recent research related to the hypotheses. While engaging this topic and its broader impacts on society, students learn important biological concepts such as cellular chemistry, cell division, DNA structure and function, and cell regulation.

Other focal topics follow to sustain student engagement and interest in class and in their learning; these include genetic engineering and the stem-cell debate, HIV-AIDS, drug and alcohol abuse, human overpopulation, and the biodiversity crisis. Each topic is introduced with context readings and analysis of relevant statistics and data. Interest is sustained through additional readings, discussions, relevant news clips and videos, and short reflective writing assignments. While these focal topics function as umbrellas under which students learn much basic science content and make connections to live as citizens, they are also required to synthesize the material in the specific context of their chosen profession.

Students are further prepared for work in their future classrooms by participating in active, inquiry-based laboratories and through a novel assignment that requires them to reflect on biological content covered throughout a focal topic and then locate relevant K–8 Virginia Standards of Learning (SOLs)that apply to the specific content (Virginia Department of Education, 2007). This encourages students to consider and make connections between the college-level concepts learned in class and the K–8 content they will be teaching in the future.

Assessment tools

To evaluate change in pre-service teachers' dispositions I constructed a survey composed of twenty statements designed to assess attitudes related to science and the teaching of science at the K–8 level (Table 1, below). Students were asked to reflect on their level of agreement with each statement and respond using a Likert scale (Edwards, 1957), where 1 = strongly disagree, 3 = neutral, and 5 = strongly agree. The twenty survey statements were constructed around four categories focusing on different dispositions and capacities. Statements 1–5 addressed students' level of confidence in their science content knowledge, science process skills, and ability to teach scientific concepts. Statements 6–10 assessed students' awareness of the importance of learning and teaching science in a greater societal context. Statements 11–15 assessed students' appreciation of scientific contributions to society and the importance of scientific research. Statements 16–20 addressed students' feelings of achievement related to their personal development in how they think about science and science teaching. Additionally, students were solicited for comments regarding their feelings or attitudes about science in general and their ability and desire to teach science in their future classrooms.

Participants

The assessment plan and protocol was approved by the Human and Animal Subjects Research Review Committee of Longwood University prior to the initiation of data collection and was renewed annually. Students were informed of the study, assured the anonymity of their responses, and provided the option to participate. The disposition assessment and solicitation of comments were administered on the first day of class and again during the last week of class for four consecutive semesters (fall 2005, spring 2006, fall 2006, spring 2007). Of 309 students enrolled in the course during this period, 91 percent (n = 281) participated in the pre-course assessment and 84.5 percent (n = 261) in the post-course assessment. Of the participants completing the pre-assessment, 12.8 percent (n = 36) provided pre-assessment comments while 15 percent (n = 39) provided post-assessment comments. The student population in Biology 114 was predominantly underclassmen and female (95.8 percent). The majority of participants (84.6 percent, n = 238) planned to start a teaching career in the K–6 grade levels.

TABLE 1. Disposition Assessment Tool Developed for Biology 114

Statement Number	Disposition
1	I feel confident about my knowledge of the content areas in the life sciences.
2	I feel confident about my ability to work in a laboratory setting with students doing hands-on science activities.
3	I feel confident about my ability to perform in-class science demonstrations for my students.
4	I feel confident about my ability to use effective teaching practices as demonstrated in my science classes.
5	I feel confident about my ability to create teaching lesson plans that promote student understanding in the sciences.
6	I am aware of the interrelationships that exist between science and other disciplines such as mathematics, history, economics, and literature.
7	I am aware of the influence science has on our daily living.
8	I am aware of current developments and trends in science through a variety of media sources e.g. newspaper, science magazines, television.
9	I am aware of the need for my students to develop a sense of value for the many science connections around them.
10	I am aware of the importance of developing the science process skills of my students in addition to science content knowledge.

Statement Number	Disposition
11	I have an appreciation for the discoveries and contributions of science throughout history.
12	I have an appreciation for the applications of these discoveries as they relate to contemporary use.
13	I have an appreciation for the importance of continued scientific research.
14	I have an appreciation for the ways in which scientific research benefits humanity on a daily basis.
15	I have an appreciation for the need to communicate the advances of science to my students.
16	I have a feeling of achievement because of my students' success on the SOL assessments in science.
17	I have a feeling of achievement because of a positive change in my way of thinking about the teaching of science.
18	I have a feeling of achievement because of greater sense of personal accomplishment.
19	I have a feeling of achievement because of a personal realization of the need for continued training and professional growth in science teaching.
20	I have a sense of achievement that comes with the knowledge that I am helping my students develop into contributing, scientifically literate citizens.

Analysis

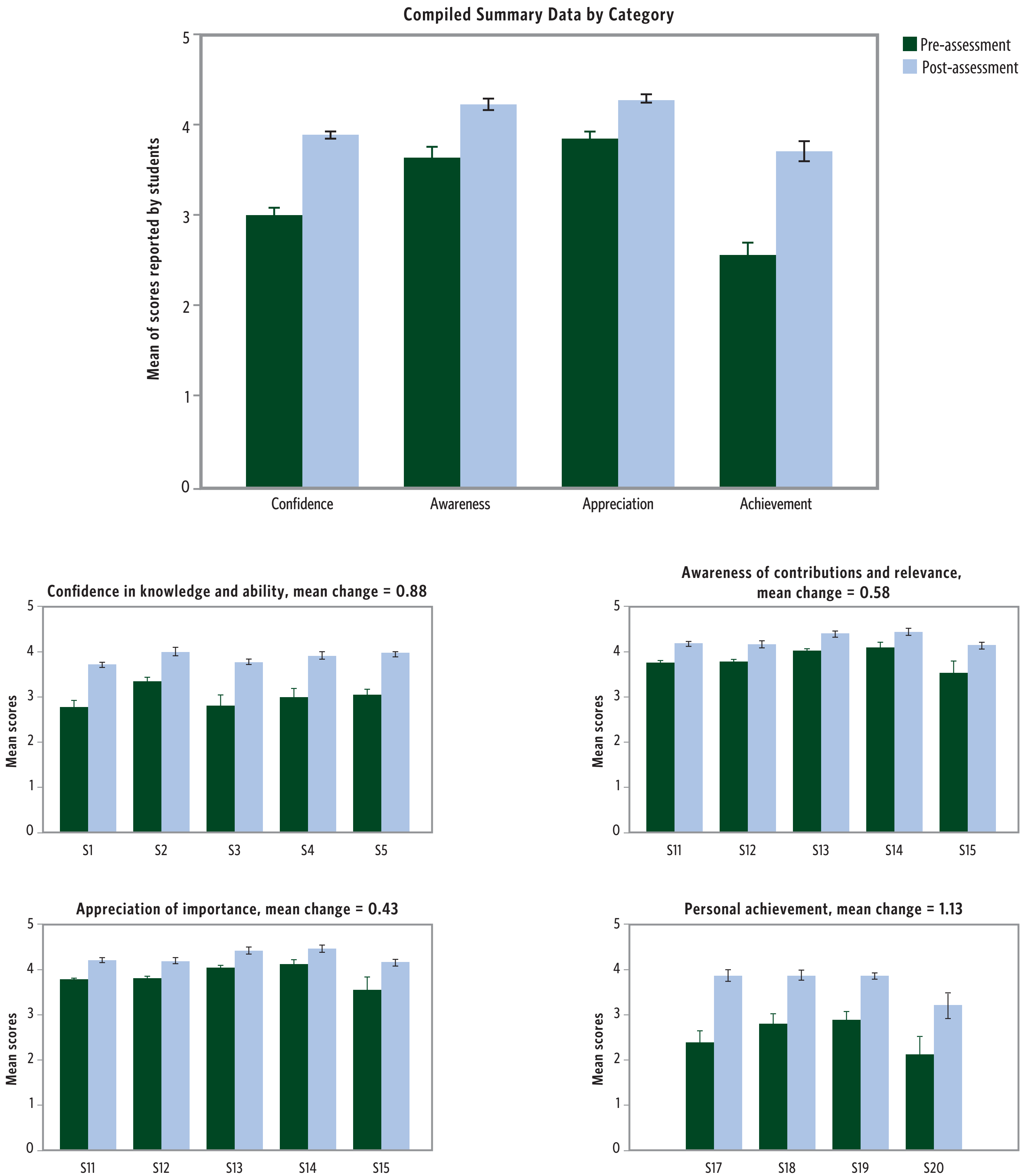
Survey data were pooled from all four semesters into pre- and post-assessment groups. For this report on the project to date, I calculated means and standard errors of student responses to nineteen survey statements. One survey statement (number 16) was omitted from all analyses due to relevancy of the statement to the survey population. I also compiled summary data by disposition category and report pre- and post-assessment means of scores and the mean change in pre- and post-assessment scores by category.

Results

Pre-service K–8 teachers participating in the Biology 114 pre- and post-course disposition assessments demonstrated a favorable change in their general attitudes toward science and science teaching. The mean of scores reported by students increased for all nineteen survey statements between the pre- and post-assessment (Figure 1). The largest positive mean change in response between pre- and post-assessment occurred in the personal achievement category (mean $\Delta = 1.13$), indicating participants felt more positive in their personal development of how they think about science and science teaching after completing the course (Figure 1). The second largest mean change in student response was in the category addressing students' level of confidence in their science content knowledge, science process skills, and ability to teach scientific concepts (mean $\Delta = 0.88$).

I also found consistent improvements between pre- and post-assessment comments regarding participants' feelings

FIGURE 1. Biology 114 Pre- and Post-Assessment Mean Scores and Standard Errors for Student Responses by Survey Statement and by Disposition Category



NOTE: For Fall 2005–Spring 2007. The mean change between pre- and post-assessment response is reported by disposition category.

or attitudes about science in general and their ability and desire to teach science in their future classrooms. Students also responded favorably in post-assessment responses to the SENCER-style approach of the course. A representative sample of these comments is provided in Table 2. During the pre-assessment, 6.4 percent ($n = 18$) of participants indicated a career plan that included obtaining middle-school science licensure; in the post-assessment, that percentage had increased to 8.9 percent ($n = 23$).

Discussion

Recent research suggests that college science courses that contain elements of inquiry-based and hands-on learning (Palmer, 2001), practical application to teaching (Korb, Sirola and Climack, 2005), and engagement with broader real-world issues (Middlecamp, Phillips, Bentley, and Baldwin, 2006) affect positive change in undergraduate students' dispositions toward science. This preliminary study of the outcomes of Biology 114, a course that incorporates each of

TABLE 2. Representative Sample of Pre- and Post-Assessment Comments

Comments First Day of Class	Comments Last Day of Class
I do not feel equipped to teach science yet but hopefully I will after completing science requirements.	I really liked this class. It was the only one in my four years here that I learned meaningful information that was explained in an easy way.
I have never been a science person but I hope I will give my students good experiences with it.	I have learned a lot and know there are more methods I can learn, I just have to ask questions and research.
I really need more knowledge about science before I will be confident enough to teach it to my future students.	I have decided to take on teaching science in middle school after this semester of 3 science courses.
Too hard, ugh, yucky, why me?	Doing the SOL assignment was very helpful in relating our science class to what we will be teaching in the future.
I wish I was stronger in science, but it is the most difficult subject area for me.	This class has made me start considering going on to further my education and obtain a masters.
I do not think I was prepared in elementary, middle, or high school in science/math departments.	Bio 114 has topics that genuinely effect [sic] and we can relate to it in our everyday lives. As students, if we see the significance, than we want our children to as well.
In high school I did not have good science teachers. I wish I had so I would like science more.	My attitude about science has dramatically changed for the better since the beginning of the semester.
I feel that I am often confused because there is so much information to learn.	I really like relating our information [to] the elementary SOLs.
I hope that one day I can effectively teach my students about science and feel adequately trained to do so as I advance in my studies.	The SOL assignments were a terrific resource to help us prepare for the classroom. I strongly suggest that you keep them as a part of this class.
It's something I fear—I am *not* saying I could not teach it—but I would need much more preparation. So right now I am *not* confident, but if I were to teach it, I would make sure I become confident.	After this course, I have thought about teaching middle school science.
I enjoy science but it takes a while for me to understand what I'm studying.	Bio 114 changed the way I look at science and definitely increased my appreciation of the subject.
I have a positive outlook on science but do not feel we have been trained well to teach and be enthusiastic about science.	I learned a lot in this class, and I can't wait to use this knowledge.

NOTE: Participants asked to reflect on feelings or attitudes about science in general and their ability and desire to teach science in their future classrooms these elements in a SENCER teaching approach, lends further support to these positive effects on pre-service teachers. Though the recorded changes were uniformly positive in four semesters of data collection, the means and degrees of change varied among disposition categories.

Students' self-reported feelings of achievement related to their personal development in how they think about science and science teaching (statements 17–20) showed the most change, while student confidence in their science content knowledge, science process skills, and ability to teach scientific concepts (statements 1–5) showed the second greatest change. These results demonstrate the course was successful at improving students' confidence in their science abilities, which should translate into a more positive attitude toward teaching science in their own classrooms (Young, 1998).

