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# Greening the Curriculum: Traditional and Online Offerings for Science and Nonscience Majors

**Abstract:**
This chapter describes the efforts of the faculty at Worcester State University (WSU) to infuse green chemistry into the undergraduate chemistry curriculum. It specifically focuses on the structure of two stand-alone classes. One is aimed at a chemistry audience and is an upper-level elective for the major. The other is an online course aimed at a nonscience audience. Both are three-credit lecture-only classes.

**Keywords:** green chemistry, sustainability, chemical education, online courses, undergraduate course design

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## 1 Introduction

Since the publication of the 12 principles of green chemistry, education of the next generation of chemists has been seen as a cornerstone to the acceptance and development of green chemistry as a field [1]. To this end, several courses have been offered at various universities in the United States and Canada in different formats: (1) as part of an existing course; (2) as a seminar; (3) and as a stand-alone course [2–6]. An online green chemistry course is also available through Carnegie Mellon University [7]. Some classes have a focus on nonmajors [8, 9]. Several resources currently exist for greening organic chemistry labs [10, 12, 13] but fewer exist for other fields of chemistry. Despite the above-mentioned examples, it is important to document as many successful attempts at various levels so as to promote the wider adoption of green chemistry in undergraduate curricula.

Worcester State University (WSU) is a 4-year primarily undergraduate institution located in Worcester, MA. The chemistry department offers both a major and a minor, and currently has around 150 registered majors. As part of the chemistry major, students are expected to complete a minimum of 45 credits of chemistry coursework, of which 12 credits are elective credits. Green chemistry concepts were first introduced at WSU in the organic laboratory sequence in 2003. The labs performed were adapted from Doxsee and Hutchison's [15] green organic lab manual. Since that time, we have created a green and environmental chemistry concentration within the chemistry major (Figure 1), which requires students to take an upper-level green chemistry course, environmental chemistry, and a choice of two related electives. We offer an environmental toxicology course as well as a green/environmental laboratory course. We believe that we have strong offerings for our science majors and continue to infuse green chemistry throughout the chemistry curriculum. Additionally, to fill a perceived need for students who are not science majors, we have developed an online course covering green chemistry and sustainability topics. This chapter will provide a template for our stand-alone green chemistry course for chemistry and environmental science majors and our online course on green chemistry and sustainability.



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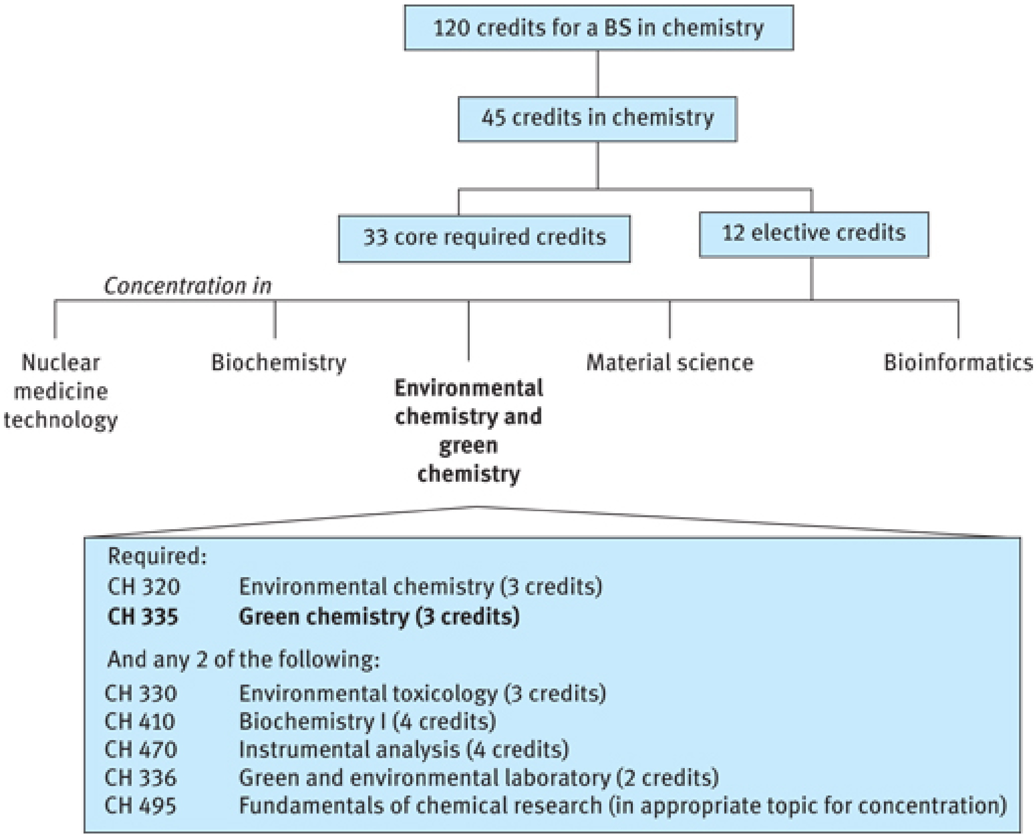


