Appropriate and Sustainable Engineering (ASE) Concentration

Introduction

As part of a new General Engineering (GE) program beginning Fall 2009, the Appropriate and Sustainable Engineering (ASE) Concentration is focused on engineering at the crossroads between stewardship to our planet and service to the poor as shown in Figure 1. We seek to address our environmental footprint in the developed world though sustainable engineering solutions while addressing the needs of the world’s poor through development of appropriate technology. Sustainable design can be characterized as maintaining or improving material and social conditions for human health and the environment over time without exceeding the ecological capabilities that support them. Appropriate technology can be characterized as being small scale, energy efficient, environmentally sound, socially acceptable, and technologically appropriate to be built and maintained by the local community. In the development of this program, we believe that it is critical to seek engineering solutions that lie in the crossroads of these two approaches.

As a result, this program will serve multiple purposes. First, the program will prepare students interested in work in the developing world with a solid and relevant engineering background, along with courses to prepare them to engage positively in other cultures. This could include an international engineering internship in the developing world. Second, we aim to recruit students from developing countries to participate in this program to bring critical skills back to their native countries. Finally, as our own resources become limited in this country, the need for engineers to address issues related to sustainability will grow, and students from this program will be well equipped to address this challenge here in the U.S. This program joins a growing number of program addressing sustainability and appropriate technology issues (e.g., the Engineering for Developing Communities program at Univ. of Colorado, Boulder.)

This paper is focused on development of the program’s learning outcomes, the resulting curriculum development, the use of project-based courses, and program assessment.

Program Learning Outcomes

The program learning outcomes we seek for our Appropriate and Sustainable Engineering Concentration within the General Engineering degree program are focused in three areas: competence, community, and character. These support our goals for the program, our
university’s learning outcomes, and ABET program outcomes. Table 1 shows the related university and ABET outcomes for each program learning outcome under the three areas. The competence outcomes are focused on the application of engineering knowledge, the understanding of the implications of engineering solutions on society, and the ability to use contemporary engineering tools and engage in lifelong learning. The community outcome is focused on effective and respectful interaction with a diverse engineering and global community. The final outcome category of character focuses on individual integrity and ethical conduct.

Table 1. General Engineering (GE) Appropriate and Sustainable Engineering (ASE) Concentration Desired Program Outcomes for Graduates Compared with University Learning and ABET Program Outcomes

<table>
<thead>
<tr>
<th>Related University Learning Outcomes</th>
<th>GE – ASE Outcomes</th>
<th>Related ABET Program Outcomes³</th>
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<tbody>
<tr>
<td>I. Competence</td>
<td></td>
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<tr>
<td>Demonstrates knowledge in disciplinary field.</td>
<td>I.A. Applies knowledge of mathematics, science, and engineering, and inquiry and critical-thinking skills to identify, formulate, and solve problems, design, conduct and analyze experiments, and design systems, components, or process to meet desired constraints using appropriate and sustainable technology and design practices.</td>
<td>(a) an ability to apply knowledge of mathematics, science, and engineering</td>
</tr>
<tr>
<td>Applies knowledge, inquiry, and critical-thinking skills in problem solving.</td>
<td>(b) an ability to design and conduct experiments, as well as to analyze and interpret data</td>
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<tr>
<td>Integrates liberal arts and disciplinary knowledge.</td>
<td>(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability</td>
<td></td>
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<tr>
<td>Demonstrates a global perspective.</td>
<td>(d) an ability to communicate effectively</td>
<td>(h) the broad education necessary to understand the impact of engineering solutions in a contemporary global, economic, environmental, and societal context</td>
</tr>
<tr>
<td>I.B. Integrates the liberal arts with engineering knowledge to understand the impact of engineering solutions in a contemporary global, economic, environmental, and societal context</td>
<td>(e) an ability to identify, formulate, and solve engineering problems</td>
<td>(j) a knowledge of contemporary issues</td>
</tr>
<tr>
<td>I.C. Demonstrates an ability to use contemporary engineering tools necessary for engineering practice, and shows the ability to engage in lifelong learning to stay current with technology.</td>
<td>(i) a recognition of the need for, and an ability to engage in life-long learning</td>
<td></td>
</tr>
<tr>
<td>Communicates effectively.</td>
<td>II. Communicates and interacts effectively with a diverse engineering and global community through responsible discourse and respect for each other.</td>
<td>(d) an ability to function on multidisciplinary teams</td>
</tr>
<tr>
<td>Demonstrates interpersonal skills necessary for effective personal and professional relationships.</td>
<td>Engages with diverse others.</td>
<td>(g) an ability to communicate effectively</td>
</tr>
<tr>
<td>Reflects upon ideas and actions</td>
<td>III. Embodies personal and professional integrity by serving the public good in doing what is right and doing so with an awareness of consequences.</td>
<td>(f) an understanding of professional and ethical responsibility</td>
</tr>
<tr>
<td>Balances interests of self, others, and the community in pursuit of the common good.</td>
<td></td>
<td></td>
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</tbody>
</table>

