A Novel Set of Core Courses for a new MS Sustainable Engineering Degree Program

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Abstract

A new MS Sustainable Engineering degree program has recently been launched by Villanova University’s Engineering College. The program is open to all engineering and science undergraduate majors. The concept behind the program is to broaden students’ outlooks from narrow, silo viewpoints to consider holistic potential engineering solutions centered on the sustainability theme.

A novel three course core curriculum has been designed to give every MS student an integrated and comprehensive understanding of Sustainable Engineering.

The core curriculum starts with an introductory course entitled “Sustainability and Climate Change: Challenges and Opportunities” in which the students gain a comprehensive understanding of the framework for practical sustainable solutions for Products, Processes and Infrastructure. The second core course entitled “Impact Assessment, Life Cycle Evaluations and Industrial Ecology” is centered on the central concept of “whole system thinking across the value chain/life cycle”. The third, and final core course, is devoted to understanding and applying the Economic and Social Equity perspectives to Sustainable Engineering solutions. This final core course, team taught with Professors from the Liberal Arts and Business schools, is designed to expose engineering students to social justice and economic issues.

The pedagogical approach to teaching these courses is through assigning many student team projects and case study analyses which allow the students to build a proven “toolbox” and then apply the tools on a diverse set of real world problems. Our learning objective is to have the students think “outside the box” and undertake a contemplation of the full set of impacts in engineering solutions.

The first two courses have been taught twice to classes of students from all engineering and science disciplines. Students have been totally engaged and transformed in these courses. The third course is presently being developed and taught for the first time this semester. Details of the course content, examples of some of the case studies, and student experiences will be described in this paper.

Introduction and Structure of MS Sustainable Engineering Degree Program

Sustainability has become a mainstream issue for engineers working for multi-national corporations, consulting organizations, non-profits and the government. Recently, several books on sustainability have been published in the popular press [1,2] as well as textbooks for students and professionals [3,4]. The term “Sustainability” has been used very widely to include the topics of environmental sustainability, business sustainability, life cycle analysis, impact assessment, sustainable development, sustainable infrastructure and sustainable energy. Many of these programs are located within a specific university department or school, e.g. chemical engineering, environmental engineering, business schools, etc. As we considered the approach that we wanted to develop for our new Master’s program in Sustainable Engineering, we wanted ensure that the approach was a broad, multi-disciplinary approach that not only included the technical aspects of sustainability but also took account of cultural, social, economic, ethical and social justice considerations. This is a truly distinctive approach to our
program compared to existing, more traditional programs. To ensure the breadth of understanding that we wish to impart to our students, the core courses were structured so that the first two courses provide the technical education and the third course provides the broader context (although this is also woven into the first two courses as well).

Our new inter-disciplinary Master’s degree in Sustainable Engineering was launched in December 2010. The program is available to all engineering and science disciplines and is structured with three 3 credit hour core courses after which students branch off into one of four tracks – renewable energy, environmental sustainability, water resources and the built environment (although this latter track is still under development). The courses that are offered in each of the tracks are presented below:

Courses offered in the Renewable Energy track include:

- ECE 7800 Renewable Energy Systems
- EGR 7800 Solar Thermal Energy Conversion
- EGR 7850 Electrochemical Power Sources
- ECE 7000 Energy and Environmental Policy and Economics

Additional Energy Elective Courses include:

- ECE 8580 Power Electronics
- ECE 8000 Electric Machines
- ECE 8830 Electric Drives
- ECE 8320 Control Systems
- ECE 8010 Power Systems Modeling

Courses offered in the Environmental Sustainability track include:

- CEE 7011: Hazardous Waste Management
- CHE 8561: Air Pollution Control
- CEE 7513: Fate and Transport of Contaminants
- CHE 7003: Toxicology and Health Effects of Industrial Operations
- CHE 7511: Microbiology for Environmental Engineers
- CHE 8588: Biochemical Engineering II
- CEE 7701: Aquatic Chemistry for Environmental Engineers
- CEE 8707: Physical/Chemical Treatment Processes
- CEE 8708: Biological Treatment Processes
- CHE 8571: Separation Processes I
- CHE 8572: Separation processes II
- CHE 8531: Nanomaterials, Catalysis and Energy Transformations for a Sustainable Future

