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Sustainability Across the Curriculum*

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This paper deals with the innovative curriculum developed at the College of Engineering at Rowan University to integrate sustainable development across the undergraduate curriculum. Teaching modules focus on the concept of sustainable development for infrastructure, chemical, electrical, mechanical and environmental systems. These modules have been developed for all levels of engineering courses starting from the freshman to the senior classes. Implementation of course content is easier than traditional engineering programs, as the college has multidisciplinary "clinic courses" for all engineering students. Sustainability concepts have also been reinforced in traditional engineering classes and via service learning activities. Service learning activities are promoted through the Engineers without Borders Student chapter.

Keywords: sustainability; green engineering; curriculum

INTRODUCTION

ENGINEERS PLAY a major role in the development of world economy, which is tied to innovation in product development, faster production and efficient utilization of materials and energy. However, to reach the illusive goal of "sustainable societies" engineers have to address the reduction of the negative impacts of these processes upon humans and their environment. The traditional engineering curriculum focused more on mathematics, science and technology, with little emphasis on the impact of engineering activities on society. It is only in recent years, since the ABET 2000 criteria [1] was implemented, that attention has been focused on issues such as ethics, green engineering, community impact and sustainability.

Sustainability is intimately related to pollution prevention. The term "sustainable development" has been widely used in scientific, business, and public institutions since it was first defined in the Bruntland Commission's *Our Common Future* in 1987 [2]. Sustainable development in that context refers to "development" that meets the needs of the present without compromising the ability of further generations to meet their own needs. It is imperative that science and engineering education and research focus on pollution prevention and sustainability simultaneously. Traditional engineering education has lacked a systematic approach to decision making that is guided by ethics, justice, equality and a holistic knowledge base that goes beyond a particular specialization [2].

Ritter [3] indicated that the USEPA definition of green engineering was more broadly defined recently as "transforming existing engineering disciplines and practices to those that lead to *sustainability*. Green Engineering incorporates development and implementation of products, processes, and systems that meet technical and cost objectives while protecting human health and welfare and elevating the protection of the biosphere as a criterion in engineering solutions." The USEPA [4] has developed nine green engineering principles which engineers should follow to fully implement green engineering solutions:

1. Engineer processes and products holistically, use systems analysis, and integrate environmental impact assessment tools.
2. Conserve and improve natural ecosystems while protecting human health and well-being.
3. Use life cycle thinking in all engineering activities.
4. Ensure that all material and energy inputs and outputs are as inherently safe and benign as possible.
5. Minimize depletion of natural resources.
6. Strive to prevent waste.
7. Develop and apply engineering solutions, while being cognizant of local geography, aspirations and cultures.
8. Create engineering solutions beyond current or dominant technologies; improve, innovate and invent (technologies) to achieve *sustainability*.
9. Actively engage communities and stakeholders in development of engineering solutions.

The need to introduce green engineering/sustainability concepts to undergraduate engineering students has become recognized as increasingly important all around the world [5–7]. In the USA, the Engineering Accreditation Commission (ABET) in their criteria for 2004–2005 advocates the integration and implementation of a broad education to understand the impact of engineering solutions in a global, economic, environmental and societal context. Discipline specific criteria, such as in chemical engineering, further specify that engi-

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neers must have "ethics, safety and the environment" included in the curriculum. Several international professional engineering accreditation bodies from New Zealand, Australia, South Africa, Ireland and Canada have similar wording to that in the USA accreditation requirements [8–12]. The United Kingdom requires that chartered and incorporated engineers must "undertake engineering activities in a way that contributes to sustainable development" [13]. Therefore there is a tremendous international consensus of accreditation bodies on the importance and urgency of introducing green engineering and sustainability concepts in engineering education.

In recent years, NSF has funded a number of educational efforts to include green engineering and sustainability issues (DUE #0410516, EEC #0353744, DUE #0088501). Most of these efforts have typically resided in a specific program at the lead institution. Certain institutions, such as Purdue University (EPICS Program), the University of Dayton (ETHOS program), Colorado University at Boulder (ITL Center), the University of Pittsburg (Mascaro Center for Sustainability), Virginia Polytechnic and State University (green engineering focus within their B.Sc. program), Carnegie Mellon (Green Design Institute), the University of Texas at El Paso (Sustainable Engineering Initiative) and Georgia Tech have focused on integrating green engineering, sustainable development and service learning into engineering education in the last couple of years, with very positive and encouraging outcomes.

