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A Course in Sustainable Manufacturing

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Abstract: Sustainable manufacturing is a vision that the manufacturing community has for contributing to the global society's ability to address sustainability issues. While there is no standard definition of sustainable manufacturing, one universally accepted notion is that sustainable manufacturing must optimally address a comprehensive set of highly interdependent objectives from environmental, economic and social perspectives. This is impossible without systems' thinking that guides the sustainable manufacturing activities every step of the way from product idea generation, to adoption of sustainable design and manufacturing processes, to selection of sustainable materials, and ultimately to product disposal, reuse or recycling. New course on sustainable manufacturing has been developed and offered several years now at Syracuse University, USA. An underlying principle in developing and offering the course is the premise that sustainability manufacturing requires a holistic view to a complete product lifecycle from the moment of conceiving new product ideas till the end of the product life, while simultaneously considering the impact of decisions made in each phase of the manufacturing activity on sustainability. The principle has been realized by: (i) adoption of a broadened definition of manufacturing and (ii) a semester-long project of developing sustainable products. In the course, manufacturing means not only material transformation processes but also manufacturing systems including supply chain considerations for sustainability. The sustainable product development project provides students with a context where they can apply methods, techniques and tools being acquired from the course. Also the developed products can lead to further entrepreneurial opportunities.

1 INTRODUCTION

We live in a period of human history with an unprecedented rate of changes. World population doubled between 1950 and 2010 while worldwide GDP tripled between 1960 and 2010; and the percentage of extremely poor population halved between 1990 and 2010 (United States Census Bureau 2015, The World Bank 2015). The concern for how we sustain the world we live in becomes a pressing reality.

1.1 Manufacturing engineering education for sustainability

Manufacturing has a key role to play in sustainable development because of its significant share in economic development activities. Contrary to common myths that addressing sustainability issues may have a curbing effect on economic development, findings suggest that companies proactively adopting sustainable manufacturing practices grow more innovative and competitive, resulting in substantial economic benefits among others (Rusinko 2007, Carbon Disclosure Project 2014).

Early works in sustainable manufacturing focused on environmentally conscious manufacturing processes as well as topics in such as energy conservation, design for environment, remanufacturing and recycling. However, the scope of sustainable manufacturing has been enlarged to include concepts and technologies such as lean manufacturing, waste avoidance, innovative manufacturing processes and green supply chains (Despeisse et al. 2012).

Yet, the manufacturing engineering education hasn't caught up with meeting the magnitude or seriousness of the global problem in sustainability as well as changes happening in the manufacturing sector (Dym 2010).

1.2 Challenges in teaching sustainable engineering and manufacturing

There are numerous challenges that need to be addressed or overcome when incorporating sustainability issues in engineering education in general, but particularly in manufacturing engineering education:

- The concept of sustainability is vast and far more complex than conventional engineering topics. However, rooted in scientific thinking, the academia has been accustomed to handle clearly bounded, well defined, and narrowly yet deeply focused subjects. Such a reductionist paradigm is a notion to overcome when incorporating sustainability into engineering education.
- The definition of manufacturing needs to be comprehensive as well. When sustainability is introduced in manufacturing engineering education, the scope of manufacturing cannot be narrow. Rather the entire lifecycle of manufacturing should be considered altogether, which hasn't been a norm at least in individual course offerings.
- The concept of sustainability is relatively new and has only recently gained wider acceptance. Therefore, previous examples and best practices are relatively fewer. Although some serious efforts have been put in for sustainability in engineering education in recent years, compared to other well-established fields in engineering, resources available to instructors are still limited.
- Significant commitment and investment from the faculty members are required, especially for those who newly wish to introduce sustainability in their courses or curriculum. It is inevitable that such a faculty member need to spend considerable time and efforts in learning and gathering relevant materials. This challenge is particularly strong among manufacturing engineering educators since conventional education in the field hasn't embraced sustainability as a critical component.
- As Albert Einstein famously put, "we cannot solve our problems with the same thinking we used when we created them." In other words, the engineering education where sustainability is to be addressed should find a way to promote innovation and creativity, which has not necessarily been a common preparation for engineering faculty.

This paper presents the details of a new course on sustainable manufacturing developed at Syracuse University, including its contents, pedagogical approach, and analysis of students learning outcomes. The paper is organized as follows: Section 2 provides a brief review of related literature. Details of course contents including its structure, topics, and schedule are presented in Section 3. Students' project, a major component of the course, is explained in Section 4. Section 5 discusses students learning outcome assessment. The paper concludes with discussion and future works in Section 6.