**Figure 1:** The chemistry curriculum at WSU and the “green and environmental chemistry” concentration.

## 2 Green Chemistry – Upper-Level Chemistry Course

Green chemistry has been taught at Worcester State biannually since the spring of 2009. Both in the spring of 2009 and 2010, the class was taught with a lab. However, this did not do justice to the lab component and this class is now taught as lecture only. The class had an enrollment of approximately 25 students every time it was offered. The prerequisites for this course include a one-year sequence of general chemistry and organic chemistry as a corequisite. Students taking this class span the science spectrum and include chemistry, biology, biotechnology, and environmental science majors. The course addresses the 12 principles of green chemistry through the use of journal articles.

### 2.1 Course Outline

Introduction to green chemistry. Introduction to the 12 principles of green chemistry.Difference between sustainability and green chemistryAtom economy and other green metricsGreen metrics and solid state reactions/solventless reactionsAqueous reactionsAlternative solvent media $scCO_2$, polymers, fluorous solventsGreen analytical chemistry – focus on chromatographyIonic liquids – a case studyCatalysis as green chemistry and examples in biocatalysisCase study: adipic acid synthesisTopics in toxicology. Designing for biodegradability/Biodegradability vs. toxicologyUse of renewable materials for chemistry/renewable vs. sustainableAlternate energy/energy considerations for reactionsTools of green chemistry: microwaves, sonication, photochemistry

### 2.2 Course Format and Development

No textbook was used or recommended for this class. The reason for this is the author’s opinion that the state of the art in green chemistry is ever-evolving. Therefore, all topics were taught from current peer-reviewed literature. Second, teaching from the peer-reviewed literature satisfies a key need for higher order thinking in the undergraduate curriculum. Green chemistry makes peer-reviewed literature accessible to students at that level. Sometimes, transcripts from the green chemistry presidential awards and Nobel prizes were used.

Literature reading was emphasized and assessed throughout, including a final exam with 50 % dedicated to paper reading and questions. Students were provided with the reference to a research article in the appropriate topic. Students were usually given 1 week to find and read the article. Initially, the paper structure was discussed in class and reinforced through presentations by the instructor on the topic. As time progressed, students were given an article and asked to answer questions based on the reading before coming to class. Toward the end of the course, students were given a paper and an in-class quiz was given on their reading of the paper. This structured approach allowed the students to be gradually introduced to reading full research papers. At the end of the semester, almost all the students attested to their increase in confidence when it came to reading peer-reviewed literature. For the final, in addition to a traditional exam, students were asked to write an abstract for a paper, and answer questions based on their reading of two articles they had never seen before but based on topics covered in class. The performance on the final indicated that students did indeed feel comfortable reading and understanding literature especially with respect to the 12 principles, as indicated by them in the end-of-semester surveys.

One of the difficulties for both the student and the instructor while teaching green chemistry is the various types of chemistry spanning various fields that are presented in a single class. To reduce switching topics every class and make the paper reading more area focused, the life cycle of ionic liquids [16] and adipic acid synthesis [17] were chosen as case studies. Ionic liquids were initially hailed as green but subsequent research has shown that as a class of solvents these may or may not be green. This case study allows for a very detailed discussion of "greenness" as it applies through the life cycle of a product. Adipic acid is a raw material for the synthesis of nylon and provides an interesting industry-based case study. Using these subareas, papers were chosen for the more broad topics of catalysis, toxicity, and biodegradability. The use of case studies also enabled discussion of relative "greenness" of various synthetic strategies and comparisons. In order to make more focused comparisons particularly with regard to biodegradability and toxicity, students were introduced to databases and trained to use them effectively. Energy and economic considerations were stressed throughout. Additionally, not all reactions discussed were necessarily completely green, and students were trained to look at a process holistically. Green comparisons between various ways to carry out the same process were discussed and tested. The students had to use their judgment skills to carry out these comparisons and this was really different from the skills they are usually exposed to in other chemistry classes. Students were able to understand that there are several shades of "green," and one process while effective in satisfying one or more principles of green chemistry may fail in other areas. They were continuously challenged to make judgments about the various options and came to gain some perspective about the economic and industrial barriers to adoption of greener techniques.

