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Part I
Educating Students in Sustainable Engineering (I)
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There have been widespread calls for the types of action that will create a sustainable society. As a response, sustainable development criteria have been incorporated into undergraduate engineering accreditation requirements. Engineering education is also responding, with sustainable development knowledge and skills being increasingly integrated into the curriculum at both a course and subject level. However, there has been less focus on the type of instructional strategies needed to achieve these learning outcomes. A focus on learning strategies is necessary to create the integrated and interdisciplinary perspective required for sustainability education. Active learning strategies, which use methods that can accommodate conceptually and practically diverse data and divergent epistemologies are needed. Roleplay-simulation, online debates and scenario building are active, participatory instructional strategies. These methods were applied in a subject about Technology Assessment within the context of exploring issues about science, technology and society. These methods were found to be effective for developing and demonstrating understandings about the multiple dimensions (e.g. social, technical, environmental, economic, political) of complex engineering activities. These active and participatory learning methods have a clear place in the engineering curriculum if the transformation in thinking, values and actions required for a move towards sustainability is to be achieved.

Keywords: simulation; sustainable development; e-learning; water; computer mediated communication

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

In this paper we address the need for curricular changes that foster sustainable thinking and review a number of engineering curricular changes at selected universities, drawing comparisons to medical and other fields. For each engineering program, we examined the level at which sustainability concepts and active-learning methods were integrated into its curricula. A majority of the universities examined "bolted-on" various components of sustainability or student-centered learning into their existing programs. Only one university examined has made significant efforts to redesign engineering education in terms of sustainability and pedagogy. A number of barriers hindering the re-orientation of engineering curricula toward "sustainable" engineering are discussed.

Keywords: sustainability; problem-based learning; intellectual development

This paper reports on a course that utilized problem-based learning in order to engage engineering students to develop indicators of campus sustainability. The course structure and project are evaluated against the attributes of intellectual development and learning approaches and the problem-based learning method. In addition, the degree to which students addressed the importance of balance and integration of societal, environmental and economic considerations is evaluated. A secondary intent is to offer an adaptable framework to aid other universities in developing a set of sustainability indicators. Results showed the multidimensionality of the selected indicators.

Keywords: sustainable development; sustainability; indicator; university; problem based learning

Science, engineering and technology (SET) are critical to achieving and maintaining a high quality of life, economic growth, global competitiveness, a clean environment and effective governance for the public good—some of the key characteristics of sustainability. A nation's ability to meet these goals significantly depends on the capacity and competency of its workforce to develop innovative products, processes and services that advance prosperity while maintaining and restoring environmental systems. In order to continue towards this paradigm shift, advance sustainability in the long term and supply a skilled and knowledgeable workforce to both the private and public sectors, educating the next generation in sustainability is critical. Engaging women and underrepresented groups in SET will build additional capacity in these fields that are critical to advancing economic, environmental and societal goals. There is an increasing amount of anecdotal evidence which shows that students are remarkably enthusiastic about education for sustainability and are engaged at many levels both within and outside the classroom. There may be several unique characteristics to the ideas and visions of sustainability that may contribute to making this concept especially attractive to women and underrepresented groups.

Keywords: sustainability; recruitment; retention; women; underrepresented groups; diversity; environment; green engineering

Many universities espouse the idea that discipline integration is a prerequisite for successful implementation of sustainability in education. However, few engineering curricula have taken the step to integrate concepts of sustainable development with an international experience. This paper discusses the professional, educational and global drivers for curricular change in this important area and demonstrates how an undergraduate International Senior Design and graduate Master's International program, both of which are based on international sustainable development, can be integrated into an Undergraduate Minor and Graduate Certificate to provide a more interdisciplinary basis for educating engineers on global concepts of sustainability. Importantly, the paper also discusses whether such initiatives may result in improvement of diversity in the engineering student population.

Keywords: diversity; graduate certificate; interdisciplinary education; international senior design; masters degree; sustainable engineering; sustainability; undergraduate minor

Sustainable energy development is satisfying the energy needs of the present generation without compromising future generations in satisfying these same needs. It encompasses three areas: economy, environment and society. Producing energy in a sustainable manner can be accomplished through energy efficiency and renewable sources of energy, among others. Sustainable energy education must be structured in an interdisciplinary manner whereby engineering modules are complemented with legal, social, economic, managerial and environmental coursework. Seminars complement academic instruction. Developing skills in these non-engineering areas is achieved through group projects with non-engineering students.

