GEMs for Chemists: A Community-Based Approach to Develop Greener Education Materials

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Abstract

Green Chemistry is the design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances. Often referred to as a form of molecular- level pollution prevention, the incorporation of green chemistry principles into the chemistry curriculum is providing new opportunities to enhance the curriculum and engage a broader spectrum of students in the study of chemistry. A key to gaining broad adoption of a greener chemistry curriculum and sustaining the development of new educational materials is to actively involve faculty from across the country in creating these materials. This paper will describe how the development and dissemination of the GEMs database (http://greenchem.uoregon.edu/gems.html) has facilitated a unique, community-based approach to educational materials development that has the potential to both catalyze an exponential increase in the number of faculty involved with and exposed to the green curriculum and provide a diverse and continuously evolving collection of educational materials. GEMs is an interactive, web-based database of Greener Education Materials for Chemists. The database is designed to be a comprehensive resource of educational materials including laboratory exercises, lecture materials, course syllabi and multimedia content that illustrate chemical concepts important for green chemistry.

Paper

The **G**reener **E**ducation **M**aterial**s** for Chemists database or GEMs is an interactive collection of educational materials focused on green chemistry that is providing a foundation for community-based approaches to curriculum development (1). After a brief introduction to green chemistry, the paper describes how the development and dissemination of GEMs has been instrumental in building and supporting a group of educators who are currently exploring two very different collaborative models for developing new materials in this area. The community-based textbook project represents a multiple-author effort to incorporate green chemistry concepts throughout a non-majors chemistry textbook, while the ambassador site project integrates the identification and development of new laboratory exercises at regionally distributed “ambassador sites” with dissemination via GEMs. These projects illustrate how community-based approaches to educational materials development have the potential both to dramatically increase the number of faculty involved with and exposed to the green curriculum and to provide a diverse and continuously evolving collection of new materials for greener education.

Green Chemistry Education

As environmental awareness has grown, chemists have become increasing interested in developing new methods for chemical syntheses and processes that reduce or eliminate the use and generation of hazardous materials. Often referred to as a form of molecular-level pollution prevention, green chemistry relies on a set of principles that can be used to design or re-design materials and chemical transformations to be safer for human health and the environment (2).

The incorporation of green chemistry principles into the chemistry curriculum is providing new opportunities to both enhance the curriculum and engage a broader spectrum of students in the study of chemistry (3). Students resonate with the proactive approach that green chemistry offers because many of them care about the environment and are looking for ways to “make a difference” in society.

The principle-based approach of green chemistry provides a unique framework for educational materials development. The interdisciplinary nature of green chemistry and its role in protecting human health and the environment provides educators with a variety of opportunities to incorporate green chemistry principles throughout the curriculum. This flexibility enables educators to share their enthusiasm for chemistry with a receptive student audience as they connect chemistry concepts to complex problems facing society. As students evaluate the impact of the chemical enterprise, they develop an appreciation for the tools and methodology involved in characterizing complex chemical processes and also explore the ethical considerations often associated with these types of assessments.

Societal pressures and economic incentives demand that chemists develop new ways to carry out vital chemical processes using “green” (environmentally benign) methods. The strategies and tools of green chemistry are essential for today’s chemistry students, who will become key players in addressing the need to discover and develop new and more sustainable chemical processes. Equally important is the opportunity to introduce these strategies and methods to an even larger group of students who will not become practicing chemists, but rather educators, policy makers, or concerned citizens who want to be educated participants in our modern technological society.

Community-Based Design and Development of GEMs

Although many faculty and students recognize the benefits of a greener curriculum, widespread incorporation of green chemistry concepts has been limited by the availability of educational materials and successful models for incorporating these concepts into both the classroom and teaching laboratory. Initially, educational materials that incorporate green chemistry were often difficult to find because they were scattered throughout a myriad of print and Internet publications (4). To address this problem, members of the green chemistry community designed, developed and tested "GEMs for Chemists," a searchable, web-accessible database of Greener Education Materials that went live in June 2005 (1).

GEMs is designed to be a comprehensive resource of educational materials including laboratory exercises, lecture materials, course syllabi and multimedia content that illustrate chemical concepts important for green chemistry. Each item in the collection has anoverview page that includes a summary of the item and its connection to green chemistry. The GEMs search interface enables users to create complex searches in which multiple terms and keywords can be added to develop search criteria that produce a narrow and precise set of results. Since educators are often frustrated by the prospect of adding additional content to an already crowded curriculum, the site can be used to identify key chemistry concepts and techniques and then search for replacement activities or content that is greener.

