

Engineering Clinics: An Integration of Research into the Undergraduate Engineering Curriculum

The College of Engineering at Rowan University had its origins in 1992 because a local industrialist, Henry M. Rowan, made a generous gift of 100 million dollars to then Glassboro State College (Chandrupatla, Dusseau, Schmalzel, & Slater, 1996). As a result of the donation, the Rowan Engineering program was started in 1996 with the primary mission of developing an innovative engineering curriculum that will produce engineers suited to meet the needs of a challenging workplace in the 21st century. The Rowan engineering program implements the use of innovative methods of teaching and learning to prepare students for entry into a rapidly changing and highly competitive marketplace (Marchese, Hesketh, & Jahan, 1997; Newell, Marchese, Ramachandran, Sukumaran, & Harvey, 1999; Dahm & Newell, 2001). The hallmark of the Rowan engineering program is a unique common set of classes known as the Engineering Clinics.

The Engineering Clinics are an eight-semester course sequence from the freshman to the senior year. The Clinics are designed to address the challenges arising from changes in engineering education requiring incorporation of more design into the curriculum. Design represents the solution of open-ended problems that challenge students to apply higher-level skills such as analysis, synthesis and evaluation.

Many engineering programs currently include a capstone design course to meet the design needs, but this approach has some shortcomings. In a one- or two-semester course, the need to include such varied skills as communications, project management and teamwork necessarily takes away from the focus on design skills development. Furthermore, the traditional capstone design course often is not multidisciplinary, which is a valuable experience for preparing students for the

workplace. Finally, the capstone project occurs at the end of a student's undergraduate career, minimizing opportunities for students to continuously apply skills learned in the supporting coursework. Engineering Clinics allows students to practice a wide range of engineering skills in a multidisciplinary environment while honing their design skills throughout their four-year career.

The overall learning objectives of the Engineering Clinics are for the students to

- demonstrate an expanded knowledge of the general practices and the profession of engineering through immersion in an engineering project environment of moderate complexity.
- demonstrate an ability to work effectively in a multidisciplinary team.
- demonstrate acquisition of new technology skills through use or development of appropriate computer hardware, software, and/or instrumentation.
- demonstrate understanding of business and entrepreneurial skills by developing business, marketing, and venture plans, or other approved instrument.



Students visiting a green building to better understand Sustainable Design Principles.

- demonstrate effective use of project and personnel management techniques.
- integrate engineering professionalism and ethics in their work and as it relates to the context of engineering technology in society.
- demonstrate improved communication skills including written, oral, and multimedia.
- conduct a patent search and write a patent disclosure for novel work.
- utilize information obtained from sources that cross geopolitical and language barriers.

Table 1 shows an overview of the clinic content in the eight-semester Engineering 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 theme of engineering design pervades throughout and is incrementally introduced. This incremental approach to teaching design and research has been shown to be beneficial (Wood, Jensen, Bezdek, & Otto, 2001). The table further shows the innovative infusion of formal technical writing and public presentation in the Sophomore Clinics. Faculty members from the College of Communications team-teach these components with engineering faculty. Thus, students acquire important communication skills that are necessary for their Junior and Senior engineering courses and clinics and for success in the marketplace.

Table 1

Overview of course content in the 8-semester Engineering Clinic sequence

Year	Engineering Clinic Theme (Fall)	Engineering Clinic Theme (Spring)
Freshman	Engineering Measurements	Competitive Assessment Laboratory
Sophomore	16-Week Multidisciplinary Design Project/Composition & Rhetoric	6-Week Multidisciplinary Design Project/Public Speaking
Junior & Senior	Multidisciplinary Capstone Design/Research Project	

In the following sections, the Engineering Clinics will be described in more detail to explain the gradual progression from the freshman to the senior year, with examples of projects from recent years.



Students coat Oreo cookies with chocolate, measure and record mass, recalculate a nutritional label and perform a simple statistical analysis as an introduction to quality control.

Freshman Clinics

The Freshman Engineering Clinic is a multidisciplinary “Introduction to Engineering” course, consisting of one hour of classroom time and three hours of laboratory time each week. This course serves as an introduction to the practice and profession of engineering through a project involving teamwork and cooperative learning, problem solving, the design process, safety, professionalism and ethics. Secondary benefits of the course include development of technical communication skills in graphical, written, and oral formats; a survey of fundamental concepts from the four engineering disciplines (Chemical, Civil & Environmental, Electrical & Computer, and Mechanical) as well as college survival skills such as time management, studying and test taking. Examples of the fall and spring semester projects are described below.

