AC 2008-2837: ORGANIZATION OF AN INTRODUCTORY GREEN ENGINEERING COURSE FOR ENGINEERING UNDERGRADUATES

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Organization of an Introductory Green Engineering Course for Engineering Undergraduates

Abstract

An "Introduction to Green Engineering" course is one of two core courses required for a Green Engineering minor. Since the course attracts students from all disciplines within the College of Engineering, it is challenging to teach given the variety of backgrounds, specific skills and knowledge, and perspectives. Analysis of course assessment data and revision to the course content and teaching methods are part of an on-going effort to improve this course.

The Green Engineering course has lectures which present background material on the key environmental and energy issues facing society. To differentiate this course from one in environmental science, an engineering analysis component is included with the assignment of four mini-projects which are completed by teams of not more than four students. The projects are: 1) biomass logistics, a project to document the increase in per-Mg feedstock hauling cost as plant capacity increases; 2) climate, a project to calculate per capita carbon release for Virginia Tech students, Blacksburg residents, and Montgomery County residents; 3) wetland design, a project to design a constructed wetland facility for the treatment of small municipality wastewater; and 4) biomaterials, an optimization problem to design a structural component using an optimum mix of recycled plastic and organic fiber.

Introduction

Our current fossil-fuel based United States and world economy is not sustainable. Engineers from every discipline have a role to play; they have an important contribution to make as we transition to a more sustainable existence. President Bill Clinton spoke at the 100th anniversary of the American Society of Agricultural and Biological Engineers and reviewed the challenges facing society today. He said, "This is a wonderful time to be an engineer.[4]" Yes, the challenges are great and will affect the daily lives of most people on this planet. *The fundamental goal of the Green Engineering course is to help engineers from all disciplines see how they can use their unique knowledge to move toward sustainability, where sustainability is defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs[1].*

This paper describes the on-going development of a course, "Introduction to Green Engineering," which is offered by the College of Engineering (COE) and is available to students from any engineering discipline at Virginia Tech. The Green Engineering program has been in existence at Virginia Tech for about a decade with a formal curriculum associated with it for the past 6 years. This course is one of two core courses required for an 18 credit minor. The other core course is "Environmental Life Cycle Analysis." To complete the minor, students also select 6 credits from approved engineering electives and 6 credits from approved environmentally-focused, but not engineering, courses.

Background

The Introduction to Green Engineering course, here after referred to as the "Green Engineering" course, has gained in popularity in the past three years. A growing awareness that anthropogenic activities may be causing global climate change, and the increase in oil prices with the resultant increase in all energy prices, has heightened the awareness of the connection between energy use and the environment. The following facts are being widely discussed in the scientific community and are beginning to be discussed more seriously in the political community:

1. The combustion of coal, oil, and natural gas is releasing millions of tons of fossilized carbon into the atmosphere. It is estimated that the CO_2 concentration in the atmosphere at the beginning of the industrial age was about 280 ppm. Today it is in the neighborhood of 370 ppm. There is legitimate concern that global climate change is resulting from this increase.
2. The poor air quality in most cities around the world is causing a degradation of human health. In Mexico City, the largest city in the world, air quality is so ppoor that simply living in the city presents the same health risks as smoking three packs of cigarettes a day[1].
3. Potable water supply is an issue for much of the world population. The United Nations proclaimed that all peoples have the right to have access to drinking water in quantities and of a quality equal to their basic needs; in 2000 one in every three persons in the developing world (1200 million people) lacked these two provisions[3]. Even in the United States, some cities have grown so fast that water quantity has become an issue, as evidenced by rationing in some parts of the Southeast during the historic drought of 2007.

These current scientific issues formed the framework for the topics included in the course lecture material and emphasized in the course mini-projects. Lectures provide a foundation of knowledge and incorporate the latest challenges presented to engineers, while also hosting class discussion on possible solutions to these challenges. Students then complete a mini-project in small groups where they work through a practical example of an engineering challenge in these areas.