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The Program Curriculum

In order to achieve the learning outcomes shown in Table 1, we aim to provide students with broad based engineering fundamentals and problem solving skills, hands-on application of appropriate and sustainable technology, the ability to effectively engage with the global community, and avenues for character formation. Some of these outcomes are addressed in specific courses and others are addressed throughout the curriculum. The curriculum is also designed according to the ABET criterion for engineering curriculum including a) one year of a combination of college level mathematics and basic sciences (some with experimental experience), b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design, and c) a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives, and d) a major design experience based on the knowledge and skills acquired in earlier course work and incorporating appropriate engineering standards and multiple realistic constraints.

There are three major components in the appropriate and sustainable concentration degree: 1) the university general education requirements (75 quarter credits); 2) the general engineering core requirements (69 quarter credits); and 3) ASE concentration specific requirements (61 quarter credits). The ASE specific requirements include required courses (42 credits), technical electives (10 credits), and application electives (9 credits).

General Education Requirements

The university general education requirements address in a broad sense competence in the liberal arts, community, and character formation (Program learning outcomes I.B, II, and III in Table 1.) They include a common core of 35 credits that provides a foundation in the liberal arts and an exploratory curriculum that includes 40 credits in the Arts and Humanities (10 credits), Social Sciences (10 credits), Natural Sciences (15 credits, including both biological science and physical science courses) and Math (5 credits).

General Engineering Core Requirements

The general engineering core requirements are common to all concentrations and include mathematics, chemistry, physics, programming, probability and statistics, circuits, junior level design, internship courses, and the senior design and capstone project. A listing of these requirements is shown in Table 2 along with related learning outcomes from Table 1. Ten credits of the university general education natural science requirement and the entire math requirement
can be satisfied by these core requirements (resulting in a 15 credit overlap as shown in Figure 2). Appropriate and sustainable engineering students will team with electrical and/or mechanical engineering students to complete design projects in the junior level design course. This is an open ended project designed to prepare students for both their internships and their senior design and capstone project.

The internship is a required part of the curriculum - all engineering students must complete an engineering internship between their junior and senior year. Students can fulfill this requirement by working for a company, a government facility, or a non-profit agency in an engineering role, or by participating in an engineering related REU program. Thus, students have the opportunity to work on appropriate technologies in the developing world through non-profit agencies or on sustainable engineering in the U.S. through local companies.

A major design experience is met through the senior design and capstone courses that are the focal point of the senior year. This series is modeled on our exiting electrical engineering senior design and capstone courses. The appropriate and sustainable engineering students, however, will have the opportunity to work on projects with students from a variety of engineering disciplines, including electrical, computer, and mechanical engineering. Eventually we would also like to include non-engineering students on these projects as well.

**Appropriate and Sustainable Engineering Concentration Requirements**

The appropriate and sustainable engineering concentration requirements seek to provide a broad based engineering background along with a specific focus on appropriate and sustainable
engineering issues related to energy, water, and design. Concentration requirements are shown in Table 3. Hands-on applications are integrated throughout the program, along with a focus on an understanding of the impacts of engineering solutions on economic, environmental, and societal issues throughout the world. Therefore, in addition to the required fundamental courses for the general engineering core requirements, courses in circuits, mechanics, and the thermal-fluid sciences are required to help provide this broad-based engineering background.

Three project-oriented courses targeted towards appropriate and sustainable issues related to energy, water, and design form the nucleus of the program. The first of the three is a project based class focused on alternative energy sources (EGR 3611 ASE I: Alternative Energies). Different energy sources, including solar, wind, hydropower, and hydrogen fuel cells, are introduced, and methods are investigated to convert these energies into useful forms. Projects include the design, construction, and testing of different systems. The second is focused on water as a resource – both in the U.S. and in the developing world (EGR 3612 ASE II: Hydrosystems). It is a combination classroom/project class that is concentrated on water distribution and portable water treatment systems and water as a resource. Projects include design of a water distribution system for a small rural village and a biosand filter water treatment system. The third course (EGR 3613 ASE: Systems Design) will focus on systems design and life cycle assessment, and will include analysis and design of engineered systems as they relate to their appropriate application and environmental, economic, and societal sustainability.

Along with these required courses, students are required to take ten credits of technical electives and nine credits of application electives. The technical electives include upper division engineering, math, and physics courses. The application electives are non-engineering courses focused on environmental, economic, and/or societal issues. These are designed to provide the students better insight into issues related to appropriateness and sustainability in the developed and/or developing world.

