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Inclusion of Green Chemistry as a Subject in National Education Program

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Abstract

Green chemistry is the scheme of chemical processes that minimize or almost exclude the consumption and creation of hazardous substances. The intention of green chemistry is to promote the innovation in designing new chemicals so that they improve human health and the environment. Incorporating green chemistry in an undergraduate program is a effective method for teaching green chemistry. In addition to the basic issue of funding mechanisms, other difficulties for teaching green chemistry acknowledged by the respondents included lack of tools and resources and already crowded curricula. In this paper an attempt has been made to understand how green chemistry brings value to the chemistry curriculum. Software tools in green chemistry, including compelling industry examples that can be used as green chemistry teaching tools are also discussed. This paper seeks to provide an overview of the approaches to building Green Chemistry into the chemistry curriculum by highlighting some of the outstanding work in the field.

Key-words

Green Chemistry, Educational Curriculum, Traditional Chemical Education, Software tools

1. Introduction

The education in chemistry must keep up with the latest innovations, discoveries, concepts and techniques. The Green Chemistry is the scheme of chemical processes that minimize or almost exclude the consumption and creation of toxic substances. The path that the field of chemistry followed is without fully considering the consequences of either creation or the methods and processes. This is due to the fact that historically we have had little understanding of the effect of chemicals on health and environment. In recent years, science has vividly increased our knowledge of the various types of hostile consequences of chemicals and a molecular-level understanding of these consequences, thereby allowing us to scheme our chemical products and transformation processes in order to minimize consequences. This is the base of the green chemistry effort, which has been bringing about a wide range of innovations.

2. The Traditional Chemical Education

In traditional education of chemistry, chemical transformations are achieved with little or no regard to hazard or consequence. Smartness in chemical processes is rarely described in terms of atom economy, step economy, hazard, amount of waste generated or other impacts of the chemistry beyond the effects on yield and purity of the target product. In customary pattern we have been trained to bear the fact that handling of explosive, toxic and other risky materials is simply part of the nature of the profession. Reducing risk, which is defined as a function of both hazard and exposure, is almost always achieved by minimizing exposure. In teaching laboratories, this translates to reliance on capital- and upkeep-intensive fume hoods, dependence on personal protective equipment, strict safety training to avoid injury, and adoption of micro scale experiments to limit the amounts of dangerous reagents used. To students, the origin of chemical reagents is largely a mystery, and likewise, little thought is given to what happens to the materials poured into the hazardous waste collection jars at the end of every experiment.

Green chemistry education pursues to enhance chemists' understanding of the impacts of their design choices and experiments. Inclusion of the 12 Principles of Green Chemistry in Curricula [1] shaped the field of chemistry in an entirely different light. Hazard and waste become recognized as design flaws or, more positively, as opportunities for innovation [2]. Experiments can be performed in laboratories that are more comfortable and inviting as well as more economical to maintain.

3. Introduction of Green Chemistry as a Field

The concept of green chemistry was introduced as a response to the Pollution Prevention Act of 1990, which declared that U.S. national policy should eliminate pollution by improved design instead of treatment and disposal. The mid-to-late 1990s saw an increase in the number of international meetings at United Kingdom, Spain, and Italy devoted to green chemistry. In 1998 the 12 Principles of Green Chemistry were published, which provides

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the new field with a clear set of guidelines for further development [1]. The Royal Society of Chemistry launched a journal 'Green Chemistry' in the year 1999. The 2005 Nobel Prize for Chemistry awarded to Chauvin, Grubbs, and Schrock for their work in the field of green chemistry.

4. Green Chemistry in the Classroom

The increasing acceptance of green chemistry in the last decade has been paralleled by the rapid development of green chemistry educational programs worldwide, mostly at the graduate and post-graduate levels. Following are the course objectives of various green chemistry programs:

- To understand sustainability ethics as they apply to chemistry and establish the arguments for recognizing 'green' criteria.
- To reflect on motives and forces that have entrenched technologies those are potentially harmful to the environment [3].
- To introduce the 12 Principles, define 'green chemistry' and study successful examples of green technologies.
- To identify the key challenges facing green chemistry and consider what will be required to solve them [4].
- To identify reagents, reactions, and technologies that should be and realistically could be targeted for replacement by green alternatives.
- To become familiar with leading research in green chemistry and the related fields of public health and sustainability science.

The course stresses the link between fundamental chemical concepts and the real-world impacts of chemists' design choices. For example, bond-dissociation energy is taught in the context of ozone depletion, flame retardants, and bleaching technologies; substitution and elimination reactions are discussed in terms of their role in the environment. As green chemistry continues to mature and incorporate learning from a variety of disciplines, courses in the field will provide students with better tools for understanding the molecular bases of acute and chronic toxicity, endocrine-disrupting properties, and physical and global hazards.