Interestingly, though still positive overall, there was less cumulative change in dispositions related to students' awareness of the importance of learning and teaching science in a greater societal context (statements 6–10) and in dispositions related to appreciation of scientific contributions and the importance of scientific research (statements 11–15). Mean scores for pre-assessment responses to statements in these two disposition categories were higher than were the mean scores for pre-assessment responses in the former two categories. Relatively high responses to pre-assessment statements in these categories suggest students entered the course with at least a perceived awareness and appreciation for the contributions and relevance of science. Exposure to intense media coverage of many controversial and capacious issues involving science may foster student perceptions of being informed and aware of these specific issues. This response trend may also be related to students' previous science experiences, a possible covariate that will be explored in future analyses.

The amount of change between pre- and post-assessment mean of scores reported by students increased over the course of four semesters. In fact, in consecutive semesters, students responded increasingly more positively to post-assessment survey statements in all four disposition categories. This temporal trend of improvement in science dispositions likely reflects the time required to develop and refine course content and context in this SENCER model. This consideration is important for others wishing to adopt this pedagogical approach.

Informal discussions with students further support post-assessment comments that students appreciated making science content relevant to teaching and to everyday living experiences: they find worth in studying science when they recognize it relates to their life and profession (Korb, Sirola and Climack, 2005). Many students found it challenging to match course content to K–8 SOLs and then provide a rationale for those connections, especially with the more abstract or complex college-level concepts that had no obvious K–8 counterpart. As these assignments had direct connection to their future teaching, students found them useful and helpful, even if difficult (Table 2). For an instructor with little formal training in teaching methodologies, these structured assignments provided an intentional link between content and teaching; yet by placing the burden on the students to make and justify their own connections to elementary course content, I was able to maintain class focus on subject content and context instead of on teaching methods.

Future plans for this endeavor include a continuation of the assessments in Biology 114 and discussions with colleagues on expanding the use of the pedagogical methods discussed here to other science courses required in the Liberal Studies major program. Also, as this dataset grows, I will examine the roll of covariates on assessment responses; factors such as the number of previous science courses the student has taken prior to Biology 114 and the grade level the student plans to teach may function to determine the degree of change in assessment responses. Additionally, I intend to broaden the use of these assessments to test the hypothesis that dispositions toward science, science teaching, and civic engagement continue to improve, first, as pre-service teachers move into their pre-professional education training and second, as new teachers gain actual experience in their own classrooms.

Biology 114 continues to evolve as a course as I modify content and context to reflect new trends and research in focal areas and discover alternative ways to engage future teachers in biology and science teaching. Future teachers who enter the workforce with an appreciation of and sense of excitement for the sciences will help to break the cycle and ensure that our children leave school with a better understanding of our world and the immense challenges and opportunities we face.

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in the development of the assessment tool, and Dr. Alix Fink, for her encouragement and advice on the challenges and rewards of teaching through focal topics.

About the Author

Dr. Mark Fink is an Associate Professor of Biology at Longwood University. His research at Longwood focuses on basic and applied questions relating to the ecology of birds. His current research focuses on aspects of avian reproductive ecology and understanding the impacts of habitat alteration on reproductive success and population dynamics of early-successional birds of the Virginia Piedmont.

He is also interested in pedagogical questions relating to how undergraduate students, especially pre-service teachers, best learn science concepts and appreciation. He is currently examining the influence of existing science courses at Longwood University on dispositions toward science and science education among pre-service and in-service K–8 teachers.

Dr. Fink has been at Longwood since 2001. He has a doctoral degree in biology from the University of Missouri and Master of Science degree in wildlife and fisheries science from Texas A&M University.

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PROJECT REPORT

Quantifying the Atmospheric Impact and Carbon Footprint of an Urban Biomass Incinerator

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Abstract

This study examines the carbon footprint of a proposed biomass incinerator in Minneapolis and Saint Paul, Minnesota. This research was integrated as a service-learning project into the curriculum of an undergraduate differential equations course. Mathematical models were developed and analyzed to examine the local contribution of emissions to the atmosphere and the extent of land needed to offset incinerator emissions both in the short (daily) and long (yearly) term. Our results show the sensitivity of atmospheric carbon content to the incinerator output rating, area and type of land dedicated for offsets, and atmospheric wind speed. The amount of managed land ranges from 7,000–20,000 hectares of land, or approximately the area of Saint Paul. The land requirements seem feasible in the context of the amount of available (unmanaged) land both locally and worldwide, but these requirements are diminished given the potential air quality effects resulting from biomass incineration.

Introduction

The Rock-Tenn paper recycling plant located in Saint Paul, Minnesota employs over 500 people and contributes significantly to the economic health of the greater Minneapolis-Saint Paul metropolitan area (Nelson 2007). The company initially had its thermal energy supplied by Xcel Energy, the local power provider. In late 2007, Xcel Energy decommissioned the plant that supplied Rock-Tenn's thermal energy. Alternative sources of energy were needed to maintain the long-term sustainability of the recycling plant.

Refuse derived fuel (RDF) was a proposed alternative to provide energy for the recycling plant. This technique derives energy from the incineration of plant material, refuse, and compost (Nelson 2007). RDF is an example of bioenergy. Generally defined as the use of plant material to supply energy, bioenergy supplies 15 percent of the world's energy needs (Lemus and Lal 2005). Bioenergy is an alternative energy to fossil fuels. Trees, through the process of photosynthesis, convert carbon dioxide into carbon, so any combustion of tree residue (and associated release to the atmosphere of this comparatively recently-fixed carbon) theoretically results in no net change of atmospheric carbon (Smith 2006).

Surrounding the Rock-Tenn plant are residential neighborhoods. In response to the proposed plan of the biomass incinerator, a grassroots organization, Neighbors Against the Burner, formed to oppose the incinerator, citing air quality effects on health (Pope et al. 2002) as one of its main objections. Based on the strong community response, in November 2008 the Saint Paul City Council passed a resolution against having the biomass incinerator be the energy source for Rock-Tenn. The Council advocated investigation of other alternative energy options, such as using biogas from anaerobic digestion (Saint Paul City Council 2008).

Augsburg College is a private, liberal arts college in Minneapolis, Minnesota, approximately three miles from the Rock-Tenn Recycling Plant. In spring semester 2008 as part of a semester-long research project for a course on differential equations, 11 students, with this author as the instructor, engaged in a service-learning project to investigate the atmospheric effects and carbon footprint of the proposed biomass incinerator. The project was integrated into the course content to provide a real-life example that had both civic and environmental connections. Two key research questions were addressed by the students:

1. How much do incinerator emissions elevate local atmospheric carbon?
2. What conditions need to be satisfied for carbon neutrality both short and long term?

For the purposes of this study, carbon neutrality implies zero net change in the atmospheric carbon content.

Methods

This study was integrated in the curriculum for a one-semester differential equations course. At the beginning of the term the instructor introduced the project objectives. The students formed teams to investigate the project objectives through construction and analysis of a mathematical model. The teams reported updates with the instructor throughout the semester. Additionally, a representative from Neighbors Against the Burner attended a class session to answer student questions and provide feedback. At the end of the term, students presented their results and wrote a report describing their results in the context of the mathematical, environmental, and civic dimensions of the project. The results presented in this study derive from these student projects.

Mathematical models

All mathematical models are formulated to measure the rate of change in atmospheric carbon content. Two overarching processes are assumed to affect this rate of change: emissions from the burner (increasing atmospheric carbon content) and biophysical processes that decrease atmospheric carbon. The following word equation describes this process:

$$\text{Rate of change of atmospheric carbon} = \text{Incinerator emissions} - \text{Biophysical processes} \quad (1)$$

Emissions from the incinerator are assumed to occur at a constant rate, dependent on the emission type and incinerator output rating. To maintain carbon neutrality, we assume the existence of an active forest that removes carbon. With these assumptions, each team then had to quantify the appropriate mathematical model based on Equation 1. The mathematical models are qualitatively described below; additional mathematical descriptions are in the Appendix.

Emissions Contribution to Atmospheric Carbon. Emissions from the incinerator and subsequent dispersion into the atmosphere create a plume of incinerated material and gases. This model, derived from models of contaminant transport in fluids (Brannan and Boyce 2007; Falta Nao and Basu 2005), describes the rate that incinerated carbon enters the plume. The biophysical process term is assumed to be directly proportional to the wind speed versus higher wind speed values decrease the amount of carbon near the incinerator and increase the concentration of carbon in the plume. Outputs from this model could subsequently be used to quantify spatial distribution of carbon in the plume through diffusion, advection, and other atmospheric properties.

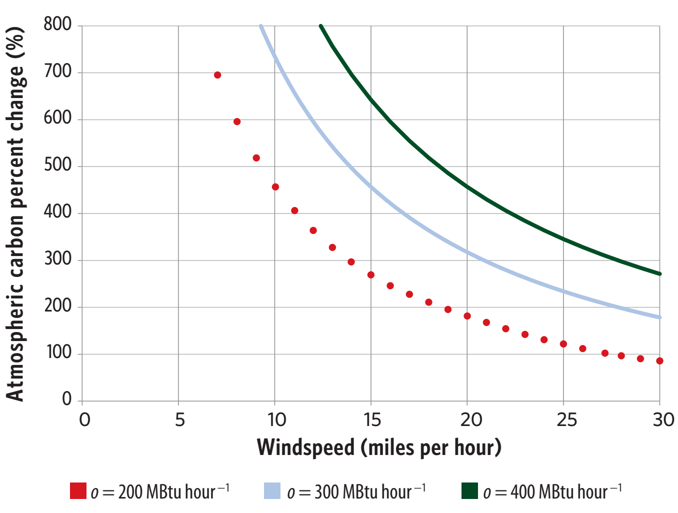
The incinerator emissions are inversely proportional to the smokestack output area, assumed to be 250 square meters for this study. The flow (in terms of volume per time) of emissions into the smokestack must equal the flow of emissions into the atmosphere. If the area of the smokestack increases, the rate of change of atmospheric carbon must decrease to maintain the constant flow of emissions.

Short and long term carbon neutrality. Long term atmospheric measurements of carbon dioxide over various ecosystems have shown the short and long term responses of ecosystems to carbon uptake through the dynamic processes of photosynthesis (conversion of carbon dioxide to simple sugars) and respiration (release of carbon dioxide to the atmosphere) (Baldocchi et al. 2001; Wofsy et al. 1993). Aggregated up to annual timescales, this balance between photosynthesis and respiration typically is negative (meaning the photosynthesis flux is stronger than all respiratory fluxes), indicating the ecosystem is a sink of carbon to the atmosphere. Diurnal fluctuations in temperature and moisture, seasonal variation, species composition, and plant species successional stage all contribute to an ecosystem being a given source or sink of carbon to the atmosphere (Baldocchi et al. 2001). The productivity of a forest (or its ability to decrease atmospheric carbon) can therefore be quantified with long-term records of net carbon uptake.

As previously stated, we assume the existence of a forest that will offset incinerator emissions. In our models this is represented by having the emissions term inversely proportional to the forest area. As forest area increases, emissions contribute proportionally less to atmospheric carbon because there are more trees to remove atmospheric carbon.

The biophysical process term was quantified in two different ways to describe short term (daily) and long term (yearly) carbon uptake. Short term carbon uptake was modeled with a dynamic, periodic term modeled after patterns of diurnal net ecosystem carbon exchange (Wofsy et al. 1993). Long term carbon uptake or forest productivity was assumed to occur at a constant rate, with values determined from Baldocchi et al. (2001).

FIGURE 1. Model Results of Atmospheric Carbon Content from Incinerator Emissions as a Function of Wind Speed



NOTE: Contours represent different output ratings, *o*. Positive vertical axis values suggest that the incinerator is increasing atmospheric carbon dioxide levels, or a "carbon-positive" incinerator.

Results

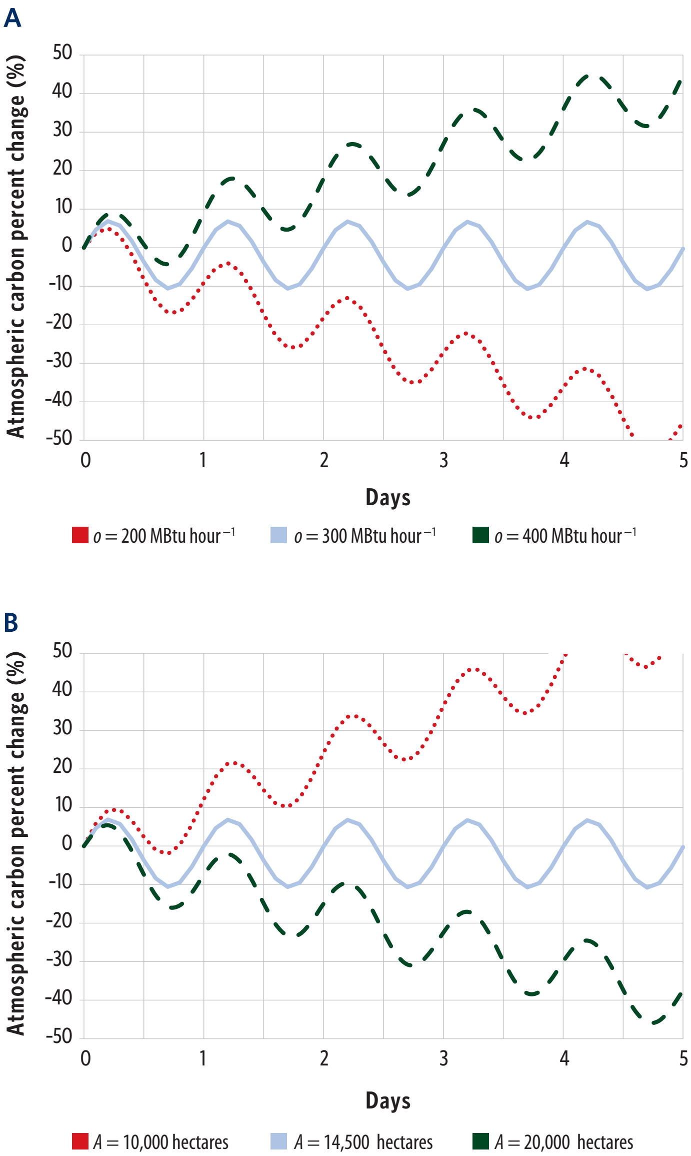
Figure 1 shows results of the influence of wind speed on atmospheric carbon content. As wind speed increases, local emissions decrease independent of burner output. Increasing the incinerator output rating *o* (measured in MBtu per hour) also increases atmospheric carbon content, inferring a higher concentration of carbon in the plume.