ROWAN UNIVERSITY

The College of Engineering at Rowan University is incorporating teaching modules that focus on the concept of sustainable development for infrastructure, chemical, electrical, mechanical and environmental systems. "Sustainable", in a broad sense, indicates technologies that are low cost, easy to maintain and minimize adverse environmental impacts.

The initiative is based on an evolving vision of "science and technology for sustainability" [2] that is:

- *anchored* in concerns for human conditions and the environment globally;
- *conservative* of basic life support systems and biodiversity; and
- *integrative* of bridging efforts across the natural, social and engineering sciences, the environment and development communities, multiple sectors of human activity, geographic and temporal scales and, more generally, the worlds of knowledge and action.

The Rowan engineering program strongly supports an innovative curriculum that emphasizes quality undergraduate education integrated with innovative design and multidisciplinary research experiences [14–15]. Established in 1996, the Rowan engineering curriculum was developed with the ABET 2000 criteria in mind and fully supports the integration of basic components of environmental education for all engineering students. 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 25 to 30 students in each discipline to guarantee quality education.

EXISTING CURRICULUM

Engineering clinics

The Rowan engineering program has a novel curriculum in which all students enroll in "engineering clinic" classes every semester [16–17]. These classes amount to a total of 20 credits over the four years. Clinic classes are designed to stimulate students' interests in multidisciplinary open-ended challenging engineering projects. The clinic structure is presented in Table 1. The earlier freshman and sophomore clinics focus on faculty-directed engineering projects that primarily include environmental education and sustainable development themes.

Freshman clinic

The freshman clinic exposes incoming students to the engineering profession and engineering design. The first semester focuses on building soft skills such as technical writing, oral presentations, data analyses and plotting. Students conduct experiments that focus on engineering measurements [18–19]. Lectures on engineering ethics,

Table 1. Overview of course content in the eight-semester engineering clinic sequence

Year	Engineering Clinic Theme (Fall)	Engineering Clinic Theme (Spring)
Freshman	Engineering Measurements	Reverse Engineering
Sophomore	16-Week Multidisciplinary Design Project (Project Theme: Biofuels)	16-Week Multidisciplinary Design Project (Project Theme: Sustainability for the Rowan Campus)
Junior	Product/Process Development or Research; Service Learning	Product/Process Development or Research; Service Learning
Senior	Multidisciplinary Capstone Design/Research Project	

professionalism and sustainability are included to ensure that all engineering students have an early exposure to these important topics.

The second semester of the freshman clinic focuses on an intense study of engineering design through reverse engineering of a consumer product or a commercial process [20–22]. Products examined include hair dryers, soccer helmets, refrigerators, water filters, electric toothbrushes, and remote-control cars. Processes have included beer processing and water filtration. The reverse engineering theme allows students to research engineering design, including engineering drawings and development of intrusive and non-intrusive experiments for product testing. The entire semester-long project further allows students to study and research the environmental issues related to the design, processing and manufacturing of their product. Students investigate life cycle analyses (recylability, reuse, and disposal) and use of green materials and processes for manufacturing of their product. Students are also introduced to the famous "cradle to grave" and "design for the environment" (DFE) terms.

Recently an aquarium has been introduced as a reverse engineering product [23]. This theme adds a valuable component on the impact of engineering on aquatic life, ecosystems and the environment. An aquarium is an exquisite combination of interacting systems which can be analyzed using multidisciplinary engineering principles. Students are engaged in the scientific discovery process using exciting hands-on activities which are used to introduce chemical, mechanical, electrical, civil and environmental principles. The aquarium theme also adds to the need for an understanding of biological systems, ecosystems, pollution prevention and sustainable development. Students can learn first-hand the impact of their engineering design or decisions on aquatic life. The aquarium theme is also used to investigate ethical, social and environmental issues through classroom and homework activities. These topics bring tremendous strength to the theme, as engineers of the future must have a fundamental understanding of their role in the design and analysis of complex interacting systems, as well as the relevance of ethical and social issues in maintaining a sustainable society.

The Rowan curriculum therefore has integrated topics of pollution prevention, green engineering and sustainability for all of their engineering students as early as their freshman year.