Keywords: sustainable development; energy; masters; University of Calgary; OLADE; LAC

This paper begins by describing the evolution of the concept of green design over the last several decades. In its earliest form, the focus was on reducing waste, pollution, and resource use. In its current form, it includes the concepts of sustainability and industrial ecology, adding in a focus on nature and the future. This reflects a shift to renewable resources as well as considering the impact of technology on society. The author recommends two additional principles that need to be more explicitly incorporated into green design: ecological constraints and natural systems as models. A succinct definition of green design is proposed: green design means practicing engineering with the inclusion of natural systems, both as a model and as a fundamental consideration, for the improvement of the quality of all life. Following this introduction is a description of how these principles have been incorporated into first-year engineering courses. In the author's course, students are introduced to key concepts through readings, videos, lectures, and exercises, and then they apply the concepts to hands-on projects including cardboard furniture and loudspeaker redesign. A comprehensive summary of tools, resources and techniques is presented.

Keywords: green design; sustainability; first-year; biomimicry

A new sequence of courses at Carnegie Mellon University exposes students to concepts in the emerging discipline of Sustainable Engineering and prepares them to play leadership roles in the years ahead. This sequence includes four half-semester courses: (1) Introduction to Sustainable Engineering; (2) Industrial Ecology and Sustainable Engineering Design; (3) Life Cycle Assessment, and (4) Case Studies in Sustainable Engineering. Students successfully completing this sequence have an appreciation for the myriad ways in which engineering decisions can affect the environment and for the responsibilities of engineers in helping society cope with future challenges.

Keywords: sustainability; sustainable engineering; education; college courses

A course in 'Sustainability and Design for Environment' has engaged engineering, science, architecture, forestry, business administration, law and public policy students at the University of Washington since 1998. The course is divided into two distinct phases. Phase 1 constructs a Design for Environment (DFE) knowledge base in each individual student through lecture and homework assignments. Topics have evolved to include interactions between technology and the environment, design and other types of decision making, energy efficiency, environmental management for industrial processes, materials selection in product design, product delivery and use, product design for recovery and disassembly, environmental and cost metrics and implementation issues. Phase 2 further develops DFE knowledge through an interdisciplinary team project. Evolution of the team project has taken students from the development of a business plan, a streamlined 'Life Cycle Assessment', or disassembly process design for a company that will collect, refurbish, disassemble and recover postconsumer electronic materials to the development of a rating system for a product, process or activity of their choice based on, for example, the LEED Green Building Rating System, the US Environmental Protection Agency's Energy Star programme, or the US Department of Energy's Energy Guide programme. The five-fold growth in enrolment in the class that has occurred since its inception mirrors the growth in the number of environmentally focused courses and degree programmes on the campus. Co-listing the course in different units allows more students to use the course towards their degree and should ensure a continuing interdisciplinary mix of students.

Keywords: design for environment; interdisciplinary pedagogy; sustainability; team projects

Technical innovation is necessary but should not be overestimated on the way towards sustainability. Asking ourselves what kind of knowledge and skills engineers need for a more sustainable design of technologies, processes and products, we came to at least three answers: 1) Knowledge about targets and impacts: scientific knowledge about possible impacts on health, safety and the environment and on 'carrying capacities' of socio-ecological systems (sources and sinks); 2) Knowledge about technologies and interventions: methods to analyse and evaluate technologies, processes and products and to design more sustainable and robust solutions; 3) Knowledge about innovation processes, about the complexity of socio-economic systems (e.g. innovation systems) and knowledge about the options for engineers to influence processes within these systems, as well as skills that lend the ability to make optimal use of these options. The curriculum development in the Division of Technological Design and Development at the University of Bremen's Production Engineering Department can thus be summarized by the terms 'impacts', 'methods' and 'innovation processes', with a scope that is influenced strongly by the emerging field of industrial ecology. One of the strengths of our research and course programme is the full integration with the rest of the engineering department making both very practice orientated. We attach special importance to the taught knowledge being relevant in everyday engineering practice and implement this, among other things, by complementing our lectures and seminars with field trips, guest speakers from academia and industry, and interdisciplinary student projects in co-operation with other divisions and industry partners.

