Introducing Emerging Technologies into the Curriculum through a Multidisciplinary Research Experience

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Abstract
This paper describes Rowan University's novel approach to integrating emerging technologies into the chemical engineering curriculum. Through an eight-semester project-based course sequence, every engineering student works in multidisciplinary on a series of projects, many of which are sponsored by regional industries. In addition to providing a mechanism to introduce emerging technologies, the clinics provide the students with experience in working in multidisciplinary teams, exposure to industrial projects with real deadlines and deliverables and an opportunity to develop their oral and written communication skills. Several brief case studies of clinic projects are also discussed.

Introduction
Students and employers clamor for more exposure to emerging technologies such as biotechnology, advanced materials, pharmaceutical production, particle technologies, food engineering, and green engineering (1,2). However, it is difficult to work these topics into an already overcrowded chemical engineering curriculum, which already average 133 credits (3). Often, professors attempt to address this problem by developing and assigning homework problems within their classes that touch on these issues (4-6). Although these are certainly worthwhile activities, these problems and unit operations lab experiments usually do not give the students the level of exposure that they and their future employers want. In some programs, selected undergraduate students are given the opportunity to work with a professor on his or her research through an honors program. Unfortunately, a small fraction of students are able to participate in these programs.

At the same time, industries report both that new hires lack experience in working in multidisciplinary team environments and that effectiveness in teams is an essential skill for professional success (7-9). Many universities are responding to this challenge by introducing multidisciplinary laboratory or design courses (10,11). At Rowan University, we have developed a method of addressing these diverse challenges, while also implementing pedagogical valuable hands-on learning experiences (12,13) and technical communications (14-16).

At Rowan University, all engineering students participate in an eight-semester course sequence known as the engineering clinics (17). In the Junior and Senior years, these clinic courses involve multidisciplinary student teams working on semester-long or year-long research projects led by an engineering professor. Most of these projects have been sponsored by regional industries. Student teams have worked on emerging topics including enhancing the compressive properties of Kevlar, examining the performance of polymer fiber-wrapped concrete systems, advanced vegetable processing technology, metals purification, combustion, and many other areas of interest. Every engineering student participates in these projects and benefits from hands-on learning, exposure to emerging technologies, industrial contact, teamwork experience and technical communications.

The Clinic Sequence

In 1992, a local industrialist Henry M. Rowan made a $100,000,000 donation to the then Glassboro State College in order to establish a high-quality engineering school in southern New Jersey. This gift has enabled the university to create an innovative and forward-looking engineering program. Since 1996, the exceptional capabilities of each incoming class of approximately 100 engineering students at Rowan (avg. SAT score of 1260; avg. class rank of top 13%) have repeatedly verified the need for a quality undergraduate engineering school in the quickly growing region of southern New Jersey.

The College of Engineering at Rowan is comprised of four departments: Chemical; Civil; Electrical and Computer; and Mechanical. Each department has been designed to serve 25 to 30 students per year, resulting in 100 to 120 students per year in the College. The size of the College has been optimized such that it is large enough to provide specialization in separate and credible departments, yet small enough to permit a truly multidisciplinary curriculum in which laboratory/design courses are offered simultaneously to all engineering students in all four disciplines. Indeed, the hallmark of the engineering program at Rowan University is the multidisciplinary, project-oriented Engineering Clinic sequence.

The Engineering Clinics are taken each semester by every engineering student at Rowan University. In the Engineering Clinic, which is based on the medical school model, students and faculty from all four engineering departments work side-by-side on laboratory experiments, real world design projects and research. The solutions of these problems require not only proficiency in the technical principles, but, as importantly, require a mastery of written and oral communication skills and the ability to work as part of a multidisciplinary team. Table 1 contains an overview of course content in the 8-semester engineering clinic sequence. As shown in the table, each clinic course has a specific theme although the underlying concept of engineering design pervades throughout.

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	Reverse Engineering
Sophomore	Written Communication and Design	16-Week Multidisciplinary Design Projects and Oral Communication
Junior	Year-Long Multidisciplinary	Research Projects
Senior	Year-Long Multidisciplinary	Research Projects

Typical Project Life

The typical life of an engineering clinic project starts well before the first day of the semester. Typically some event triggers a phone call or a meeting with a professor and a company member. This could be a recruiting event, student internship or even a newspaper article about the university or company. Based on this contact a relationship is developed between the company and the university. Typically this starts with an invitation of interested company officials to the university. From this information visit the company begins to have an understanding of the unique nature of the engineering clinics and the hands-on opportunities that are students have experience starting in the freshman year. This is followed with a visit by interested faculty to the plant site.

The next stage is to match faculty interest with the operations of the company. Then further meetings are setup to brainstorm and sketch out project ideas. Professors research these ideas to develop and scope the difficulty level of the 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.

The Fall semester begins on Tuesday with a project fair in which all students are introduced to the projects. Students are given 24 hours to submit their choices of in and out of major projects. On Wednesday afternoon programs meet to place students in projects. This meeting is followed with a college meeting to obtain out of discipline students. In many cases, students from biology, chemistry, computer science and business are recruited on these projects. On Thursday the projects begin.

