Pure Appl. Chem., Vol. 73, No. 8, pp. 1247–1250, 2001.

Greening the curriculum. American Chemical Society education programs*

Sylvia A. Ware

Education and International Activities Division, American Chemical Society, 1155 Sixteenth Street, NW, Washington, DC 20036, USA

Abstract: The American Chemical Society (ACS) Education and International Activities Division is currently working with the U.S. Environmental Protection Agency to produce a series of green chemistry educational materials. To date, products include a searchable, online annotated bibliography of green chemistry references; a collection of cases describing real-world green chemistry solutions; and a Web site for green chemistry materials and information. Various workshops, short courses, and symposia have been provided to share the green chemistry story. Two planning conferences of green chemistry experts have been held to provide direction to the project. In addition to an overview of the above products and services, the project goals and future plans will be described, and the ways in which green chemistry concepts are being integrated across the ACS educational programs in general.

INTRODUCTION

The ACS Chemists' Code of Conduct includes the following statements:

> "Chemists have a professional responsibility to serve the public interest and welfare and to further knowledge of science. Chemists should be concerned with the health and welfare of co-workers, consumers and the community…. Chemists should understand and anticipate the environmental consequences of their work. Chemists have a responsibility to avoid pollution and to protect the environment."

One way in which ACS is supporting these statements is through a variety of green chemistry activities, including support for the annual Presidential Challenge Awards in Green Chemistry, and the subsequent annual conference in green chemistry and engineering held at the National Academy of Sciences in Washington, DC. Most recently, the ACS has increased its efforts in green chemistry education through the ACS Division of Education and International Activities, and through affiliation with the Green Chemistry Institute. This paper will focus on the activities of the Division.

GETTING STARTED

In 1998, the Division signed the first of two cooperative agreements with the U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, to: a) develop and disseminate educational materials on green chemistry topics and b) find ways to promote green chemistry to audiences as disparate as the chemistry community and the general public. A number of workshops were held, bringing in experts on green chemistry from industry, academia, and government to develop a coherent program that met the needs of EPA, and built upon the strengths of existing ACS educational programs.

---

*Lecture presented at the IUPAC CHEMRAWN XIV Conference on Green Chemistry: Toward Environmentally Benign Processes and Products, Boulder, Colorado, USA, 9–13 June 2001. Other presentations are published in this issue, pp. 1229–1330.

In beginning this program, a number of issues had to be resolved. Firstly, what is the core knowledge that should be conveyed when teaching green chemistry? The term "green chemistry" is used to describe the design of chemical processes and products to reduce or eliminate the use and generation of hazardous substances, and to conserve materials and energy. The basic premise is to solve pollution problems by eliminating or minimizing pollution in the first instance. This is pollution prevention upstream at the molecular level. The corpus of knowledge in green chemistry is summarized in the "12 Principles of Green Chemistry" expounded by Anastas and Warner [1]. Where does this knowledge fit in the chemistry curriculum? To what degree of complexity can these principles be developed?

Of course, it is impossible to answer these questions without deciding on the educational level at which the materials are to be introduced. The typical U.S. high school course does not cover sufficient chemistry (especially not organic reactions) to allow for a full development of green chemistry principles. However, there is a sufficient background to begin to introduce some green chemistry at the high school level. (It was our judgement that the science background of younger students was too low to teach green chemistry as chemistry, although the basic idea of preventing pollution by not polluting in the first place can obviously be introduced at the upper elementary level.) However, the high school chemistry syllabus is already overcrowded with other topics, most of which are included in the examinations that the students will take before they leave high school.

Undergraduate and graduate students are the more obvious targets for exposure to a green chemistry syllabus. They have the broader understanding of chemistry, and most are going to use chemistry in their future careers. However, the question also arises here: Where does green chemistry fit in a crowded curriculum? Should we develop relatively brief materials to infuse into existing courses (and, if so, which ones?) or should we consider development of stand-alone modules, or even a stand-alone course?

We were also concerned that the materials we developed were consistent with our philosophy of promoting a "student-centered, active learning" classroom. It seemed inconsistent with our approach to learning chemistry to produce lecture material for teachers, and not hands-on activities for students. It would be easier to do the former, but more rewarding to do the latter. We were also concerned with perhaps "overselling" green chemistry as a solution to all pollution issues facing us today, although we were very cognizant of the intellectual excitement that could be generated among students studying green chemistry. We certainly wished to exploit that excitement.

ACS TOOL-BOX FOR GREEN CHEMISTRY

It was decided to begin our efforts by adding to, or adapting, existing educational materials produced by the Education Division. The Division has developed a chemistry text for non-science majors in college called *Chemistry in Context*, and a high school text, *Chemistry in the Community (ChemCom).* Both books are nontraditional texts in that they introduce the chemistry needed to understand important societal issues involving chemistry on a "need-to-know" basis. The third edition of *Chemistry in Context* was revised to include vignettes describing the various winners of the Presidential Green Chemistry Challenge Awards as they fitted comfortably into the text. Each vignette was identified by a green chemistry logo. There was no attempt made to teach green chemistry, merely to teach *about* successful applications of green chemistry. Green chemistry was discussed in the fourth edition of *ChemCom* in more detail in that students were introduced to the basic principles of green chemistry and asked to compare the characteristics of green chemistry with the Responsible Care® program of the American Chemistry Council. While neither text includes as much green chemistry as one might wish, these efforts represent an important beginning; there will be an increase in the green chemistry content of subsequent editions.

