New Directions in Teaching Chemistry: Fostering Environmental Consciousness in Chemistry Classrooms

Final Report

Presented by

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Abstract

The concept of green chemistry, building environmental and social awareness into the design of molecules, is of great concern and importance to our future generations. My MIL research project applies green chemistry principles to classroom teaching. Various activities are based on the twelve principles of green chemistry. The resulting economic benefits in the laboratories and the increased environmental consciousness among students were investigated. Students walked the walk by participating in campus and district sustainability day events. The designed activities and assessment data are explained in the final report.

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Background Information

Green chemists are individuals who will do no harm to the environment. Recently, a survey indicated that people at large had no knowledge of 'green chemistry'. Some even commented that it almost sounds like a new oxymoron. Without chemistry, life would cease to exist. Chemistry is part of everything we do today. History however, shows that there is nothing green about chemistry. Many cities in the U.S experience air pollution as a result of chemical waste. The Cuyahoga River in Cleveland caught fire because of flammable chemicals. Silent Spring by Rachel Carson focuses on the devastating effects of chemical pesticides. Charles Perrow of Yale University states in Normal Accidents: "The accident that released deadly methyl isocyanate gas in Union Carbide's plant, India, resulting in at least 4000 deaths and over 200,000 injuries, was for me the most significant catastrophe…Bhopal was that rare accident that could hardly have been worse; they are hard to arrange." These accidents still linger in peoples' minds.

Green chemistry, a 21st century revolution is brewing. Green chemistry or sustainable chemistry is defined as "the utilization of a set of principles that reduces or eliminates the use or generation of hazardous substances in the design, manufacture, and applications of chemical products."[1] Paul Anastas, the father of green chemistry and the head of the Green Chemistry Institute of the American Chemical Society, states "In the past, we (chemists) have created a mess and then come up with bandages to make it less bad." Green chemistry tries to do everything right from the beginning stage. John Warner, Professor of Chemistry, University of Massachusetts-Lowell (the only graduate school to offer a doctoral program in green chemistry), says, "…that the designer of a chemical is responsible for what will happen to the world after the agent is put in place." Green chemistry is now transforming the fundamental principles of how chemistry is done in laboratories. On October 5, 2005, the Nobel Prize Committee honored three organic chemists, Chauvin, Grubbs and Schrock, for their contribution to green (or sustainable) chemistry.[2] The committee made a bold statement by paying tribute to green chemistry, "This represents a great step forward for 'green chemistry', reducing potentially hazardous waste through smarter production……..how important basic science has been applied for the benefit of man, society and the environment." Chemists no longer have to make chemicals that destroy the planet. Within chemistry is a revolution that could change everything. It is important to note that green chemistry is not environmental chemistry. Environmental chemistry advocates how to better handle chemicals and how to clean up hazardous wastes. Green chemistry is the redesign of processes to avoid the use and generation of toxic chemicals. Green chemistry is not a separate branch of chemistry. It is a responsible way of doing chemistry.

This new style of chemical approach is well articulated in the twelve fundamental principles of green chemistry.[1] These are listed below.

1. **It is better to prevent waste than to treat or clean it up after it is formed.**
2. **Synthetic methods should be designed to incorporate all materials used in the process.**
3. **Synthetic methods should be designed to use and generate substances with little or no toxicity to humans and environment.**
4. **Chemical products should be designed to preserve effectiveness while reducing toxicity.**
5. **The use of solvents should be avoided whenever possible, when used, innocuous.**
6. **Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthesis must be performed at ambient pressure and temperature.**
7. **Raw materials should be renewable rather than depleting.**
8. **Unnecessary blocking groups, protection, deprotection steps should be avoided.**
9. **Catalytic agents are superior to stoichiometric reagents.**
10. **Chemical products should be designed so that they degrade into non-persistent, innocuous substances at the end of their useful life.**
11. **Analytical methods should be developed to allow for monitoring and control prior to the formation of hazardous substances.**
12. **Substances used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions and fires.**

Tools and techniques to make chemistry 'benign by design' are being developed at a rapid pace. The pace observed is due to a sensible recognition of the fact that environmentally friendly processes are economical and beneficial in the long term. There are many professional societies[3] and academic institutions[4] that lead the green chemistry revolution.