Fall Semester Projects

From the inception of the Freshman Engineering Clinic I until the fall of 2004, the laboratory part of the course consisted of one laboratory module each week, totaling three from each of the four disciplines, with engineering measurements as the central course theme. The students “tracked” through the four disciplines and were often taught by different faculty each week doing lab experiments. In the fall of 2005, the course was changed to keep students with one faculty member on one project, but the faculty emphasized the multidisciplinary nature of his/her project. Projects included food processing, carbon nanotubes, fluidized beds, Lego™ robots, sustainability, and electrical circuits, and all were based on engineering measurements.



Students determine the optimum temperature, dipping time and fluidization regime to obtain a specified average coating.

Spring Semester Projects

Freshman Clinics for the spring semester are focused mainly on engineering design through reverse engineering and competitive assessment of a consumer product (Farrell, 1999; Jahan, 1999). The underlying learning objective behind reverse engineering is explained by Sheppard (1992). Competitive assessment is the systematic testing of existing products for the purpose of improvement and comparison. Comparable products are reverse engineered to understand the mechanism(s) by which they work, as well as instrumented to comparatively assess their performance and effectiveness from both technical and economic viewpoints. Past projects included studies of the following products or processes: electric toothbrushes, soccer helmets, living aquariums, portable water filters, beer brewing, thermoelectric coolers, blood pressure cuffs, carbon monoxide detectors and engineering principles related to the human body.

Sophomore Clinics

Sophomore Engineering Clinic is focused on introducing students to open-ended design problems. Fall semester of the Sophomore Clinic is focused on a single, semester-long project, culminating in construction and testing. In the spring semester, the students are typically separated into two groups, each completing a separate project. One project culminates in construction and testing. The other typically results in a paper design or evaluation. By integrating the Sophomore Clinics engineering experience with writing and speaking classes taught by faculty from the College of Communications, the importance of communication skills are reinforced. Two examples, one each from Fall and Spring, are described below.

Fall Semester Project

The “Hoistinator” is a Sophomore Clinic crane design project conducted in Fall 2003, 2004 and 2005. Students worked in teams of four to five to design and build a crane that can lift at least 400 pounds to a height of 36 inches, using, at maximum, 150 in³ of aluminum and 50 in³ of plastic as construction materials. In addition, teams were rewarded for designing cranes that were economic and environmentally friendly, which meant that the teams also conducted lifecycle and present-worth analyses. Finally, the teams were required to design and build a digital timer circuit that would determine the exact time required for the crane to lift the weight to a height of 36 inches. All the cranes were tested with weights up to 1200 lb. The project drew upon meaningful concepts from all four engineering disciplines.

Spring Semester Project

The engineering design project for Spring 2002 and 2003 was developed to assist the University in fulfilling its commitment to reducing greenhouse gas emissions by 3.5% below 1990 levels by 2005. Sophomore engineering teams worked closely with faculty, university facilities engineers, and representatives from the New Jersey Higher Education Partnership for Sustainability (NJHEPS) to devise an action plan for reducing the University’s CO² load on the environment (Hollar & Sukumaran, 2002; Sukumaran, Chen, Mehta, Mirchandani, & Hollar, 2004). Student teams:

- Calculated greenhouse gas emissions for the university from 1990 to present according to the NJHEPS format.
- Investigated low-cost solutions to improve energy efficiency.
- Investigated alternative energy sources such as fuel cells, solar panels, and geothermal units that can be incorporated into the future growth of the university.
- Performed an economic analysis and reported any short-term and long-term costs or savings associated with implementing low-cost solutions and/or alternative energy sources.
- Formulated a well-supported, articulate oral argument for using alternative energy sources at Rowan University.

Deliverables for the course included a report detailing Rowan’s estimated greenhouse gas emissions from 1990 to the present, a midterm presentation that discussed low-cost energy saving solutions, progress reports (both oral and written), and a final presentation and report to



Students measuring temperature and power for competitive assessment of thermoelectric coolers.

the Facilities personnel and faculty that included an in-depth economic analysis of the various energy savings solutions. As a result of their analyses, the campus is in the process of implementing some of their suggestions including installation of photo voltaic panels, design of a new co-generation plant and testing and use of biodiesel fuel tractors.

Junior/Senior Clinics

Rowan Engineering Clinics in the junior and senior years change significantly because students are now prepared for more rigorous research as a result of their experience in the freshman and sophomore clinics and classes. The projects are also highly diverse in terms of their deliverables, collaborations and nature of work performed. The Clinics in the Junior/Senior year offer the faculty and students venues to conduct applied and fundamental research. The research is mostly funded, but some projects are voluntary in nature or supported by the College of Engineering. The literature contains many examples of the benefits of undergraduate research experiences (Kardash, 2000; Mabrouk & Peters, 2000; Zydney, Bennett, Shahid, & Bauer, 2002).