The learning objectives for Green Engineering include the following:

- Define the key environmental issues society is facing and give specific examples of how engineers from all engineering disciplines can provide technology that reduces the environmental impact of human activity.
- Analyze the key interactions between economic and environmental issues as regards to providing the basic human need for water, food, and shelter within the terrestrial and climate constraints of a given country.
- Analyze the key interactions between production and processing of biomaterials (food, fiber, chemicals, and pharmaceuticals) and environmental issues as regards to air and water quality.
- Analyze the key interactions between energy and the environment as regards to emissions into the atmosphere and resource depletion.

- Understand, as a basis for life cycle analysis (LCA) and sustainability, that the materials used for every design must ultimately be returned to the land, water, and air resource base or be indefinitely reused/recycled in closed-loop manufacturing processes.
- Understand the importance of the engineer's role in defining technical constraints for the formation of public policy.

Typically, the Green Engineering course participants are undergraduate juniors and seniors. An ecology course is not a prerequisite, thus a certain amount of fundamental material is presented to help frame the engineering issues. It has been a challenge to develop the course material with an effective balance between fundamental ecological information and the rigorous analysis expected in an engineering course. For example, students in the Biological Systems Engineering (BSE) curriculum who take the course have adequate preparation in the biological sciences and are ready for a more advanced treatment of the interactions in our biosphere. On the other hand, students in the Industrial and Systems Engineering (ISE) curriculum have much less preparation in the biological and ecological sciences. For example, ISE students are not required to complete even a basic college-level biology course. However, the ISE students bring a stronger preparation in systems analysis than the BSE students. The challenge is to advance the knowledge of students from both ends of the spectrum and all those in between.

Course Organization

The course meets for two 75-minute periods per week. In general, the first 40 to 50 minutes is used for lecture and class discussion. The last 15 to 25 minutes are provided for team meetings. There are four mini-projects or design scenarios assigned and these are completed by teams of not more than four students. (Discussion of the mini-projects is given in the next section.) The grading is broken down with mini-projects accounting for 50% of the grade, mid-term exam (15%), unannounced quizzes (5%), homework (10%) and a final exam (20%). Students turn in written mini-project reports that conform to technical writing standards.

A listing of the lecture topics for the 2007 presentation of the course is given in Table 1. The teaching assistant, a doctoral student in BSE, presented the water resource lectures. The text book for the course in 2006 was an ecology text[2]. The text book for the course in 2007 was an environmental science text[5].

The four class periods after the Thanksgiving break are used for guest lecture given by experts in their respective fields. These lectures review material already presented; however, is the material is presented from the perspective of a specialist rather than that of the generalist (Cundiff) who presents the material initially. For example, Dr. Justin Barone discussed biomaterials created from agricultural waste products such as chicken feathers in 2007. These lectures effectively serve as a review for the final exam.

The lecture topic sequence for the Green Engineering course followed the three ecological characteristics of life presented by Miller[1].

1. Obtaining energy
2. Growth
3. Reproduction

These characteristics form a rough outline for the course, with energy being the main theme. Humans have a powerful capacity to obtain and use energy. In a society like the United States, much of the energy is converted to work, with resulting unavoidable losses defined by the second law of thermodynamics.

Table 1. Lecture Topics for the 2007 presentation of Introduction to Green Engineering

Lecture No.	Topic
1	Introduction and overview of global environmental issues
2	Biomass logistics
3	Green engineering overview – Director, Green Engineering Program
4	Renewable energy
5	Renewable energy
6	Non-renewable energy
7	Non-renewable energy
8	Carbon in the environment
9	Air quality issues
10	Climate and terrestrial biodiversity
11	Water resources (global)
12	Water resources (national)
13	Water quality
14	Water pollution and treatment
15	Midterm test
16	Food resources (global)
17	Food resources (national agriculture)
18	Food resources (national agriculture)
19	Human population
20	Biomaterials (overview)
21	Solid and hazardous waste
22	Environmental policy and decision making
23	Environmental policy and decision making
24	Sustainable cities
25	Sustainable buildings
26	Guest Lecture 1 – Bioenergy potential (D. Parris, Crop and soil environmental scientist)
27	Guest Lecture 2 – Green products (S. McGinnis, Director, Green Engineering Program)
28	Guest Lecture 3 – Biomaterials from processing residues (J. Baron, Biological Systems Engineering)
29	Guest Lecture 4 – Ecological Engineering (C. Hession, Ecological Engineer)