2 LITERATURE REVIEW

There are numerous studies on raising the awareness of sustainability in engineering education, posing important questions to address, or assessing a trend as well as the status of the progress. For example, Ashford (2004) asks some fundamental questions on engineering education to address sustainable development in its teaching and research. This is one of the early papers articulating major challenges that the engineering education community needs to address in order to effectively cover the sustainable development in its teaching and research. Huntzinger et al. (2007) describe the need for curricula changes necessary for fostering sustainability thinking and associated challenges. They examined the level of changes occurring at selected universities and found that a majority tried to incorporate the sustainability components into existing programs as opposed to redesigning a curriculum completely. Mulder et al. (2012) analyse how engineering universities made changes in their curricula towards sustainable development. They present the types of changes needed in terms of approaches, visions, philosophies and cultural concerns. They also suggest that engineers need to learn to think long term and

strive to achieve long-term sustainable solutions. Murphy et al. (2009) report findings from the analysis of two questionnaires regarding sustainable engineering education, conducted through the Center for Sustainable Engineering at Carnegie Mellon University. They report that there is significant activity in education and research related to sustainable engineering at an individual program level, but little at overall organizational or a national level.

Various faculty members share their experience in developing and teaching new courses in sustainable engineering, entire curriculum or degree programs. Bonnet et al. (2006) describe their experience of teaching sustainable entrepreneurship to chemical and materials science engineering students at Delft University of Technology between 1996 and 2002. They share some details of their motivations, course structures as well as student projects that culminate with business plans. Kamp (2006) also shares the experience of changing their engineering education curricula at Delft University of Technology by incorporating sustainable development components. Schafer and Richards (2007) describe a sustainable engineering project under which students progress from concept to commercialization. Bremer et al. (2010) present their teaching experience of incorporating active learning projects that exposes students in ITESM, Mexico to creative, innovative and inventive culture. Daly et al. (2014) analyze the data that they collected from course instructor, student interviews, student surveys and course materials to understand engineering pedagogy with regard to students' creative growth. They find that although one aspect of creativity in convergent thinking was well represented in their case study, the other aspect of divergent thinking was lacking. Lozanos (2014) describes the process for developing the Bachelor's degree curriculum in engineering for sustainable development at Tecnologico de Monterry, Mexico.

Haase (2014) reports the analysis of a nation-wide survey on the perception of sustainability issues by newly enrolled engineering students in Denmark. The author identifies three different approaches these students take and the reported information can be used in curriculum design and pedagogical approaches. On the other hand, Nicolaou and Conlon (2012) present their analysis on the level of knowledge and understanding of final year engineering students about sustainable development. They used a survey data collected from final year engineering students in three Irish higher education institutions. They report that final year engineering students' knowledge in sustainable development is still deficient, particularly in its social aspect.

Concerning other effects of incorporating sustainability in their course, Oehlberg et al. (2010) present data gathered from a freshman course covering sustainable human-centered design. They conclude that enrollment diversity can be improved by incorporating sustainability and service learning projects, particularly among women and ethnic minority students.

For a brief history of engineering practice and education in sustainable development, please refer to an interesting paper by Lucena and Schneider (2008). Leydens and Lucena (2014) address the less-covered social aspect of sustainability in engineering education.

3 COURSE STRUCTURE AND CONTENT

New course on sustainable manufacturing has been developed as a part of campus-wide sustainability initiative at Syracuse University. It is an elective course that upper level undergraduate students as well as graduate students can take. The course is offered through the Department of Mechanical and Aerospace Engineering, but open to any student from any engineering discipline. It is offered as 3-credit course (three hours per week for 14 weeks) once a year.

In the course, students learn (i) the vision of sustainable manufacturing and product development, and its relation to larger societal issues, (ii) processes, techniques and tools for developing sustainable products, (iii) sustainable manufacturing processes and systems, (iv) how to measure sustainable manufacturing practices, and (v) effective strategies for deploying sustainable manufacturing.

The course consists of four parts that are interrelated: (i) lectures on sustainability and sustainable manufacturing, (ii) lectures on new product development, (iii) discussion on case studies and (iv) students’ semester-long project on developing new sustainable products. The lectures are scheduled that

knowledge and skills on sustainable manufacturing and new product development can be built progressively and timely for students' projects. For example, background and motivations for study are given in the first lecture, followed by a lecture on generating opportunity ideas for new products. Then an assignment due the following week is given for generating sustainable new product ideas. Real-life cases provide a context for class and online discussions as well as corresponding assignments.

3.1 Course Topics

Main course topics are summarized in Figure 1 and explained in this section.