Table 3. Additional Appropriate and Sustainable Engineering Concentration Requirements (61 Quarter Credits)

<table>
<thead>
<tr>
<th>Subject Area</th>
<th>Number</th>
<th>Course Name</th>
<th>Quarter Credits</th>
<th>Related Learning Outcomes (Table 1)</th>
<th>Total Area Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appropriate and Sustainable Engineering Concentration Core</td>
<td>EE 2727</td>
<td>Electric Circuits II (4 + lab)</td>
<td>4</td>
<td>I.A, C</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>EGR 2891</td>
<td>Statics</td>
<td>4</td>
<td>I.A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EGR 3400</td>
<td>Kinematics and Dynamics</td>
<td>5</td>
<td>I.A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EGR 3310</td>
<td>Mechanics of Materials</td>
<td>4</td>
<td>I.A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EGR 2500</td>
<td>Thermo-Fluids I</td>
<td>5</td>
<td>I.A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EGR 3501</td>
<td>Thermo-Fluids II</td>
<td>5</td>
<td>I.A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EGR 3612</td>
<td>Appr. &amp; Sustain. Engr. II: Hydro-Systems</td>
<td>4</td>
<td>I.A, B, II</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MAT 3238</td>
<td>Vector Calculus</td>
<td>3</td>
<td>I.A</td>
<td></td>
</tr>
</tbody>
</table>

Total Appropriate and Sustainable Engr. Conc. Core Required Quarter Credits: 42

Total Technical Elective Quarter Credits: 10

Total Application Elective Quarter Credits: 9

Total Additional Appropriate and Sustainable Engineering Concentration Quarter Credits: 61
Project-Oriented Courses

The three project-oriented courses are a focal point of the program. These courses differ from standard engineering courses with their heavy emphasis on open-ended projects. The first of these, EGR 3611 ASE I: Alternative Energies is described in detail below. The other two courses are and will be designed in using a similar structure.

Overall goal of EGR 3611 is to expose students to energy technologies that are appropriate for small scale applications, particularly in developing countries. The exact choice of coverage changes year to year, depending on the needs of the students; however, it usually covers:

- Hydroelectric generation: Site assessment, flow calculations, energy availability, etc.
- Wind power for electricity generation: Site assessment, energy evaluation, etc.
- Cooking fuels: Wood stoves, methane digesters.

A description of the assessment approach used for the course, the project-based instruction techniques, and some detailed project examples are provided below.

Assessment Approach

The approach used for assessment is adapted from our physics program. The purpose of assessment is to determine what the students have actually learned, not what they know. This information is not used to assign grades to the students (although the post test is also used as a summative assessment tool, i.e. a quiz). Instead, this information is used to evaluate student learning and professor teaching. It is used to change both what we teach and how we teach it.

In our lower division physics courses, these data are obtained by administering pre-tests and post tests to our students. At the beginning of each term, students are given a major pre-test looking at concepts (not math skills) taught during that term. At the end of the term, they receive the same test. We then calculate the student “gain” and the class “gain” to determine what was learned, or more importantly what was not learned. In addition, short pre- and post-tests are give on a weekly basis, to provide a finer measure of what worked and what needs more work. This has allowed us to craft a curriculum and teaching method that is demonstratively fostering significant gains in student learning. These assessment methods have been applied in the alternative energies class (EGR 3611). A weekly project homework acts as the post test for the material covered this class. The results of the homework clearly indicate if the students understood the covered concepts and allows for easy identification of deficits in the instruction of that material.

Project Based Instruction

EGR 3611 ASE I: Alternative Energies is a project-based course (rather than a traditional lecture format). Each of the course sections culminates in a project where the students assemble or construct a set of apparatus and then perform measurements on/with that apparatus to aid understanding of the theory. This focuses the theory and the lectures to what is immediately
necessary to understand, design and optimize that particular apparatus. The homework for each week is designed to be an opportunity to investigate a smaller subset of the overall ideas using a real world problem that incorporates the lecture material, text books and other reference materials, with the focus being the upcoming project. It also makes the homework very open ended – much like real-world applications – with no single correct answer but many possible incorrect answers.

Detailed Project Examples

The above concepts are illustrated with some examples from the hydroelectric power generation section of the class. The project for this section involves analyzing an existing, small scale, hydroelectric plant owned by our university located on a remote biology field station. The property consists of several hundred acres of forested land on a private, undeveloped island, including two small fresh water lakes connected by a stream, some laboratory and dorm buildings and a small (35 KVA) hydro electric power generation station. The text for this section of the class is the *Micro Hydro Design Manual*, an excellent field guide for evaluating, designing, and building a small scale hydroelectric system. The history of hydro generation, basic fluid dynamics, pipe flow, power generation using various turbines, and site evaluation are covered in class to prepare students for a weekend field trip to the island.