Energy conversion, specifically the combustion of fossil fuels, results in air quality problems. Once a gas is released into the atmosphere, it knows no political boundary. It becomes a "global environment" issue. For some students, discussing the interrelationships between energy and air quality is their first understanding that their individual activities have a global impact.

The next module of the course deals with water resources, pollution, and remediation. This module includes many aspects of water resources, beginning with and continuously framed by the hydrologic cycle. Technical materials are embedded between historical and current water resources topics, such as the increasing need to improve water quality in the United States, the unequal distribution of potable drinking water around the world, and the innovative technology we, as engineers, may use and develop to overcome these problems. Because agriculture is the largest user of water globally, the water resources module is followed by the food resources module.

To move society toward sustainability, we must use more products produced from organic feedstocks. This module is referred to as the "biomaterials module." It follows the food resources module to promote the important discussion of the food versus fuel dilemma. Specifically, should organic materials that can be used for food be diverted into the production of fuel and chemicals, which are then processed into a host of other products?

Today in both the popular and scientific arenas there is a great deal of discussion about "green products," and this discussion fits nicely into the course biomaterials module. Also, the importance of life cycle analysis as an engineering design criterion is introduced to the students during the biomaterials module, thus preparing students for the second of the required courses in the Green Engineering option.

The last module within the course deals with environmental protection policy and energy policy. It reviews progress made by the Environmental Protection Agency (EPA) since passage of the 1970 Clean Air Act. There is a documentable change in the United States business climate. "Over the past 30 years, the amount of energy and natural resources the United States' economy used to produce each constant dollar of output has steadily declined, as have many forms of pollution.[5]" Being "green" and more energy efficient is good business. This point in the course is the time that students from all disciplines realize that their engineering practice, no matter what industry they are in, can help society move toward sustainability.

The policy module is highlighted by a guest lecture by Professor Richard Rich on sustainable cities. In general, cities are islands of humanity which are dependent on the surrounding countryside for its food, water, energy, and other needs. It is fascinating to learn of the things being done in cities around the world to move toward sustainability. In some cases, individual buildings are being designed to capture needed energy and water on site and thus incur a minimum demand on urban utilities.

Mini-Projects

The mini-projects are designed to add an analysis component to the course. They are typically a two-week assignment for a team of not more than four students. For the last two years the students have been presented with biomass logistics, biomaterials selection, constructed wetland design, and climate analysis projects.

Biomass Logistics Mini-project

Biomass is a distributed resource; it must be collected at a conversion plant from surrounding fields/forests. As plant capacity increases, so does the required feedstock production area and the the average trucking distance. Therefore, with an increase in plant capacity there is a concurrent increase in hauling cost, which increases the average feedstock delivery cost. This design project solves a feedstock delivery problem given assumptions about the surrounding production area. An example of the results is given in Figure 1. Students with some systems analysis background do an excellent job with this project, as it is a routine assignment for them. The figure depicts the increase in hauling cost as a function of plant capacity for feedstock production areas ranging from 2.5 to 10% of the land area surrounding the plant.