3.1.1 Lectures on Sustainable Manufacturing

A series of lectures on this portion of the course begins with introduction to sustainability and reasons why we need to care about. But early on it is emphasized that the course is actually doing something about the sustainability as opposed debating or contemplating about the sustainability issues. The course theme is also justified from various reports and data on current thoughts of business leaders and entrepreneurs. The concept of life cycle assessment (LCA) is introduced to broaden students' perspective on products' impact on sustainability. While environmental aspect is discussed much in the LCA lectures owing to its development history, recent advances in expanding the LCA concept to other legs of the triple bottom line model of sustainability are also covered. The LCA lectures have been developed in such a way that students are actually able to conduct LCA on their products (even if their scopes are limited) utilizing available software and tools. Lectures are also given on other sustainable manufacturing topics such as product design, selection of materials and processes, and lean manufacturing.

Students are expected to demonstrate their understanding and mastery of the covered topics throughout their projects. Therefore, each lecture can be considered a launching pad for students to explore further, not an end itself. Typically, students realize much need for additional studies as their projects progress. The series of lectures concludes with social entrepreneurship where plentiful real examples are discussed and continuation of student projects beyond the course is encouraged.

3.1.2 Case Studies

Five cases are discussed in the courses as shown in Figure 1. All of these cases are Harvard business cases written for class discussion. Students are asked to read each case thoroughly before they participate in on-line discussion in the Blackboard system. A short lecture is given to summarize each case and point out important issues or decisions to make in each case. Each case is again discussed in class to complement the on-line discussion. The case discussions are scheduled in appropriate sessions to reinforce new concepts that students are learning, to provide additional motivation for their next assignment, or to supplement course coverage by real-world examples.

3.1.3 Lectures on New Product Development

A thread of lectures on new product development is carefully scheduled with a desirable progress of students' product development projects (Ulrich and Eppinger 2011). It begins with many examples of new products and sustainable new products with the intention of opening students' eyes to unlimited opportunities. Then a lecture on how to create opportunity ideas is provided. Theories and principles as well as practical tips on becoming more creative and innovative at this stage are presented. The first assignment is given where students can actually generate new product ideas and submit them by the following session. After students' ideas are presented, the whole class votes on better ideas and teams for the next stage are formed. After that, a lecture on the next stage of understanding customer needs is given followed by the next assignment of actually soliciting and understanding customer needs. This pattern of student presentations, lectures on NPD, and assignments on the following task, repeats for the rest of NPD stages as presented in Figure 1.

3.2 Course Schedule

The schedule of the current course offering is shown in Figure 1. Letting students present their project assignments first in each session turned out to be very effective in their learning since they are eager to share what they accomplished in the previous week. During students' presentations, questions and discussion are constantly encouraged so that all students are actively engaged in even others' projects. Then, a lecture on relevant topics of sustainability or new product development is followed so that students are motivated or equipped with necessary background for the following week's project assignment. It is important to maintain some flexibility over the semester so that the schedule can be adjusted in order to maximize students' learning outcomes.

	Lectures	*Cases*	*NPD Projects*
Session 1	Introduction		Identification of New Product Opportunities
Session 2	Sustainability in Business	Sustainability at Millipore	Presentation: Opportunities
Session 3		SweetWater	Presentation: Product Ideas Customer Needs
Session 4			Presentation: Needs Analysis Product Specifications Concept Generation
Session 5	LCA (i)		Presentation: Product Concepts Concept Selection
Session 6	Product Design for Sustainability	Cradle-to-Cradle Design at Herman Miller	*Project Consulting*
Session 7	LCA (ii)		*Project Consulting*
Session 8		Team New Zealand	Concept Testing & Prototyping
Session 9			Presentation: Project Progresses *Project Consulting*
Session 10	LCA (iii)		*Project Consulting*
Session 11	Sustainable Manufacturing Processes		*Project Consulting*
Session 12	Lean Manufacturing		Presentation: Prototypes
Session 13	Social Entrepreneurship	Ashoka: Innovators for the Public	*Project Consulting*
Session 14	Conclusion		Final Presentations

Figure 1: Course Schedule

4 STUDENT PROJECTS

Since the course was offered for the first time in 2010, it has been offered six times in spring semesters. Altogether over 200 students took the course and nearly 70 student projects have been carried out. All the projects begin with students' actively thinking about opportunity ideas for new sustainable products.

Each student is required to come up with at least 15 ideas in the beginning. From all the generated product ideas, better ideas are selected mainly by students' votes. After three or four stages of tournament type selection processes (Terwiesch and Ulrich 2009), final product ideas along with student teams are determined.

