AC 2009-1944: THE ROLE OF GREEN CHEMISTRY IN AN INDUSTRIAL ECOLOGY COURSE

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Role of Green Chemistry in an Industrial Ecology Course

Abstract

The National Academy of Engineering released the Grand Challenges facing engineering in the next century. Environmental sustainability is related to at least 5 of the fourteen challenges. To address these challenges, a multi disciplinary team of six faculty members from engineering, business, and chemistry developed a course entitled, "Environmentally Conscious Design and Manufacturing". In this course there are six distinct modules agreed upon as necessary to meet the environmental challenge of re-designing common products sustainably. The course is based upon the Ford Partnership for Advanced Studies (PAS) pedagogy which emphasizes active learning through "hands-on activities". The original six modules include (1) Historical Social and Ethical Perspectives, (2) Life Cycle Analysis, (3) Material Selection, (4) Process Design, (5) End of Life Options, and (6) Environmentally Responsible Management. In addition to these original modules Green Chemistry was added as a seventh module to add an important lab component to the course. Each module was designed to become a stand alone module able to be disseminated and used in any course.

In the Green Chemistry module students synthesized biodiesel and analyzed the products through chemical analysis and using it as fuel in a jet engine. The 12 principles of Green Chemistry were presented as foundational knowledge for comparing the life cycle of petroleum-based diesel to vegetable-based biodiesel. Students' learning was assessed quantitatively for each module along with qualitative comments using the Strengths, Improvements, and Insights (SII) format. From feedback gathered in the first course offering, the Green Chemistry module was enhanced to include the use of the student-made biodiesel in a laboratory jet engine housed in the Mechanical Engineering Department. In addition to the student assessment, the role of Green Chemistry in this course was assessed by an outside advisory team composed of engineers from industry and other educational institutions.

Introduction

National Academy of Engineers Grand Challenges has outlined 12 grand challenges that engineers face in order to make the world "a better place". Those challenges include many facets of energy production and sustainability including management of the nitrogen cycle, make solar energy more economical, develop carbon sequestration methods, and provide access to clean water.[1] These challenges will be tackled by the engineers of today and tomorrow therefore today's faculty must give students the tools to bring sustainable practices into the design and manufacturing of products. To this end a multi-disciplinary university team was established to address the challenges of educating future engineers in the area of sustainable practices in industry. This team is composed of faculty, staff and students from across the university. Faculty members include two members of the Department of Mechanical Engineering, one faculty member from each of the Departments of Business, Industrial Engineering, Chemistry and Liberal Studies. Staff members have participated from University Advancement and a representative student was active in the original course design. The faculty group, the Kettering Industrial Ecology Team, received a three year grant from the National Science Foundation to develop an innovative course in Environmentally Conscious Design and Manufacturing (IME 540). The course borrows upon the pedagogy developed by the Ford Partnership for Advanced Studies (Ford PAS) which includes emphasis on learner-centered, hands-on, experiential learning through analysis of everyday objects and products. The original course consisted of six modules with associated learning objectives related to the Historical, Social, and Ethical Perspectives, Lifecycle Analysis, Material Selection, Manufacturing Process Design, End of Use Strategies, and Environmentally Responsible Management. IME 540 is open to all Kettering students with senior standing. There are no prerequisites for the course.

The Environmentally Conscious Design and Manufacturing course is team taught, with each faculty member developing and teaching one of the learning modules. This allows for multiple perspectives in multiple areas of sustainability education and draws upon the expertise of all six faculty members. All of the modules use distinct innovative pedagogical techniques. The modules have been presented and disseminated in various ways including a workshop associated with ASEE in 2008.[2,3,4]

Course Modules

The first module, the Historical, Social and Ethical Perspectives, introduces the concepts of industrial ecology and sustainable manufacturing by focusing on the industrial revolution from the perspective of its social and environmental impacts. Cotton textile production is used as a case study with a common product, the t-shirt, used as an object lesson. Students receive a different kind of t-shirt with a course logo that has been made without the negative impacts of traditional – and present-day – cotton garment production. At this point, student groups must choose a common product for analysis throughout the course.

The second module looks at Life Cycle Analysis. Strategies for assessing the impact of each life-cycle stage are presented and the students explore the advantages and challenges associated with each. In this module students are asked to take apart and weigh the component of a common product and calculate the environmental impact using a Okala Ecological Design *screening* LCA method.[5]

In the third module, Material Selection, students analyze a common product with a goal of reducing the environmental impact while also meeting functional material requirements and reducing material costs. Office furniture is presented as a case study. Students begin by using their own intuition to determine the best material for their product and then apply decision matrices to determine a better material. Finally, as part of the Material Selection Module, the students use CES Edu Pack software by Granta

Design to determine the best material for their product based upon the performance of the product. [6]

The fourth module focuses on the design of the manufacturing process by implementing a case study for designing a sustainable manufacturing process with continuous improvement. The case study used is the Global Engine Manufacturing Alliance “World Engine” which the students have the opportunity to visit. A waste audit is performed and alternative methods for waste and energy reduction are discussed.

Another portion of the life cycle is addressed in the fifth course module, End of Life Options. Strategies and challenges associated with reducing the environmental impact of a product after it has been used by a consumer or business is discussed with the idea of cradle-to-cradle[7] rather than cradle-to-grave design. Lecture topics focus on remanufacturing, recycling and disposal options. Students visit a landfill to understand the consequences of poor end-of-life design. They are exposed to the idea of a sanitary landfill design as well as how methane is generated from the waste to generate energy.