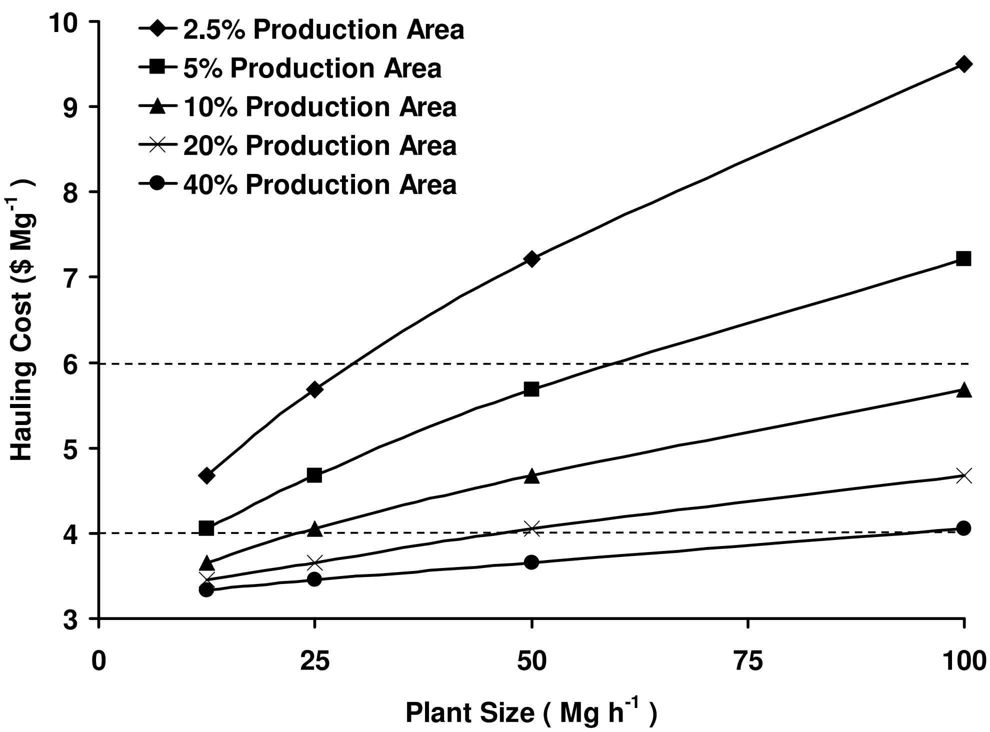

Figure 1. Example of project results for the biomass logistics mini-project in the Green Engineering course.

Climate Mini-project

Students are given local population data, vehicle numbers, and data for the Virginia Tech and Radford Arsenal coal-fired power plants for 1990 and 2005. These data and a carbon emissions calculator published by the EPA are used to calculate the per capita carbon release for a Virginia Tech student, a Blacksburg resident, and a Montgomery County resident (http://www.epa.gov/climatechange/emissions/ind_calculator.html). Typical results are 3.1

Mg/y for a Virginia Tech student 3.2 Mg/y for a Blacksburg resident, and 3.3 Mg/y for a Montgomery County resident. To conclude the analysis students are asked to discuss the causes for these differences and how specific decisions affect an individual's ecological footprint. For example living in the city and riding mass transport verses living in a rural or suburban area and driving personal automobiles.

Constructed Wetland Design Mini-project

The constructed wetland project applies theory from lectures on water resources, pollution, and pollution treatment. Students are required to calculate the removal of biochemical oxygen demand (BOD), total suspended solids (TSS), and fecal coliform bacteria to design both pre-treatment lagoons and wetland cells. Students supply plan and profile design drawings of the lagoons and wetlands, as well as an overall site plan. Students are also required to discuss wetland and pond construction, planting, and maintenance. The final requirement for the design teams is to compare the expected cost of treating waste with a constructed wetland verses a traditional mechanical plant, considering the land cost required for the constructed wetlands. Student designs have included two to three pretreatment lagoons in parallel followed by an array of wetlands cells in both series and parallel (fig. 2). Multiple designs are valid for this project as long as removal requirements for both BOD and TSS are met. This project is difficult for groups without a biological, chemical, civil, or environmental engineering background because traditional engineering education is deterministic in nature. Therefore, many of the Green Engineering students struggle to design a natural system where multiple different designs are valid.

