29. Green Chemistry

Dennis N. Kevill

What is "Green Chemistry"? Simply put, it is an eye-catching name for environmental chemistry. The concept of using environmentally friendly materials has become a major consideration in both consumer and industrial production. However, to fit into this category not only the end product but the process used to produce it must be "green." Much research is being carried out with the aim of developing environmentally friendly processes that minimize the use of energy and the production of toxic side products (wastes). Especially beneficial is when a process can be developed that minimizes waste because the side products also have uses.

Needless to say, the concept of green chemistry has been abused. We can probably all point to commercials that would be laughable, except that since they are repeated on a regular basis, it appears they must be commercially successful. A common approach to salesmanship based on the green phenomenon is to describe something as "all natural – contains no chemicals." Strictly speaking, of course, this statement is only true in reference to a vacuum.

Most aspects of green are positive, such as the establishment of the federal Environmental Protection Agency (EPA), which sets maximum limits for exposure to or release of a wide range of common pollutants, and the Superfund, for cleaning and restoring previously unsupervised (and often undocumented) toxic waste sites. Also notable are the removal of asbestos from schools and other buildings and the proliferating emission controls for automobiles and other modes of transportation.

A full consideration of any situation where green chemistry applies involves not only the chemistry itself but also a biological assessment of the extent of risk involved for various levels of pollutants to humans (where medical considerations are also involved) and to all other forms of life. This, in turn, involves the use of mathematical models and a statistical assessment of risk factors. Further, a critical evaluation of reports from the EPA or local authorities regarding environmental protection requires the ability to read technical documents and, if input is desired, to write to legislators and officials. Also, the ability to dissect questionable claims based on green considerations is a requirement for being an informed consumer. A workshop on green chemistry would therefore benefit from input by representatives from biology, mathematics, and English composition.

In late 2001, the American Chemical Society (ACS) publication, *Journal of Chemical Education*, began an ongoing series entitled "Topics from Green Chemistry." This series is edited by the assistant director of the Green Chemistry Institute of the ACS. The initial article defined green chemistry as "pollution prevention at the most fundamental level of atoms and molecules" (Kirchhoff, 2001, p. 1577). In practical terms, the institute promotes the practicing of chemistry in an environmentally responsible manner and has developed "The Twelve Principles of Green Chemistry" (Anastas & Warner, 1998; Hjeresen, Schutt & Boese, 2000; Ritter, 2001).

The idea of incorporating a green chemistry component into the NSF–Rockford Schools program arose after listening to organizational presentations in September and October 2000. It was not a major component of my teaching or research activities, but I had recently read a couple of environmental chemistry books (Baird, 1999; Spiro & Stigliani, 2003) intended as texts for upper-level undergraduate special-topics courses and had attended two green chemistry symposia at National Meetings of the ACS.

Initially the workshop was planned only for one day, with contributions from chemistry, biochemistry, and biology. After further discussions, we decided to develop a two-day workshop, and subsequently we added contributions from English and mathematics. On each day, the teachers received an overview of aspects of environmental problems, the biological implications of those problems, ways in which mathematical modeling can be applied, the interpretation of technical reports, and techniques for persuading local, state, and federal authorities to take action to alleviate pollution and punish polluters. It is important to note that when working with the university during class time, one may run into difficulty scheduling laboratories and classrooms; however, it is important to note that Northern Illinois University's Department of Chemistry and Biochemistry were willing to make accommodations.

Organization of the Agenda

After the broad outline for the workshop had been established (two days with participants from biology, mathematics, and English, as well as chemistry and biochemistry), the university faculty met to establish an agenda for the first day with suggestions for the second day. We deliberately did not finalize the program for the second day to allow input from the teachers after the end of the first day. I developed an agenda that was then circulated to the others for comments. The idea for the first day was to place an emphasis on waste management and water pollution, with air and soil pollution to be emphasized on the second day.

Handouts for Participants

At the beginning of the presentation, each participant received two handouts. One consisted of copies of the projections used during the talk, and the other was a collection of items from recent issues of the *Journal of Chemical Education*. The first sheet appeared under the heading "Green Chemistry – Innovations for a Cleaner World" (Kirchhoff, 2001). The next article described a high school project incorporating fieldwork and showing an approach integrating high school chemistry with environmental studies. The linking study involved the analysis of water removed from a brook joining two lakes near a high school in northern Michigan (Randall, 1997). This was followed by a report from the secondary school section of the journal outlining a joint U.S.–Mexico program concerning water pollution in the two countries. The article described high school activities for the analysis of lead, atrazine (a water-soluble herbicide), and nitrate content (Kelter, Grundman, Hage, Carr & Castro-Acuña, 1997).