Figures 2a-b show model results of the daily temporal change in atmospheric carbon content. Vertical axis values in Figures 2a-b are scaled as a percent change from the initial atmospheric carbon content. Positive vertical axis values suggest that the incinerator is increasing atmospheric carbon dioxide levels, or a "carbon-positive" incinerator, whereas negative vertical axis values indicate the incinerator is "carbon-negative," or that the forest removes additional carbon dioxide beyond incinerator emissions. The periodic behavior in atmospheric carbon results from the selection of a periodic function for the carbon uptake function (see the Appendix). Daytime has a stronger net carbon uptake, indicating trees in the forest are removing carbon from the atmosphere through photosynthesis, thereby decreasing atmospheric carbon content. As photosynthesis is a light-dependent reaction, during the night the forest is a source of atmospheric carbon.

Figure 2a reflects short term temporal emissions when the output rating of the boiler *o* is varied from 200 to 400 MBtu per hour. These output ratings were estimated from similar steam-producing systems as the one studied by the students (Energy Products of Idaho 2009). In all cases, it is assumed that there is an actively growing forest of 14,500 hectares (approximately the area of Saint Paul) to offset incinerator emissions. For an output rating of 400 MBtu per hour the atmospheric concentration is increasing at a constant rate of 10 percent per day, whereas for an output rating of 200 MBtu per hour the forest is large enough to reduce atmospheric carbon content by 10 percent per day.

Figure 2b shows the effect of changing the forest area on atmospheric carbon content. If the forest area is reduced to 10,000 hectares, then the incinerator becomes a source of carbon to the atmosphere with emissions growing at a rate of approximately 10 percent per day, indicating that the forest itself is not large enough to offset emissions from the plant.

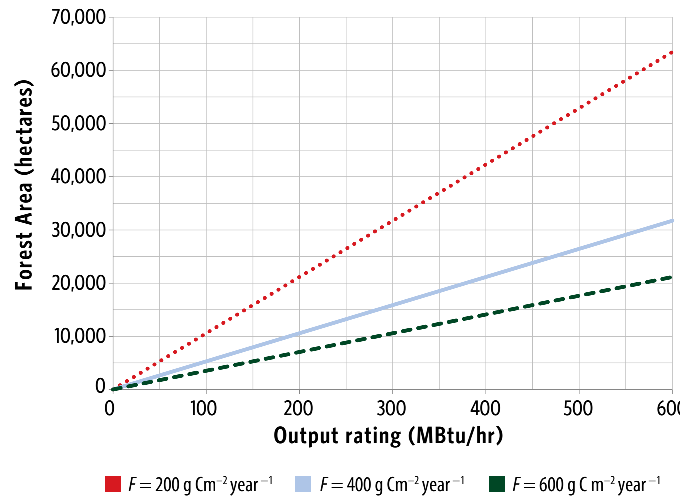
FIGURE 2. Model Results for the Short-Term Carbon Neutrality of the Burner



NOTE: Results expressed as the percent change of atmospheric carbon content from the initial condition. Positive vertical axis values suggest that the incinerator is increasing atmospheric carbon dioxide levels, or a "carbon-positive" incinerator, whereas negative vertical axis values indicate the incinerator is "carbon-negative," or that the forest removes additional carbon dioxide beyond incinerator emissions. A shows how the output rating o of the incinerator influences the carbon neutrality of the incinerator, and B shows how the forest area influences the carbon neutrality of the incinerator.

On the other hand, if the forest area is increased to 20,000 hectares, then the incinerator is "carbon negative," decreasing atmospheric carbon concentrations approximately 10 percent per day.

FIGURE 3. Model Results for the Long-Term Carbon Neutrality of the Incinerator



NOTE: Results a function of incinerator output rating and forest area, assuming that there will be no net change in atmospheric carbon dioxide. Contours signify different values of the yearly forest net carbon uptake or uptake (F).

Figure 3 shows the area of land that would need to be dedicated to maintain long-term carbon neutrality as a function of the output rating. As the output rating increases, a larger forest area will be needed to sustain carbon neutrality. The slope of the linear dependency in Figure 3 depends on the forest productivity (F) in removing carbon dioxide from the atmosphere. Different values of F result from the overall forest species composition (Baldocchi et al. 2001). The less productive forest (smaller values of F) will require a larger area to offset incinerator emissions.

Discussion

Evaluation of model results

A strong concern to the incinerator is the decrease in air quality in the neighborhoods surrounding the recycling plant. The results shown in Figure 1 qualitatively support this concern. Higher incinerator output ratings increase the amount of atmospheric carbon in the emissions plume. While atmospheric carbon decreases with increasing wind speed, conservation of mass infers that this carbon is dispersed to neighborhoods surrounding the incinerator.

Recent studies have shown linkages between public health and air quality (Pope et al. 2002; Zhang and Smith 2007). In addition to the carbon released through incineration, aerosols and other particulate matter may also be released into the atmosphere by incineration. While these other aerosols were not investigated in this study, the models presented here could easily be adapted to take these into consideration. Additionally, coupling this model to an atmospheric transport model could quantitatively describe increases in carbon or other aerosols and the spatial extent to neighborhoods around the incinerator.

Our results indicate that the amount of forest area needed to maintain carbon neutrality ranges between 7000–20000 hectares, depending on the type of species planted and the output rating (Figures 2 and 3). These estimates are a small fraction of land both locally and worldwide that could be dedicated to bioenergy. In Minnesota approximately 563,000 hectares of land could be rehabilitated to support bioenergy crops (Lemus and Lal 2005). Worldwide, the amount of land in need of restoration from degraded agricultural soils is approximately 1965 million hectares (Lemus and Lal 2005), which is a large proportion of the 2380 million hectares of land not classified as urbanized or protected (Read 2008). The total area of managed, or plantation, forests are 187 million hectares, consisting of 5 percent of worldwide forest area (Mead 2005).

Dedicating land to bioenergy crops helps to mitigate increasing levels of atmospheric carbon dioxide, restore soil organic carbon that were depleted from agricultural practices, and prevent erosion (Lemus and Lal 2005; Lal 2004; Sartori et al. 2006). In spite of these benefits and comparatively small area of land required to offset incinerator emissions, other factors not accounted for in our models would modify our estimates for the amount of land needed to offset emissions. First, technological advances will be required for their application, which may not be appropriate at all regional and local levels (Smith 2008). Second, bioenergy should be part of a suite of strategies targeted to mitigate climate change, which include the reduction of existing emissions through changes in consumption and improving agricultural efficiency (Smith 2008; Rhodes and Keith 2008). Third, life-cycle analyses for bioenergy crops (Adler, Del Grosso, and Parton 2007; Spartari, Zhang, and Maclean 2006) have shown a slight decrease in their mitigation potential when the growth and maintenance of the bioenergy crop (which requires energy) is taken into consideration. Additionally a recent study by Fargione et al. (Fargione et al. 2008) has quantified a substantial carbon "debt" incurred by clearing land for bioenergy crops. Further investigation into these factors is needed to refine and quantify the carbon footprint of the incinerator.

Evaluation of teaching and learning outcomes

Key learning outcomes of the project were to (a) develop and apply differential equation models to a contextual situation, (b) interpret results in the context of the carbon neutrality of the burner, and (c) provide valued recommendations based on the observations of the mathematical models.

The use of a service-learning-based project aligned well with both course learning objectives as well as the Augsburg College mission, which has a strong history in service learning (Hesser 1998). The students were given a survey to assess project outcomes in three categories: (a) overall learning (application and connection to course learning outcomes), (b) resource utilization (ability to complete the project independently), and (c) community connection (public acknowledgment of student efforts). The eleven students in the class responded to each category on a 5 point Likert scale. The average results were 3.9 (median 4) for the overall learning, 4.2 (median 4) for resource utilization, and 3.6 (median 4) for community connection. Students overall remarked positively about the service-learning project. One student remarked that "It was interesting to see real-world applications of math," and another student commented "The project was an excellent way of learning how to put our concepts into a practical perspective, and it was also edifying to learn the nature of carbon neutrality."

Based on the evaluations, it can be concluded from the student assessments that the first two outcomes were met (the construction, application, and interpretation of mathematical models). The lower ranking of the community connection category indicated not fully meeting the final objective. While students articulated recommendations on model results, a stronger connection to the relevant stakeholders in the issue (Neighbors Against the Burner and Rock-Tenn Recycling) could have been made. Multiple student evaluations expressed the desire for a tour of the recycling plant, or have more interaction with local community organizations beyond the mid-term visit. It would have been desirable to have a public forum of presentation of results, thereby increasing the visibility of the project in the college community.

This project has shown the qualitative contribution of the biomass incinerator to local atmospheric carbon content and the amount of land required to offset incinerator emissions. The project articulated the value of mathematical models and connected classroom learning to a civic and environmental issue.

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About the Author

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Appendix: Description of Mathematical Models

The quantity described in all models is the atmospheric carbon density (grams carbon per square meter, or g C m^{-2}), represented with the variable c. Models were expressed as a differential equation, and where appropriate, solved directly or with standard numerical techniques (Blanchard, Devaney, and Hall 2006). The initial condition (c_0) for all models assumes a fixed CO_2 mixing ratio of 385 parts per million by volume (National Oceanic and Atmospheric Administration 2009; Peters et al. 2007), assuming an air density of 44.6 mol m^{-3} (Campbell and Norman 1998) uniformly distributed up to 21.5 m above the ground surface. Energy units are expressed in MBtu, or a million British thermal units.

Model results were investigated in the context of the following key parameters:

1. Incinerator output rating o (MBtu hr^{-1}),
2. Atmospheric wind speed v (m hr^{-1}, expressed in all figures and results as miles hr^{-1})
3. Forest area A (m^2, expressed in all figures and results as hectares)
4. Forest annual net carbon uptake or productivity F (g C m^{-2} $year^{-1}$)

Emissions Contribution to Atmospheric Carbon

The model of the emissions contribution to atmospheric carbon was modified from models of contaminant transport in fluids (Brannan and Boyce 2007; Falta Nao and Basu 2005) with the following differential equation:

$$\frac{dc}{dt} = \alpha \cdot \varepsilon \; \frac{E \cdot o}{S} - \frac{c}{c_0} \cdot m_0 \cdot v, \qquad \text{(A1)}$$

where c, t, o, and v are defined above, t is time (hours), α is a conversion factor from grams to pounds (453.59 grams $pound^{-1}$), ε is a conversion factor to determine the amount of carbon in carbon dioxide (0.2727 g C g^{-1} CO_2), E is the emissions fuel type for wood (assumed to be 195 lbs CO_2 $MBtu^{-1}$ [Palmer 2008]), o is the boiler output rating, S is the incinerator total smokestack area (assumed to be 250 m^2). For a circular smokestack this would be a diameter of 17.8 m, and mo is the initial atmospheric carbon volume (0.206 g C m^{-3}). Assuming the carbon dioxide concentration equilibrates rapidly to steady state (that is, $dc/dt = 0$), an expression can be determined that relates atmospheric carbon content c to the wind speed v, as shown in Figure 1 for different values of the output rating o.

Short- and Long-Term Carbon Neutrality

The short term carbon uptake was determined via the following differential equation:

$$\frac{dc}{dt} = \alpha \cdot \varepsilon \; \frac{E \cdot o}{A} + f_1 \cdot \cos(f_2 \cdot t + f_3) - f_4 \qquad \text{(A2)}$$

where c, t, α, ε, E, and A are defined above. The periodic function represents the diurnal uptake pattern typically found in a forest (Wofsy et al. 1993). For this study, $f_1 = 0.1$ g C m^{-2} hr^{-1}, $f_2 = \pi/12 \approx 0.262$ hr^{-1}, $f_3 = 0.524$, and $f_4 = 0.05$ g C m^{-2} hr^{-1}. The values of f_1, f_2, f_3, and f_4, were visually determined from data of the average diurnal uptake pattern for a coniferous forest during the peak summer carbon uptake period (Monson et al. 2002; Zobitz et al. 2007).