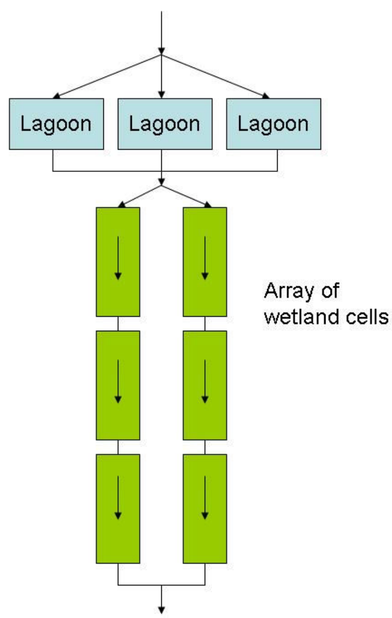

Figure 2. Example student constructed wetland plan design. The blue rectangles represent pretreatment lagoons. The wetland cell array (green) consists of two parallel strands of three wetland cells in series.

Biomaterials Mini-project

The biomaterials project is an optimization problem. The project goal is to develop a composite with a desired Young's modulus while minimizing the total energy investment. The students are given the properties of four materials: recycled plastic, wood fiber, chicken feather fiber, and cotton fibers. The students select a fiber to add to the plastic matrix to increase the Young's modulus. Data are given on modulus versus fill fraction percentage for the three fibers (wood, feather, cotton), as well as the production energy sequestered in the recycled plastic. These fibers are considered wastes from other industries and no sequestered energy was assigned.

Student Grade Distributions

The frequency distribution of the grades for the mini-projects and the two exams for both semesters are shown in Figure 3. The histograms strongly suggest the project grades did not follow a normal distribution, and that most students received passing scores on all four projects. This shows that students successfully assimilated the lecture material to a level of understanding that allowed them to apply it to the mini-project design scenarios.