## 2.3 Modes of Assessment

The class was assessed based on regular in class quizzes (25 %) and two take-home exams (25 %). Fifty percent of the second exam was dedicated to reading two papers that the students had previously not seen and answering questions based on reading as well as writing a green context for the articles when abstract was not provided. In addition, students had to write a final paper (a literature review on any topic with a green chemistry focus) worth 25 %.

A major thrust of the course was to emphasize both written and oral communication. This is particularly important for a field like green chemistry, where spreading the word is as important as being a conscientious chemist. In general, it is known that the perception of chemists among the public is not very favorable, and concerns about pollution have contributed to this image. Better communication of green chemistry will help change this image [16]. In order to address this need, training students to communicate science and green chemistry in particular is a key goal of this course.

Several assignments (20 %) were designed with this in mind, the most novel of these being collaboration with a communications class. A professor from communications science was invited to guest lecture on the assignment at hand and particularly communicating science to a nonscience audience. Every student in the green chemistry class was paired with a student in an introductory communications class. Students in the green chemistry class were interviewed by their counterpart in the communications class. The interview included a profile of the student and questions about green chemistry and the source of the student's interest in green chemistry. At the end of the assignment, the communications major published a "biobox" of the student interviewed, and the green chemistry students wrote a reflection of the interview and their ability to communicate the concept of green chemistry to the uninformed nonscience major. Among other assignments, students were asked to write two blogs through the semester. The blogs were based on newspaper articles, other blogs, and popular media. Twitter handles were provided to students for easy discovery. Most blogs focused on energy-related issues although these were not stressed in class. This indicates a prevalence of these articles in popular media and perhaps an instinctive connection between energy and green chemistry made by the students. Students were also asked to make a presentation as a group, on a Presidential Green Chemistry Award of their choice. Here the focus was on collecting company profiles and consulting the patent literature rather than peer-reviewed publications. The use of a variety of tools to search various forms of literature in this class rather than merely focusing on a textbook allowed for students to realize the breadth of information available to them. It also allowed them to develop and hone the skills necessary to locate this information more effectively and efficiently. This instructor believes that these skills are invaluable and will lead to more skilled lifelong learners.

### 2.4 Student Survey Results

When surveyed on interest and understanding of journal articles after this class, the student responses were very positive with a large majority of students ranking their interest between 3 and 4 on a scale of 5. It was even more encouraging that most students rated their understanding of journal articles between 4 and 5. Increased student confidence in searching, retrieving, and understanding literature is a very positive outcome not only for this course but for the entire chemistry curriculum.

This increase in interest and confidence was also reflected in the final paper assignment at the end of the semester. It is the opinion of this instructor that the quality of the final papers was much better than previous iterations of this class and included the use of journal articles. On average, the papers were better researched and reflected a better understanding of the subject.

According to the student survey, interest in the specific communication assignment discussed were low with a majority of scoring their interest between 1 and 3. This is to be expected as many chemists are outside their comfort zone when it comes to communication. This is an important skill as discussed before, so this instructor does not see these ratings as negative. Some student responses are shown below:

- "I think it was more beneficial to use articles instead of a textbook and I feel as if I learned important skills to help me better understand them which is helpful for all science classes."
- "I realized that industry has economical advantages to adopting green chemistry."
- "Applications helped me understand how it affected my actual life + industry motivations."