The collection is also searchable by a variety of parameters, including chemistry concepts, laboratory techniques, green chemistry principles and target audience. This "shopping cart" approach enables users to browse available resources, familiarize themselves with green chemistry terms and concepts, and then build their searches from an organized list of search parameters. In addition, users can access a summary of additional resources that includes ideas for implementation, assessment materials, demonstrations and links to related resources.

The design and development of GEMs has been a highly collaborative process involving the Green Chemistry Group in the Department of Chemistry at the University of Oregon (UO), the UO's Center for Educational Technologies, and over one hundred educators that have participated in the UO Green Chemistry in Education Workshops since 2001. A demonstration website was used to facilitate a needs assessment which showed that development of new materials and successful incorporation of green chemistry into the curriculum depends on meeting the needs of faculty in the following four key areas:

- **Choice.** Educators consistently express the need for a diverse collection of high-quality materials. Faculty want the ability to identify content targeted to a specific chemistry concept or laboratory technique as well as the opportunity to examine different models for incorporation into the curriculum.

- **Instructional Aids.** A significant roadblock to adoption is identifying and developing supplemental materials associated with this new content. The availability of instructional aids such as detailed written instructions, experiment tips, background lecture information and video clips can assist educators in efficiently and successfully adopting the new materials. These aids improve the odds of initial success with these materials and thus, increase the likelihood of widespread and long-term adoption.

- **Support Network.** The opportunity to work with regional partners who can assist in developing, testing and championing a green chemistry curriculum is critical for the development and implementation of new materials.

- **Scholarship.** Many faculty express frustration regarding their limited ability to effectively document and disseminate their contributions to curriculum development in this area.

Faculty needs were translated into design criteria that were used to create an intuitive and user-friendly interface for the collection, enabling it to serve as an effective resource for two very different audiences: educators having a minimal understanding of green chemistry and educators having extensive experience incorporating green chemistry into the curriculum. Because GEMs was developed in partnership with users, it was possible to recruit an international group of high school, community college and university faculty to evaluate and test the site before it went live in June 2005. Currently, educators continue to be involved in creating content summaries of existing materials for the database, and as users continue to develop new materials, the database serves as a centralized tool for dissemination.

Empowering a broad range of people to participate in the design and development of this new electronic resource solidified a community of educators interested in using innovative strategies to provide a diverse and continuously evolving collection of educational materials. As a result, members of this educational community are working together to facilitate the development of new education materials in the area of green chemistry by influencing textbook content and creating regional networks of ambassador sites focused on collaborative curriculum development. This community-based approach not only enhances the capabilities of the members through the exchange of knowledge and experience but also provides unique opportunities for innovation and rapid change. These types of synergistic community-based activities are dramatically increasing the number of faculty involved with and exposed to the green curriculum while sustaining the development of new educational materials.

Community-Based Textbook Development

One method to increase the number of faculty exposed to and involved with the green chemistry curriculum is to develop innovative ways to incorporate green chemistry concepts into existing textbooks. Members of the green chemistry community have traditionally put pressure on textbook publishers to incorporate green concepts into new editions of the textbooks they market. Through these types of efforts, an opportunity emerged to incorporate green chemistry into the 11th edition of *Chemistry for Changing Times,* a popular "chemistry in society" textbook for non-science majors written by John W. Hill and Doris K. Kolb and published by Prentice Hall. The opportunity consisted of creating end-of-chapter green chemistry focus pieces that provide activities and exercises connecting green chemistry concepts to the topics covered in each chapter. The challenge for the community was to develop nineteen novel green chemistry learning modules over the course of three months in order to meet the publishing deadline.

The community-based approach to developing these materials provided new professional development opportunities for community members while at the same time generating nineteen new educational modules in the area of green chemistry that will be disseminated to large numbers of faculty and students across the country. Fifteen authors from six regions (see below) were recruited to create the end-of-chapter pieces and integrate them into the chapter content. Paul Anastas, Director of the American Chemical Society's Green Chemistry Institute, agreed to lead the project and negotiate a creative compensation package that included authorship credit for individual contributions. For many of the contributing authors, this project represented their first opportunity to participate in a textbook publishing project and this experience has empowered several of the contributors to seek additional opportunities in this area.

