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Toward the Greening of Our Minds: A New Special Topics Course

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A new special-topics course on green chemistry has been introduced at this college. This new course without lab is designed especially for science majors and minors who are interested in the future of our planet and who have previously taken general and organic chemistry. Chemical demonstrations are used to enhance the understanding of specific concepts. This course is planned so that students have the opportunity to learn about green chemistry and its effects on the environment and the human race. The use of real-world examples illustrates how creative thinking and problem solving can yield substantial benefits to academia and industry, encouraging students to look at sustainable development, both locally and globally. Students are able to enhance their writing and oral presentation skills and improve their communication and discussion abilities while working on a green chemistry topic. The ultimate goal is for the students to be able to critically evaluate policy decisions in an environmentally conscientious manner using green chemistry as the focus.

Format of the Course and Assignments

The format of the course is aimed at enriching the students' existing knowledge about general and organic chemistry while they learned about green chemistry concepts. Complementary materials such as journal and news articles were given to the students when discussing a specific topic in the roundtable format. The semester was divided in five sections, each of which focused on specific topics for each class period as detailed below.

Foundations of Green Chemistry

The first fifth of the semester concentrates on giving the students the foundations of green chemistry. Introductory classes are based on formal instructor lectures punctuated by some group discussions. The background material introduces examples of traditional approaches to performing chemical reactions in a laboratory setting, the common ways to dispose of and treat solid and hazardous waste, and the NIMBY (not in my backyard) syndrome. Definitions, tools, and applications of green chemistry in industry and academia are then described *(1–4).* Each lecture is interspersed with a call for questions every 10 minutes, where each student is asked to give his or her opinion on the topic covered and to submit one or two questions to the class. The small class size of thirteen students is ideal for this type of activity. Large classes can be divided into smaller groups that are asked to submit their questions as a group to allow the students to become more engaged and develop individual understanding of the green topic. The students learn by intellectually doing rather than listening to the professor feed them knowledge.

Applications in Academia and Industry

The second section focuses on some of the applications of green chemistry principles in academia and industry. A list of existing applications and specific examples is presented to the students who pick real-life examples of interest to them. The students are given some background about the topic and are instructed how to search the literature, but no content or format for the following discussion is provided. The students learn about real-world examples by exploring the literature and communicate their findings during the next class period. This is an individual task constituting 10% of the course grade that persuades each student to come to class prepared with a thorough and organized plan of discussion on paper. Some of the discussions focused on metal mining and primary metal industries, oil and gas industries, approaches to water purification, hybrid cars, fuel cells, alternative sources of energy, and chemical industries *(5–10).* Active learning allows the students to direct the action while the instructor serves as a mediator and facilitator of knowledge and understanding. Being active invites the students to make connections between the theoretical side and the practical side of green chemistry and, therefore, to think critically.

Individual Writing Assignment and Oral Presentation

The third section is directed toward writing a four-page article about one of the annual Presidential Green Chemistry Challenge Awards *(11)* chosen by the student. Each student picks an award topic from the list provided and compiles an article summarizing the accomplishments of the award recipient(s) according to detailed guidelines and an evaluation sheet (available in the Supplemental Material[W]). The goals of the writing assignment are for the student to become skilled at organizing information, to become aware of state-of-the art technological innovations in chemistry, and to be trained on how to think beyond the current or more obvious applications of green chemistry. The oral presentation of the award is an individual project consisting of 15 minutes of presentation followed by 10 minutes of questions and discussion. The presentation, which constitutes 50% of the final grade, is based on an evaluation by both the classmates and the professor. Students are evaluated on their understanding of the green chemistry principle(s) applied in this new strategy, their ability to compare and incorporate information about traditional and "greener" approaches, and their ability to lead a discussion on a topic of interest. The student presenting is not only the principal actor who needs to

explain clearly and concisely the goal(s) of the award and the benefits gained with this new greener design but he or she is also the leader of the discussion following the presentation.

Progress in Developing Countries

The fourth section addresses "Green chemistry and the developing countries: a myth or reality?" followed by a discussion about the book by William McDonough and Michael Braungart entitled *Remaking the Way We Make Things: Cradle to Cradle (12, 13).* It is important that students be exposed to the progress made and obstacles faced by those universities in developing countries that implement green chemistry in their curricula and the necessity for these universities to collaborate with universities in developed countries. The students develop a "greener mind" by investigating applications of green chemistry principles supplemented by the topics presented in McDonough and Braungart's book. Each student communicates the goals and findings of a chapter from the text and proposes some future trends in green chemistry.

Team Mini-Proposal

The fifth and last section is based on a mini-proposal covering a green chemistry topic presented by a team of two students. The goal of the mini-proposal is to have the students apply their greener minds to a project where an environmentally benign process or product is lacking and prepare a greener alternative. The team of students produces a mini-proposal to green up a reaction, design, or product that is not environmentally benign or does not employ any of the green chemistry principles. Some of the mini-proposal topics can be related to the following:

- The use of a greener design or synthetic pathway (use of microbial catalysts, use of enzymes, use of renewable source of energy, etc.)
- The use of a more environmentally benign solvent (a known organic reaction may require organic solvents and you may think of using an alternative and greener solvent or no solvent at all!)
- The use of a greener starting material (use of renewable resources)

This is a team project consisting of a 20-minute presentation followed by 5 minutes or more of questions and discussion. The 20 minutes should be spent equally between the two team members. An abstract describing the goals and tools of the mini-proposal is sent to everybody at least three days before the presentation. Each abstract has to be approved by the professor beforehand. Each student is evaluated by both the classmates and the professor. Part of the evaluation is individually-based and part of it is team-based. The detailed guidelines, evaluation sheet, and some of the mini-proposal topics are provided in the Supplemental Material.[W]

Student performance for the term is based on attendance and class participation (10%), written article about a Green Chemistry Presidential Challenge Award (25%), individual oral presentation on the Green Chemistry Presidential Challenge Award (30%), and the team mini-proposal presentation (35%).

Evaluation and Outcomes

The comments from the students about the teaching of the course were encouraging and enlightening. The students found that the discussion of the background material was useful, the freedom to discuss topics made class more enjoyable, and participating in a student-directed course was great. The combination of lecture, group discussions, and student presentations allowed the students to learn much more than expected. The students felt that the parts of the course where they were able to discuss topics as opposed to being lectured to those topics were more beneficial and interesting.

The students left the classroom with a complete picture not only about green chemistry but also about organizing, writing, presenting, and, most importantly, about how to think on their own. The scheme used in this teaching method aims at "learning now" and not "learning postponed". The "learning now" method is based on learning by intellectual doing. The engagement of the students, the independent individual development of understanding, communication of this understanding imposing structure, synthesis, and rehearsal support the "learning now" process. In this method it is anticipated that the students will activate their long-term memory and will therefore retain their knowledge much longer rather than having to reactivate their short-term memory right before a test (characteristic of the "learning postponed" process).

Conclusions

This course was designed for the students to play an active role in their own learning experience rather than being merely spectators as is common in traditionally taught courses. They became participants guided by the instructor, directing their own learning in this green chemistry special-topics course. The actively acquired knowledge will allow them to spread the word about green chemistry in the long term, not only on campus but, most importantly, where they will pursue their future goals in life.

[W]Supplemental Material

A list of topics covered in the mini-proposal, student handouts for the writing and presenting assignments, and evaluation forms are available in this issue of *JCE Online*.

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