## 3 "Paper or Plastic?": Online Approach for Nonmajors

A course titled "Paper or Plastic?" has been offered online as a nonlaboratory science elective since 2012. It has been offered a total of six terms as of this writing, with course enrollments for each section capped at 25. Due to high demand for online offerings, particularly those fulfilling science electives, each term has had more than one section available. Because many of the students taking this course to fulfill their science elective do not have a strong chemistry background, it was difficult to set the course up along the 12 principles of green chemistry as other courses have done [18]. Instead current issues involving green chemistry and sustainability such as climate change, pollution, polymers, toxicity, chemicals in common consumer products, sustainability, and so on are covered in separate blocks. Students are taught very basic chemistry principles at the beginning of the course and within each block, the chemistry behind the major topics within these issues are discussed. When possible, green chemistry and/or sustainable alternatives are presented. By the end of the course, students are expected to apply basic scientific principles to these different topics. It is expected that students will develop a basic understanding about green chemistry and greener alternatives to global environmental problems. While there are similar courses being taught at different institutions [7, 9, 19], this is the first example of a fully online course on green chemistry and sustainability targeting nonscience students.

### 3.1 Course Outline

Block 1: Green chemistry and sustainability

- What are green chemistry and sustainability and how are they different?
- How leaders in the industry are changing; how chemistry is done; and why is it important for the future?
- Consumerism/purchasing choices
- Global issues (this course is cross-listed with our Global Studies program)

Block 2: Fundamentals of chemistry

- Atomic structure
- Bonding and structure of molecules
- Organic molecules
- General reactivity of different molecules
- Unit Conversions
  - Basic discussion of metrics, scientific notation, and measurements

Blocks 3 and 4: Climate change

- Scientific description of climate change
- What are greenhouse gases: prevalence and potential
- Relating current weather phenomenon to climate change
- What are some solutions?

Block 5: Pollution

- What are some of the chemicals causing pollution and how are they formed?
- Indoor versus outdoor pollution
- Green chemistry solutions
- How does it differ from climate change?

Block 6: Chemicals in consumer products

- Identification of chemical hazards
- Examples to include bisphenol A (BPA), dioxin, polychlorinated biphenyls and others
- What are some greener alternatives?
- Why is it so difficult to make changes to existing products?

Block 7: Endocrine disruptors

- What are they and should we be worried about them?
- What are some greener alternatives to current common consumer products?

Block 8: Polymers

- What are polymers and what makes them different from each other?
- Recycling
- Which plastics are known to leach BPA and phthalates and which ones do not?
- Potential and downside of greener plastics

Block 9: Alternative fuel and energy sources

- Where do we get our fuel energy?
- Chemistry of fuel and energy
- Alternatives to our current fuel and energy sources

Block 10: Plastics in the environment

- Consumer use, recycling, and end-of-life disposal
- Environmental issues
- Plastics to fuel?

### 3.2 Course Format and Development

Since this class is fully online, a structure of instruction and assessment had to be created. Each week had a scheduled day to release new material, and students were given a week to complete assignments. All modes were untimed, with the exception of set weekly due dates. Note that there was not a text used for this course, although an online source for a general chemistry text was provided as a reference. Online education literature indicates that a variety of forms of material presentation and assessment modes are necessary for an effective course [20]. To that end, the following methods were developed:

### 3.3 Presentation of Material

Audio lectures were created using iPad apps (Explain Everything, ShowMe). The apps allow for annotation on a PowerPoint slide coupled with audio, which provides a lecture that is similar to what would be given in a face-to-face setting. Students are also given the PowerPoint files with no audio in addition to the audio lectures. A student survey given at the end of a term indicated that 73 % of students found the audio lectures helpful ($n = 30$). Only 3 % of those responding did not utilize them. Each block of material had one or more audio lecture associated with it. In order to maximize student utilization, each lecture was limited to roughly 15 min. If more time was necessary to explain the topic, more than one lecture was created.

Readings were provided from a variety of sources. Since many of the topics are complicated scientifically, readings had to be chosen with care in order to provide information but not overwhelm. Appropriate level readings were found in *Science, Nature, C&EN, the New York Times Science* section, and other media. A balance was attempted between more advanced scientific articles and ones that related topics to current events or issues. From the student survey, 90 % read all or most of the materials provided.

Online sources such as *TED Talks* and documentaries were provided if there were appropriate resources available for the topic in question.

### 3.4 Modes of Assessment

Quizzes were given as part of each block. Quizzes ranged from basic multiple-choice questions from the readings/lectures to essays that required students to apply the concepts from the block.