A fairly brief article (Judd, 2001) discussed online sources for information about mercury in the environment, ending with a listing of Web addresses. These were useful in the context of the contribution from English, which involved the use of websites to gain information for developing political and social arguments for environmental protection. The theme was primarily how mercury enters aquatic ecosystems, especially lakes, and then the food chain.

In looking for experiments suitable for middle and high school students that the teachers could perform during the workshop, I surveyed the "JCE Classroom Activity" sections that appear in the *Journal of Chemical Education* several times per year. Three were chosen for this activity on the first day. Since laboratory work was not possible on the second day (no laboratory being available) and since two of the three additional experiments selected would require a series of days to complete, instructions for these three experiments were included in the handouts. One concerned acid rain and the environment's acidity and buffering capacity (Halstead, 1997). A companion experiment dealt with acid snow and would have required experimentation over two to three days (Halstead, 1998). A third experiment, requiring a day or more for the recycled paper fibers to dry, involved modeling of the process involved in recycling newspapers (Gettys & Jacobsen, 2001), a good project related to waste management. The classroom activities section of the *Journal of Chemical Education* always contains the statement "This Classroom Activity may be reproduced for use in the subscriber's classroom," and photocopies of the published activities constituted additional handouts.

Activities

The English representative briefly introduced the program and stressed the importance of political and social issues connected with combating pollution and the need for an informed public. This presentation was followed by my own, outlining the relationship between pollution and population growth, the 12 principles of green chemistry (Anastas & Warner, 1998; Hjeresen et al., 2000; Ritter, 2001), the major types of pollution, the chemistry of the formation and precipitation of acid rain, and a review of the principles behind the experiments to be carried out in the afternoon. Then the biology professor discussed water pollution from a biological standpoint, and two mathematics professors showed how patterns of water pollution relate mathematically to the sources of the pollution. One presented to middle school teachers and the other to high school teachers.

The participants spent time in the laboratory, working through three experiments. The initial "Cartesian Diver" experiment (Pinkerton, 2001) showed that increased pressure (squeezing) increases the volume of water in a barely floating dropper in a capped bottle filled to the top with water. This increases the average density of the dropper above that of the water and it sinks to the bottom of the bottle. When the pressure is removed, the situation reverses itself and the dropper rises to the top. This experiment is inexpensive, uses harmless materials, and is suitable for students at any class or ability level.

The second experiment involved using zeolites as environmentally friendly water softening agents ("Cleaning Up with Chemistry," 1999). This experiment had been well checked beforehand. It was the one I chose to incorporate into the module that I prepared and presented to five streams of a gifted eighth-grade class at West Middle School in Rockford. The students seemed to enjoy it and learn from it, and the teacher has continued to use it. Only a few of the teachers present had previously carried out the experiment. The major problem with this experiment was to convince the experimenters that one *very* small drop of liquid dishwashing soap really meant *very* small. If one used more, only a portion was neutralized by the hardness of the water and the excess gave a false positive with regards to the action of the soap in the blank (no zeolite) sample.

The third experiment was very appropriate for a program emphasizing water pollution. The morning presentations had outlined the formation and precipitation of acid rain and its biological consequences. The experiment simulated acid rain falling into lakes by adding vinegar to bowls of water, one of which also contained chalk (calcium carbonate) (Gettys & Jacobsen, 2003). Lakes where the water is in contact with chalk (limestone) are capable of neutralizing the acid. In the published procedure, the acid was monitored by an acid-base indicator prepared from red cabbage. Due to time restraints, we substituted a commercial indicator.

After leaving the laboratory, the program moved to the undergraduate computer laboratory. The session focused on the importance of political action to protect the environment, coupled with the need to provide information validating the points one wants to make. The program ended with a required exit evaluation by the teachers.