Keywords: sustainability; knowledge building; innovation systems; curriculum development; interdisciplinary education

'Greening' the engineering curriculum is an important consideration for sustainable engineering education from fundamentals to design in the 21st century. This paper describes the latest advances in an educational project sponsored by the United States Environmental Protection Agency (EPA) to integrate green engineering principles into the chemical engineering curriculum. This project has engaged faculty from engineering schools across the country to develop Web-based instructional modules to allow for the seamless integration for green engineering principles such as risk concepts, green chemistry, mass and energy integration, life-cycle assessment into chemical engineering courses. Faculty have contributed to chemical engineering core courses from material and energy balances to plant design. In addition, faculty have developed modules for multidisciplinary offerings such as freshman-level introduction to engineering and upper-level system dynamics and control. This paper will review some of the innovative modules developed and show how they can be used in the chemical engineering curriculum. This educational project's goal is to integrate green engineering concepts horizontally and vertically into the curriculum by taking existing courses and integrating topics as appropriate through examples, problems and case studies. Using green engineering principles at the start of the design process can lead to processes and products of a sustainable future.

Keywords: curriculum development; green engineering; pollution prevention; sustainability; web-based course modules

Part II
Contributions in: Engineering Education Research and Policy, Engineering Mathematics, Engineering Management, Mechanical Engineering, Chemical Engineering, Manufacturing Engineering and Robotics

Engineering educators may have a sincere desire to enhance student learning but be unsure how to choose from a wide array of pedagogies. The aims of this paper are to: (i) delineate situational factors that influence the risks, benefits and implementation strategies of pedagogical choices and (ii) present a systematic approach to guide educators in choosing an optimal pedagogy. Using engineering design analysis methods, this paper presents a pedagogical assessment tool that accounts for factors related to students, course, instructor and institution. This tool may be useful for designing a course, continuous improvement of curriculum and optimizing allocation of resources.

Keywords: cooperative learning; decision matrix; inquiry-based learning; pedagogy; problem-based learning; project-based learning; service learning; subject-based learning

To help students grasp the intimate connections that exist between mathematics and its applications in engineering, a library of interactive learning modules was developed. This library covers the mathematical areas normally studied by undergraduate students and is used in engineering courses at all levels. Moreover, the library is designed not just to provide critical connections across disciplines but also to provide longitudinal subject reinforcement as students progress in their studies. In the process of developing the modules, a complete editing and publishing system was constructed that is optimized for automated maintenance and upgradeability of materials. The result is a single integrated production system for web-based educational materials. Included in this is a rigorous assessment program, involving both internal and external evaluations of each module. As will be seen, the formative evaluation obtained during the development of the library resulted in the modules successfully bridging multiple disciplines and breaking down the disciplinary barriers commonly found in their math and engineering courses.

Keywords: engineering mathematics; mathematics library learning modules; disciplinary barriers

In the face of mandated reductions in curriculum credit hours, a series of one-credit engineering science (45–60 hours for completion) modules have been developed at the University of Arizona to maintain breadth of engineering sciences and to better prepare students for passing the Fundamentals of Engineering examination. The set of modules includes engineering economics. The courses are taught in a web-based format with opportunity to interact with faculty and teaching assistants during live and electronic office hours. In this paper, we report on the development effort and the difficulties involved in faculty buy-in and in course development. We have run two experiments with the site and our results on learning and student attitudes are included.

Keywords: web-based learning; engineering economics; assessment

This paper presents the experiences and perceptions of undergraduate computer science and computer engineering students from Minority Serving Institutions with regard to the classes, teachers, academic advisors, and teaching assistants within their programs. It is based on 150 in-depth interviews with female and male students, members of five major ethnic/racial groups (White, Black, Hispanic, Asian, and American Indian). It shows that significant differences exist between female and male students with respect to their perceptions of classes, teachers, and advisors. Both male and female students noted their dissatisfaction with teaching assistants. The paper concludes with suggestions regarding policy directions to improve the situation for female students.