Authors Participating in the Textbook Project

Arkansas
Tom Goodwin (Hendrix College)
Liz Gron (Hendrix College)

Connecticut
Julie Manley (Green Chemistry Institute)

Massachusetts
Ed Brush (Bridgewater State College)
Rich Gurney (Simmons College)
Margaret Kerr (Worcester State College)
Irv Levy (Gordon College)
John Warner (University of Massachusetts Lowell)
Denyce Wicht (Suffolk University)

Oregon
Scott Reed (Portland State University)
John Thompson (Lane Community College)

Pennsylvania
Mike Cann (University of Scranton)

Washington D.C.
Paul Anastas (Green Chemistry Institute - project leader)
Kathryn Parent (Green Chemistry Institute - project coordinator)
Jennifer Young (Green Chemistry Institute)

This community-based approach to developing green educational materials enabled a diverse group of individuals to efficiently and effectively contribute their unique skills and experience to create novel green chemistry content for a chemistry textbook and catalyzed an increase in the number of green-chemistry educators involved with the textbook publishing industry. More significantly, this achievement provides a new model for the rapid development and dissemination of innovative green educational materials to new faculty and students across the country.

Ambassador Site Project

A key to gaining broad adoption of this greener curriculum and sustaining the development of new education materials is to actively involve faculty from across the country in developing these materials. GEMs is being used as a tool to support a regionally distributed approach to curriculum development and dissemination through the creation of "ambassador sites" that integrate the development of novel curricular materials with the identification of existing materials from faculty in a geographic region. The identification of regional sites for curriculum development provides educators with an opportunity to act as ambassadors for green chemistry and GEMs in their region.

Ambassador sites function as peer-led team efforts to identify, evaluate and prepare unpublished materials for dissemination via GEMs and if appropriate, eventual publication in peer-reviewed journals. The idea for this community-based approach was based on observations made during dissemination efforts associated with the University of Oregon's green organic chemistry curriculum development project. As faculty from the UO began to share their curriculum development ideas with other educators, it became clear that many instructors have already created or modified existing exercises to lessen their environmental impact. Unfortunately, most of these educational materials are never publicized or disseminated.

In an effort to facilitate the identification and development of these materials, faculty leaders were identified from among recent participants in the UO's Green Chemistry in Education Workshop who have already made significant progress in adopting and developing green chemistry educational materials at their institutions. In an effort to provide a critical mass for curriculum development at each ambassador site, multiple faculty members from each region were recruited for this project. Each ambassador site focuses its efforts on generating content for GEMs by supporting the development and testing of novel green chemistry laboratory exercises from faculty in its region. As new educators are recruited into the network, they actively engage others in development activities, so that initial efforts essentially catalyze a significant increase in the number of faculty involved with and exposed to the green curriculum. The ambassador site project provides a model for developing a diversified community of green chemistry educators, which is critically important for facilitating broad adoption of a greener chemistry curriculum and sustaining the development of new educational materials.

The number of faculty participating in the ambassador site project is growing. In summer 2004, the program began with five faculty supporting ambassador sites in Oregon, Arkansas and Massachusetts. Now the program includes thirteen faculty members from four states (see below). Members of the program are meeting in July 2006 to share experiences and strategies to support the development and dissemination of green chemistry laboratory exercises throughout the curriculum.

Arkansas
Tom Goodwin (Hendrix College)
Liz Gron (Hendrix College)

Massachusetts
Ed Brush (Bridgewater State College)
Rich Gurney (Simmons College)
Margaret Kerr (Worcester State College)
Irv Levy (Gordon College)
John Warner (University of Massachusetts Lowell)
Denyce Wicht (Suffolk University)

Minnesota
Bob Hanson (St. Olaf College)
Gary Spessard (St. Olaf College)

Oregon
Julie Haack (University of Oregon)
Carol Higginbotham (Central Oregon Community College)
John Thompson (Lane Community College)

The ambassador site model empowers faculty to develop individualized strategies for identifying and developing new educational materials. One example of an outreach activity recently completed at Gordon College in Wenham, MA is described below.

Green Organic Literacy forum (GOLum) - *GOLum III*: The Search for GEMs

Students at Gordon College have enthusiastically embraced a transition to green organic chemistry in their curriculum. Recognizing the value of outreach, both for the community served and for those who provide the outreach, teams of students enrolled in the second semester of organic chemistry completed a dozen GOLum projects during the spring semesters of 2004 and 2005. In these student-motivated endeavors to advance green organic literacy, students were required to identify an audience outside of the Division of Natural Sciences at Gordon College with whom they could share information about green chemistry. As a result of these outreach efforts, about 60 students communicated the principles of green chemistry to over 1,000 people in the greater Boston region. Outreach efforts have occurred on the Gordon College campus and in high schools (Connecticut, Maryland, Massachusetts, Nebraska, New Hampshire, and Rhode Island) and elementary schools, and also at educational workshops, science museums, and national meetings of the American Chemical Society.