My MIL research focused on the following objectives:

1. Develop educational activities emphasizing environmental consciousness and environmental literacy
2. Investigate green organic chemistry as a pedagogic tool
3. Investigate the role of classroom climate in fostering environmental consciousness

Activities

Several green chemistry activities were designed and incorporated throughout the one year organic chemistry curriculum (both lecture and lab). All activities are based on the 12 principles of green chemistry. Historically, scientific research was considered as a separate entity from classroom teaching. In this project, all classroom activities were designed from results of current research. Use of positive illustrations of real life examples of chemistry at work is a major highlight of the proposed MIL research.

The experiments performed utilized chemicals in micro scale quantities. Existing organic reactions at CGCC were replaced with greener alternatives in the form of greener reagents, greener solvents, and greener methodologies. As a result of this endeavor, the generation of hazardous waste has been entirely eliminated. The green lab experiments performed during 2006 – 2007 academic year are listed in Table 1.

Calculating % yield is a common metric used to estimate the efficiency of a chemical reaction. This parameter illustrates the extent to which a desired product is produced as a result of performing a reaction or a series of reactions. This method of calculation does not inform a student of the quantity of each side product produced in a reaction. Moreover, organic reactions, conventionally, are unbalanced. Therefore, an organic chemistry student never gives much thought to what else is formed besides the desired product. Green metrics, on the other hand, includes the fate of the by products of a chemical reaction. A variety of novel green metrics are currently explored in industries and research laboratories. However, lab texts and manuals that are in market today do not include any of these metrics. All reactions performed in our labs utilized these metrics as a measure of the 'greenness' of organic reactions. Students also identified principles of green chemistry best illustrated in each experiment performed. Students evaluated the efficiency and 'greenness' of every synthesis carried out during 2006 -2007. This new approach opened many avenues for discussion during the post lab sessions.

Lecture activities included case studies, reading and discussing several articles related to green chemistry. The lectures were modified to integrate sustainability chemistry topics throughout the curriculum. Newer green chemicals from current research were presented and contrasted with the traditionally used chemicals in the lecture text. Some sample activities are listed in Table 2. Students conducted research on various topics in green chemistry and disseminated their research via poster sessions held during the CGCC Campus Sustainability Day and the MCCCD Sustainability Dialogue Day. Refer to Table 3 for poster topics presented by students.

Table 1: Green Laboratory Experiments

	Green Reaction	**What was green in this experiment?**	**Green chemistry principles utilized**
1.	Diels-Alder Reaction at 0 °C	Low temperature 0 ° to room temperature	1, 6, 12
2.	Reactions ‘on water’	Safer solvent system (water)	1, 5, 12
3.	Synthesis of Cyclohexene from Cyclohexanol	Solventless condition	1, 5, 9, 12
4.	Bromination Reactions	Bromine generated in situ; very low temperature conditions	1, 3, 6, 10, 12
5.	Acetylation of Ferrocene	Solventless condition; reaction performed under ambient conditions	1, 5, 6, 12
6.	Iodination of Vanillin	Natural sources as starting material	1, 7, 12
7.	Grignard Synthesis at low temperature	Very mild conditions	1, 6, 12
8.	Grignard Reaction in Water	Safer solvent conditions	1, 5, 6, 12
9.	Green Oxidations	Greener oxidation conditions; water as the solvent; low temperature reactions	1, 5, 6, 8, 10, 12
10.	Combinatorial Synthesis	Single step reaction to produce many products	2, 4, 6, 8