Sophomore clinic

The sophomore clinic focuses on engineering design that investigates alternative energy sources and sustainable development. The National Renewable Resources Laboratory (NREL) projects that biomass resources can eventually provide over 50 percent of transportation fuel, reducing dependence on foreign sources of energy, alleviating air pollution problems, and increasing employment opportunities [24]. During the fall semester, students investigate the use of biofuels as an alternative source of energy [25–26]. This topic was selected to encourage students to investigate the dependence of the USA on fossil fuels and the need for a safe, environmentally friendly fuel technology for future generations. Students are exposed to global politics about fossil fuels and the environmental pollution caused by such fuels. The project requires students to design, build and test a semi-autonomous Lego robot that uses power provided by batteries charged with energy generated from microorganisms metabolizing glucose. Students are provided with biofuel cell kits developed by Benetto [27–28]. Benetto [29] has developed simple and advanced experiments to demonstrate microbial generation of electricity. A simple microbial fuel cell costing less than £50 is available from the National Center for Biotechnology Education at the University of Reading. The robots are constructed using the Lego Mindstorms^{TM} System 2.0 Kit. The project generates a lot of excitement, as the class final ends with a Robot race through a maze. The entire experience is a valuable learning exercise in sustainable development for a better world.

The sophomore clinic continues in the spring semester and builds on the sustainability theme. A more realistic project is proposed to the students. This project is sponsored by the New Jersey Higher Education Partnership for Sustainability (NJHEPS). In recent years, 56 colleges and universities in New Jersey endorsed a Sustainability Greenhouse Gas Action Plan for the state. Rowan University, as part of this "sustainability covenant," has agreed to reduce its greenhouse gas emissions to 3.5% below 1990 levels by year 2005. Sophomore students from all engineering disciplines are required to calculate CO_2 emissions for the university and propose methods for further reducing greenhouse gas emissions [30]. Students analyze the data and propose low-cost solutions to improve energy efficiency. Solutions investigate alternative energy sources that can be incorporated into the future growth of the university. Economic analysis on any short-term and long-term costs or savings associated with implementing low-cost solutions and/or alternative energy sources are also researched.

Junior/senior clinics

The upper level clinics are more open ended and the projects vary in nature depending on the research grants or faculty interests. The upper level clinics have provided a venue for faculty to conduct applied or fundamental research, which is mainly research or industry sponsored. Entrepreneurial projects are also sponsored via the NCIIA program [31]. Students are also engaged in developing products to participate in the National Professional Organization Competitions, such as the ASCE concrete canoe and steel bridge, the IEEE Micro mouse competitions, etc. Students in

these clinic projects have to address environmental and sustainable development issues as relevant to their project. Another recent addition to the upper level clinics has been the service learning projects sponsored by the Engineers without Borders Student chapter.

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 every semester till they graduate.

Discipline specific measures

Apart from the engineering clinic courses, every engineering discipline at Rowan has also taken measures to include sustainability in their curriculum. The environmental engineering courses reside in the Civil and Environmental Engineering (CEE) program. These are presented in Table 1. All CEE students are required to take two courses in environmental engineering in their junior year. These classes focus on environmental engineering fundamentals such as mass and energy balance, ecosystems and sustainability. Water and wastewater treatment and design, solid and hazardous waste regulations and management are also an integral part of these courses. Both these courses include topics, problems and projects that address sustainability. For example the wastewater treatment plant design project requires students to explore wastewater reuse options for a golf course. Students also explore energy use from methane gases released during anaerobic digestion. Other courses that have sustainability modules include the civil engineering materials, transportation and geotechnical courses. Students are exposed to the use of materials such as rubber tire scraps in asphalt pavements and the use of geomembranes in landfills as liners in order to prevent groundwater pollution.

The Chemical Engineering program has successfully integrated green engineering and sustainable development topics in all their courses [32–34]. This effort was initiated through funding received from the USEPA in 1999. Course material is disseminated via a dynamic website (www.rowan.edu/greenengineering). Table 2 presents all the chemical engineering courses that have course content addressing green engineering.

The Electrical and Computer Engineering (ECE) program has made considerable efforts to include topics on sustainable development in their traditional courses by taking innovative measures. The Power Systems Fundamentals course for sophomore ECE students uses examples to expose the intimate relationship between electricity generation and the environment [35]. Students learn that the electric industry ranks high as one of the largest in the creation of greenhouse gases (CO_2) and also for pollutants discharged (NOx, SOx) to the air. The production of inert ash in coal combustion facilities and its disposal and reuse are also discussed. Photovoltaic system design is also a part of this course. In electronics, students specifically work on a semester paper on pollution caused by the semiconductor industry. Finally, by the senior year all engineering students are encouraged to take the multidisciplinary Sustainable Design as an elective. This course is offered by the ECE program and addresses both design issues and international aspects of sustainability. The course presents an overview of the need for global sustainability and the role of engineers in developing sustainable design, energy management and conservation techniques. Life Cycle Assessment (LCA), 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 are major elements of the course.