To investigate the long-term carbon footprint, the following model was used:

$$\frac{dc}{dt} = \alpha \cdot \varepsilon \frac{E \cdot o}{A} - F, \qquad \text{(A3)}$$

where all variables are defined above. Again assuming steady state dynamics (or no change in atmospheric carbon) a linear equation between A and o can be formulated and is represented for different values of F in Figure 3.

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RESEARCH ARTICLE

SENCERizing Preservice K–8 Teacher Education: The Role of Scientific Practices

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Abstract

Recent policy reports are calling for curriculum reforms to address problems about a lack of relevance and an avoidance of the core scientific practices in science courses K–16. One important cohort is K–8 teacher candidates who need courses in which they learn core ideas in science and participate in science practices. One promising approach is infusing SENCER courses into the science course sequence for future teachers. We report a review of select SENCER courses using an Evidence-Explanation framework to assess the type and levels of science practices introduced. Results on 'Differences in Courses', 'Common Themes Among Courses', and 'Demographic Patterns' are reported.

Introduction

Recent U.S. policy reports express a growing concern for the supply of scientists, science workers and science teachers; c.f., National Research Council 2006 report *Raising Above the Gathering Storm* and the National Center on Education and the Economy 2007 report *Tough Choices Tough Times*. The STEM (Science Technology Engineering Mathematics) teacher and workforce shortages have two components (1) declines in attracting and retaining individuals into science/science education programs of study and (2) into places of employment. These recent reports show that uptake of STEM courses and careers are waning. Then there is the documented evidence that the development of youth attitudes toward science, both negative and positive, begins in and around middle school grades (ADEEWR, 2008). Thus, much of the focus for addressing the problems is on schools and schooling K–16.

Consensus review reports (Carnegie Corporation of New York, 2009) are placing much of the blame on the curriculum models citing a lack of relevance and an avoidance of the core scientific practices that frame science as a way of knowing; e.g., critiquing and communicating evidence and explanations. The NRC K–8 science education synthesis research study *Taking Science to School* (Duschl, Schweingruber & Shouse, 2007) is another consensus report that makes recommendations about the reform of science curriculum, instruction and assessment. The *TSTS* report concludes that K–8 science education should be grounded in (1) learning and using core knowledge, (2) building and refining models and (3) participating in discourse practices that promote argumentation and explanation. The report also concludes that a very different model of teacher education must be put into place. That raises an important set of issues. Where in the undergraduate curriculum do future K–8 teachers engage in and learn to use the core knowledge, building and refining models and argumentation and explanation practices?

The typical introductory survey science courses taken by non-science majors and elementary education candidates focus more on the 'what we know' of science and less on the 'how we know' and the 'why we believe' dynamics and practices of science. Determining the level and degree of scientific practices in science courses is essential for shaping and understanding preservice/inservice teachers' engagement and confidence in doing science when planning and leading science lessons in their own classroom. Science courses that focus exclusively on teaching what we know in science are inappropriate for future teachers.

Teacher candidates need courses in which they participate in science practices. One promising approach we have been considering is infusing SENCER courses into the science course sequence for future teachers (e.g., subject matter, SENCER, science teaching methods). Science Education for New Civic Engagements and Responsibilities (SENCER) course frameworks offer a potential solution to both engagement in and understanding of science practices. The SENCER commitment is to situate science learning in civic or social problems to increase relevance, engagement and achievement in science content knowledge and inquiry practices. This article reports on an analysis of a subset of SENCER courses that take up environmental problems as the civic engagement issue.

The study investigates how the design of SENCER courses provides opportunities to practice science as inquiry. The premise is that teachers gaining experience in science practices are more likely to use these practices in their own elementary school classrooms. In turn, these teachers will be in a better position to understand and hopefully address the *Taking Science To School* recommendation that K–8 science education be coordinated around the 4 Strands of Proficiency:

> Students who understand science:
>
> 1. Know, use and interpret scientific explanations of the natural world.
> 2. Generate and evaluate scientific evidence and explanations.
> 3. Understand the nature and development of scientific knowledge.
> 4. Participate productively in scientific practices and discourse (Duschl et al 2007).

One of the three *TSTS* recommendations for teacher professional development speaks directly to the issue:

> Recommendation 7: University-based science courses for teacher candidates and teachers' ongoing opportunities to learn science in-service should mirror the opportunities they will need to provide for their students, that is, incorporating practices in all four strands and giving sustained attention to the core ideas in the discipline. The topics of study should be aligned with central topics in the K–8 curriculum so that teachers come to appreciate the development of concepts and practices that appear across all grades. (Duschl et al, 2007, p 350)

Review of Literature and Analytical Frameworks

With respect to changing how and what science is taught, one important cohort of science students is preservice elementary (K–8) teachers who have low self-efficacy when it comes to science (Watters & Ginns, 2000). The K–8 education cohort's lack of confidence and experience within the science experiences they had contributes to maintaining a cycle in which the students they teach lose interest and confidence in learning science due to poor teaching strategies, misdirected curriculum and weak teacher knowledge. (Wenner, 1993). Sadler (2009) has found that socio-scientific issues (SSI) affect learners' interest and motivation, content knowledge, nature of science, higher order thinking and community of practice. Thus, it is not a surprise that SENCER courses have successfully demonstrated increases in student enthusiasm (Weston, Seymour & Thiry, 2006). However, more information is needed to determine how SENCER courses impact student achievement in core knowledge of science and with science practices that involve model-building and revision. The first step toward conducting research on the impact of SENCER courses on learning is to ascertain which SENCER courses are implementing scientific practices; e.g., raising research questioning, planning measurements and observations, collecting data, deciding evidence, locating patterns and building models, and proposing explanations. The driving question is can SENCER courses when placed between science courses and science teaching methods courses effect teacher thinking and practices.

Co-designed courses represent another model that brings science and science methods courses together. The co-designed courses are planned and taught by both science and science education faculty. Zembal-Saul (2009, 687) has found that co-designed courses that adopt a framework for teaching science as argument to preservice elementary teachers served "as a powerful scaffold for preservice teachers' developing thinking and practice . . . [as well as] attention to classroom discourse and the role of the teacher in monitoring and assessing childrens' thinking." Schwartz (2009) found similar positive effects on preservice teachers' principled reasoning and practices after using an instructional framework focusing on modeling-centered inquiry coupled with using reform-based criteria from Project 2061 to analyze and modify curriculum materials. What these two studies demonstrate and the SENCER model supports is the effectiveness coherently aligned courses can have on students' engagement and learning. Such shifts in undergraduate courses and teaching frameworks will contribute to breaking the cycle that perpetuates low interest and high anxiety in the sciences at all levels of education, K–16.

Research shows that preservice elementary school teachers tend to enter the profession with inadequate knowledge of scientific content and practice. Preservice elementary teachers answer only 50 percent of questions correctly on a General Science Test Level II (Wenner, 1993). Stevens and Wenner's (1996) surveys of upper level undergraduate elementary education majors are consistent with other research that 43 percent of practicing teachers had completed no more than one year of science course work in college (Manning, Esler, & Baird, 1982; Eisneberg, 1977). The lack of courses and experiences in science reflected the low self-efficacy in science among preservice elementary school teachers (Stevens & Wenner, 1996; Wenner, 1993).

If no changes are made to current coursework required of preservice elementary school teachers, they will continue to have low self-efficacy in science and therefore avoid teaching this subject (Stevens & Wenner, 1996). Thus, teachers are unlikely to use inquiry within their science lessons with the result that students are not exposed to scientific practices. The cycle of negative experiences with science does not have to be accepted as an educational norm; as the studies by Zembal-Saul and by Schwartz demonstrate. Changes can be made that coherently align science courses with methods courses.

SENCER courses can serve as a bridge to connect real-world issues and scientific knowledge with the positive impact of raising motivation and engagement among non-majors' and preservice elementary teaches' to learn science (SENCER, 2009). Evidence shows that learning science within the context of a current social problem helps to motivate preservice teachers and enables them to form goals that include learning scientific concepts and practices (Watters and Ginns, 2000; Sadler, 2009). Preservice elementary teachers who experience scientific practices and do investigations that build and refine scientific evidence and explanations can more informed decision makers about science and the teaching of science.

Evidence-Explanation Continuum Framework

While it is important that SENCER courses successfully motivate preservice elementary teachers to learn about science content, it is also essential that science courses provide opportunities to use scientific knowledge and practices. The targeted science practices for this review of SENCER courses are from the Evidence-Explanation (E-E) continuum (Duschl, 2003, 2008). The E-E continuum represents a step-wise framework of data gathering and analyzing practices. The appeal to adopting the E-E continuum as a framework for designing science education curriculum, instruction and assessment models is that it helps work out the details of the critiquing and communicating discourse processes inherent in TSTS Strand 4—Participate productively in scientific practices and discourse. The E-E continuum recognizes how cognitive structures and social practices guide judgments about scientific data texts. It does so by formatting into the instructional sequence select junctures of reasoning, e.g., data texts transformations. At each of these junctures or transformations, instruction pauses to allow students to make and report judgments. Then students are encouraged to engage in rhetoric/argument, representation/communication and modeling/theorizing practices. The critical transformations or judgments in the E-E continuum include:

1. Selecting or generating data to become evidence,
2. Using evidence to ascertain patterns of evidence and models.
3. Employing the models and patterns to propose explanations.

Another important judgment is, of course, deciding what data to obtain and what observations or measurements are needed (Lehrer & Schauble, 2006; Petrosino, Lehrer & Schauble, 2003). The development of measurement to launch the E-E continuum is critically important. Such decisions and judgments are critical entities for explicitly teaching students about the nature of science (Duschl, 2000; Kuhn & Reiser, 2004; Kenyon and Reiser, 2004). How raw data are selected and analyzed to be evidence, how evidence is selected and analyzed to generate patterns and models, and how the patterns and models are used for scientific explanations are important 'transitional' practices in doing science. Each transition involves data texts and making epistemic judgments about 'what counts.'

In a full-inquiry or a guided-inquiry, students formulate scientific questions, plan methods, collect data, decide which data to use as evidence, and create patterns and explanations from the selected evidence (Duschl, 2003). Science engagement becomes more of a cognitive and social dialectical process as groups and group members discuss why they differed in data selected to be evidence and varied in the evidence used for explanations (Olson & Loucks-Horsley, 2000). Students' participating in these interactions tend to build new knowledge and/or to correct previous misconceptions about a scientific concept (Olson & Loucks-Horsley, 2000).

Research Context and Methods

The research question asks to what extent do SENCER courses model and use scientific practices that are linked to obtaining and using evidence to develop explanations? SENCER courses were selected from the SENCER website and examined to determine the opportunities provided to engage in scientific practices. Only SENCER courses designed around environmental topics (e.g., water, earth, soil, rocks) were selected because these courses offer up integrated science opportunities. Next, course syllabi, projects and activities were reviewed to ascertain students use, or the potential for use, of data-driven E-E scientific practices.

SENCER courses were considered to emphasize planning and asking questions if students asked their own research question, designed their own experiment, or designed an engineering project. A course that stressed data collection showed that students went into the field and collected soil, water, or air, or they took measurements of samples. A SENCER course provided students practice in evidence if they decided which data to keep as inferred by students representing data or creating graphs. Practice in evidence was also inferred if students analyzed data later. Students could not complete this activity without deciding which evidence to use. A course gave students experience in patterns if students determined how the evidence was modeled as seen by analysis of evidence or running statistics on evidence. Lastly, a course allowed students to practice using explanation if students connected their project to previous research or theories as seen in library searches, if they made predictions for another phenomenon based off of their results, or if they discussed recommendations. Courses that included scientific content but focused on practices used in the humanities such as research and communication with another culture and were left out of this study. A summary of the criteria for evaluating the courses appears in Table 1,below.