Courses offered in the Watershed Sustainability track include:

- CEE 7010 Lake, Stream, and Wetland Ecology
- CEE 7111 Introduction to Hydraulic Eng. And Hydrology
- CEE 7211 Water Resource Planning and Management
- CEE 8501 Surface Water Hydrology
- CEE 8502 Watershed Modeling
- CEE 8503 Open Channel Hydraulics
- CEE 8512 River Mechanics and Engineering
- CEE 8507 Environmental Flow
- CEE 8508 Urban Hydrology and Storm Water Management
- CEE 8510 Groundwater Hydrology
Students taking a track must take a total of 21 credit hours worth of additional course work beyond the core courses, 9 credit hours of which may be focused on a research project.

While the tracks offer in-depth courses in specialized areas, the core courses offer a much more broadening experience and the research projects that students perform in this program are much more cross-disciplinary. In the next section we describe the core courses in more detail, explain the pedagogical approach to teaching these core courses, and describe their impact on students to date.

**MS Sustainable Engineering Core Course Sequence**

Three courses make up the core courses of the MS Sustainable Engineering program:

EGR 7110 Sustainability and Climate Change: Challenges and Opportunities
EGR 7111 Impact Assessment, Life Cycle Evaluations, and Industrial Ecology
EGR 7112 Economic and Social Integrators

The purpose of the three core courses is to introduce students to “Sustainability” from the full perspective of technical, economic, and social/ethical viewpoints. The central concept is to provide the students with a holistic sense of current problems, present a set of Sustainability principles and build a toolbox that will evolve with this rapidly expanding field. The students test and evaluate the tools through a diverse set of applications and student team projects. The students are challenged to think outside the silos of their individual disciplines and to broaden their perspectives.

**Overview of EGR 7110 Climate Change and Sustainability**

This course integrates Sustainability and Climate Change into a holistic approach. A three step model is used:

1) Build an integrated framework for Sustainability with Climate Change as an aspect of Sustainability
2) Assemble a toolbox for engineering solutions
3) Apply the toolbox to a wide variety of current problems – focusing on technical, social and economic solutions – all three legs of sustainability.

The students are challenged to view themselves in the professional working environment in preparing a variety of role based individual assignments. We further challenge the students to work in 3 to 5 person teams on providing solutions, with justifications, on hypothetical problems based on real world examples.

For example, we have utilized the Princeton Wedge Stabilization program [5] to evaluate and select a personal portfolio of technologies to reduce Green House gas emissions by 50% in 2050. The students also calculate their own carbon and ecological footprints and assess alternatives to reduce by 25% and 50%. Other examples include an examination of the impacts of alternate diets and how individuals can switch to lower impact foods while also increasing their nutritional benefits. In summary, the group projects truly get the students interested in personal, company and company impacts while providing the tools to implement engineering solutions.

**Overview of EGR 7111 Impact Assessment, Life Cycle Evaluations, and Industrial Ecology**

This course has a central focus on “whole systems thinking” as a key to broadening the student engineer’s perspective. Students work on individual and team projects in each of the following thematic areas:

1) Product Life Cycle Assessment
2) Service Life Cycle Assessment
3) Built environment/Infrastructure – currently under development

The main objective of the course is to introduce students to whole systems thinking across the life cycle of a product or service. The course starts with an overall picture of key global issues such as alternative energy futures, sustainable consumption and ecosystem services. The four-step ISO life cycle process is applied through two sets of team projects.

We challenge the students to move outside their comfort zones of technically-based environmental issues and tackle the much more diverse set of issues around the social and economic dimensions. Each team project requires a deliverable dealing with the technical environmental issues along with the social and economic.

Over the last two years, the students have conducted about 40 life cycle assessment evaluations for products, services and infrastructure. Examples include some everyday issues like real vs. artificial Christmas trees or soy milk vs. cow milk. Broader issues include the systemic impacts on the grid from providing plug-in hybrids not only for transportation but also for grid storage and reduction in peak load generation requirements. We have also evaluated traditional book publishing and retail store purchasing vs. on-line purchasing and e-books. In all cases, by looking at the full spectrum of environmental, social and economic impacts we learned about tradeoffs within the environmental impacts as well as tradeoffs and impacts among the social and economic perspectives.