Mechanical courses specifically address design for the environment and use of green materials and processes in manufacturing. A mechanical engineering design elective called Design for X is currently offered to expose students to topics such as design for the environment, design for disassembly and design for recyclability.

Table 2. Traditional environmental engineering courses

Year	Course
Junior	Environmental Engineering I:
(Required for all CEE Students)	Fundamentals such as Mass Balance and Reactor Kinetics
	Water and Wastewater Treatment and Design
Junior	Environmental Engineering II:
(Required for all CEE Students)	Air Pollution
	Solid and Hazardous Waste Management: Regulations and Remedial Technology
Senior Elective	Site Remediation
Senior Elective	Integrated Solid Waste Management
Senior Elective	Fate and Transport of Organic Pollutants
Senior Elective	Advanced Wastewater Treatment

Table 3. Potential green engineering concepts integrated into chemical engineering courses at Rowan University

Chemical Engineering Course	Green Engineering Topic
Mass & Energy Balances	Emissions Terminology/Calculations
	"Green" Material and Energy Balances; LCA (Life Cycle Assessment)
Mass Transfer/Equilibrium Stage Separations	Mass Separating Agent
	Risk Assessment
Material Science	Estimation of properties, LCA
Heat Transfer	Introduction to Heat Integration
Chemical Thermodynamics	Estimation of Chemical Properties
Separation Processes	Pollution Prevention Strategies
	Novel "Green" Separation Process Integration
	Case Studies; LCA
Chemical Reaction Engineering	Pollution Prevention Strategies
	Green Chemistry; Case Studies; LCA
Process/Plant Design	Heat Integration & Mass Integration
	Flowsheet Analysis
	Case Studies; LCA
Process Dynamics & Control	Pollution Prevention Modeling and Control
Unit Operations Laboratory	Green Engineering Experiments

Recently the college identified courses that currently include sustainability topics and courses that need to integrate sustainability. This is presented in Table 4. This is a college-wide effort to promote and integrate sustainability so that any engineering student graduating from Rowan University has a fundamental understanding of the global need for "sustainable societies". Efforts are in place to develop lessons, activities and assignments that will adopt the sustainability theme in courses that currently do not have well-developed modules. It is anticipated that by 2008 all courses will have a sustainability component.

REU SITE IN POLLUTION PREVENTION AND SUSTAINABILITY

The College of Engineering established an NSF (National Science Foundation) REU (Research Experiences for Undergraduates) in pollution prevention and sustainability in 2001 [36–39]. This program provides science and engineering students with the opportunity to work with a professor during the summer on research promoting pollution prevention and sustainability. The initiative is based on current global efforts to integrate sustainability into the science and engineering curriculum. This program has been extremely successful in terms of student applications, as many comment that the overall theme is very attractive. Students in the past have worked on research subjects such as:

- Arsenic Removal in Drinking Water
- BugPower: Fueling our Future with Microorganisms
- Metal Removal from Industrial Wastewater
- Developing "Green" Controlled Release Systems for Drug Delivery
- Use of Jute in Strengthening Asphalt Mixtures
- Stormwater Management in Chestnut Branch Watershed
- Environmentally Conscious Disassembly of End-of-Life Computers
- Chemical Kinetic Model Development and Flow Reactor Studies of Biodiesel Fuel Blends
- Long-Life Smart Structures for Laser Data Transmission
- Invertebrates as Bio-indicators of the Water Quality of the Maurice River
- Design of Detoxifying Systems for Organonitriles Mediated by Cyanogenic Enzymes

The program also includes workshops on environmental ethics, environmental justice and community impact via pollution. The REU program has been successful in helping students from other traditional colleges and universities to learn about issues related to global sustainability. Students are assessed on the impact of the REU theme and the REU workshops. Assessment results indicate that the students leave the REU program with a better understanding of their roles in developing "sustainable societies".