The names of the courses located on the SENCER website appear in Tables 2 and 3. Scientific practices identified were recorded as an X in Table 3 with further details on how the course fulfilled the criteria. Courses that did not meet the criteria received an N/R (no result). Each X was worth one point on the scale. Each scientific practice identified was worth one point on the scale. A scale from 1–5 was created to effectively compare scientific practices identified in each of the course modules. A score of 1 indicated that the course module only incorporated one portion of scientific practice, and a score of 5 indicated that the course emphasized all five portions

TABLE 1. Criteria for Evaluating SENCER Courses

E-E Continuum Component	SENCER Course Criteria for Inclusion of E-E Continuum Component
Asking questions and planning	Students: ask their own research question(s), design their own experiment. or design engineering project
Data collection	Field Work: Soil, water, air collection, or sample measurements
Evidence	Students decide evidence to keep; inferred from data representations or graphs or later data analysis in the pattern component of the E-E continuum
Patterns	Students determine how evidence is modeled; inferred from analysis of evidence or running statistics on evidence
Explanation	Connection of project to previous research; library searches; predictions for another phenomenon based off of results; or discuss recommendations

TABLE 2. Selected SENCER Courses

Course Title/Civic Problem*	Institution	Classification	Class Size†	Student Year	Major	Class Time‡
Introduction to Statistics with Community-based Project. No specific focus; students choose topic	Metropolitan State University, Saint Paul, MN	Public university, urban	32	Nontraditional students (working)	Applied math; biology; management; nursing; social work; math teaching	3.3 hrs
Ordinary Differential Equations in Real-World Situations: No specific focus; various data sets given to solve	Bryn Mawr College, Bryn Mawr, PA	Women's liberal arts college	15–20	Junior, senior	Math	1.3 hrs, twice
The Power of Water. Create the most efficient turbine to power small rural community	Longwood University, Farmville, VA	State institution	60–90, lecture 24, lab	Sophomore	General education	3-hr lecture; 2-hr lab
Science on the Connecticut Coast: Investigations of an Urbanized Shoreline: Determine human impact in local marshes/beaches	Southern Connecticut State University, New Haven, CT	State institution	20	Freshman, sophomore	Non-majors	2-hr lecture/ lab; 3-hr field
Renewable Environment: Transforming Urban Neighborhoods: Determine impact of urbanization on environment	Saint Mary's College of California, Moraga, CA	Christian Brothers College	n/a	n/a	n/a	3-hr × 2
Riverscape (five courses): Determine human impact on water quality	Hampton University, Hampton, VA	Private university	5–25	Sophomore, graduate student	Undergrad and graduate preservice teachers	1 time
Chemistry and Policy: A Course Intersection: Determine human impact on soil quality and learn how to communicate results to general public	Vassar College, Poughkeepsie, NY	Liberal arts college	n/a	n/a	Chemistry, non-majors interested in policy	1-hr lecture × 3; 4-hr lab
Environment and Disease: Determine if connection exists between human impact on environment and widespread disease	Bard College, Annandale-on-Hudson, NY	Liberal arts and sciences college	n/a	Freshman	n/a	1.3-hr lecture × 2; 2.5-hr lab
Energy and the Environment: Topic varies, but students study some aspect of water quality	New York University, New York City, NY	Private university (14 schools)	120–30, lecture 20, lab	n/a	n/a	1.25-hr lecture; 1.67-hr lab
Geology and the Development of Modern Africa: Investigate the best location to conduct mining in Africa, using geological techniques	Hamilton College, Clinton, NY	Private liberal arts college	n/a	n/a	n/a	4 hr
Chemistry and the Environment: Create questions related to environmental quality around campus	Santa Clara University, Santa Clara, CA	Jesuit Catholic university	n/a	n/a	n/a	n/a
Science, Society, Global Catastrophe: No particular research question; students practicing steps of scientific process	University of Wisconsin, Marathon, Wausau, WI	Public university, freshman sophomore	25	Freshman, sophomore	n/a	n/a

* Looking at, e.g., water quality; for some, do they even have a SENCER focus?
† Students per class.
‡ Per week.

of scientific practice within the E-E continuum. Therefore, a course with a score of 1 did not emphasize scientific practice whereas a course receiving a score of 5 heavily emphasizes scientific practice.

Course demographics were also investigated from the SENCER website. Information researched included type of institution, class size, student year, major and class time (Table 2). Demographic information was then used to interpret any differences seen in level of scientific practice among SENCER course modules.

Results and Findings

The results and findings are reported in 3 sections: Differences in Courses, Common Themes Among Courses, and Demographic Patterns.

Differences in Courses

Differences in courses are presented from the highest emphasis on scientific practices (5) to lowest emphasis of scientific practices (1). Two courses, "The Power of Water" and "Chemistry and the Environment," received a 5 because they provided students with practice in each aspect of scientific inquiry (Table 3). However, they approached various aspects of inquiry differently due to the nature of the problem being solved. "The Power of Water" took an engineering method in which students designed the most efficient micro-hydropower turbine for a hypothetical small rural village whereas "Chemistry and the Environment" students formulated their own question to research about some environmental chemistry issue on their campus.

Most of the courses scored a 4 (Table 3), these included "Introduction to Statistics with Community-based Project," "Chemistry and Policy", "Renewable Environment: Transforming Urban Neighborhoods," "Riverscape," "Environment and Disease," "Energy and the Environment," and "Geology and the Development of Modern Africa." These six courses differed from "The Power of Water" and "Chemistry and the Environment" because they did not allow students to explain their patterns or models. Two courses that received a 4 did expose students to explanation, but left out some other aspect of scientific practices in inquiry. Students in "Chemistry and Policy" did not create their own scientific question to study, and "Riverscape" did not provide students with practice in creating create patterns. The "Riverscape" course is a major source of interest because it was designed specifically for preservice elementary school teachers in the attempt to gain appeal in science and learn scientific practices.

Two courses provided students with the opportunity to use 3 out of 5 practices within scientific inquiry, giving them a score of 3. "Renewable Environment: Transforming Urban Neighborhoods" and "Science in the Connecticut Coast," allowed students to collect data, provide evidence, and create patterns or models. However, students did not practice the planning and explanation stages of scientific inquiry.

Two courses that gave students experience in the fewest scientific practices scored a 2. There were no courses that scored a 1. "Science, Society, and Global Catastrophe" and "Math Modeling" differed in the inclusion of scientific practices. "Science, Society, Global Catastrophe" gave students training in finding evidence and creating patterns and models but not in the remainder of scientific practices. "Math Modeling" enabled students to practice finding evidence and creating explanations, but the course provided students with the remaining portions of scientific inquiry.

Common Themes Among Courses

SENCER courses with differing levels of scientific practices tended to have common themes for practicing scientific inquiry. One major theme was the use of collaboration as seen through group work on a scientific project. Most course modules shown on the SENCER website specifically state that students work in groups for their projects. Others such as "Riverscape" and "Chemistry and Policy" do not directly state that students do group work, although collaboration is emphasized within the course. The only course that did not emphasize collaboration was "Renewable Environment: Transforming Urban Neighborhoods," although this information may have been left off of the SENCER website. While not specifically stated within the E-E continuum, collaboration plays an important role within inquiry. Students who are able to discuss scientific concepts with one another can articulate ideas and argue enabling them to reconstruct their own ideas of scientific meaning (Olson & Loucks-Horsley, 2000).

Another common theme among high practice SENCER courses was that students communicated their results with one another in various formats. Most courses incorporated formal presentations at the end of the project for the rest of the class. Others used formal presentations, although they were created for different audiences such as the general public

TABLE 3. Scored Courses

Course	Total Score	Planning	Data Collection	Evidence	Patterns and Models	Explanation
Introduction to Statistics with Community-Based Project	4	X: come up with own question- write proposal	X: gather data	X: represent data	X: run stats and interpret data	
Math Modeling	2	N/R	N/R	N/R	X: find patterns	X: predictions; make questions from patterns/models
The Power of Water	5	X: create design of turbine	X: gather data	X: made graphs	X: interpret graphs	X: library research
Science in the Connecticut Coast	5	X: plan how they gather data	X: gather lots of data	X: inference because says that students analyze data later	X: analyze data	X: discuss results at conferences with other scientists
Renewable Environment: Transforming Urban Neighborhoods	3	N/R	X: gather data	X: inference because learning to interpret	X: learn to interpret	
Riverscape	4	X: question plus their own experiment	X: gather data	X: report results in proper format	N/R	X: search scientific literature; inference that attempting to explain
Chemistry and Policy	4	N/R	X: spectroscopy, chromatography, and electrochemistry; learn the importance of adequate sampling	X: inferring chose which data to use if communicating results	X: communicate results to those with less knowledge	X: discuss recommendations
Environment and Disease	3	N/R	X: learn challenge of collecting data	X: inference, analyze results	X: analyze data and interpret data- use of models	
Energy and the Environment	4	X: create own question to study and design experiments	X: collect H_2O sample	X: plot into graphs on excel spreadsheet	X: generate their own scientific conclusion- present to peers	
Geology and the Development of Modern Africa	4	X: planning how to implement surveys	X: collect data and gather samples	X: inferring yes because analyzing data	X: analyze data to present to investors	
Chemistry and the Environment	5	X: develop hypothesis and make experiment	X: varied water/air samples	X: inferring yes if making recommendations	X: inferring yes if make recommendations	X: make recommendations
Science, Society, Global Catastrophe	2	N/R	N/R	X: choosing which data to use in activities	X: math and statistical modeling exercises/ interpretation of data	

X = scientific practices identified, with further details on how the course fulfilled the criteria.
N/R = no result for courses that did not meet the criteria
Each X = one point as totaled in the Total Score column.

or for a buyer of potential land for diamond extraction. Other course modules such as "Science in the Connecticut Coast" and "Environment and Disease" based communication more on discussion of scientific concepts. Despite differences in the means of presenting ideas in class, communication of results is an important skill essential to inquiry-based learning.

Demographic Patterns

The SENCER courses differed in demographic information. The total number of students participating in class was widespread between 5 and 130 students (Table 2). Laboratories decreased class size to roughly 20 students. However, more information is needed for "The Power of Water" laboratory class size. Student year ranged from freshmen to graduate students within the course. Student type varied greatly from non-majors and preservice elementary school teachers to math or chemistry majors. Total class time differed among the courses in addition to the way the time spent was scheduled (Table 2).

None of the demographic information influenced the degree to which students gained practice in using science. Although class size is variable among courses, it had no impact on amount of scientific practices emphasized. Courses with large class sizes such as "The Power of Water" and "Energy and the Environment" provided students with similar practice in using science to smaller classes such as "Riverscape."

Additionally, student major had little impact on scientific practices emphasized within SENCER courses. Majors used a varying number of scientific practices among the courses studied. Math students in "Introduction to Statistics with Community-Based Project" used more areas of scientific practice than math majors in "Math Modeling" as seen in Table 3. Majors also did not use any more scientific practices than non-majors in these courses. "The Power of Water" allowed students to use all 5 elements of scientific practice in inquiry whereas majors in "Math Modeling" were only given the opportunity to practice 2 aspects.

Class year also did not affect the ability to expose students to use scientific practices. As expected, SENCER courses enabled upperclassmen and graduate students to gain practice in conducting science as seen in "Riverscape." However, many SENCER classes also provided underclassmen with a rich experience in practicing science. For example, "The Power of Water," consisting of sophomores, provided students with practice in every area of scientific inquiry.

Lastly, class time did not affect student exposure to using scientific practices. Courses that received the same scores consisted of a wide variety of time scheduled. "Chemistry and Policy" devoted much more time toward class time than "Environment and Disease," but students experienced the same number of scientific practices.

Conclusions

Distinctions in SENCER course characteristics have led to varying opportunities for students to gain experience in doing scientific practice as seen in this study's scores. Those with the highest scores allow students to have the greatest amount of ownership over their own work. Courses with a score of 5 provide students with the ultimate source of ownership in allowing them to choose their own question to study. Modules with scores of 3 and 4 may not allow students to ask their own questions to study, but they do provide students with responsibility over the remainder of scientific practices in the E-E continuum. Courses with the lowest scores provide students with the least amount of ownership over their own work. Students are given a piece of someone else's project and continue a small portion of that project. For example, students are given another project's data set that they are expected to analyze. Future SENCER courses should consider giving students as much ownership over their work as possible to encourage student experience in using scientific practices.

The nature of data collection also had an impact on the level of scientific practices used within course modules. Courses in which there was easy access to collect soil or water samples of interest along with equipment to measure samples showed a higher level of scientific practices within the E-E continuum. Courses such as "Math Modeling" and "Science, Society, and Global Catastrophe" may not have allowed for easy access to gather water or soil samples. Therefore, the course was unable to provide students with the opportunity to gain practice in data collection. "Geology and the Development of Africa" found a loophole that enabled students to gather their own data by using a computer simulation. Students did not actually collect rock samples in this class, but were able to collect data from their computer simulation. Perhaps computer simulations could be used in other courses that do not have easy access to take samples from the environment.

While these characteristics provide critical information to increase a SENCER course's use of scientific practices, traits that have no effect on level of scientific practices also offer great insight to increase student experience in performing science.

It is reassuring that SENCER courses can be flexible enough in incorporating inquiry for small as well as large class sizes. Future courses using the SENCER approach may be designed knowing that students can successfully learn scientific practices within a large classroom size. SENCER courses may cater to majors and especially to non-majors who have little experience in scientific practices. It is appropriate to use SENCER not only for upper level courses, but it is also critical to apply these modules to lower level classes.

SENCER courses provide a way to incorporate scientific practices within student learning. The integration of social issues with science builds preservice teacher interest in scientific practices. As these students gain experience in using scientific tools, they become more confident in incorporating science into their future elementary classroom. Perhaps our future teachers' greater enthusiasm for science will spark student interest in the sciences.