Keywords: academic advisement; minority-serving institution; pedagogy; retention

This paper examines the results of an international team-based operations management assignment that runs between two universities. The work shows the benefits of giving students a taste of real-life operations management problems both from a technical point of view as well as the challenges faced when working to short timescales, with unfamiliar team players and across time zones. The work has generated valuable understanding of the approach required to set up such inter-institution assignments. It has enabled a process model to be developed to allow others to extract the key stages required for setting up and running them.

Keywords: operations management; international team assignment; educational technologies

This paper deals with a Web-based Integrated Knowledge-based Inter-discipline Study Portal (IIDSP) for teaching/learning of inter-disciplinary study modules in engineering and management education. A portal has been developed on an integrated knowledge-based approach within engineering, computational sciences and management domains. A due regard is focused on preparation of labs, exercises, simulation procedures and case studies applying the newest achievements of multimedia techniques and the means of visualization. The experience of six European Union countries has been used. Each partner as an informative agent represents his/her own development integrated via the Internet Web and forms the entire common educational system. Within an individual site, the site controller controls his/her own activities and communicates with other sites via the portal through the network interfaces. It is a multi-user method which combines the techniques of HTML, Java/Tapestry application framework and Web server Apache Tomcat. The presented development is intended to update the educational process in universities and colleges and to raise the vocational qualification of company engineers. It is being implemented both in university education process and in industry for employees re-training.

Keywords: engineering and management; inter-disciplines; portal; study modules; web-based education

Traditionally, the goals of engineering laboratory instruction have been to introduce students to various measurement devices along with associated methods of interpreting results in the context of experimental uncertainties. There is usually an emphasis on the demonstration of fundamental engineering principles in applications-oriented projects. Often, theoretical engineering models are used to compare predicted outcomes with the experimental results in order to demonstrate the appropriateness and/or limitations of the theoretical model. When making these comparisons, the uncertainty associated with an experiment's measurements is usually included; however, there is seldom consideration of the uncertainty associated with the theoretical model calculations. Students in the Mechanical Engineering (ME) program at Mississippi State University (MSU) are applying the concept of engineering model validation using uncertainty analysis. In this paper, their experiences are used to illustrate how this approach has been implemented in the undergraduate laboratory classes. The methodology is developed for model validation, and a case study from our senior mechanical engineering laboratory is presented which illustrates how the uncertainty of the model is combined with that from the experimental result to provide a quantification of the model's validity.

Keywords: uncertainty; experimentation; modeling; validation; laboratories

Engineers constantly design and reconfigure automated systems to accommodate shifts in product design or manufacturing priorities. Often engineers require years of experience to become expert in this area. This paper addresses the motive, contents, and evaluation of a web-based robotic workcell design tool kit created to help students learn the design process systematically. The motive is based on interviews with application engineers at system integration companies. Components include problem, design and analysis. In addition, the toolkit allows the instructor to add new design problems that can capture users' mouse movements and key selections for research and teaching purposes.

Keywords: Robotic workcell; engineering design; automated manufacturing systems; system integration

This paper introduces a chemical process automation virtual laboratory to teach programmable logic component (PLC) programming to chemical engineering students. The virtual laboratory was used in the practice part of an electrical engineering course and focuses on the basic automation of chemical processes. The students have been provided with the open CoDeSys software and the initial program (containing the virtual process simulation) created by the instructors. The students developed their own applications both in local practices and at home. In the local classes they can exchange doubts and ideas with the other students and the instructors. Based on students' course completion surveys, the experience has proved to be positive.

Keywords: project-based learning; PLC programming; chemical engineering; virtual laboratory

Rapid prototyping technologies (RP) enable solid models to be obtained from designs generated using CAD applications. Their increasing popularity in industry is due to the reductions in cost and time associated with the use of these models when verifying product development stages and improvements in end quality. However, these technologies can also be applied to enhance students' active learning in the teaching of multiple subjects connected with product development. Students can bring their designs to fruition and check any decisions taken in an economically acceptable way. This work shows how RP technologies can be exploited for teaching, using the full development of a gear pump. The work has been carried out with educational aims in the Product Development Laboratory of Madrid Polytechnic University (UPM), for the subject Design and Manufacturing with Polymers.

Keywords: educational innovation; collaborative learning; stereolithography; vacuum casting; machine design; rapid prototyping.