The Division produces a magazine for high school students, *ChemMatters*, and a magazine for undergraduates majoring in chemistry called *in Chemistry*. Green chemistry articles appear in both

magazines on a regular basis and give us the opportunity to reach large numbers of students (about 50 000 and 10 000 per issue, respectively) with information on green chemistry.

When deciding on the new materials to develop, once again the Presidential Awards were viewed as a resource. Cann and Connelly [4] produced a booklet for ACS of 10 case studies based on the awards. Each case study includes an overview, background information, green chemistry principle(s) illustrated and applied, questions for the student, and references. A sample case study can be found on the ACS Web site at http:www.acs.org/education/greenchemistry/. The Awards were also used as the basis for a 20-minute video, "Green Chemistry: Innovations for a Cleaner World". This video is also available on the Web, broken into five discrete segments. Both the case studies and the video are materials that can be infused into a range of undergraduate courses depending on the instructor. In addition, the video is suitable for high school and general public audiences.

Also available through the ACS Web site is a Green Chemistry Annotated Bibliography that consists of a searchable database of general references and a secondary database of abstracts from the Green Chemistry Challenge Awards. This database is comprehensive, but not exhaustive, and serves as an introduction to the literature only.

Other resources under development at the undergraduate level include a series of laboratory experiments and demonstrations that are being produced and tested by four different groups, primarily, but not exclusively, for the first organic course. These materials will also be available via the Web, as well as in printed form.

New materials at the secondary school level are being developed through a partnership among the Royal Society of Chemistry, the Gesellschaft Deutscher Chemiker, and the ACS. The intention is to develop a comprehensive set of materials that can be completely, or partially, integrated into upper secondary chemistry courses in all three countries. There will a PowerPoint and viewgraph introduction to green chemistry and a series of activities and background readings illustrating six of the principles of green chemistry, notably:

1. Get off to a safe start: Identify reactions that use nontoxic starting materials to make a desired product.
2. Use renewable resources: Find ways to use renewable starting materials.
3. Find safer solvents: Eliminate the use of toxic solvents to dissolve the reacting materials.
4. Economize on atoms: Design reactions in which all or most of the reactant atoms end up in the desired product.
5. Lower energy input: Use methods that minimize energy requirements.
6. Return safe substances to the environment: Produce benign or easily degradable materials.

There will be two or three student activities per principle. There will also be an annotated version of the activities for teachers, giving guidance on where, and how, these activities could be integrated into the regular course. The decision to reduce the 12 principles to 6, was taken as a matter of practicality—it is easier to integrate 6 important ideas into an over-crowded curriculum than 12!

Infusing green chemistry concepts into the undergraduate or graduate curriculum is easier than adding green chemistry at the secondary level. But even in tertiary education, most lecturers are not, at present, especially familiar with green chemistry, or convinced as to its importance. Thus, it is necessary to reach faculty with information on green chemistry through workshops, seminars, and symposia. It is also important to reach future chemists, which the ACS is accomplishing through special programming activities for undergraduate students who are affiliated with the ACS in student chapters in colleges and universities across the nation. Green chemistry workshops for students are held at ACS national and regional meetings; a new program is being planned to recognize student affiliates chapters for "green" activities; and the ACS is initiating a mini-grant program to encourage student chapters to work on green chemistry projects.

CONCLUSIONS

The examples discussed above can be considered as part of an evolving "tool-box" designed to promote green chemistry to various audiences. They meet the need to make information and support materials more widely available, as quickly as possible. The materials are by no means comprehensive, but they can easily be integrated into existing courses at both the secondary and undergraduate levels, and they can be customized by the teachers. Green chemistry is a topic that interests students deeply and may, in fact, attract new students to careers in chemistry.

If our efforts to bring green chemistry into the mainstream of chemistry instruction are successful, then it may be unnecessary to use the designation "green". Green chemistry topics will be an essential component of all chemistry courses.

REFERENCES

1. P. T. Anastas and J. C. Warner. *Green Chemistry: Theory and Practice*, p. 30, Oxford University Press, New York (1998).
2. C. L. Stanitski, L. P. Eubanks, C. H. Middlecamp, W. H. Stratton. *Chemistry in Context* 3rd ed. McGraw-Hill Higher Education, Dubuque, IA (2000).
3. ACS (American Chemical Society). *Chemistry in the Community* 4th ed., W. H. Freeman, New York (2000).
4. M. C. Cann and M. E. Connelly. *Real-World Cases in Green Chemistry*, American Chemical Society, Washington, DC (2000).