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REVIEW ARTICLE

Emerging Topics in the Study of Life on Earth:

Systems Approaches to Biological and Cultural Diversity

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There is broad consensus in the international scientific community that the world is facing a biodiversity crisis—the accelerated loss of life on Earth brought about by human activity. Threats to biodiversity have been variously classified by different authors (Diamond 1989, Laverty and Sterling 2004, Brook et al. 2008), but typically include ecosystem loss and fragmentation, unsustainable use, invasive species, pollution, and climate change. Across the globe, traditional and indigenous cultures are affected by many of the same threats affecting biological diversity, including the unsustainable use of natural resources, changes in traditional land use, and cultural assimilation. Academics and practitioners alike agree that to stem the erosion of biological and cultural diversity, we need to engage theoretical and applied perspectives from the natural sciences, social sciences, and humanities. In addition, we need to approach biological and cultural diversity from an integrated, systems-based perspective that emphasizes interconnections and interactions—and teach our students to do the same (Huggett 1993, Richmond 1993, Ford 1999, Sterman 2000, Richmond 2001, Kunsch et al. 2007, Nguyen et al. 2009). Fortunately, in our experience as scientists, social scientists, and teachers, sustaining diversity is a topic that interests students and can easily transcend and tie together diverse fields beyond biology, from statistics to law, from medicine to public policy. In this review, we highlight emerging topics related to sustaining biological and cultural diversity that are amenable to a systems-based approach. In the final section, we offer brief notes on active, student-engaged tools and approaches through which these topics can be taught to increase understanding of systems-based approaches by students.

Humans depend upon biodiversity in obvious as well as subtle ways: we need biodiversity to satisfy basic needs such as food and medicine, and to enrich our lives culturally or spiritually (Krupnick and Jolly 2002, Weladjii and Holand 2003, MEA 2005, West 2005, Losey and Vaughan 2006, Lambden et al. 2007, Ridder 2007). Yet in an increasingly technological world, people often forget how fundamental biodiversity is to daily life. When we hear about species going extinct or ecosystems being degraded, we assume that other species or ecosystems are around to take their place, or that in the end it does not really affect us. We rarely feel individually responsible for the loss of biodiversity, although human activities are the leading threat to the Earth's biodiversity. Immersed in our managed environments and virtual worlds, surrounded by houses and offices, streets and shopping malls, our direct contact with "nature" often consists of aquaria in our living rooms or manicured parks to which we drive in private automobiles. In many places it is hard to remember that food in the grocery store did not spring forth packaged, ready to cook and serve. Yet if we were to put a bubble over the managed environments of our cities and towns and tried to survive with no input from the natural world, we would quickly perish—humans are part of the natural system.

Simultaneously, at a time when the environmental and social consequences of human-induced changes such as deforestation, desertification, degradation and reduction of global water resources, and climate change are increasingly severe (MEA 2005), we are witnessing a homogenization of human cultures, livelihoods, and languages. In response, we need to broaden our traditional definition of what constitutes valid scientific data or "evidence," and appreciate and learn from the vast variety of approaches to human-environment relationships that have developed across the world's diverse cultures and languages, often through close interactions with the natural environment and based on a perception of humans as part of, rather than separate from, nature. The humanities, including history, philosophy, and the arts, play critical roles in exploring these issues. For example, cross-disciplinary scholarship has illuminated the critical intersections between art, science, and the environment in a broader cultural context (Blandy et al. 1998, Lambert and Khosla 2000, Thornes 2008). As global citizens, we need to re-examine and redefine the place of humans as part of life on earth, and to achieve a clearer understanding of the interconnections among biological, cultural, and linguistic diversity.

To achieve this vision, students need to be able to understand issues and challenges from an integrated, systems-based perspective; one way to achieve this goal is by teaching with active, systems-based techniques (Bosch et al. 2007, Westra et al. 2007, Mahon et al. 2008). In the classroom, teachers can use case-based examples that illustrate causal chains and attenuating or reinforcing feedback interactions. For example, students working through a case study of a fishery[1] as a complex system would discover that the system extends from the resource base and its supporting ecosystem through harvesting and distribution to the consumer, whether local or as a buyer in the global marketplace. In addition, students could identify disparate factors affecting the fishery, such as shifts in climate regime, rise or fall in energy costs, and government policies to protect or exploit a resource, and explore how their interactions can determine the collapse or the long-term sustainability of the fishery. Students may also consider the history of the fishery and the culture of the fishing community, a lesson that can reinforce the importance of understanding baselines and viewing cases from a historical perspective (Jackson et al 2001). Such an exercise reveals the system to be diverse, dynamic, and complex, and demonstrates that effective governance must recognize the interconnections and adaptive capacity of the fishery.

In this essay, we highlight several emerging topics in the study of cultural and biological diversity that could be used to develop systems-based skills in students, and then discuss specific implementation strategies for teaching these topics. Notwithstanding the contribution of the humanities disciplines to some of these topics, given our own disciplinary backgrounds, we focus on contributions from the natural and social sciences. We begin with two topics that illustrate the importance of biodiversity to humans (ecosystem services and ecosystem resilience), and then move on to consider climate change, human health, and cultural diversity. We continue with sections on community based conservation and engaging the public, and conclude with a discussion of how these topics can be taught in order to foster systems-based thinking in students.

Biodiversity and Ecosystem Services

An ecosystem is comprised of all the organisms that live in a particular place, and their abiotic (non-living) environment. The outcomes of interactions between organisms and the physical environment include complex processes, such as nutrient cycling, soil development, and water budgeting, which are all considered ecosystem functions. When these outcomes and processes are viewed in light of their benefit to humans, they are considered an *ecosystem service*. These services are far-ranging and include: the regulation of atmospheric gases that affect global and local climates including the air we breathe; maintenance of the hydrologic cycle; control of nutrient and

1 For an example, see the exercise Marine Reserves and Local Fisheries—an Interactive Simulation (NCEP 2009b).

energy flow, including waste decomposition, detoxification, soil renewal, nitrogen fixation, and photosynthesis; a genetic library; maintenance of reproduction, such as pollination and seed dispersal in plants we rely on for food, clothing or shelter; and control of agricultural pests. Humans can rarely completely replace these services and, if they can, it is often only at considerable cost (e.g., Costanza et al. 1997, Daily et al. 1997, Daily et al. 2000, Heal 2000, MEA 2005).

Plants and their pollinators (such as wasps, birds, bats, and bees) are increasingly threatened around the world (Buchmann and Nabhan 1995; Kremen and Ricketts 2000), yet pollination is critical to most major agricultural crops and virtually impossible to replace. In some places, a lack of pollinators has forced conversion to hand pollination (Partap and Partap 2000). There is a growing body of research that is attempting to estimate the replacement costs for natural and managed pollinators (e.g., Allsopp et al. 2004). In the Maoxian region of China, an important apple-growing region, it takes roughly 20–25 people to pollinate the apples in an orchard in one day, and costs the farmer roughly 70 US dollars. If pollination were done by rented honeybees, farmers would pay only 14 US dollars. Although the region has a long history of beekeeping, the pesticides used on the apple trees have made beekeepers unwilling to rent their bees to farmers (Partap and Partap 2000).

The relationship between biodiversity and ecosystem services is complex, and remains an active area of research (e.g., Naeem et al. 1995, Kremen 2005, Balvanera et al. 2006, Hector and Bagchi 2007, Schmitz 2009). Integral to any effort to sustain ecosystem services is an understanding of what traits and components of the system must be conserved in order for a particular service to persist. There is uncertainty regarding the ability of ecosystem services to persist in the face of reduced species diversity, and more research is needed to fully understand the importance of high levels of biodiversity on ecosystem function (Diaz et al. 2006). Despite these uncertainties, we do know the importance of individual species to ecosystem services is largely determined by the species' functional traits, or the ways in which a species interacts with its ecosystem, rather than just the number of species present (Chapin et al. 1997, Duffy 2002, Chalcraft and Resetarits 2003, Hooper et al. 2005, Wright et al. 2006, Violle et al. 2007, Diaz et al. 2006). We also know that functional diversity (the variety of different roles played by all species in an ecosystem) in the ecosystem is an important determinant of the magnitude of the impact the loss of a species will have on the ecosystem. In some cases there are multiple species that perform the same role in keeping an ecosystem functioning; for example there could be many types of invertebrates that assist in the decomposition of leaf litter. If a high number of species perform similar tasks, the loss of one functionally redundant species is likely to have a smaller effect than if only one species could perform the task, and it is lost from the system (Chapin et al. 1997, Tilman et al. 1997).

Recent research is considering ecosystems as multi-functional systems, rather than focusing on one ecosystem process, and is striving to measure the importance of species based on their roles in supporting multiple ecosystem functions (e.g., Hector and Bagchi 2007, Gamfeldt et al. 2008, Kirwan et al. 2009). These efforts indicate that measuring the impacts of species-loss on one ecosystem service at a time may undervalue the total contribution of species diversity to ecosystem function as a whole. As a consequence, overall ecosystem function may be more susceptible to species loss than single ecosystem services are, and thus, may be more vulnerable than earlier research may have suggested (Gamfeldt et al. 2008). Clearly, an integrated, systems-based approach is needed to understand the relationship between biodiversity and ecosystem services.

An emerging strategy for conservation involves incorporating ecosystem services into economic markets by making direct payments to local actors (payment for ecosystem services, PES). One such system in Nicaragua used payment to farmers as incentive for integrating additional trees into agricultural or grazing lands (Pagiola et al. 2007). PES practices can produce on-site benefits such as improved pasture production and fruit, fuel wood, timber, and fodder production. Adding trees to an agricultural system can also have off-site benefits for ecosystem services, such as carbon sequestration and maintenance of the hydrological system, and farmers were paid for both these on-site and off-site benefits. In this case, the additional payment for off-site benefits encouraged farmers to participate; on-site gains alone were not sufficient motivation to change behavior. Monetizing the positive contribution to ecosystem services created the incentive for local actors to shift practices.

PES can have beneficial social as well as ecological outcomes, as many underdeveloped and poor areas have the potential to provide large amounts of currently un-monetized ecosystem services (Bulte et al. 2008). For example, Wunder and Alban (2008) report on a program in Ecuador, where the residents of the Pimampiro municipality pay the largely indigenous and poor owners of the upstream forests to refrain from converting forest to agricultural land in order to protect the city's drinking water supply. PES programs must therefore evaluate the social setting in which they will be instituted, in addition to evaluating the ecological and economic costs and benefits, to determine the success of PES actions. PES supporters also have an obligation to consider the impacts of their actions on social structures and the rights of those involved (Bulte et al. 2008, Carr 2008).

Biodiversity and Ecosystem Resilience

Ecosystem resilience is the ability of a system to adapt and respond to changing environmental conditions. The relationship between biodiversity and resilience is complex and controversial (Lehman and Tilman 2000, Pfisterer and Schmid 2002), and an area of active research. Resilience theory is based on the idea that as certain thresholds are passed, long periods of gradual ecological change are punctuated by nonlinear, rapid, unpredictable, and extreme shifts in ecosystem composition and function (Folke et al. 2006), an ecosystem "regime shift." In the modern era, these sudden shifts have often been initiated by human activities, such as increased intensity of resource use, deforestation or ecosystem conversion, species introductions, or pollution. For example, Osterblom et al. (2007) suggest the Baltic Sea went through three key transitions in the last century. The first was a shift from a seal-dominated to a cod-dominated system; they conclude that this was due to a 95 percent reduction of the seal population, initially due to hunting (1900–40) and then due to pollution (1965–75). The second was a shift from an oligotrophic (low-level of primary productivity) to a eutrophic (high-level of primary productivity) state; this was mainly caused by anthropogenic nutrient loading around the 1950s. Finally, they suggest that by the 1970s the shift to a eutrophic state reduced cod numbers and, in combination with overfishing of cod, may lead to a regime shift from a cod-dominated to a clupeid-dominated system. Currently, Osterblom et al. (2007) only consider the shift from oligotrophic to eutrophic conditions as a true regime shift, meaning that it has reached a stable state and will remain eutrophic even with reduced nutrient loading. This shift will have lasting impacts on the cod fisheries of the Baltic and on the biodiversity of the region.

In general, the loss of rare species has a lower impact on ecosystem function than the loss of abundant species (Diaz et al. 2006). Some species, however, have important ecological roles despite their relatively low numbers and are called *keystone species*. Removal of one or several keystone species may have ecosystem-wide consequences immediately, or decades or centuries later (Jackson et al. 2001). The point at which major ecological changes, or regime shifts, will take place is highly unpredictable, but advances are being made in our ability to predict when species losses will result in these shifts. Current systems-based research continues to expand our knowledge of precursors of regime shifts, such as increased variability of state variables, or variables that determine the stable regime of an ecosystem (e.g. increasingly variable phosphorous levels before a shift to a eutrophic lake system; Carpenter and Brock 2006). This improved understanding should assist in improved ecosystem management. With advance warning, managers may be more likely to determine when efforts are needed to protect species, and when built-in redundancies are sufficient to sustain ecosystems in their current states. It is also possible that while some losses of biodiversity may not drive regime shifts directly, they can leave ecosystems more vulnerable to future changes that could have previously been absorbed (Folke et al. 2004). In the face of the biodiversity crisis, understanding resilience will be essential in directing limited conservation efforts to best protect ecosystem services.