Table 2: Lecture Activities

Description of the Activity
1. Mimicking nature's clean and efficient ways[5] Abstract: Chemists have always tried to mimic natural systems in order to develop more efficient chemical reactions that are also harmless to humans and the environment. Activities: Read the article, team discussions on the implication of using biomaterials, enzymes and other natural systems in chemical laboratories; students submitted reflective statements via CGCC eportfolio. 2. Green Chemistry Proves It Pays Companies…….. from CNNMoney.com & Fortune Magazine[6] Activities: Read the essay. Select a small part of the article that provokes a strong reaction. Respond by agreeing, disagreeing or arguing with the chosen excerpt, Double Entry Journal 3. QuickTime Movie: What would a sustainable version of a chemical industry look like? Activities: Students in teams watched this movie; wrote a personal reflection summary of long term sustainability. 4. Use of Natural Resources As Starting Materials[7] Article: Oranges a building block for 'greener' plastic: A promising plastic without petroleum Activities: Students were assigned the task of creating a list of 5 everyday ethical dilemma related to sustainability. 5. Greener Chemistry in Every Career[8] Students were asked the question: So, you are studying chemistry? Doesn't chemistry cause pollution and destroy the Earth? Student opinions were posted on the class eportfolio site. 6. Architects and chemists strive to place an environmental stamp on their work[9] Activities: Students were asked to research green buildings and identify the major LEED universities and LEED buildings. The teams submitted their responses via eportfolio.

7. Dupont to pay $10.5 million in EPA case[10]

Activity: Students explored the current EPA regulations related to chemical accidents.

8. House passes green chemistry bill[11]

Activity: Students reported their findings on the political philosophy on green chemistry in the United States.

9. Eating Healthy: Novozymes (PGAA Awards)[12]

Activities: Discussed the role of catalysis in sustainability; Used catalysis as a major concept in designing chemical reactions.

Poster presentations - Not That Easy Being Green? Try A Catalyst; What Does Catalysis Do For The Environment?

10. An Atom Is A Terrible Thing To Waste (PGAA Awards)[12]

Activities: Students participated in role playing of atom economy. Performed atom economical reactions in the laboratory.

Poster presentations – Atom Economy and Its Value To Society

11. The Case of the Perfect Synthesis of Ibuprofen, Zoloft and Viagra (PGAA Awards)[12]

Activities: Students were actively involved these three major case studies. This method was used to introduce green synthetic methodology.

12. The Case of Clean Cosmetics

Activities: Students explored the various petrochemicals that are used as raw materials; the potential hazards and environmental concerns.

13. The Mystery of the Lingering Pesticide[13]

Activities: The controversial use of DDT Vs Malaria was investigated.

14. The Vegetarian Car[14]

Activities: Bio fuels were the main focus of discussion.

Table 3: Green Chemistry Posters

Title of Poster	Green Chemistry Principle
Atom Economy And Its value to Society	2
Not That Easy Being Green? Try A Catalyst	9
What Does Catalysis Do For The Environment?	9
Oil Spills And Accidents	12
Pollution Prevention	3, 4 and 12
Green Cleaning Agents: A Design for Degradation	1, 3, 4, 7 and 10

Assessment

The proposed MIL project was piloted in General Organic Chemistry 2006 – 2007 fall and spring semesters sections. The class comprised of sophomores, juniors and seniors. Student learning was assessed using Participant Perception Indicator tool[15] and NSF's SALG[16] tool (Student Assessment of Learning Gains). Few of the results obtained are depicted in the following pages (Charts 1 -5).

Chart 1: What modalities worked well to learn and apply green chemistry?

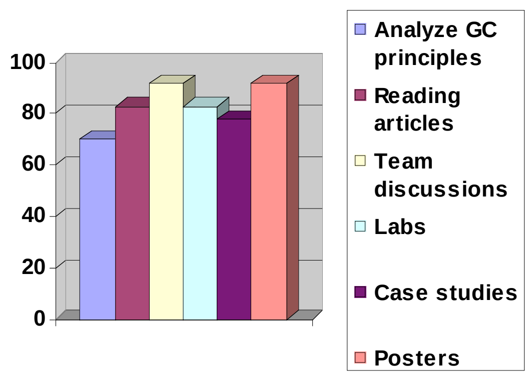


Chart 2: What resources did you use for green chemistry activities?