SERVICE LEARNING AND SUSTAINABILITY

Rowan has integrated Engineers without Borders (EWB)-USA into its curriculum through its upper level junior and senior engineering clinics. EWB-USA is a non-profit organization, founded

Table 4. Engineering courses at Rowan University that will integrate sustainability topics

General	Civil and Environmental	Electrical and Computer	Mechanical	Chemical
Freshman Clinic	Reinforced Concrete Design	Network I	Applied Heat Transfer	Material & Energy Balances
Sophomore Clinic	Analysis and Design of Steel Frames	Network II	Biomechanics	Mass Transfer/ Equilibrium Stage Separations
Engineering Materials	Bridge Design	Electronic I/II	Product Design	Material Science
Fluid Mechanics	Geotechnical Engineering	Digital II	Thermodynamics	Heat Transfer
Statics	Foundations	Computer Architecture I/II	Design for X	Chemical Thermodynamics
Solid Mechanics	Civil Engineering Materials	Engineering Frontiers	Mechanical Design and Synthesis	Separation Processes
Dynamics	Transportation Engineering	Clinic Consultant	Combustion	Chemical Reaction Engineering
Junior Clinics	Solid and Hazardous Waste Treatment	Advanced Microprocessor Design		Process/Plant Design
Senior Clinics	Water and Wastewater Treatment and Design	An Introduction to Nanoelectronics	Machine Design	Process Dynamics & Control
	Site Remediation Principles	Power System Fundamentals		Unit Operations Laboratory
	Design of Masonry and Timber	Advanced Power Systems		
	Water Resources Engineering	Sustainable Design		
	Environmental Fluid Mechanics			

Note. Shaded courses indicate existing sustainability component.

in 2000, which helps underdeveloped communities around the world with their engineering needs [40]. Its mission is to introduce sustainable solutions that can be maintained by each host community, while developing a more globally aware engineer. Rowan students have worked on two major EWB projects: one in Honduras and the other in Thailand. Both projects required students to develop water distribution systems for poor communities. A brief description of the trip to Honduras is provided below.

The Honduras project focused on the community of Mataderos in the Yoro District of Honduras. This community was in dire need of potable water and the focus of the project was to develop a water distribution and wastewater management system for this community [41]. This project presented a challenging opportunity for the Rowan engineering students, as they had to apply their engineering theory to a real-life problem that was not only outside of the classroom, but also outside of their country!! Students had to first understand the culture of the community of Mataderos by researching the history of Honduras and its society. The project thus presented social, cultural, and environmental challenges along with the need of technical expertise. The students in the USA have easy access to precipitation, land use, power and water use data. In this case no such data was available. Students recognized that they had to devise a solution that had to work for the people of Mataderos, who did not even speak English and the literacy rate was poor. The water system would have to be simple so that an uneducated person could operate and maintain it on a daily basis. The Honduras government further imposed restrictions on materials, stating that all materials

would have to be purchased from Honduras. Thus, the project became much more than just an academic exercise. The families of Mataderos were depending on the efforts of Rowan students to improve their lives. Students through their research identified that the people of Mataderos are all descendants of the indigenous people of Honduras. They all live very similar lives and practice the same faith, with very little economic distinction between them. A team of students along with a faculty adviser travelled to Honduras for an inital survey of the situation and to develop some engineering plans for solving the water crisis. On return, one of the Rowan students summarized the impact of the EWB project as follows:

The people of Mataderos are not people of privilege. They have reached out to EWB-USA, because they were deemed marginalized or not contributing to Honduras on the whole. Even by their own country's standards they are poor. It is humbling for someone from an US university to experience the lifestyle in Mataderos. By American standards they have nothing, but by simply spending a little time with them one is struck by the notion that while they may be the most impoverished people one could ever meet, they are also the most generous. An engineer could only realize this lesson from this type of engineering project and while it isn't technical, it is one of the most profound lessons anyone could learn.

CONCLUSIONS

The College of Engineering at Rowan University has taken numerous initiatives to integrate sustainability throughout their curriculum. Efforts have been made to integrate alternative energy sources and energy consumption, life cycle analyses, and design for the environment topics as early as the freshman and sophomore years for all engineering students. Discipline specific courses are also integrating sustainability topics. Students from all over the USA participating in the Rowan NSF REU are also exposed to pollution prevention and sustainability research experiences. These research experiences help promote the need for environmentally friendly design to maintain sustainable societies. Finally, the students have an opportunity to join the EWB chapter as early as the freshman year and become involved in service learning activities that primarily introduce sustainable solutions that can be maintained by communities throughout the world. In essence, the Rowan engineering program is focused on developing a more globally aware engineer dedicated to the development of sustainable design to promote sustainable societies.

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