Collaborations and industrial partnerships range from projects with regional industry to international projects with universities and businesses. The research has been funded by various federal agencies (National Science Foundation, U.S. Environmental Protection Agency, US Navy, National Institutes of Health, Federal Aviation Administration, U.S. Department of Transportation, NASA), state and county agencies (New Jersey Department of Transportation, NJ. Division of Environmental Protection, Gloucester County Utilities Authority), foreign government agencies (Centro de Tecnología in Chile) as well as private companies (e.g. Biothane, US Filter, Lockheed Martin, Johnson Matthey, General Mills, K-Tron Electronics, Dura-Bar,

Exxon-Mobil) and research foundations (e.g. Engineering Information Foundation, Water Environment Research Foundation). The clinics at this stage also allow students to work on projects that are linked to professional organization sponsored competitions. In addition, students can even propose their own ideas and be funded through the National Collegiate Inventors and Innovators Alliance (NCIIA) Venture Capital Fund, specifically ear-marked for the development of original inventions by multidisciplinary student teams within the Junior and Senior Engineering Clinics (Marchese, Schmalzel, & Weaver, 2004). Two Junior/Senior Engineering Clinic experiences are described below.

Examples from the Various Disciplines

Since Spring 1999, the U.S. Air Force has funded Rowan University and Dr. Everett as Principal Investigator to conduct technology demonstrations at four different Air Force Bases. More than 20 different undergraduate students and two Master's students have worked on this project. A technology demonstration project was recently completed at Dover AFB, Delaware, of Biogeochemical Reductive Dechlorination (BiRD). BiRD is a process in which bacteria are stimulated to create FeS in-situ. FeS is a reduced mineral that abiotically reacts with certain chlorinated solvents, including Trichloroethene, destroying them by reductive dechlorination. Undergraduates helped conduct baseline analyses of water and sediment from the site, injected over 50,000 liters of sodium lactate and magnesium sulfate (to stimulate FeS generation), and monitored post-injection results. In Fall 2005, a clinic team is working with sediment from Lipari Landfill, a Superfund site. The students are conducting microcosm studies to determine if the BiRD process can be used to remediate the site. Teams of Civil and Environmental, Chemical, and Mechanical Engineering undergraduates have obtained real world experience through this project in site characterization and remediation, chemical analysis, data manipulation, and presentation.

Dr. Gephardt in Chemical Engineering heads one of the international clinic projects. The project involves working with universities and small businesses in Chile to develop and optimize aquaculture processes. The work has involved developing processes to manufacture natural nutrients and pigments for farmed salmon using supercritical fluid technology. Most recently, it has involved optimization of the aquaculture of abalone, a high-value culinary delicacy. The project has been instrumental in designing and implementing a monitoring and control strategy for the bath components in the

aquaculture tanks and optimization of the filtration and circulation in the process. The project requires travel to Chile in 2006 to implement the process scheme developed at Rowan University. An important aspect of the Clinic involves exposing students to Chilean culture and to Spanish, so students will study the country and learn conversational Spanish prior to their travel. During their stay in Chile, students will visit local industries and centers of cultural significance. They will live on campus and have opportunities to work and socialize with Chilean students.

Benefits of the Engineering Clinics

Assessment and Retention Data

In 2004, Dr. Harriet Hartman completed an NSF study assessing the institutional environment in the College of Engineering. A goal of this analysis was to determine whether the Engineering Clinics are favorable to women's retention, self-confidence, satisfaction and commitment to engineering. Many features of the Engineering Clinics have the characteristics of being "female-friendly (e.g. interdisciplinary teamwork, hands-on experience, integration of communication skills, entrepreneurial opportunities, industry partnerships, nurturing climate, personal faculty-student relationships, and the relatively high proportion of female role models). Because these features of the engineering program overlapped with curricular and climate reform advocated by those trying to help more women succeed in engineering, they were expected to help women (and all other students) feel that they belong and can develop as engineers, and to encourage their persistence in the program to its end.

All undergraduate female engineering students participated in the study and the male students were studied as a comparison group. Students were surveyed during required courses, which ensured a high response rate that was less biased toward those particularly committed to engineering. Official transcripts provided records of academic achievement and focus group interviews were held with female students.

Hartman and Hartman (2004) reported that overall, the gender differences in background characteristics like family income and parental education levels and pre-college preparation seem balanced, without one gender having much advantage or disadvantage when compared with the other. In terms of pre-college math and science background, females had fewer computer science courses before



Assembling the "Hoistinator".