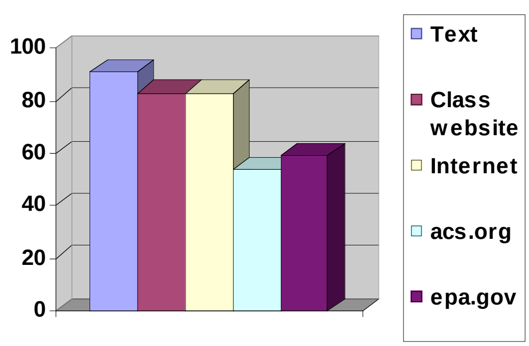


Chart 3: Did you refer back constantly to the twelve principles of green chemistry during lectures and labs?

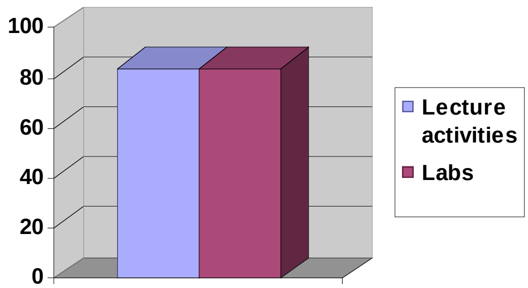


Chart 4: Estimating student understanding and applications

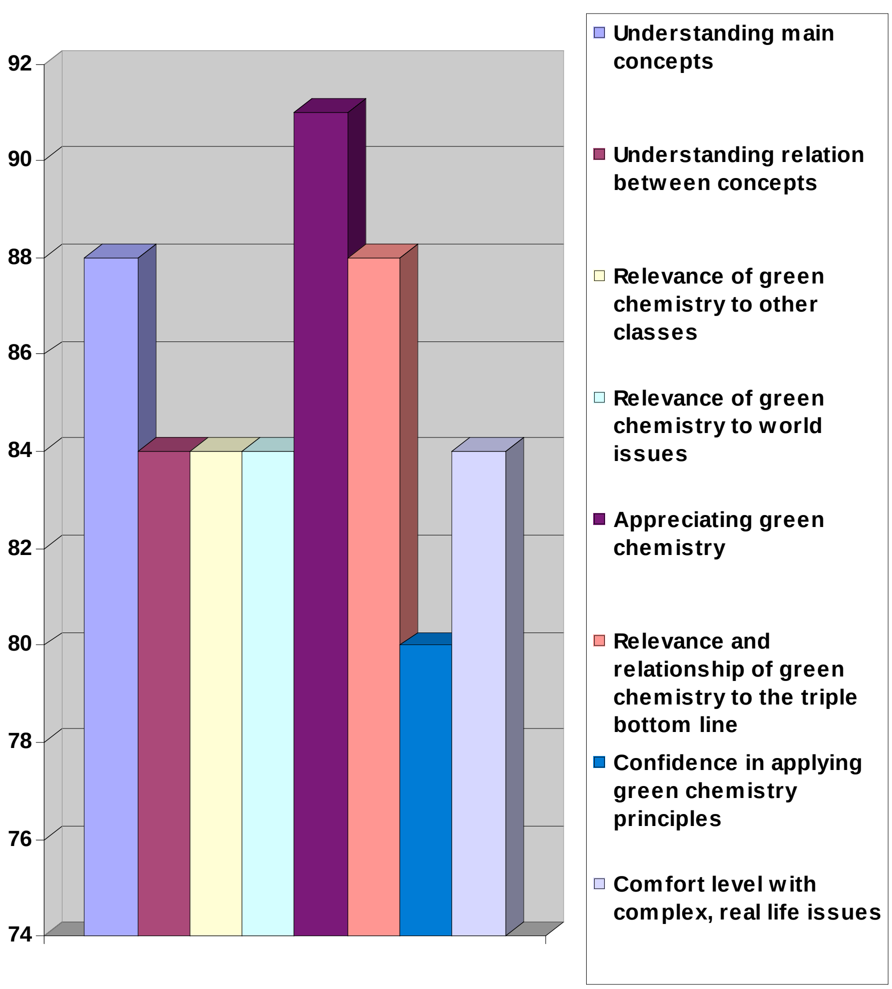
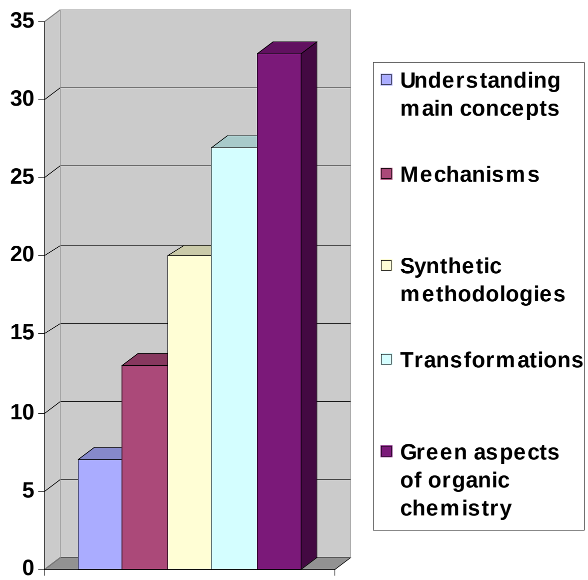


