DESIGN AND RESEARCH ACROSS THE CURRICULUM

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Abstract **¾** *The College of Engineering at Rowan University was initiated as a result of a $100 million donation in 1992 from the Rowan Foundation. The engineering faculty use innovative methods of teaching and learning to better prepare students for entry into a rapidly changing and highly competitive marketplace. To best meet these objectives, the four engineering programs of Chemical, Civil and Environmental, Electrical and Computer, and Mechanical Engineering have common engineering clinic classes throughout their programs of study, in which undergraduates work in teams on hands-on open-ended projects. The primary goal of Rowan University's engineering clinic classes is to immerse students in multidisciplinary design/research projects that teach engineering principles in both laboratory and real-world settings. While most traditional engineering schools provide students a taste of independent research well into their senior year in some form of capstone design, the Rowan engineering program experience allows students to be exposed to the intricacies of realistic open-ended engineering research and design as early as their freshman years. This paper focuses on the innovative engineering curriculum developed at Rowan University.*

Index Terms **¾** *Research, Design, Engineering, Clinics*

INTRODUCTION

Founded in 1923 as Glassboro State Teachers College, Rowan University 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 [1]. The Rowan Engineering program strongly supports curriculum-wide emphasis on quality undergraduate education integrated with innovative design and multidisciplinary research. The College of Engineering has a novel curriculum in which all students enroll in '*engineering clinic*" classes every semester [2]-[4]. These classes are designed to stimulate students' interests in multidisciplinary open-ended challenging engineering projects, which are mainly research or industry oriented. 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 multi-disciplinary 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. In addition to the clinic, specialized courses are taught to deliver a well-blended combination of theoretical and practical skills.

The Rowan University College of Engineering has a brand new engineering building, including state-of-the-art equipment and computer resources, and a dedicated and extremely competent faculty. Rowan Foundation's generous gift has enabled the university to establish perhaps the most innovative and forward-thinking engineering program in the country.

This paper focuses on the innovative design and research experiences that the four engineering disciplines provide at Rowan University through the engineering *clinic* classes and other discipline specific courses.

ENGINEERING CLINICS

The 4-year, 24-credit Engineering Clinic sequence offers students at Rowan University the opportunity to incrementally learn the science and art of design by continuously applying the technical skills they have obtained in traditional coursework. We have seamlessly infused design into all levels of the curriculum by developing an 8-semester course sequence called the Engineering Clinic. In the Engineering Clinic, students learn the art and science of design in a multidisciplinary team environment. The Engineering Clinic allows students to practice communications and teamwork skills in a multidisciplinary environment while honing their design skills throughout their four-year career.

The overall objectives of the engineering clinics are to:

(i) Demonstrate expanded knowledge of the general practices and the profession of engineering through immersion in an engineering project environment of moderate complexity.

(ii) Demonstrate an ability to work effectively in a multidisciplinary team.

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(iii) Demonstrate acquisition of new technology skills through use or development of appropriate computer hardware, software, and/or instrumentation.

(iv) Demonstrate understanding of business and entrepreneurial skills by developing a business plan, market plan, venture plan, or other approved instrument.

(v) Demonstrate effective use of project and personnel management techniques.

(vi) Meet customer needs.

(vii) Integrate engineering professionalism and ethics in their work and as it relates to the context of engineering in society.

(viii) Demonstrate improved communication skills including written, oral, and multimedia. Conduct a patent search and write a patent disclosure for novel work.

(ix) Utilize information obtained from sources that cross geopolitical and language barriers.

In the first semester of the freshman year, students learn basic engineering skills (problem solving, teamwork fundamentals, engineering measurements) and are introduced to the variety of activities in each of the four disciplines at Rowan (Chemical, Civil and Environmental, Electrical and Computer, and Mechanical Engineering) [5]. 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 [6]-[7]. In this manner, students are introduced to design by studying the designs (good or otherwise) of practicing engineering designers. Past products examined include hair dryers, water filters, electric toothbrushes, beer brewing processes and remote-control cars, to name a few. Other topics included in this semester are engineering ethics and intellectual property, both of which complement well the course themes of reverse engineering/competitive assessment. To support the Freshman Clinic, we have received funding from the National Science Foundation in 1998 to build five "competitive assessment stations"– customized workstations with a PC, data acquisition, temperature, pressure and flow transducers, function generators, and oscilloscope. The sophomore clinic focuses on design taught from the viewpoint of the four disciplines: chemical, civil, electrical & computer, and mechanical [8]-[9]. In the sophomore year, the Clinic's emphases shift to technical communications skills and the application of design. The students are organized into "corporations" that design and build products using advanced engineering tools while developing their speaking and writing skills through the embedded assignments [10]-[11]. 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. Clearly, projects such as these are central to developing the design, problem solving and project management skills that are lacking in the traditional engineering coursework. 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.