The course then instills in the students that all sustainable practices performed in industry must be economically sound. This idea is presented in the sixth module, Environmentally Responsible Management. In these sessions best practices are presented that focus on aligning environmental and profit goals (the triple bottom line), green supply chains, environmental management systems (ISO14000), cap and trade approaches, using full cost accounting, and creating a culture of sustainability. Students play a cap and trade game and also enjoy a case study of Starbucks coffee as an example of an environmentally responsible company.

These modules look at products based upon the materials used, however the chemistry used to make the products was initially not included. The team of faculty decided that the area of chemistry should be introduced to the students especially the area of green chemistry.

Incorporation of Green Chemistry

The inclusion of green chemistry into an industrial ecology class allows for incorporation of the entire life cycle of the product including the chemical synthesis of the material. As stated by Thomas Graedel:

> “It is appropriate to expand the concept of green chemistry so to place its approach squarely within the industrial ecology context. …adding a life-cycle perspective to green chemistry enlarges its scope and enhances its environmental benefits.” [8]
>
> -Thomas Graedel

Green chemistry is governed by 12 principles listed below that incorporate the learning objectives of the Environmentally Conscious Design and Manufacturing class by analyzing the synthesis of chemical materials from the perspective of the creation of the product. The 12 principles of Green Chemistry were created as a partnership between the American Chemical Society and the Environmental Protection Agency. [8]

12 Principles of Green Chemistry

1. Prevent waste
2. Design safer chemicals and products
3. Design less hazardous chemical syntheses
4. Use renewable feedstock
5. Use catalysts, not stoichiometric reagents
6. Avoid chemical derivatives
7. Maximize atom economy
8. Use safer solvents and reaction conditions
9. Increase energy efficiency
10. Design chemicals and products to degrade after use
11. Analyze in real time to prevent pollution
12. Minimize the potential for accidents

The Green Chemistry module was added to the class as an experimental module to determine if it has a place in the Environmentally Conscious Design and Manufacturing course. In the experiential green Chemistry module students synthesized biodiesel using the transesterification of oil in the laboratory setting.[9] The 12 principles of Green Chemistry were presented as foundational knowledge for comparing the life cycle of petroleum-based diesel and vegetable-based biodiesel. Background lecture focused on the sources for biodiesel, the performance of bio-based fuels and associated emissions. The students were introduced to the chemical hazards associated with the creation of biodiesel. The students then analyzed their products using Infrared Spectroscopy. Based on student feedback, during the second and subsequent course offerings, students were able to run their biodiesel on a jet engine in the Mechanical Engineering laboratory to see the impact it has on engine performance.

Assessment

As an experimental module the incorporation of the green chemistry was assessed as a permanent addition to the course. The students were surveyed to determine if green chemistry should be incorporated into the course. The summative assessment results showed that approximately 84% of the twelve students surveyed either agreed or strongly agreed that green chemistry had a place in the industrial ecology course.

Throughout the course students assessed each module employing the SII assessment tool. In this activity students are asked to provide two strengths, one area for improvement and one insight for the module. This allows for formative assessment of the class. For the green chemistry module the strengths of the class that were reported by the students were that “students who are normally not exposed to much chemistry are able to see the challenges and benefits of green chemistry.” In addition the students stated that they “…loved the fact that we actually got to build something that we learned about…it really put into real world terms and made it easier to understand and get into it." Student's anecdotal responses included "great example of Green Chemistry and how processes can be improved" and "One of the best classes in the curriculum thus far."

Students suggested improvements for the course the first time that green chemistry was incorporated including "it would be interesting to see the efficiency of the biodiesel with the motor." A separate student's comment from the first class was that "It could be better integrated with the work for other modules so as to allow for timing to permit the students to see a comparison of performance between a biodiesel-fueled and diesel-fueled engine." In response to this assessment, the running of the biodiesel on a jet engine was incorporated. Selective insights of the students were that "Alternative fuels are viable as long as we prioritize out resources effectively", in addition "… that simple and practical solutions to the environmental problems exist." As shown by the formative and summative assessment the inclusion of green chemistry as assessed by the students was positive.

The class is also assessed by an outside advisory team that is composed of members from industry such as Ford, GM, Herman Miller, Steelcase among others. In addition, other faculty members from other institutions are members of the advisory board. They were asked the question: "I believe the topic of Green Chemistry should be integrated into IME 540." Four out of six respondents agreed or strongly agreed to this statement. One stated concern was "About Green Chemistry -> the topic is appropriate but if too much is put into one course, the course will have breadth but no depth. I think depth is important so this issue must be weighed." Narratives that were provided by the advisory board state, that "Green Chemistry is emerging to be one of the next big issues." The formative and summative assessment reflected that green chemistry should be incorporated into the Environmentally Conscious Design and Manufacturing course as long as adequate depth was included on all other topics.

To assess the knowledge gained from all modules a perception of knowledge survey was given. The students were asked if their perception of their knowledge of each of the learning objectives. Before the green chemistry all students of the six surveyed reported that they had very little knowledge of the 12 principles of green chemistry. After completing the biodiesel exercise they stated they were knowledgeable of the 12 principles of green chemistry and were able to apply the principles to the synthesis of biodiesel.

Conclusions

According to the assessment by the students and the advisory board green chemistry belongs in the Environmentally Conscious Design and Manufacturing course. The green chemistry module will become a permanent module in the course. In addition, from the biodiesel laboratory exercise the students have a general knowledge of the 12 Principles of Green Chemistry and have more exposure to the applications of chemistry.

The impact of this class reaches far beyond the classroom. Broader impacts of the course were the development of the student group, the Green Engineering Organization (GEO) that supports sustainability initiatives on campus. The faculty was awarded the TRW/CETL Educational Scholar Award at the university because of the unique pedagogy that was employed.

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