Green chemistry courses are equally important in meeting the goal of equipping the next generation of students to ensure a sustainable future. Business people, in chemical and chemistry-related industries, consumers, and parents concerned about the future of their children all can benefit from being able to make informed decisions about green chemistry issues in their daily lives. Courses in green chemistry and sustainability issues for non-majors are now appearing at institutions worldwide.

Emphasis on environmental ethics inspires many students to raise awareness of green chemistry among the general campus population through high-profile special events and publications. However, additional content on the history, trends, and social and cultural aspects of green chemistry is included. The course also requires students to learn about and perform quantitative exercises related to percent yield, atom economy, and introductory toxicology. In addition, students are introduced to green chemistry resources that are highly relevant to daily life. Business case studies are used to show how green chemistry can deliver economic benefits in addition to solving environmental problems.

5. Green Chemistry in the Laboratory

Green chemistry program for the laboratory was developed in the mid-1990s by the University of Oregon (UO). The program was motivated by the need to use less-toxic solvents and reagents. The efforts led to publication of a laboratory manual entitled *Green Organic Chemistry: Strategies, Tools, and Laboratory Experiments* [5].In this manual, the experiments are designed to replace traditional experiments in laboratories. This manual still covers fundamental organic chemistry reactions and techniques, but teaches them in the context of green chemistry topics.

The green laboratory course is currently best established for the organic chemistry, but there are also green experiments for the analytical chemistry laboratories. By green chemistry workshops students gain practical experience and the experiments are designed to show that the greening of analytical methodology follows many of the 12 Principles of Green Chemistry, including waste prevention, use of safer solvents, and reduction of derivatives, pollution and accident prevention. An interesting approach to emphasizing greenness requires students to perform conventional lab techniques and the corresponding green replacements side-by-side in order to give the students a tangible appreciation for the waste prevention and risk reduction made possible by green chemistry principles.

6. Green Chemistry in Research Training

Most research training in green chemistry takes place under the auspices of traditional chemistry departments, where students pursue graduate or postgraduate research. In the last 10 years, such research centers have proliferated around the country. In many cases, government funding has helped establish green chemistry centers. Many green chemistry networks originated through interuniversity collaborations. Degree programs specifically in green chemistry in universities are available but still rare.

7. Green Chemistry Seminars and Workshops

Workshops are very effective in inspiring faculty to adopt green chemistry laboratory curricula. Many of the programs were designed for the undergraduate students. Green Chemistry Seminars and Workshops feature expert speakers, tutorial sessions, a poster session with awards, and interactive discussions on green chemistry topics such as catalysis, alternative solvents, green reagents, and research policy. Among the activities during workshop are demonstrations of green chemistry laboratory experiments and discussions of methods for developing green chemistry workbooks and problem sets. The potential benefits that seminars and workshop could bring to both green chemistry policy and education in country are tremendous, testifying to the power of workshops to bring about real change. The 'training the trainer' model, in which experienced green chemists teach other educators how to design green chemistry education workshops of their own, is among the most efficient and effective ways to disseminate green chemistry educational materials.

8. Green Chemistry Tools and Databases

Numerous teaching materials, tools, and databases for students and teachers are available on Internet at no cost. The Greener Education Materials (GEMs) database (developed by the University of Oregon) is perhaps the best web-based source of educational laboratory materials. The database includes modules developed by the University of Scranton's 'Greening across the Chemistry Curriculum' program. The GEMs database allows searching by green chemistry principles, laboratory techniques, and fundamental chemistry concepts. The website also shares comments about how the experiments may be improved.

The Green Chemistry Institute of the American Chemical Society has created a web site offering freely downloadable green chemistry activities and experiments geared toward all levels of education. The Green Chemistry Expert System (GCES) is a freely downloadable computer program for computers running the Microsoft Windows operating system. It is built around a database of more than 500 green chemistry publications, covering topics such as green solvents and reagents, green chemical processing, green synthesis and manufacturing. These databases are a useful tool for exploring early successes in green chemistry and learning about green technologies that have been implemented on the commercial scale.

9. Green Chemistry for Younger Students

Preparing the next generation of green chemists depends not only on training undergraduate and graduate chemistry majors but also on reaching out to younger students. At the senior secondary level, green chemistry education is an excellent way to attract bright students to the chemistry profession. The undergraduate students should interact with senior secondary students, highlighting the power of green chemistry to innovate and solve problems and giving a positive impression of chemistry in general. The 'green' goal can also be achieved through activities such as teaching green chemistry in the community.

10. Conclusion

This review represents only the tip of the iceberg both of what is currently taking place and what needs to take place in the future. While this paper does not claim to be comprehensive, it does provide an overview of some of the approaches being considered. The green chemistry education work in countries that have different environmental, educational, economic, cultural, historical, and social circumstances demonstrates that the applicability of the field of green chemistry is as broad as that of the field of chemistry itself.

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