Participants learned about using websites to obtain a balanced view of a current issue. A handout outlined the uses and sources of energy, with a chart showing per-capita energy consumption for various countries; the United States ranked second, marginally behind Canada. It was then shown how the principal sources of energy had dramatically changed in the United States, with 91 percent from wood burning in 1850, 71 percent from coal burning in 1900, and about 40 percent from oil and 24 percent each from natural gas and coal in 1990. The presentation cited the relevance of these figures to the severity of pollution, outlined the extent to which the energy content of different fuels was usefully employed, including losses in transmission, the energy consumption of appliances, and the processes used to refine crude petroleum. We also mentioned alternative fuels for automobiles − in response to a request from a teacher. Participants discussed global warning, the greenhouse effect, and ozone-layer depletion, followed by the effects of smog and the constituent oxides of carbon, sulfur, and nitrogen on animals and plants.

The mathematics contribution was originally planned as involving a half-hour presentation, by an undergraduate mathematics major, about an internship he had held the previous summer at a federal government laboratory. This was to be followed by separate presentations to middle school and high school teachers, as on the first day of the workshop. However, when he was developing his presentation, it became clear that a meaningful and understandable presentation would benefit from a longer time period. We agreed to give him the full time assigned to mathematics.

His theme was how mathematics can be applied to atmospheric sciences (meteorology) and concentrated on aspects of vertical air motion, a topic that he had studied in his internship. Air motion is influenced by many factors, but primarily by gravity, friction, pressure differences, types of terrain, changes in elevation, and land use. Mountains can have a profound influence on the weather around them. Studies of the vertical motion of air are important in weather forecasting, especially for consideration of thunderstorms and other types of severe weather. Another factor involving the vertical motion of air is the formation of smog, which occurs when an inversion of temperature hinders the vertical motion of the smog constituents. Smogs are especially severe in mountain valleys (Los Angeles, Mexico City, etc.), where lateral motion is also hindered. The presentation led to a lively discussion.

The final topics in the workshop highlighted soil pollution, which had not received appreciable attention earlier. The origin and extent of hazardous waste sites were discussed, including the economics of cleanup and details of the federal Superfund program. The common contaminants and types of hazardous wastes were discussed, followed by domestic garbage and landfills. Finally, we presented the four "R's" of waste management: Reduce (amount of material used), Reuse (materials once formulated), Recycle (materials by re-fabricating components), and Recover (energy content if materials cannot be reused or recycled).

Relevance to Illinois Learning Standards

The Illinois State Board of Education adopted learning standards in 1997, which had been formulated by its Standards and Assessment Division. Our workshops were relevant to at least four of the seven recognized learning areas. Concentrating only on those areas where there was a clear and important relationship to the standards, I will consider first the science goals, listed as 11–13 within the standards. The overall goal 12 is to "understand the fundamental concepts, principles and interconnections of the life, physical, and earth/space sciences." The second workshop was especially well-connected to part B, "Know and apply concepts that describe how living things interact with each other and with their environment." In each case (such as 12B), there are then lists of what the students should be able to do after early elementary, late elementary, middle/junior high school, early high school, and late high school levels. The workshop concentrated on middle and high school, and items covered during the workshop would be relevant at all three of those levels. Also relevant is goal 12C, "Know and apply concepts that describe properties of matter and energy and the interactions between them." Energy considerations, such as generation of energy in environmentally friendly ways and minimizing energy usage, were an important component of the workshop.

The workshop was especially relevant to two of the six learning standards (subgoals) listed under 12. The learning standard 12E is "Know and apply concepts that describe the features and processes of the Earth and its resources." Relating to this learning standard at the different levels, everything mentioned under middle school is directly relevant to topics discussed in the workshop. Benchmark 12.E.3a analyzes and explains the large-scale dynamic forces influencing land, water, and atmospheric systems; benchmark 12.E.3b involves description of interactions between organisms and earth, oceans, and atmosphere that cause changes such as erosion and El Niño/La Niña; benchmark 12.E.3c evaluates the biodegradability of renewable and nonrenewable natural resources (directly related to the consideration of landfills). In benchmark 12.E.4a (early high school), the consideration of how external and internal energy sources drive weather patterns is closely related to the discussion of weather forecasting. For late high school (benchmark 12.E.5), the analysis of the processes involved in short-term and long-term events was the basis for the mathematics presentation to high school teachers on the first day of the workshop.