In carrying out the projects, students are required to apply sustainable practices as much as possible in every step of the product development process, including but not limited to:

- solicitation and interpretation of customer needs
- design for sustainability, recycle, reuse
- adoption of sustainable materials
- adoption of sustainable manufacturing processes
- design of sustainable manufacturing systems and sustainable supply chains
- adoption of alternative energy sources
- justification of lifecycle costs
- use of LCA to systematically understand the impact of each decision or trade-off decisions

Some examples of noteworthy projects are:

- Automatic outlet regulator - after some idle time, an outlet ejects its content
- Smart store - showing refrigerator's content without opening its door
- Waterless dishwasher - using various means other than water, dishes are being cleaned
- Wise shutter - depending on outside and inside conditions, shutters adjust automatically
- Auto off desk lamp - after a pre-set idle time, the desk lamp goes off automatically
- Self-sustaining cell phone charger - powered by user's walking only
- Reusable grocery bag - a new concept reusable grocery bag
- Kinetic mouse - mouse powered only by users' motions during mouse usage
- Bikerules - signal indicator connected to smart phone apps via map functions

Most students were not able to follow through further their conceived products mainly due to their need to finish the degrees or getting jobs, etc. However, it is encouraging to observe that actual products developed by others now exist in market. Those products are very similar to our student project ideas, but were introduced to the market a few years later, thus validating the merit of our student projects.

Notably, the Bikerules team decided to go further beyond the course requirement. Their product is a device that automatically blinks turn signals by smart phone apps connected to a road map. The product promotes the use of bikes through a convenient navigating system and improved safety. The team took part in Syracuse University's Invention & Creativity Competition in spring 2014 and won the 'Most Creative' award and a sizable seed fund. Their team leader joined Syracuse Student Sandbox, an incubator that helps aspiring entrepreneurs advance their ventures from idea to a company in Syracuse Technology Garden - the Syracuse region's ecosystem providing comprehensive entrepreneurial support. Working in the incubator, they developed an alpha-prototype using 3D-printers and Android 4.0 platform, along with logo, website, business model and marketing plan. The product drew much attention from various media and earned another prestigious competition at the end of summer 2014. After the summer break, the Bikerules team started seeking angel investors and venture capitalists.

5 STUDENTS LEARNING OUTCOME ASSESSMENT

Specific learning outcomes in the course are prescribed as:

At the end of the course, students are able to

- compare and evaluate alternative manufacturing processes in terms of energy and materials consumption;
- develop a new product addressing sustainability issues;
- describe pros and cons of alternative manufacturing systems and supply chains on sustainability;
- compare and evaluate alternative energy sources to manufacture a product;

- conduct a life cycle assessment (LCA) on a product;
- function better in a multi-disciplinary team;
- adopt a new behaviour to address sustainability issues.

The learning outcomes are assessed throughout the progress of student projects. Every week, students submit assignments on their projects, case studies, or problems. Student progresses on the expected learning outcomes are being monitored each week and feedbacks are provided to students. In addition, quality of student works and presentation skills are assessed. Individual contributions to teamwork are also evaluated through self-evaluation, peer-evaluation and instructor-evaluation.

6 DISCUSSION AND FUTURE WORKS

The course was designed after an extensive preparation through a thorough literature review and numerous travels for attending conferences and related meetings in 2008 and 2009. The large enrollment in the course from the first offering suggests strong interests among students. Due to the project components, it was decided that limiting the class size is ideal for best learning outcomes. Therefore, the current enrollment has been kept around 20 students. With more students than 25, not all students have an adequate amount of time to participate in project discussion as well as case discussion. An assistant or two have proven to be very helpful to manage class activities on time.

Coincidentally during spring semester when this course has been offered, Syracuse University provides numerous competition opportunities for students to pitch their new ideas ultimately for entrepreneurial opportunities. This has been an added bonus to the students enrolled in the course since they have additional motivating factors to carry out successful projects. Even though students choose not to participate in those events, they seem to be still encouraged to do their best as they are aware that external encouragements and opportunities are abound.

For the success of the course, it is essential for the instructor to be flexible and adaptable as already indicated in Section 3. Another flexibility introduced in recent years is on-line discussion of cases. Discussion in both on-line format as well as in-class format turned out to be preferred especially by the international students who have some difficulties in participating in class discussion. Student presentation times are another area deserving flexibility as students learn much not only from their own presentations but also from interaction with the instructor and other students during the presentations.

A longitudinal study on students' progress on learning key concepts from a same cohort of students as well as over several years is being conducted. A particular emphasis is whether constraints such as sustainability are impediment or stimulus to creativity and innovation. We analyze initial opportunity ideas that students generated in the beginning of their project and likewise analyze their final projects. We observe a definite trend of students' gaining more balanced views on sustainability in terms of its three aspects - environmental, economic and social. In addition, more systematic and thorough assessment plans are underway. Students' understanding of sustainability at the beginning and at the end of the course may be assessed in a more formal way (Haase 2014, Nicolaou and Conlon 2012).

For future, we may explore several new ideas. The course may be offered jointly with other universities from different countries. Such joint offerings may shed light on any cultural, educational or background differences in the students and ignite further creative thoughts or innovations due to a truly global collaborative environment. With the advancement of distance learning technology and the growing exposure to the alternative delivery modes by professors and students, such collaboration opportunities may come easier than before.

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