The first homework assignment requires the students to perform an evaluation of the site to determine if they would recommend building this existing power plant on that site. Each student receives a detailed TOPO map of the island (Figure 3), a USGS report describing regional ground water recharging rates, an article on calculating water runoff from various land formations, links to local weather stations, and links to information on how to calculate evaporation rates. The homework assignment refers to the text and describes the overall steps required to perform the analysis. The same basic homework has been assigned each year the class has been taught, and to date, not many students have completed the assignment without making significant errors. In fact, the only students that have made the correct recommendation have done so by making several significant counteracting errors in their analysis. Each year the instructor reviews the homework and determines the common errors the students make. If there is a common pattern to the errors, course notes are updated to better scaffold the learning so that the students are more prepared to take advantage of the information provided in the references.

Past errors for this assignment and include: Not properly calculating the size of the watershed, not accounting for local micro climate variation in rainfall, not properly accounting for the percentage of the rainfall that makes it into the lake, and not properly estimating the evaporation from the lake. Noting the types of errors has resulted in changes in

Figure 3. TOPO map of the island.
the course. For example, putting more emphasize on the variability of rainfall in the region (from 20 to 60 inches per year) has reduced rainfall estimates errors.

This assignment also provides the students a first-hand glimpse at a real-life application. It turns out that the answer to the overall problem is that the site is not a good candidate for the hydroelectric generation plant. Each year the plant can run for at most 3 months. The project sponsor, apparently, did not perform an adequate analysis of this site before commissioning the hydro plant. The construction company also did not advise the client of this error. This is a very good learning experience for the students – even the professionals make mistakes.

The second homework assignment for this project involves calculating the expected volume flow rate and power generated from a small scale turbine using various head heights, pipe diameters and nozzle diameters, and comparing these results to actual field measurements on the island. Students measure the volumetric flow rate at three different head heights, using three different diameter pipes and six different diameter nozzles hooked up to a 5,000 gallon water tank located on the island as shown in Figure 4. A small Pelton turbine generator (Figure 5) is connected to each of the pipe configurations and the power generated is measured under various load conditions. This becomes a multi-parameter optimization problem which is difficult for the students to evaluate without significant guidance. The students can now produce estimates that are within ten percent of the measured values.

The most difficult concept for the students to learn is the matching of the flow rate to the turbine and the electrical load. Although the students can work with the related equations, they do not have an intuitive feel for what is going on or how the various factors interact until they take and analyze the data in the field. Again, this illustrates the value of hands-on learning.

As part of the post project analysis, the students calculate the maximum power versus load for each of the head heights, pipe diameters and nozzle diameters. Results are presented to the class in graphical form, and the class evaluates the results in a discussion format. After significant discussion the students begin to see the interaction of the various variables and have a better feel for the formulas in the text. Only after seeing the operation of the small scale turbine and working with the data do they begin to appreciate the problem of matching the volume flow rate of the water to the turbine and load on the generator. On the last day of the field trip, the class tours the existing 35 KVA commercial hydroelectric plant (Figure 6) to get a better understanding of this technology.
Program Assessment

An assessment plan is and will continue to be implemented to evaluate the program outcomes in Table 1. The assessment plan includes evaluation of the outcomes for specific courses (Table 2) as well as a comprehensive assessment of the overall program. Quantifiable metrics for each of the stated outcomes in Table 1 provide the basis of the assessment plan. The outcomes for specific courses will be evaluated using the techniques outlined above for EGR 3611 (i.e., pre- and post-testing), along with student evaluations. Assessment of the internship is achieved through evaluations completed by the student’s supervisor and student assessment in the follow-up internship class. The comprehensive assessment of the program outcomes is based on the approach used to evaluate specific course outcomes. A comprehensive pre-test given during the freshmen year covering all of the outcomes in Table 1 provides the basis of student knowledge coming into the program. The same test will be given to the outgoing seniors to determine the gain in student learning. Finally, alumni will be surveyed five years after graduation to assess the student’s ability to apply the knowledge learned. Courses will be changed as needed based on the course assessment results, as outlined above for EGR 3611. A comprehensive program review will be conducted every five years to make programmatic changes based on the comprehensive assessment outcomes.

Summary

This new concentration focused on Appropriate and Sustainable Engineering is aimed at addressing our environmental footprint in the developed world though sustainable engineering solutions while addressing the needs of the world’s poor through development of appropriate technology. Students will receive a broad-based engineering background coupled with hands-on, design oriented applications of appropriate and sustainable engineering solutions. In addition, students learn to understand the implications of technology on the global society, the economy, and the environment through application electives and the university liberal arts core curriculum.

Bibliography