It might at first seem strange that a representative from the English Department would participate in a green chemistry workshop. The descriptions given in the discussion of activities for the English representative's introduction to Web-based activities and the consideration of how to evaluate commercial claims made for products and services show that his presentations related not only to the English standards but also to important sections of the science goal 13: "Understand the relationship among science, technology, and society in historical and contemporary contexts." This goal was divided into two learning standards, the second of which is described as "Know and apply concepts that describe the interaction between science, technology and society." Among the benchmarks for middle school and high school are: 13.B.3e, “Identify advantages and disadvantages of natural resource conservation and management programs”; 13.B.3f, “Apply classroom-developed criteria to determine the effects of policies on local science and technology issues” (e.g., energy consumption, landfills, water quality); 13.B.4d, “Analyze local examples of resource use, technology use, or conservation programs; document findings; and make recommendations for improvements”; 13.B.4e, “Evaluate claims derived from purported scientific studies used in advertising and marketing strategies”; and 13.B.5e, “Assess how scientific and technological progress has affected other fields of study, careers and job markets and aspects of everyday life.” A teacher seeking to present these topics would benefit from having attended our presentation.

The mathematics presentations were relevant to aspects of the learning standards for mathematics (Goals 6–10). The discussion of graphs as an aid in predicting weather patterns was consistent with benchmark 8.D.3a, “Solve problems using numeric, graphic, or symbolic representations of variables, expressions, equations, and inequalities.” Similarly, the general learning standards B and C, under goal 10 were involved in most of the mathematics presentations. Standard 10B states, “Formulate questions, design data collection methods, gather and analyze data and communicate findings,” and standard 10C states, “Determine, describe and apply the probabilities of events” – exactly what was involved in the treatments of the mathematics of predicting future weather patterns and population growth, the latter being very relevant to pollution issues and destruction of natural resources.

There was also a tie-in with aspects of the English/language arts goals (1–5). The aim of Goal 5 is to “Use the language arts to acquire, assess and communicate information.” The three learning standards (subgroups) are:

A. Locate, organize, and use information from various sources to answer questions, solve problems, and communicate ideas.
B. Analyze and evaluate information acquired from various sources.
C. Apply acquired information, concepts, and ideas to communicate in a variety of formats.

Our presentations and the participants’ work at the computers directly involved A and B, with environmental issues as a specific example. Also, the teachers were given advice as to how the treatment of the information obtained could be presented in the context of learning standard 5C.

Aspects of the workshop were relevant to some of the social science goals (14–18). Goal 15 states, “Understand economic systems, with an emphasis on the United States.” Environmental issues have economic consequences, and this was a theme throughout the workshop. The early high school benchmark 15.E.4b is “Describe social and environmental benefits and consequences of production and consumption.” Standard 16E also involves environmental history: “Understand Illinois, United States, and world environmental history.” For example, the workshop’s consideration of the history of energy sources and their dramatic changes over the last 150 years would be highly relevant. Standard 17B was also addressed: “Analyze and explain characteristics and interactions of the Earth’s physical systems.” Especially relevant was benchmark 17.B.3a, “Explain how physical processes including climate, plate tectonics, erosion, soil formation, water cycle and circulation patterns in the ocean shape patterns in the environment and influence availability and quality of natural resources."

Exit Evaluations

At the end of each of the two days, the teachers completed exit evaluations. The evaluation sheet asked five questions to be marked on a Likert scale ranging from "strongly agree" (5) to "strongly disagree" (1). There were also three questions allowing for written comments. The five scaled questions were:

1) This activity increased my knowledge and skills in my areas of certification, endorsement, or teaching assignment.
2) The relevance of this activity to ISBE teaching standards was clear.
3) It was clear that the activity was presented by persons with education and experience in the subject matter.
4) The material was presented in an organized, easily understood manner.
5) This activity included discussion, critique, or application of what was presented, observed, learned, or demonstrated.

For both days, all participants marked "strongly agree" for each of the five questions. Clearly, they were happy with the content, organization, and presentation. Every evaluation form had something written in the section asking about the best features of the activity, but considerably fewer participants offered suggestions for improvement or other comments and reactions. The teachers very much appreciated being able to go to the laboratory and work through the experiments that they would take back to the classroom. Written comments strongly indicated that the workshops should have an appreciable hands-on component so as to maintain interest.

Conclusion

While the workshops were a resounding success, they can be improved. I would like to extend them to three days and complement lectures with hands-on opportunities for the teachers to do experiments suitable for middle and high school students. The second-day presentation by the undergraduate student, about his internship, was a great success and suggests we should try other less traditional presentations. We might also devote some time to safety in the laboratory (Webber, 2002). Perhaps the university's safety officer could present. Many of the safety features to be observed in university laboratories would apply equally in secondary school laboratories.

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