Environmental education for all engineers


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Abstract Environmental engineering education at universities is a rapidly changing field globally. Traditionally it has resided in the civil engineering program addressing water and wastewater quality, treatment, design and regulatory issues. In recent years environmental engineering has become a much broader field encompassing water, wastewater, soil pollution, air pollution, risk assessment, ecosystems, human health, toxicology, sustainable development, regulatory aspects and much more. The need to introduce environmental engineering/green engineering/pollution prevention/design for the environment concepts to undergraduate engineering students has become recognized to be increasingly important. This need is being driven in part through the US Engineering Accreditation Commission Accreditation Board criteria 2000. Thus there has been a major shift in environmental engineering education and it no longer resides only within the civil engineering discipline. This paper focuses on the development of innovative curricula for a brand new engineering program at Rowan University that integrates environmental education for all engineers. A common course known as "engineering clinic" was developed for all engineering students throughout their eight semesters of engineering education. One of the clinic goals is to integrate engineering design and the environment. The program, in its seventh year, indicates successful implementation of environmental education in all four engineering disciplines in their course work and clinics.

Keywords Clinic; education; engineering; environmental; green

Introduction

Rowan University was founded in 1923 as Glassboro State Teachers College. Over the years it has evolved into a comprehensive regional state university with six colleges. The College of Engineering was initiated as a result of a major donation in 1992 from the Rowan Foundation (Rowan and Smith, 1995). A local industrialist Henry M. Rowan made this generous contribution to establish an innovative engineering program that would provide a quality education meeting the challenges of the 21st century. Thus the College of Engineering has a brand new engineering building, including state-of-the-art equipment and computer resources, and a dedicated and extremely competent diverse faculty.

The College of Engineering at Rowan University is composed of four departments: Chemical Engineering; Civil and Environmental Engineering; Electrical and Computer Engineering; and Mechanical Engineering. The class sizes are limited to 20 to 25 students in each discipline to guarantee quality education. This class size not only allows specialization in separate departments but also assures the easy integration of a truly multi-disciplinary curriculum in which laboratory/design/research experiences are offered simultaneously to all engineering students in all four disciplines. As a brand new program the College has had the flexibility of incorporating novel methods of teaching to address the US Engineering Accreditation Commission Accreditation Board for Engineering and Technology (ABET) criteria 2000.
The Rowan Engineering program strongly supports an innovative curriculum that emphasizes quality undergraduate education integrated with innovative design and multidisciplinary research experiences (Jahan et al., 1997). The need to introduce environmental engineering/green engineering/pollution prevention/design for the environment concepts to undergraduate engineering students has become recognized to be increasingly important (Wells, 1997) and is required by ABET criteria 2000. ABET criteria 2000 further requires the integration and implementation of a broad education to understand the impact of engineering solutions in a global context. The Rowan engineering curriculum was thus developed with the above criteria in mind and fully supports the integration of basic components of environmental education for all engineering students. The College of Engineering has a novel curriculum in which all students enroll in “engineering clinic” classes every semester (Jahan et al., 1998; Marchese et al., 1997). These classes are designed to stimulate students’ interests in multidisciplinary open-ended challenging engineering projects, which are mainly research or industry sponsored.

**Engineering clinics**

Beginning in the freshman year, all students enroll in clinics and work with students and faculty from all engineering disciplines on laboratory experiments, real-world design projects, and research projects of increasing complexity. Key clinic features include: (a) creating inter- and multidisciplinary experiences through collaborative laboratories and coursework; (b) stressing total quality management (TQM) as the necessary framework for solving complex problems; (c) incorporation of state-of-the-art technologies (d) and creating continuous opportunities for technical writing and communication (Johnson et al., 2001a,b). In addition to the clinics, specialized courses are taught to deliver a well-blended combination of the impact of engineering design and the environment.

The major hallmark of the engineering clinic sequence is engineering design. The clinics help engineering students to incrementally learn the science and art of engineering design and provide a base for the students to understand the relationship of the environment, pollution prevention, ethics and laws to engineering design. The clinics allow students to apply knowledge from concurrent coursework and also to be exposed to topics that might be taught formally in future classes. The engineering clinics allow students to be part of a multidisciplinary team. It further allows students to practice oral and written communications and teamwork skills in a multidisciplinary environment.

The overall objectives of the engineering clinics as outlined in the course syllabus are to:

1. Demonstrate expanded knowledge of the general practices and the profession of engineering through immersion in an engineering project environment of moderate complexity.
2. Demonstrate an ability to work effectively in a multidisciplinary team.
3. Demonstrate acquisition of new technology skills through use or development of appropriate computer hardware, software, and/or instrumentation.
4. Demonstrate understanding of business and entrepreneurial skills by developing a business plan, market plan, venture plan, or other approved instrument.
5. Demonstrate effective use of project and personnel management techniques.
7. Integrate engineering professionalism and ethics in their work and as it relates to the context of engineering in society.
8. Demonstrate improved communication skills including written, oral, and multimedia.
   Conduct a patent search and write a patent disclosure for novel work.
9. Utilize information obtained from sources that cross geopolitical and language barriers.