Chart 5: How much of the following do you think you will remember and carry with you into other classes or aspects of your life?



From Chart 1, it is clear that all modalities of teaching and learning were popular. The most notable ones are classroom discussions and poster presentations. Although the text used during 2006 – 2007 did not have significant content related to green chemistry, students referred more to the text than other resources. It may be an action resulting out of constant habit. acs.org and epa.gov are the resources that are most valuable to instructors but students have least used these web sites. From Chart 3, we can see that the twelve principles of green chemistry formed the pivotal point for all student activities. As a result of green activities, students cared more for the environment. The confidence level in applying green methods is quite high (~ 80%). Among the various concepts taught in this organic chemistry course (CHM235/236), students noted that they will best remember the green aspects of the course. It is evident from all these data that green chemistry can be used as a pedagogic tool to increase environmental awareness in students. The assessment tools helped me redesign the curriculum from the point of view of desired learning, not what will be merely covered. The redesigned course is therefore, not merely a list of activities. An assessment task report was generated and is presented here.

Assessment Task Report

1. What understandings or goals will be assessed through the project?

> 1. Environmental consiousness
> 2. Applicability of green chemistry to organic chemistry, other sciences and world issues

2. Through what performance task will students demonstrate understanding?

> Eportfolio assignments
> Classroom discussions
> Case studies
> Double entry journals etc

3. What student products and performances will provide evidence of desired understanding?

> 1. Student eportfolio responses
> 2. Assessment feedback
> 3. CGCC Sustainability Day participation
> 4. MCCCD Sustainabiity Dialogue Day poster presentations

4. By what criteria will student products and performances be evaluated?

> 1. Do posters highlight at least one principle of green chemistry?
> 2. Do student responses discuss the importance of environmental literacy? Relate to world issues?

An effort was made to explore student understanding on certain specific details about green chemistry. A number of essential questions raised are listed below.

- Why study green chemistry? So what?

- What makes the study of green chemistry universal?
- If the unit on _____ case study is a story, what's the moral of the story?
- What's the Big Idea implied in green reactions?
- What larger concept underlies green chemistry?
- What issues concern green chemists?
- What problems impede the progress of green chemistry?
- What couldn't we do if we didn't understand 'benign by design'?
- How is green chemistry used and applied in the larger world?
- What is the real world insight about green chemistry?
- What is the value of studying green chemistry?

Student responses to these questions will help me further fine tune the curriculum design to incorporate global issues.

Final Thoughts

I found the MIL fellowship to be both an exciting and an educational experience. I had a wonderful opportunity to discover what challenges practicing green chemistry in classrooms had to offer. The journey has only begun. The most satisfying part of the fellowship was that I shared many unforgettable moments in serious ways with other MIL fellows. As a result of a year long research, I designed green activities worth implementing, but as Randy Bass puts it, "discovered problems worth pursuing."

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