Typical Junior/Senior Engineering Clinic Project Life

The typical life of an engineering clinic project starts well before the first day of the semester. Professors meet with industry/local government to develop and scope the difficulty level of a project to upper level engineering students. The professor must also engineer the project to have outcomes that can be achieved within one and two semesters that will satisfy the students and the sponsor. Finally a budget is prepared for the project and negotiations are undertaken with the company to finalize the agreement. In many cases this includes a confidentiality agreement with the company and the university. The above steps take at least a year to obtain a clinic project agreement. Traditional funded research projects are also offered through the upper level clinics. Funding has been obtained from the National Science Foundation, the USEPA, US Army and Navy and state agencies (NJDOT, NJWRRI, NJDEP).

DISCIPLINE SPECIFIC ACTIVITIES

Civil and Environmental Engineering

Apart from the engineering clinics, the Civil and Environmental Engineering program at Rowan University has also adopted an innovative curriculum project entitled Garden City [12]. This project is similar to Sooner City, a design project at the University of Oklahoma [13]-[14]. Sooner City has already been recognized as an educational reform worthy of widespread adoption. NSF has showcased the project for two consecutive years in the NSF Project Showcase at the ASEE national conferences. Both Garden and Sooner city projects are in response to the call for more design in the curriculum, a call being made by the engineering accrediting agency, by practitioners who are dissatisfied with the design skills of graduates, and by faculty who want to promote higher-level thinking skills and improve retention. For the project, incoming students are given a plat of undeveloped land that, by the time they graduate, will be turned into a blueprint for certain segments of the city (time constraints prevent the design of an entire city). 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, buildings, transportation systems, channel design, floodplain analysis, and geotechnical work. A common, four-year design project unifies the curriculum and allows material learned in early courses to carry forward, unlike the "traditional" paradigm wherein courses frequently stand as independent entities with no apparent connection. Also, the project allows students to develop a professional design portfolio that can be presented to perspective employers, be used as a valuable reference for future design tasks [13]. The primary goal of the Garden City project is to produce graduates who can consistently think at a higher level, and who are thus capable of handling open-ended design projects that require creativity, exploring alternative solutions, self-analysis, and awareness of economic, social, and political issues.

The Civil and Environmental Engineering program at Rowan University also offers a two-semester industry sponsored traditional senior capstone design project [15]. The project is a real traditional civil engineering project that reinforces drawing, map reading, planning, cost estimation, scheduling, project management, regulations, site development and engineering design. Students work in teams of four or five. Oral presentations and written reports are also an integral part of this course. The presence of real practitioners and a real project impacts students in numerous ways. Industrial sponsors may have already completed the projects themselves or they may be addressing them simultaneously with the students. One or two faculty members coordinate the course. The coordinator(s) are responsible for selecting the project and administering the course including the bulk of the evaluation effort. The remaining faculty serve as consultants to the students and coordinator. The student teams function as independent consulting firms with one student serving as the team leader. It is anticipated that within a team, individuals will split the work along discipline specific lines. However, students are expected to be familiar with all aspects of the work and will likely have to carry part of the load in more than one sub-discipline. The industry sponsors initially present the project to the student teams and attend and assist in evaluating mid and end-of-semester oral presentations. The industry sponsors also provide pertinent site data and help the coordinators scale the project to a level that can be managed by senior engineering students.

Chemical Engineering

The design experience in chemical engineering is also integrated throughout the chemical engineering courses. A chemical production project is started in the sophomore year (2^{nd} year) and students continue to work on this project in their remaining 3 years. Each year, a new design project is introduced. For example, this years project for the 2^{nd} year class (graduating in 2001) is cumene production from benzene and propylene. In this year they conduct mass and energy balances around the chemical production plant. They also conduct preliminary cost analysis of raw materials and operating costs. In subsequent courses of heat transfer, equilibrium stage operations, reactor design, separations they conduct a detailed design of specific units. For example with the cumene production students will design distillation towers to remove propane, excess benzene and other byproducts from cumene. This analysis will include add capital costs and operating costs of this equipment. The design project is completed in their senior (4^{th} year) by integrating each component into the overall plant design. Then steps are taken to optimize the plant. In each of these courses aspects of green engineering are introduced. In this manner chemical engineers will consider environmental implications at the beginning and subsequent stages of the design process.

Many of the engineering clinic projects are sponsored by industry in chemical engineering. In these projects, industry supplies a problem of interest and provides financial resources and industrial personnel. These interactions create an exciting, challenging and practical engineering experience for our engineering undergraduates. The impact of clinic projects on students has resulted in the following outcomes:

1. Understanding of the economics of high value added chemicals
2. Design, fabrication and operation of new and innovative technologies
3. Examination of scale-up from laboratory scale at Rowan to pilot plant scale
4. Experience with direct interaction of students with plant operators, chemists, engineers and managers.