Table 1 indicates an overview of the engineering clinic content in the 8-semester engi-
Table 1 Overview of course content in the 8-semester engineering clinic sequence

<table>
<thead>
<tr>
<th>Year</th>
<th>Engineering clinic theme (fall)</th>
<th>Engineering clinic theme (spring)</th>
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</thead>
<tbody>
<tr>
<td>Freshman</td>
<td>Engineering measurements</td>
<td>Competitive assessment laboratory</td>
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<tr>
<td>Sophomore</td>
<td>16-week multidisciplinary design</td>
<td>16-week multidisciplinary design</td>
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<tr>
<td></td>
<td>project/composition and rhetoric</td>
<td>project/public speaking</td>
</tr>
<tr>
<td>Junior</td>
<td>Product/process development or research</td>
<td>Product/process development or research</td>
</tr>
<tr>
<td>Senior</td>
<td>Multidisciplinary capstone design/research</td>
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</tbody>
</table>

neering clinic sequence. Students earn a total of 24 credits through the engineering clinics. As shown in the table, each clinic course has a specific theme although the main theme of engineering design pervades throughout. The table further indicates the innovative infusion of formal technical writing and public presentation in the sophomore clinics. Faculty from the College of Communications teach these components alongside with the engineering faculty (Newell et al., 1999). Students thus acquire important communication skills that are much needed in their junior and senior engineering courses and clinics.

**Freshman clinic**

In the first semester of the freshman year, students learn basic engineering skills (problem solving, teamwork fundamentals, engineering measurements). Students are introduced to a variety of activities relevant to the four engineering disciplines (Hesketh et al., 1998; Jahan et al., 1998). This is followed in the second semester by intense study of engineering design through reverse engineering (“dissection”) and competitive assessment (instrumentation, testing and side-by-side comparison of technical performance) of a consumer product (Jahan, 1999; Farrell, 1999). Products examined include hair dryers, water filters, electric toothbrushes, beer brewing processes, electronic mouse and remote-control cars. The rationale behind using reverse engineering is that it allows the students to study engineering design of practising engineers. Students are required to make observations and research the environmental issues as relevant to the design of their product. Environmental topics typically include life cycle analyses (recyclability, reuse, disposal) and use of green materials and processes for manufacturing their product. If relevant, human health implications are also studied. The Rowan curriculum therefore addresses environmental education for all of their engineering students as early as their freshman year.

**Sophomore clinic**

The sophomore clinic focuses on engineering design with special emphasis on two major environmental topics: alternate energy sources and sustainable development. Faculty from all four engineering disciplines participate in this course alongside with the writing and public speaking faculty.

The design project for the fall semester typically is to investigate the use of biofuels as an alternate source of energy (Jahan et al., 2002). Biofuels are alcohols, ethers, esters, and other chemicals made from cellulosic biomass such as herbaceous and woody plants, agricultural and forestry residues, and a large portion of municipal solid and industrial waste. The students are assigned to design, build and test a semi-autonomous robot that uses power provided by batteries charged up with energy generated from microorganisms metabolizing glucose. The project provides insight to the world’s dependence on fossil fuels, sources of fossil fuel, environmental pollution from fossil fuels and global politics. It encourages all engineering students to think about the need for a clean, safe source of energy for the future generations.
The sophomore clinic in the spring semester focuses on sustainability (Hollar and Sukumaran, 2002). All 56 colleges and universities in New Jersey recently joined together to endorse a Sustainability Greenhouse Gas Action Plan for New Jersey. In signing this “sustainability covenant,” Rowan University has pledged to reduce its greenhouse gas emissions to 3.5% below 1990 levels by 2005. This agreement is the basis for a novel collaboration between the New Jersey Higher Education Partnership for Sustainability (NJHEPS) and the College of Engineering at Rowan University. Sophomore students from all engineering disciplines calculate CO$_2$ emissions for the university and propose methods for further reducing greenhouse gas emissions. Again this clinic is a venue for encouraging students to focus on sustainability and understand the role of engineers in sustainable development.

**Junior/senior clinic**

The junior and senior clinics emphasize multidisciplinary design on projects of progressive complexity. The majority of these projects are funded by local industry, faculty research grants or departmental budgets (Jahan et al., 2001; Gabler et al., 2000). Students work on projects suggested by industry, government, non-profit, and community groups, and entrepreneur/faculty interests. By the junior/senior years, students are well equipped to embark on completely original, entrepreneurial enterprises or design of experiments or products as relevant to their specific interests. Students in these clinic projects again have to address environmental issues as relevant to their project. Issues such as life cycle analyses, use of green materials and processes, regulations etc. are topics that must be addressed.

The eight semesters of engineering clinics at Rowan University thus provide a solid base on important environmental topics relevant to engineering design and the practice of engineering. The clinics are an innovative venue for providing environmental awareness and education to all engineering students.

**Discipline specific activities**

Apart from the engineering clinics, all four engineering disciplines have integrated environmental education in their curriculum. The traditional environmental engineering program resides within the civil and environmental engineering program at Rowan University. The program offers traditional courses in environmental engineering as indicated in Table 2.