Climate Change Effects on Biodiversity

As mentioned above, climate change as a threat to biodiversity has received increasing levels of attention in recent years. In February 2007 the Intergovernmental Panel on Climate Change (IPCC) released its Fourth Assessment Report (IPCC 2007a). This report, with its observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, rising global mean sea level, regional changes in precipitation patterns, and variations in extreme weather, provides unequivocal evidence that the Earth's climate is changing. In this report, the IPCC (2007a) indicates that most of the observed increase in globally averaged temperatures since the mid-20th century is *very likely*[2] due to the

2 Treatment of uncertainty as defined in the IPCC synthesis report (2007a, p. 27): "virtually certain >99%; extremely likely >95%; very likely >90%; likely >66%; more likely than not > 50%; about as likely as not 33% to 66%; unlikely <33%; very unlikely <10%; extremely unlikely <5%; exceptionally unlikely <1%."

increase in human-caused, or anthropogenic, greenhouse gas concentrations. Over the next two decades, a global average warming of about 0.2°C per decade is projected for a range of emissions scenarios, and continued greenhouse gas emissions at or above current rates will cause further warming and induce many changes in the global climate system during the 21st century that will almost certainly be larger than those observed during the 20th century.

Evidence from the fossil record (Davis and Shaw 2001) demonstrates that changes in climate can have a profound influence on the myriad of species that comprise Earth's biodiversity. Scientists expect that climate change to date and predicted change over the coming century will have a significant influence on this diversity (Berry et al. 2002, Thomas et al. 2004, Malcolm et al. 2006). These effects have been investigated in hundreds of individual studies, and several important reviews and meta-analyses, including Walther et al. (2002), Parmesan and Yohe (2003), Root et al. (2003), Lovejoy and Hannah (2005), Parmesan (2006), and Parmesan (2007). Documented effects include upslope and poleward shifts in distribution to escape rising temperatures, changes in disease risk, phenological responses such as changes in the timing of flowering and fruiting, coral bleaching, and impacts on ecosystems as a whole. Scientists, social scientists, and members of local communities are also accumulating information on present and predicted future impacts of climate change on human populations, including changes to food security, health, climate, and the physical environment. (e.g., IPCC 2001, 2007b, Patz et al. 2005, ACIA 2005, Mustonen 2005, Macchi et al. 2007, Salick and Byg 2007, Frumkin and McMichael 2008, Patz et al. 2008).

Predictions of continued rapid climate change over the coming century have prompted many attempts to estimate future impacts on biodiversity. One study estimated that, on the basis of a mid-range climate warming scenario for 2050, 15–37 percent of species in their sample of 1,103 study species would be on a trajectory toward extinction. (Thomas et al. 2004). Such predictions of extremely high extinction risk due to climate change have generated debate among scientists, politicians, and the broader general public. Uncertainties inherent in the predictions, along with debate as to how (if at all) society should manage the threat, make this a controversial topic. This is complicated by the fact that a growing body of evidence supports the idea that individual threats to biodiversity rarely occur in isolation. Threats occurring together could be *additive*, in that the combined effect is the sum of each. However, in some cases, threats can be *synergistic*, where the simultaneous action of individual threats has a greater total effect than the sum of individual effects (Brook et al. 2008). To be synergistic, threats must not only interact, but they must do so in a mutually reinforcing manner that contributes to population decline, and possibly to local extirpation and/or global extinction for one or more species. The strongest evidence for synergy among threats to biodiversity would be data that allow examining the effects of each threat separately as compared with the effects of the threats considered together. However, the number of studies taking this approach is still small, and they have usually been performed under experimental or semi-experimental conditions (e.g., Davies et al. 2004, Mora et al. 2007). To date, most published examples of synergies with climate change are projections, simulations or models. For example, investigators have suggested that climate change may be facilitating the spread of chytrid fungus that is causing amphibian extinctions in Central America (Pounds et al. 2006; Rohr et al. 2008; but see also Lips et al. [2008]).

Species have survived major climatic changes throughout their evolutionary history (Davis and Shaw 2001). However, scientists concur (IPCC 2007a) that contemporary anthropogenic climate change presents a significant threat to biodiversity. A key factor that differentiates contemporary climate change from past changes is the potential synergies with multiple other threats, in particular ecosystem loss and fragmentation. Natural systems exist today on a planet that is dominated by humans, with 40–50 percent of the ice-free land surface now transformed for human use, primarily in the form of agricultural and urban systems (Chapin et al. 2000). Climate change thus presents an important challenge for conservation efforts and human populations. The variety of possible effects of climate change across various domains, and the potential for climate change to interact with other threats to biodiversity, illustrate the need to consider climate change from a systems-based perspective.

Health and Biodiversity

Particularly when considered broadly (i.e. not just as the absence of illness but including physical, mental, and social stability, and in inclusive spatial and temporal contexts), human health depends on biodiversity. This does not mean that all components of biodiversity have a positive effect on health at all times (consider for example that parasites are part of biodiversity), but rather that ultimately the health of all species on the planet depends on our shared ecological context. Human health and well-being requires *goods* (i.e. benefits derived from tangible commodities) and *services* (such as the ecosystem services discussed above) provided by biodiversity, and can therefore be negatively affected by its loss. The linkages between biodiversity and human health have been the focus of much recent attention and intense study and have been highlighted by international bodies such as the World Health Organization as well as conservation non governmental organizations (WHO 2006, WCS 2009).

Food, medicine, and medical models are among the goods derived from biodiversity that are critical for sustaining human health. Aside from purely synthetic food products, all of the nutrients we consume are derived from a plant, fungus, or animal species. People all over the world meet their daily caloric and nutritional needs through some combination of wild and domesticated sources, many of which are currently threatened. Studies have estimated that at least 80 percent of the world's population relies on compounds obtained mainly from plants as their primary source of health care (Fabricant and Farnsworth 2001, Kumar 2004). The importance of medicines derived from living things is not limited to the developing world: more than half of the most commonly prescribed drugs in the United States come from, are derived from, or are patterned after one or more compounds originally found in a live organism (Grifo and Chivian 1999). Finally, species belonging to many different taxa are invaluable in biomedical research and play a critical role in advancing our understanding of human anatomy, physiology, and disease.

Ecosystem services, as discussed earlier, support productive natural systems and large-scale ecological interactions such as pollination, pest control, soil creation and maintenance and nitrogen fixation, and are therefore critical for their persistence and the continued provision of the goods mentioned above. Other biodiversity mediated processes that benefit health and wellbeing include water filtration, flood regulation (Andreassian 2004), and waste removal (Nichols et al. 2008). In other cases, ecosystems can protect humans from natural disasters, such as cyclones (Das and Vincent 2009). Finally, empirical and theoretical evidence support the idea that species diversity can act as a buffer for the transmission of some infectious agents, including the Lyme spirochete, West Nile virus, and Hanta viruses (Ostfeld and Keesing 2000, Swaddle and Calos 2008, Suzán et al. 2009).

The differentiation between goods and services is a useful distinction with which to approach complex linkages among species and foster understanding and engagement in their conservation. In reality however, all goods are themselves the result of complex ecological interactions involving many species and their abiotic environments, and therefore broad, systems-level thinking is required to characterize, quantify, and conserve all these critically important benefits we obtain from biodiversity. As a consequence, the study of the relationship between health and biological diversity requires multidisciplinary collaboration, among biomedical professionals, ecologists and conservation biologists, and others. This kind of system-wide approach will augment our capacity to sustain the health of all species and conserve the biodiversity on which it ultimately depends.

Sustaining Cultural Diversity

The past two decades have witnessed an upsurge of interest in the links and synergies between linguistic, cultural, and biological diversity (Harmon 1996, 2002, Smith 2001, Toledo, 2002, Carlson and Maffi 2004, Stepp et al. 2004, Loh and Harmon 2005, Maffi 2001a, b, 2005, Cocks 2006). As previously mentioned, the world's biodiversity and the vast and diverse pool of cultural knowledge, arts, beliefs, values, practices, and languages developed by humanity over time are under threat by many of the same human-induced forces (Maffi 2001b, Harmon 2002). These circumstances call for integrated approaches in research and action since culture and nature interact at many levels that span values and beliefs to knowledge and livelihoods. Yet, both in scientific inquiry and in the realms of policy and management, the categories of "nature" and "culture" are still often treated as distinct and unrelated entities, mirroring a common perception of humans as separate from the natural environment. This conceptual dichotomy is also reflected in, and reinforced by, the mutual isolation that has historically characterized teaching in the humanities and natural and social sciences, leading to fragmentation and limited communication or collaboration among different fields concerned with diversity and sustainability in nature and in culture (Brosius 1999, Oviedo et al. 2000, Borrini-Feyerabend et al. 2004, Maffi 2004, Brosius and Redford 2006). The resulting approaches, in both theory and practice, have generally failed to recognize the interconnectedness of natural and cultural processes and of the threats they are facing, or at least to bring cross-cutting expertise to bear on these issues. Thus, they have not succeeded in stemming the erosion of the diversity of life in all its manifestations. The persistent loss of this biocultural diversity is resulting in an ever less resilient world (Wollock 2001, Maffi 2005).

Recent years have seen the emergence of integrative disciplines that seek to better comprehend the complex interactions between culture and nature, and that work to incorporate insights from both the biological and the social sciences, as well as from humanistic inquiry, non-Western perspectives, and traditional cultural knowledge systems. These include biocultural diversity, social-ecological systems, nature-society theory, anthropology of nature, ethnobiology, ethnobotany, ethnoecology, ecological and environmental anthropology, human ecology, human geography, environmental ethics and history, ecofeminist theory/ecofeminism, historical ecology, symbolic ecology, systems ecology and political ecology, among others (Berlin 1992, Cronon 1996, Kormondy and Brown 1998, Adger 2000, Moran and Gillett-Netting 2000, Townsend 2000, Egan and Howell 2001, Maffi 2001b, 2005, 2007, Harmon 2002, Toledo 2002, Berkes and Turner 2006, Rapport 2007a, b). Recent ethnographic and archaeological research has also shown that our conceptualization of the relationship between nature and culture must include a temporal dimension as humans have interacted with environments through co-evolutionary processes for many generations (Balée 2006). For example, pre-colonial Native Americans shaped landscapes once considered to be "pristine" through periodic burning (Cronon 1983) and some areas of Amazonia have been intensively managed by indigenous people for centuries (Heckenberger et al 2007). We need to examine and understand the formation of contemporary and past cultural landscapes and patterns of biodiversity and how interactions between societies and environments change through time. Agencies, institutions, and organizations broadly responsible for environmental conservation and management, development, and cultural issues (for instance UNESCO, UNEP, Convention on Biological Diversity, and IUCN—The World Conservation Union), are expressing interest in this kind of broad, integrative work and its policy implications (UNESCO 2006). This indicates that now is the time to both assess the scientific advances in all of these integrative fields and foster their contributions to addressing the vital issues of environmental, linguistic, and social sustainability, as well as to promote communication among different ways of knowing through both scientific and traditional knowledge systems. Effective, systems-based teaching should help establish more integrated approaches to research, policy, and management in years to come.

Adger (2000) has defined social resilience as "the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change." A group's exposure to stress as a result of ecological change is known as social vulnerability. Social vulnerability is generally high for many indigenous and traditional peoples, who are often economically marginalized and rely directly on the natural environment for their food and livelihoods (Adger 2000, IPCC 2001, 2007b, Diffenbaugh et al. 2007, Macchi et al. 2007, Salick and Byg 2007). For these reasons, some threats to biological diversity, such as climate change and ecosystem loss and fragmentation, may be particularly acute threats to the lifeways of indigenous and traditional peoples. In particular, scientists and local communities in the northern latitudes have documented ongoing changes in their environment due to climate warming, such as reductions in sea and lake ice, loss of forest resources, changes in prey populations, and increased risk to coastal infrastructure (Lee et al. 2000, NAST 2001, CCME 2003, Weladji and Holand 2003, ACIA 2005, Ford 2007, Lambden et al. 2007). As climate change impacts arctic ecosystems, the predictive power of some traditional knowledge is reduced (Krupnick and Jolly 2002, Ford et al. 2007, Sakakibara 2008, Sakakibara 2009), which has the potential to leave societal structures weakened (Weladjii and Holand 2003, Lambden et al. 2007). It is therefore not surprising that some of the first initiatives bringing indigenous communities together to frame and address common problems related to climate change have occurred in the northern latitudes. Examples of these efforts include the compilation of the Stories of the Raven by the group Snowchange (Mustonen 2005) and the Arctic Climate Impact Assessment (2005), which was prepared by more than 300 participants from 15 countries and includes many examples of the local traditional knowledge of Inuit, Sami, Athabaskans, Gwich'in, Aleut and other Arctic Indigenous Peoples.