Industrially sponsored projects usually begin with a brief introduction by the professor followed by a step learning curve by the students. They are required to read introductory material provided by the professor to become familiar with the industry. In the second week, industry representatives give a presentation to the students on the project. At this meeting, students begin to develop a rapport with the industry representatives. They begin to see what aspects of a project are important to industry. They see that industry has very short deadlines and expects to see experimental results. They see that these projects have a goal that will directly impact the operations of the plant and the engineers and scientists in the meeting room.

For the next several weeks students work on the project. With industry projects students have a budget to purchase equipment and supplies and there is pressure to begin obtaining this equipment. The students have informal meetings at least once a month with the industry representatives and weekly with project faculty. Formal presentations to the industry are given in the 8th and 14th week of the semester. At these meetings with industry students' begin to realize that the engineering clinic is not an ordinary class in which they submit their unfinished homework and expect a grade. Instead they see that Industry expects results and solutions to their problems. This aspect of the project motivates students to work to achieve obtain project outcomes as opposed to only working during the 3 hour laboratory period that meets only twice a week. It also prepares students for the real world.

Case Studies of Industrially-Sponsored Clinic Projects

Polymer Fiber-Wrapped Concrete

In this project, a multidisciplinary team of chemical engineering and civil engineering students analyzed the influence of epoxy selection and fireproofing on polymeric fiber-wrapped concrete members exposed to various heating cycles. This project was sponsored by Fyfe Company, a manufacturer of fiber wraps and construction materials. The student activities included: identifying potential safety hazards, developing a detailed literature review, formulating a budget, planning and scheduling a year-long project, casting and wrapping concrete cylinders, designing the experimental plan, failure testing each cylinder, performing data analysis and developing conclusions regarding the processing variables.

The students were forced to interact with members of the university community beyond their normal contacts. For example, the students made arrangements with the art to department to use their large kilns for an initial coupon study. They met with faculty in the mathematics department to discuss experimental designs and interpretation of experimental data. They also arranged for shipment of the fiber-wrap material with the company.

This project provided the students with considerable exposure to epoxide chemistry, materials testing, concrete, fiber wraps, and other emerging areas in advanced materials. Concurrently, the students served as the primary point of contact between the project and its industrial sponsor. They gained experience in producing specific deliverables for an external industrial client. They also were given many opportunities to present their work both internally and externally, culminating in receiving the best undergraduate student poster award at the 2000 Uni-Tech Conference.

Advanced Vegetable Processing Technology

In a project sponsored by Campbell's Soup Company, a team of students researched 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's 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.

Metals Purification

The metals purification projects have been sponsored by Johnson Matthey Inc. A precious metals refinery is operated at West Deptford which is less than 15 miles from the university. This close proximity facilitates the numerous interactions and projects that we have with Johnson Matthey. Johnson Matthey has sponsored 3 years of engineering clinic projects. The objective of all of these projects is to investigate novel and innovative techniques that have a potential to replace current refinery process units.
Johnson Matthey is a precious metals refinery located in West Deptford, NJ. The company refines precious metals such as Pt, Pd, and Rh from feed streams containing many metal species. These feed streams range from spent catalysts in which precious metals are recovered and recycled to feed streams from mines. In the refinery are many dissolution, selective precipitation, and filtration steps. Using new and innovative processes the plant capacity, product purity, and the processing cost have the potential to be improved. In essence, students have an opportunity in the engineering clinic to conduct engineering projects that are equivalent in scope to those done by engineers in the plant. Our most successful project resulted in Johnson Matthey adding several new processing units to their refinery.

The impact of these 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 in both West Deptford and Sonning England.
4. Experience with direct interaction of students with plant operators, chemists, engineers and managers.

All of the above outcomes are enhanced with the industrially-sponsored project.

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Biographical Sketches

James A. Newell is an Associate Professor of Chemical Engineering at Rowan University. He serves as the Secretary/Treasurer of the Chemical Engineering Division of ASEE and has published in *Chemical Engineering Education, The International Journal of Engineering Education, Carbon,* and *High Performance Polymers.* He won the Dow Outstanding new faculty award in 1997.

Stephanie Farrell is an Associate Professor of Chemical Engineering at Rowan University. Her research interests lie in the areas of biotechnology and controlled release and has actively published novel experimental methods for undergraduate education. She is the recipient of the 1999 Dow Outstanding New Faculty Award for the MidAtlantic region and the 2001 Martin Award.

Robert Hesketh is a Professor of Chemical Engineering at Rowan University. He is the 1999 recipient of the Ray Fahien Award, the 1998 recipient of the Dow Outstanding New faculty award, and a two timw winner of the Martin Award. In 2000, he co-chaired the first topical conference on education at the National AIChE meeting in Los Angeles. He serves as membership chair of the ChE division of ASEE.

C. Stewart Slater is the Chair of the Chemical Engineering Department at Rowan University. His awards include the Westinghouse, Carlson, Dow, and Martin (twice). He is the founding chair of the innovative, hands-on undergraduate focused chemical engineering program at Rowan. He is on the editorial board for *Chemical Engineering Education* and *The International Journal of Engineering Education*.