An example of a chemical engineering project at Rowan University in which a student team works with industry is provided below.

Campbell's Soup Company sponsored a team of students to research cutting edge technologies applied to the processing of vegetables for soups and juices. The multidisciplinary team comprised two undergraduate chemical engineering students, one civil engineering student, and one biology student. In addition, one chemical engineering master's student served as the project manager. Through this project, students investigated advanced membrane separation techniques as well as enzymatic, thermal, and physical/mechanical treatment techniques applied to vegetable processing. Their responsibilities included HAZOP analysis, project planning, budget formulation and management, literature and patent reviews, experimental design, data analysis, and developing a proposal for a second phase of the project. In addition to the engineering expertise the students acquired through this work, they gained familiarity with FDA regulations on food processing. Engineers from Campbell have demonstrated a high level of commitment to the project and to student learning by attending monthly progress meetings. This industrial interaction helped maintain a high level of motivation among the students, and helped maintain focus and a fast pace of productivity. In addition to the progress meetings, the student team also conducted a lunch-and-learn seminar at Campbell's to share their research with engineers, scientists, and marketing representatives from the company. The enthusiastic response of the audience at Campbell's reaffirmed the industrial relevance and impact of the team's research.

Electrical and Computer Engineering

The ECE program has been structured to provide sufficient breadth and depth in a combination of Electrical Engineering (EE) and Computer Engineering (CpE) topics so as to meet ABET accreditation requirements in both. That is, only a single ECE degree is offered. This dual objective combined with the credit load of the Engineering Clinics, means that a variety of approaches have been employed to achieve success. One of the most marked features of the Rowan ECE program is the *absence* of traditional separate laboratory courses. Standard EE and CpE programs normally include a variety of laboratory courses such as Electronics, Digital Systems, Communications, and others. At Rowan, the Engineering Clinics constitute a substantial laboratory component, but they are largely uncoupled from regular courses. In order to obtain focused laboratory experiences, a lab component has been *designed into* the majority of the ECE courses. Examples of courses with lab components include

- Networks I and II (Sophomore)- Basic circuit theory courses include labs to acquaint students with simulation (P-Spice) and electrical measurements using standard bench instrumentation (Oscilloscope, DMM, function generator, power supply).
- Digital Systems I (Sophomore)- Introductory digital systems course includes a companion FPGA laboratory experience.
- Digital Systems II (Junior)- The first course in microprocessors heavily incorporates lab experiences.
- Electromagnetics I and II (Junior)- The electromagnetics courses include lab experiences to amplify electrostatics and transmission line concepts.
- Electrical Communications (Junior)- Communication theory concepts including analog and digital communication techniques are treated in a series of companion labs.

The spectrum of design within the ECE curriculum spans small design exercises in conjunction with course topics, through semester-long design projects within a course, to the full-semester Engineering Clinic design projects. The use of "project-based" instruction is a method that is being further developed. For example, in the introductory electronics course, we have developed an approach termed *Macroelectronics*, which emphasizes system-level concepts as opposed to the exclusively device-oriented view.

The Engineering Clinic exposes students to design in the broadest possible context—i.e., solving multidisciplinary design problems that are not directly connected to a specific course content. However, building strong discipline-specific design skills requires significant design experiences within courses. To this end, a number of courses include a significant project-based component [16]-[19]. For example, in the Macroelectronics approach used in electronics, we seek to accomplish the following:

1. Introduce fundamental concepts of electronic systems through the use of macroelectronics.
2. Employ a project-based learning environment to increase motivation.
3. Selectively cover microelectronics topics, partially guided by project requirements.

The design project takes on an essential role in this method. Projects help students see the relevance of classroom material; in addition, the projects become a source of topics that can be explored in the classroom. Example Macroelectronic design projects have included a semiconductor curve tracer, function generator, power supply, audio amplifier, and digital multimeter. Because each instrument design project constitutes a system in addition to being a collection of electronic subsystems, students gain a more complete grasp of the total technologies involved.

Rowan has a very small full-time graduate enrollment (12 students). This has a marked impact on the ability of faculty to conduct modest-scale research projects. However, the Engineering Clinic has served as one means to support certain types of research efforts for the ECE faculty. Prime candidates for ECE Clinic projects are research projects requiring the development of custom experimental apparatus. Projects of significant scale may spawn design elements in several environments. For example, recent work involving small-particle studies included Clinic projects and was also used as a project in an instrumentation course [16]. Our experience suggests that it is often easiest to link pairs of disciplines together; for example, Mechanical

Engineering (ME) and ECE. Projects carefully designed to include at least two disciplines in full measure often-return very good results. In a recent project sponsored by the New Jersey Department of Transportation [20], the research goal was to develop advanced methods of automobile crash detection and reporting. This project sponsored a number of Engineering Clinic projects that supported teams of ME and ECE students. The net design goals were achieved using substantial work performed though the Clinic. In return, a significant number of students obtained a real-world design experience that they leveraged into jobs and/or graduate school.