Community-based Conservation

From individual sacred trees to royal game preserves, strategies for conservation have historically relied on protected areas, or conserving biodiversity where it exists, *in situ*. Many early parks and reserves in the Western tradition of biodiversity conservation were modeled after Yellowstone National Park (established 1872) in the United States, and advocated strict preservation policies, seeking to safeguard natural resources through the exclusion of local populations (and in cases disregarding the role they had played in shaping those landscapes) (Adams and McShane 1996, Neumann 1998, 2002, Jacoby 2001, Adams 2004). By the 1970s, new ideas of sustainable development and a growing interest in human rights and different knowledge and value systems challenged this approach. Recognizing that conservation affects people's lives (West and Brockington 2006), and that restricted access to natural resources has costs that are often borne by those least equipped to pay them (Adams et al. 2004), international conservation efforts began shifting to a more people-centered approach (Adams and Hulme 2001, Naughton-Treves et al. 2005). At the same time, the effectiveness of the protected area approach itself was in question as people realized that parks were ecological islands covering only a fraction of larger ecosystems, and management authorities frequently lacked the funds or capacity to enforce their borders. Beginning with Integrated Conservation and Development Projects (ICDPs) in the early 1990s, conservation policy began to shift from state-centric, top-down approaches to attempts to incorporate society, sustainability, and markets (Wells and Brandon 1992, Adams and Hulme 2001, Barrow and Murphree 2001). While strict reserves remain important for certain vulnerable systems, the IUCN–WCU (2009)currently recognizes six categories of protected areas of varying degrees of protection and use. Today, the mission of some protected areas has expanded to include the protection of biological *and* cultural diversity, the provision of economic benefits, poverty alleviation, and even promoting peace (i.e. "peace parks", or transboundary conservation areas) (Naughton-Treves et al. 2005). Conservation efforts are increasingly recognizing the necessity of understanding the historical ecology of these protected sites and sustaining their cultural landscapes (UNESCO 2006).

"Community-based conservation" (CBC)[3] helps conserve threatened species and critical ecosystems beyond protected area boundaries by linking natural resource protection to communities and development—in other words, by thinking of the ecosystems and inhabitants as an integrated system. Emphasizing a participatory approach to biodiversity conservation, CBC strives for a "win-win" situation where local involvement leads to economic growth and a vested interest in conservation (Adams and Hulme 2001, Berkes 2004). The case of the African elephant illustrates this logic: locally, elephants can be dangerous pests that steal crops and destroy gardens; nationally, they are major tourist attractions and the source of significant revenue. CBC seeks to expand the benefits of elephant conservation to the local level through benefit-sharing schemes or prescribing wildlife conservation as a form of land use (an alternative to agriculture or pastoralism). In this model, natural resources are recognized as renewable, opening the possibility for controlled and sustainable use. Additionally, the separation of human-dominated landscapes and "natural" landscapes is less clear, as people are explicitly included, and community perspectives and knowledge are deliberately incorporated into conservation practice.

CBC initiatives range from programs as simple as protected area or private sector outreach (e.g., Tanzania's National Parks' Community Conservation Service program, "Ujirani Mwema"[4] [Bergin 2001]) to Community Conserved Areas (CCAs), terrestrial and marine spaces that have been conserved voluntarily by local communities (Kothari 2006). An important CBC model, CCAs vary widely in size and have been initiated for a number of reasons: to protect access to livelihood resources or community land tenure, for economic gain (e.g., ecotourism), or to safeguard vulnerable wildlife or ecosystem functions. They may include sacred spaces, indigenous peoples' territories, critical wildlife habitat, resource catchment areas, or mixed landscapes (natural and agricultural ecosystems).

CBC, through innovative partnerships among conservation biologists, social scientists, and communities living in and around biodiversity hotspots, is an important complement to traditional protected areas and a vital part of the conservation toolkit. But it is not a panacea for conservation problems: for instance, the goals of biodiversity conservation and development interventions are often conflicting; communities are not homogenous entities, but represent a wide array of viewpoints and motivations, and "success" is not easily defined (see for example Agrawal and Gibson 1999, Biesbrouck 2002, Berkes 2004, Chapin 2004, Tsing et al. 2005, Rao 2006, Igoe and

3 Also referred to as "Community Conservation," "Community-based Natural Resource Management," "Community-based Forest Management," or "Community-based Wildlife Management," depending on context.

4 Swahili for "Good Neighborliness."

Croucher 2007, Nelson et al. 2007). Ultimately, however, an effective approach to biodiversity conservation will involve diverse constituencies, including international organizations, nations and national governments, non-governmental organizations, academic institutions, local grassroots groups, and individuals.

Teaching Systems Approaches to Biological and Cultural Diversity

Too often, we do not think about the interconnections in the world around us. As illustrated in the topics discussed above, change in an ecosystem can cause a chain of reactions to reverberate throughout the system, affecting the well-being of humans and other species (Diaz et al. 2006). Studies of endangered species are now pointing to the importance of coevolution, with cascading extinctions leading to the disproportionate loss in groups such as parasites and mutualists (Koh et al. 2004, Dunn et al. 2009). Researchers are also learning that synergistic interactions between different direct and indirect threats to biological and cultural diversity may amplify or exacerbate individual threats. All these interconnections are crucial for us to consider when working to sustain diversity.

As our understanding of natural ecosystems and the role of humans within them has increased, we have realized that traditional "siloed," disassembled approaches for understanding and managing complex systems are severely limited. For instance, physical scientists study long-term trends in temperature; local communities observe changes through time in animal behavior, population abundance, and timing of reproduction; biologists study climate change and its effect on species distributions; and anthropologists study adaptation in human cultures to climate change. Rarely do these individuals come together to study the feedbacks among climate change, human adaptation, and biological responses, leading to further adaptation—yet clearly each discipline is only understanding one piece of the puzzle and cannot gain a complete picture in the absence of information from the other disciplines.

In our experience, an effective way to foster systems-based and interdisciplinary thinking in students is to combine the study of actual case studies of environmental issues (such as the fisheries case study referenced in the introduction) with active approaches to teaching. Such approaches engage students directly in the learning process, and can include a variety of activities, including interactive lectures, debates and role-playing, faculty or student-led discussions, student presentations, field exercises, and others (e.g., Bonwell and Eison 1991, Meyers and Jones 1993, Bean 1996, McNeal and D'Avanzo 1997, Silberman and Auerbach 1998, Handelsman et al. 2004, McKeachie and Svinicki 2006). There is ample evidence from the education literature that active-learning modes substantially increase student performance across many disciplines (e.g., Hake 1998, McKeachie et al. 1986, NRC 1996, Olson and Loucks-Horsley 2000), including those related to biodiversity and conservation biology (Ebert-May et al. 1997, Sundberg and Moncada 1994, Lord 1999, Ryan and Campa 2000, Burrowes and Nazario 2001, Udovic et al. 2002, Chopin 2002, Burrowes 2003). Many active teaching approaches involve students working together in small groups, and often involve an element of peer-to-peer teaching and/or collaborative learning (Slavin, 1990, Johnson et al. 2007, Barkley et al. 2004), which can foster development of the critical thinking, analysis, and synthesis skills that are important to a systems-based approach.

Each of the issues discussed in this review has its own "entry point" that can encourage students to adopt systems-based thinking:

- Because of our universal dependence on ecosystem services and their cultural, ecological, and economic value, ecosystem services provide students with concrete and relevant examples of the importance of biodiversity conservation from the perspectives of many different disciplines. Case studies of efforts to conserve ecosystem services can expose students to the complexity of real-life conservation issues.
- In the current politically charged public discourse around climate change and its effects, engaging students on this issue represents a significant opportunity for teachers. Indeed, this is such an important area that the Council of Environmental Deans and Directors of the National Council for Science and the Environment has established a special Climate Solutions Curriculum Committee (2009) to provide support and guidance to university teaching of climate change. Studying climate change can help students appreciate some of the difficulties and controversies that arise when scientists attempt to extend current observations to model future predictions, and understand that natural systems are composed of an interconnected network of interacting species and threats to those species.

- As an immediate concern and a topic of personal experience for all, health is a powerful motivator for changes in behavior, and can introduce the idea of multidisciplinarity in scientific endeavors and the interrelatedness of life on the planet. For example, topics in health and the environment can be presented as medical mysteries, in which students are encouraged to discover the drivers of changes in epidemiological patterns in human or animal populations, or as choices among various interventions, using a systems-based approach.
- The intersection between culture, biodiversity, nature, and the environment offers a rich lode for exploration with students, moving easily among philosophical and ethical realms. For example, students could discuss the issue of extinction and what it means for a species, language, or culture to disappear, given that our understanding of the world is that it is dynamic and continually evolving. Readings on resilience could explore the differences between social and ecological resilience and how those might lead to different frames within which to address the problems that we face in sustaining biological and cultural diversity.
- The study of community-based conservation can expose students to different ways of perceiving nature as well as the suite of possible conservation interventions. For example, students might debate the relative successes of current efforts to implement CBC, such as those of Wildlife Management Areas in Tanzania (see Goldman 2003, Igoe and Croucher 2007, Nelson et al. 2007). Offering a variety of real world case studies for examination, whether across the world or in their own backyard, CBC effectively demonstrates to students the complexity of conservation decision-making and the necessity of inter-disciplinary efforts.

A variety of freely available electronic resources are available that can be used to support systems-based, active teaching in topics related to biological and cultural diversity. These include resources of the Network of Conservation Educators and Practitioners (NCEP 2009a) of the American Museum of Natural History, materials from the Ecological Society of America such as the TIEE project (2009) and the EcoEdNet repository (2009), along with appropriate materials from the National Center for Case Study Teaching in Science (2009).

Final Thoughts

Even as natural and and social scientists work to make their work with students more meaningful, we also need to move beyond the classroom and into engaging the public more directly on issues surrounding biological and cultural diversity. With current levels of public understanding of science—particularly in the United States—recognized as being deficient (National Science Board 2002, Baron 2003, Brossard et al. 2005, Bonney 2008, Cohn 2008), active involvement in the scientific process can serve to increase interest and literacy. Participants can also improve their abilities to understand and interpret what is going on around them and how it relates to their lives, and in the process take part in translating science practice into public discourse and in turn, transform it into action. Wilderman et al. (2004) suggest that participants working together can develop a sense of community ownership of data and feel empowered to use them for advocacy and decision-making. Additionally, projects that involve volunteers in the study of a species or habitat make it possible to address questions of a scope and scale that would not otherwise be possible. By working with citizen volunteers, scientists may broaden support for their projects and form a more direct link with their constituency (Greenwood 2003). Decisions based on participatory research may also be more effective and less controversial when stakeholders who have an interest in the results are involved in the process (Pilz et al. 2005, Calhoun and Morgan 2009). Similarly, stewardship groups (who may be involved in research, maintenance, and/or tours or other educational activities) can develop a strong sense of responsibility and attachment to a place that they care for, and will strive to protect it for the health of the local environment as well as for community well-being. In general, environmental volunteering and stewardship can result in a wide range of benefits for the organizations involved, the volunteers, and for the community, including extending an organization's work and promoting its cause; giving people a chance to connect or reconnect with nature as well as gain new skills, make social connections, and improve their physical and mental well-being; and contributing to community goals for education, health, and social and environmental justice (O'Brien et al. 2008).

Programs that encourage broad public participation can also in some cases intersect with student programs. An example of this approach is ALLARM (Alliance for Aquatic Resource Monitoring), which forms partnerships between community groups and researchers and students at Dickinson College in Pennsylvania to conduct water quality monitoring and watershed management projects. ALLARM's goals include increasing community scientific knowledge while motivating students through engaging in research to solve real-world problems (Wilderman et al. 2004). These are the overarching goals, however, and each community group defines the goals for its own project. Volunteers engage in the scientific process, from defining problems, designing the studies, collecting and analyzing samples, to interpreting data. Scientists provide training and mentoring where necessary, particularly supporting the groups through the development of a feasible study design and in interpreting data so that the community members themselves are able to understand and share their findings rather than relying on researchers to speak for them. Volunteers also have the advantage of using their local knowledge for interpretation, making connections with nearby land uses that researchers might not be aware of (Wilderman et al. 2004, Wilderman 2007).

Students of today are challenged to try to make sense of a bewildering array of information and misinformation about environmental and cultural issues. This is certainly the case with biodiversity loss and sustaining cultures. Over the past decades, we have come to understand that sustaining cultural and biological diversity does not just mean placing boundaries around a static entity. Rather, it means moving beyond the patterns we see and understanding the processes that create diversity, allowing for change and evolution while maintaining integrity of a system. Human-induced threats to biodiversity are causing not only species loss, but also are negatively impacting ecosystem processes and function and might even alter the rate of evolutionary change, which in turn can influence ecological dynamics, creating "eco-evolutionary feedbacks" (Palumbi 2001, Stockwell et al. 2003, Post and Palkovacs 2009). Though we may not have a complete understanding of the theoretical underpinnings of the interactions between ecology and evolution, it is clear that planning for biodiversity conservation needs to happen in the context of dynamic populations and threats (Mace and Purvis 2008).

In order for the next generation of adults and voters to make intelligent choices about biological and cultural diversity, they will need to understand what the consequences of their individual and collective actions are—the evolutionary force that we have become. They need to know what diversity is, to understand the relationship between human beings and diversity and how our value systems affect sustainability of biodiversity and culture (Carolan 2006, Christie et al. 2006), the difference between sustaining just patterns/static definitions of diversity rather than processes, and they need to understand what threatens diversity. Finally, students need to have a sense of what they can do about the loss of biological and cultural diversity at the individual and collective levels. Overall, they will need to take a systemic look at people and their relationship to diversity, as complex systems such as these require systems thinking for solutions (Waltner-Toews et al. 2008). As teachers, we can support them in learning to do this.

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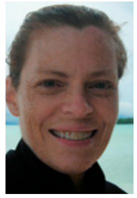

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