Overview of EGR 7112 Economic and Social Integrators

The third core course in the sequence provides the non-technical, social science perspective on sustainable engineering.

The initial offering of this third core course started in late August 2010. Each student must have completed at least one of the two prior core courses and most have taken both core courses.

This course is being offered in a seminar format primarily by the two authors of this paper but with support and input from a Philosophy professor from the College of Liberal Arts and Sciences, and an entrepreneurship professor from the School of Business, representing the three pillars of technical, economic and social perspectives. The course is being guided by the professors but is actively engaging the students in its development. The first month of the course has been focused on developing frameworks for measuring and assessing social and economic impacts of projects, products and services. The course is now shifting to having the students apply these frameworks to case studies of their choosing. The four case studies being initially explored include the Cape Wind Project, the i-Pad tablet computer, a salt water desalination plant in San Diego, and DeBeers diamonds. The students will perform a technical life cycle assessment but will be mainly focused on social and economic impacts. The students will work on this project for one month and then will move onto a second case study. In between we will provide some other case studies for discussion. One case study that we explored was the technical, social and economic impact of Engineers without Borders (EWB) projects (e.g. clean water projects) in the developing world.

To date the students have been very engaged in this course and the course has been more of a dialogue rather than a one-way street from professor to students. This engagement and critical thinking is expanding the students’ understanding of the non-technical aspects of sustainable engineering.

Impact of Core Courses on Students

We have offered the first two core courses in both the 2008-09 and 2009-10 academic years and prior to the formal launch of the MS in Sustainable Engineering program in late 2009.
The first two core courses in the sequence have been taken by approximately 75 senior engineering students and about 30 graduate students from all engineering and science backgrounds.

Many students have been strongly and positively impacted by the profound implications of man’s impact on the environment taught in the courses. The most common feedback was the course(s) changed their outlook on the environment/planet and made them very excited about being an engineer. They very much like the holistic approach of thinking about the 3 pillars of sustainability. At least 3 students converted to vegetarian/vegan as a result of taking the course and pondering their personal options. Also, the students liked the opportunity of writing memos/Powerpoint as a way to learn business communications.

By focusing the team projects on real world situations, many dealing with how the students are currently living, we assure ourselves a very practical focus and energetic response. It has been very satisfying to see the students clearly and openly deal with not only their current priorities but tackle the longer-term issues of Climate change.

Several of the senior chemical engineering students who took the course in their senior year have subsequently joined the MS Sustainable Engineering degree program.

**Future Development – A Web-Based Global Learning Community**

In addition to the core courses that we are teaching, we are also building a Web-based Sustainable Engineering Global Learning Community to extend the reach of our classroom and distance education programs. Our target audience is both students and practicing professionals.

The core of this community will be a series of learning modules built around the topics of our core curriculum. Each learning module will be supplemented by case studies, individual and group learning assignments. We will have videos of classroom instruction as well as guest lectures. Since the literature is constantly evolving in this fast paced field, we will continually update and improve our literature sources and link them to each learning module.

We want to extend the learning via an on-line forum and solicit external case studies. For example, there are very creative and innovative programs underway throughout the world operated by non-profits. We want to access these real world successes and integrate them into a Sustainable Engineering framework. We expect to launch this effort in early 2011.

**Conclusions**

We have described a novel three core course sequence that is serving as the foundation of a new MS degree in Sustainable Engineering. These three core courses provide the tools for students to be able to perform life cycle analysis, environmental impact assessment, energy and water impact assessment, etc. The courses are taught in a combination of lecture and hands-on case study project mode. The students learn by doing and are consequently very engaged with the subject matter. The first two core courses have been taught a number of times and have strongly impacted many of the students taking the classes. The third core course is being taught for the first time in the Fall 2010 term and is being taught by a cross-disciplinary group of faculty.

A web-based global learning community will be developed which will include case studies, student projects and web-based learning modules. We will also be soliciting external contributions to this website to supplement our own examples, thereby broadening the scope of the case studies available to members of the global learning community.
References