Students measuring blood pressure for various arm elevations (study of engineering principles related to the human body).

college than their male counterparts but they had several advantages over the male students in terms of participation in extra curricular math- or science-related activities, participation in honors math and science classes, and higher grades in high school science classes. They also noted that females enter Rowan with less self-confidence that they belong in engineering and with less self-confidence in their engineering abilities. This is not a generalized lack of self-confidence: the female students do not have less confidence in their overall academic abilities or communication skills. This entering gap in self-confidence is reduced after as little as one year and participation in extracurricular activities makes a particularly important contribution as compared to males. At this point, Rowan females have higher engineering self-confidence than female engineering students in other programs as shown by the WEPAN Pilot Climate Survey (Brainard, Metz, & Gillmore, 1998), and the gender gap in self-confidence at Rowan is smaller.

When Hartman and Hartman (2004) compared retention and graduation rates, it was apparent that engineering students dropped out of their majors at lower rates than the entire campus. Most notable however, is the data on retention of female engineering students shown by 6-year graduation rates. Table 2 shows increased retention through graduation reflected by significantly higher graduation rates than historical comparisons. It has been shown (Strenta, Rogers, Russell, Matier, & Scott, 1994) that the persistence rates of women in science, math and engineering majors varies between 30 to 46 percent, depending upon the type of institution. Graduation rates for Rowan's women engineering students average 69%.

Table 2 Graduation rates for cohorts 1996-2001: Females

Freshman Cohort	N Females	Graduated from an Engineering Major			Graduation Rate (Percent)		
		4 yr	5 yr	6 yr	4 yr	5 yr	6 yr
1996	15	12	0	0	80%	80%	80%
1997	16	7	2	0	44%	56%	56%
1998	17	9	1	0	53%	59%	59%
1999	19	14	1	0	74%	79%	79%
2000	24	17	1	.	71%	75%	.
2001	14	13	.	.	93%	.	.

Source: Rowan University Institutional Research and Planning (10/28/05)

Students Pursuing Graduate Degrees

The Engineering Clinics at Rowan University have also fostered a strong research environment, especially as evidenced by the percentage of students pursuing graduate degrees. Figure 1 shows the percentage of students pursuing graduate studies from each cohort class starting with our first graduating class in 2000. The total percentage over the five years for both males and females ranges anywhere between 15 and 35%. The percentage of women pursuing graduate studies ranges between 13 and 33%, compared to a national average of 17% (Reynolds & Tietjen, 2001). The percentage male students pursuing graduate studies is also very high and though it fluctuates from year to year, it ranges between 12% and 40%. This has been a very positive impact of the Engineering Clinics in fostering a spirit of enquiry and therefore research.

Figure 1

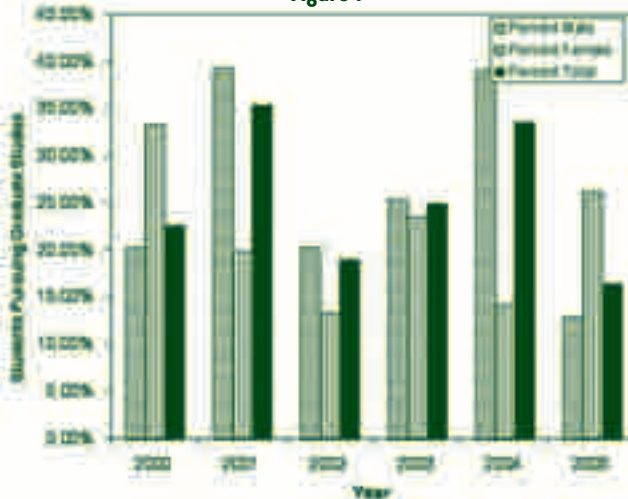


Figure 1: Percentage of Students Pursuing Graduate Degrees



Collection of soil samples for the BiRD Demonstration Project.

Conclusions

The Rowan Engineering curriculum is innovative and effective in providing students meaningful design and research experiences as early as their freshman years. The Engineering Clinics have proven to be a critical component in our ability to accomplish multidisciplinary design and implement meaningful research experiences. Similarly, the use of project-based instruction has led to the development of a cadre of students who are design-ready. Communication skills, both oral and written, are also strengthened through numerous writing and presentation activities. Student retention, especially for women, is significantly improved due to the close faculty-student interaction, a facet of the Engineering Clinic experience. The percentage of students pursuing graduate studies is also significantly improved. The clinics are a successful tool for conducting and disseminating research results that are publishable in educational and technical conference proceedings and peer reviewed journals. A survey of faculty publications in past years indicates that the faculty and students publish over 200 articles annually on average (files kept by College of Engineering Clinic Committee). The Clinic experiences result in numerous faculty/student awards and entrepreneurial achievements, including one patent with three more patents pending approval.

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