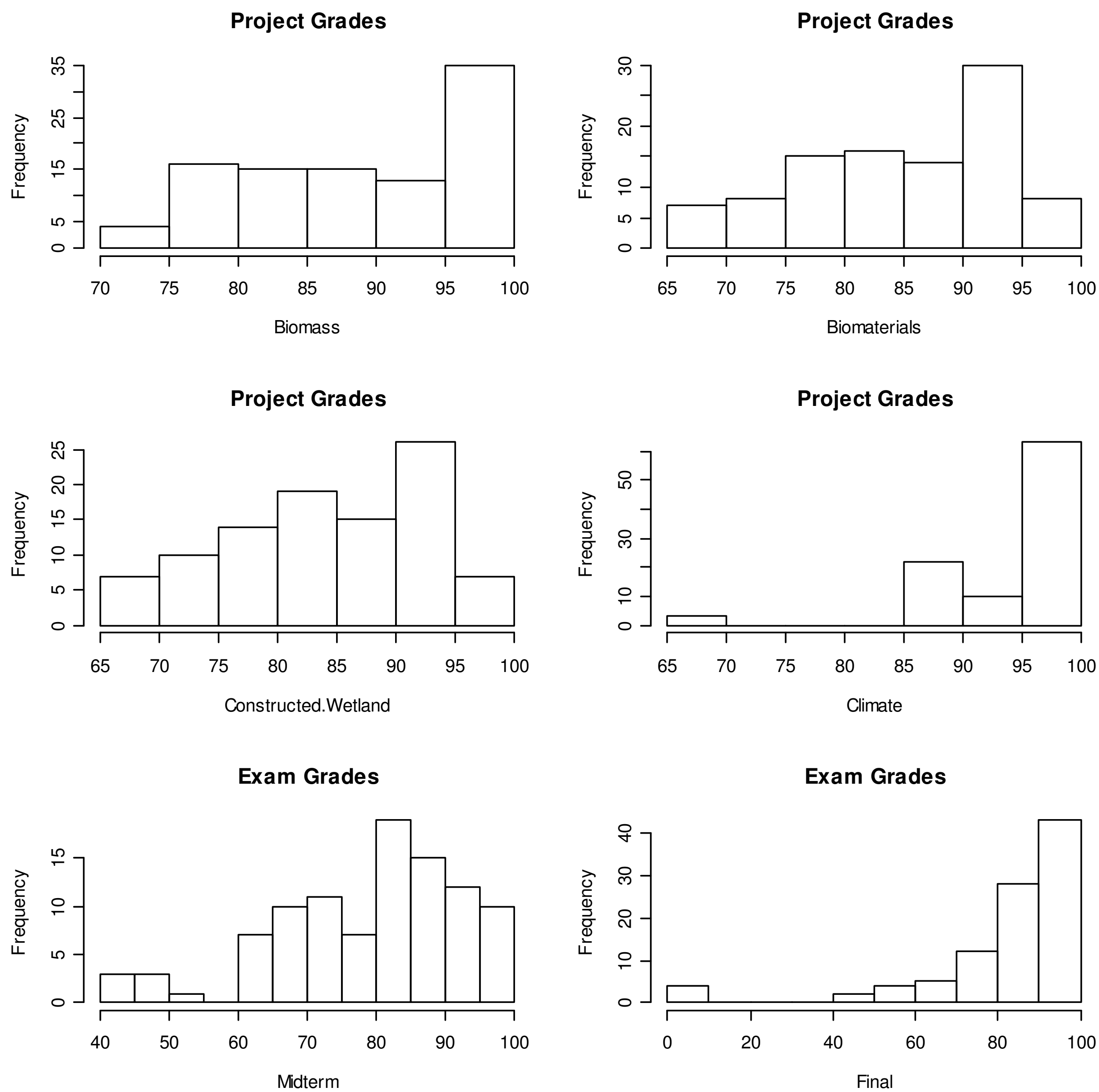

Figure 3. Frequency distributions for each of the mini-projects and exams. The y-axis shows the frequency of a score category, and the x-axis represents the numerical grade, out of 100 points, on the project or exam. The specific assignment is indicated by the label for the x-axis, while the graph title represents the category of assignment (project or exam). During both semesters there were a few students who did not attempt the final exam and are included in the analysis.

Discussion

Class project averages varied between 2006 and 2007. In 2006 the biomaterials project had the lowest average score, followed by the constructed wetland project, the biomass logistic project, and the climate project (fig. 4). In 2007 the students scored the lowest on the constructed wetland design, followed by the biomaterials and biomass logistic projects. The students achieved the highest average score on the climate project in both years. During both semesters the midterm scores were lower than the final exam scores; however, the difference between the two years was not significant at the 0.05 level.

Overall, teaching a diverse group of engineers about a subject such as green engineering, with sustainability as a design criterion was challenging in both 2006 and 2007. It will remain difficult due to the inherent curriculum differences between the engineering disciplines at the junior and senior level. Although the students all have critical thinking and problem solving skills, they have drastically varied background in biology and the design of biological systems. Due to these differences, the Green Engineering Program learned a valuable lesson through experience in 2005 that classes larger than 40-50 students make it difficult to develop discussion of key issues and a communicate a foundation for the class as a whole.

The diverse group of student backgrounds and knowledge enhances the discussion portion of the course. For example, a biological or environmental engineer views the positive and negative attributes of a dam very differently from a mechanical, structural, or even traditional agricultural engineer. It is important for young engineers to recognize these differences in backgrounds since it is rare for any structure or system to be designed with input from only one engineering discipline.

Students evaluated the course at the end of each semester. In 2006, 28 students gave an overall rating of good and 14 excellent out of a total of 45 evaluations. In 2007, 19 students gave the course an overall rating of good and 16 rated the class excellent out of 45 students. On textbook accuracy in 2006, 19 students gave a rating of fair and 14 good. The textbook was changed for the 2007 semester to try to find a more application-based book instead of an ecology textbook. However, in 2007, 12 students evaluated the new textbook as poor and 19 as fair. The text was not written as an engineering text, thus was not like most of the texts the students have used in their other courses, which include detailed development of theory and example problems. This rating should be interpreted primarily as a statement that the text was not well suited for this course, and finding the right text is a continuing challenge. Other individual student comments included suggestions for more detailed lectures and example problems similar to the mini-project design problems. Many students expressed they enjoyed the guest lecture series and would prefer to have them throughout the semester, as opposed to just during the last two weeks of class.

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