Discussion boards were given for those topics where it seemed appropriate for students to discuss their ideas and questions. An introductory discussion board was developed for the first block so students could get to know each other and make a connection with other students. This was not done initially and was suggested after the end of the first online semester by students. It has helped “break the ice” for students to discuss their major, why they are in the class, their knowledge of the environment and to indicate whether they have worries about taking a science course. Other discussion boards required students to have completed the readings and quiz for the block and to answer a set of posed questions. Each student was required to provide a comment of substance and to respond to two other students in order to receive full credit.

A mid-term exam was given that was included short answer and multiple-choice questions that related the first part of the course materials. There was a short essay question that required students to read an article and apply their knowledge to a set of questions. Due to the nature of an online class and information accessibility, all prior materials were left “live” so students could access them to take the exam. Questions were designed so that students had to apply their knowledge rather than hunt through the materials to find the correct answer.

A final paper was assigned that allowed students the opportunity to answer the question of the course: Paper or Plastic? Students are asked to do a life cycle assessment (LCA) to analyze whether or not paper shopping bags are preferable to plastic shopping bags. This is one LCA that has been done fairly extensively online with resources available suitable for an introductory-level course audience. They are asked to come up with an answer to this question and are not allowed to fall back on the obvious solution of just using reusable bags in place of either.

A final exam is given once students have completed the paper assignment. Since the LCA of paper versus plastic bags favors plastic bags, many students expressed considerable surprise because they have generally been under the impression that paper was favorable. The question of why different communities are banning plastic bags if they are so good inevitably comes up. In order to get them to see the issue in broader terms, they are required to watch a documentary on plastics in order to dissect what is true and what is overstated based on what they have learned [21]. They are asked to discuss how their thinking has changed based on what they have learned and how they think about the topic of plastics differently after taking this course. They are asked as consumers how they viewed the documentary now with their new knowledge. At the end, they are asked to evaluate their answer to the LCA in a broader context that would include reusable bags, different types of plastics, and so on. The exam is designed to be more of a reflection on learning and changes in thinking rather than a right versus wrong assessment.

### 3.5 Student Survey Results

From the survey, 93 % of the students had taken an online class before. The majors included students from psychology, elementary education, communications, business, and other humanities. They indicated that the level of the class was appropriate for an introductory level and also that the workload was consistent with that level. Standards for online courses require that students have equal time on task that face-to-face course offers [22, 23]. For this course, the design was such that they would spend 3 h per week on the materials with extra time for homework/assessment. Again, the survey indicated that what was provided gave a similar experience online as they would receive from a face-to-face class.

Throughout the term, quiz and discussion questions are given that allow the students to demonstrate a growth in knowledge and awareness of environmental issues. A formal assessment comparing student knowledge at the end of the term versus the beginning has not yet been done, but student comments throughout the term indicate an overall gain in knowledge. Samples of student responses are as follows:

- The information I have learned in this class has opened my eyes to making better choices.
- I am overwhelmed with the complexity but feel grateful that I have a starting base knowledge about these things.
- I feel more informed than I had been previously, and I will continue to read and research healthier options so that I can live a greener life.

## 4 Conclusion

New generations of chemists must definitely be trained in green chemistry. An overwhelming number of students surveyed in both formats of the course felt the course made chemistry more relevant and raised awareness of environmental issues. The applied nature of the subject and the real-world case studies do impact a student's perception of chemistry in a positive manner.

The use of current literature is particularly important in a field such as green chemistry, where new research is constantly appearing and spans various areas of chemistry where the instructor may not be well versed. While textbooks are focused more on organic chemistry, peer-reviewed literature spans a larger variety of topics and allows for the instructor to model the class based on what may be currently capturing public interest as well as student interest. This approach was used in the green chemistry class for majors and allowed for the class to be more student centered, and leads to more engaged discussion from the students in general. The students themselves did not find the lack of textbook an impediment when surveyed.

Green chemistry is more accessible than traditional chemistry to nonmajors. Green chemistry also allows for communication between diverse departments, and a wider dissemination of chemistry within the college campus.

As instructors, there are some barriers to overcome when teaching an ever-evolving subject. Several of us have not been formally trained in green chemistry, and it is hard to define the boundaries of green chemistry. Therefore, more templates are needed for wider adoption. We hope this chapter inspires a few to try their hand at teaching their version of green chemistry that fits the needs of their student body and faculty member.

### Acknowledgment

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