Mechanical Engineering

Most traditional mechanical engineering programs include a Capstone Design course that is meant to meet the design requirement, but this approach has some shortcomings. In a one- or two-semester long course, the need to include such varied skills as communications and teamwork necessarily takes away from the focus on design skills development. Furthermore, the traditional Capstone Design course is not multidisciplinary, which is a valuable experience for preparing students for the workplace. Finally, since the Capstone Design project occurs at the *end* of a student's undergraduate career, it does not allow students to continuously apply what they have learned in the supporting coursework. The Mechanical Engineering program at Rowan University uses the clinic classes to reinforce engineering design and research. The Sophomore Clinic is coordinated by a Mechanical Engineering faculty member and is team-taught by faculty from all four disciplines plus faculty from Public Speaking and College Composition. Past projects have included nondestructive testing devices, guitar effects pedals, design of a portable bridge and a design of a baseball stadium. In support of the Sophomore Clinic, we acquired funding from the National Science Foundation in 1997 for a rapid prototyping facility featuring a 3-D Systems SLA-250 stereolithography system, an Actua 3-D modeler and a Quick Circuit circuit prototyper. In 2000, we received another NSF grant to build the Creative Audio Technology Environment, a laboratory dedicated to rapid development of audio based products.

The Mechanical Engineering mantra for the Junior/Senior Clinic is "*Design, Build, Test*". To date, the Junior/Senior Clinic projects have been inspired by a mix of industry-sponsored activities and professors' interests, and typically center on a technical problem, product or process. Funding thus far has come mainly from industry and research-grant sponsorship (government and private sources). Examples of completed or ongoing projects from the ME Department are:

- Automated Crash Notification (ACN) system (Sponsored by the New Jersey Department of Transportation),
- Redesign of a Submarine Antenna Transfer Assembly (Sponsored by the NAVY Surface Warfare Center),
- Enhanced Emergency Location Transmitter (Sponsored by the New Jersey Department of Transportation)
- Coating Thickness Monitor (Sponsored by Tenneco Packaging),
- Development of a New Stair Lift Device (Sponsored by Electric Mobility Corp.), and
- Development of a Smart Rubber Material (Continental Tire).

Clearly, projects such as these are central to developing the design and problem solving skills that are lacking in the typical engineering curriculum. What is often missing, however, in the industry and faculty-created design projects, is the spirit of invention, innovation and entrepreneurship. One way to promote the entrepreneurial spirit is to provide students with the opportunity to propose their own original enterprises. Accordingly, The Mechanical Engineering Program has created the Venture Capital Fund (VCF), specifically ear-marked for the development of original products by multi-disciplinary student teams within the Junior and Senior Engineering Clinics [21]. The VCF has been funded through a series of grants from the National Collegiate Inventors and Innovators Alliance (NCIIA).

During the past 5 semesters, VCF proposals have been accepted from 11 multidisciplinary student teams. This figure represents approximately 7% of the roughly 150 Junior/Senior Clinic projects completed during this same period. In total, 17 ECE students, 15 ME students, 3 ChE students and 4 CEE students have participated in VCF projects.

CONCLUSIONS

The Rowan Engineering curriculum is innovative and effective in providing students meaningful design and research experiences as early as their freshmen years. Engineering Clinics represent a new paradigm for seamless incorporation of design/research experiences throughout the four-year curriculum. In addition to focusing on student-centered, hands-on and minds-on learning, it is multidisciplinary by design, allows for continuous practice and development of communications, teamwork and design skills, involves our constituencies, and easily incorporates the "soft" topics such as societal considerations, ethics and entrepreneurial skills. The Engineering Clinics have proven to be a critical component in our ability to accomplish multidisciplinary design. Similarly, the use of project-based instruction has led to the development of a cadre of students who are design ready. One planned improvement will be to extend project-based instruction to a broader range of courses. To help foster adaptability to other campuses, we have actively disseminated the results of our curriculum development by presenting at ASEE, FIE, AAHE, NCIIA and AIAA conferences and publishing in the International Journal of Engineering Education. Internship surveys from employers of our students for summer positions (which polled the employers on the students' technical, communications and teamwork skills) have been exemplary. And as of this date, 100% of the 2000 and 2001 graduating class have received permanent job offers or are attending graduate school.

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