After participating in the community-based textbook project in the fall of 2005, Gordon College wanted to engage undergraduate students in a community-based effort to identify greener educational materials. Students appear to intuitively recognize the importance of such a project as they experience green chemistry pedagogy in their own studies, and faculty have observed that the possibility of participating in a project that will have lasting effects is inherently satisfying to the students who are engaged in that project.

During the spring semester of 2006, the third GOLum project season focused on facilitating the identification and incorporation of existing educational materials into GEMs. Twenty-five students enrolled in the second semester of organic chemistry were organized into three teams to solicit submissions for GEMs. The first team-solicited submissions from faculty members listed in the *Directory of Graduate Research* who provided "green chemistry" as a specific research area. The second team solicited submissions from organic chemistry faculty members at colleges and universities in New England that offer a degree in chemistry. The third team solicited submissions from organic chemistry faculty members at colleges and universities in the Council for Christian Colleges and Universities. In total the students attempted to contact 437 college faculty members at hundreds of institutions nationwide.

GOLum III required the participation of a number of different stakeholders including the GEMs director and Gordon College faculty and organic chemistry students. Team leaders provided a list of 15-20 faculty names or colleges to each team member. Other details of the assignment (such as milestone due dates, etc.) are available. A list of the colleges and faculty who were identified as potential GEMs sources is available upon request.

In order to provide uniform data for later analysis, students were asked to complete solicitation summaries for each contact they attempted. This data was passed back to the team leader, who prepared a summary sheet of the final results.

Data from this project are currently being analyzed, but an initial review has revealed some interesting preliminary results. For example, of the 437 faculty members surveyed, only 12 indicated a willingness to submit materials to GEMs. While this 3% yield of actual submissions is modest, a more encouraging picture emerges when these 12 respondents are combined with the 20 respondents who requested follow-up at a later date, the 30 respondents who referred us to a colleague, and the 11 respondents who requested more information about green chemistry, giving a yield of 73 "positive" responses (17%). Overall, 48% of those contacted replied to the queries in some manner.

The initial hypothesis was that the highest yield of submissions would come from faculty who describe themselves in the *Directory of Graduate Research* as practioners of green chemistry. Counter to this prediction, this group provided actual submissions at the same 3% rate obtained from the entire group surveyed.

Students who performed the GOLum project were surveyed anonymously about the experience. Sixty percent of the students rated the experience as either "excellent" or "very good" while only 12% of the students rated the project as "poor" or "very poor". When asked to identify the most satisfying elements of the project, students responded by stating that they felt like "an ambassador for something important." The project also required many hours of effort and painstaking work and some students expressed frustration with the low level of faculty response.

Summary

The development and dissemination of GEMs has been instrumental in crystallizing a group of educators interested in working together as a community to provide a diverse and continuously evolving collection of educational materials in the area of green chemistry. Initial community-based activities focused on the development of a database of these materials that serves as both a centralized resource of educational materials and as an educational tool for faculty new to the area of green chemistry. Because the community was actively involved in the design of the database, GEMs provides opportunities for professional development and tools for meeting the challenges associated with incorporating more material into the curriculum. Through the collaborative development of GEMs, chemistry educators were able to create a resource and support a community that serves as a foundation for future community-based educational materials development.

The textbook development project and the ambassador site project are two examples of community-based efforts to increase the number of faculty involved with and exposed to the green curriculum while providing a diverse and continuously evolving collection of educational materials. One of the advantages of a community-based approach to educational materials development is flexibility. As subsets of the community identify new opportunities for educational materials development, they have the flexibility to create an infrastructure that matches their unique talents and interests. For example, the textbook project utilized the personal relationships among fifteen educators from across the country to rapidly create nineteen new educational modules without ever meeting face-to-face. The leadership and organizational skills of the project managers were critical for the success of this project. In contrast, the ambassador site project is focused on outreach activities that build personal relationships and local communities to facilitate the collaborative development of new materials.

Green chemistry provides a uniquely flexible framework for the development of new educational materials and this flexibility has been critical to the initial success of a community-based approach to curriculum development. The opportunity to collaborate with such a diverse group of educators in the area of green chemistry has facilitated innovation and created new opportunities for professional development that have been transformative for many community members. As educators, the ability to embrace and support a variety of collaborative models for curriculum development (as illustrated at this conference) will be instrumental in transforming the learning environment for future students.

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