The Civil and Environmental Engineering program also has adopted an innovative design project entitled Garden City (Everett et al., 2001). This project is similar to Sooner City, a design project at the University of Oklahoma (Kolar et al., 2001). Sooner City has already been recognized as an educational reform worthy of widespread adoption. Both Garden and Sooner City projects integrate open-ended civil engineering design in the curriculum. For the project, incoming students are given a plat of undeveloped land that they develop into a blueprint for certain segments of the city (time constraints prevent the design

**Table 2** Traditional environmental engineering courses

<table>
<thead>
<tr>
<th>Year</th>
<th>Course</th>
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<tr>
<td>Sophomore</td>
<td>Introduction to environmental engineering</td>
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<tr>
<td>Junior</td>
<td>Water treatment and design</td>
</tr>
<tr>
<td>Senior</td>
<td>Wastewater treatment and design</td>
</tr>
<tr>
<td>Senior elective</td>
<td>Hazardous waste management</td>
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<tr>
<td>Senior elective</td>
<td>Integrated solid waste management</td>
</tr>
<tr>
<td>Senior elective</td>
<td>Fate and transport of organic pollutants</td>
</tr>
<tr>
<td>Senior elective</td>
<td>Advanced wastewater treatment</td>
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</table>
of an entire city) by the time of their graduation. Design tasks include all facets of the traditional civil engineering program, such as site planning and layout, sewer and water infrastructure, water supply, wastewater treatment, solid waste management, buildings, transportation systems, channel design, floodplain analysis, and geotechnical work. Courses listed in Table 2 in the junior and senior years have a Garden City design component.

The introduction to environmental engineering course addresses common environmental engineering topics. In order to educate students about global environmental issues in a societal, political context, the course has a team project. This project allows students to research a major environmental incident outside the USA to understand the impact of regulations, politics, social customs and laws, land geography on environmental pollution. Project topics that have been assigned are presented in Table 3.

The civil and environmental engineering program at Rowan University also offers a two-semester industry sponsored traditional senior capstone design project (Cleary and Jahan, 2001). The course focuses again on open-ended traditional civil engineering projects that include common topics like engineering drawing, map reading, planning, cost estimation, scheduling, project management, regulations, site development and engineering design. The project typically also has an environmental component that requires students to study environmental impact statements, environmental regulations and environmental law as relevant to the project needs. Typically students work in teams of four or five.

The chemical engineering program has made bold steps to integrate green engineering concepts in all their courses (Hesketh et al., 2002). An exclusive senior elective/graduate course in design for pollution prevention is also offered every fall semester. The course is intended to provide the students with an understanding of current technology in the design field specifically molded for energy conservation, waste minimization and pollution prevention at the source by process modification and pollutant interception. The course does not follow a particular text since it covers a wide variety of topics. The students are first introduced to environmental regulatory law and the relationship between industrial activity and the environment. The rest of the semester is then devoted to developing the necessary skills to design and retrofit processes so the environmental impact is minimized.

The electrical and mechanical engineering programs also have incorporated environmental education in their traditional coursework. For example sophomore ECE students are made aware of the significant effect that electrical generation has on the environment. The fact that while generators are quite efficient, the means for turning them via boilers and steam turbines are quite deleterious to the environment (<35% efficient) in terms of heat generated, pollutants discharged (NOₓ, SOₓ) and the electric industry ranks high as one of the largest in the creation of greenhouse gases (CO₂) is made known to the students. In electronics, students are encouraged to work on their semester paper on pollution caused by the semiconductor industry. Mechanical courses specifically address design for the environment and use of green materials and processes in manufacturing.

Finally by the senior year all engineering students are encouraged to take the multidisciplinary sustainable design in engineering elective, which covers both design issues and international aspects of sustainability. The course presents the case for global sustainability, the engineer’s role in design, an overview of energy use and electricity production

<table>
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<tr>
<th>Table 3</th>
<th>Team project for introduction to environmental engineering</th>
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<tr>
<td>Arsenic contamination of groundwater in Bangladesh</td>
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<tr>
<td>The Union Carbide catastrophe in India</td>
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<td>Thor Chemical contamination in South Africa</td>
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technologies, energy management and conservation techniques, photovoltaic system design, alternative methods for design incorporating sustainability issues (i.e., life cycle assessment (LCA) techniques and computer modeling), ISO 14000 information, as well as a host of examples of how corporations consider LCA in new or modified product design. By the end of the course, the students are able to intelligently discuss the international and global issues that make sustainable design important and indicate that they understand the technology options for providing electricity to society and the features of energy use.

The College of Engineering also has a multiyear NSF funded grant titled “Research experiences for undergraduates in pollution prevention”. This project allows engineering students to work during the summer with a faculty on research promoting pollution prevention.

Conclusions
The Rowan engineering curriculum is innovative and effective in providing students meaningful environmental education as early as their freshman years. Engineering clinics represent a novel platform for incorporation of environmental topics throughout the four-year curriculum. The Rowan engineering curriculum has been highly successful in integrating environmental topics relevant to engineering design and practice through traditional coursework, clinics and externally funded grants or projects.

References


