INTRODUCING EMERGING TECHNOLOGIES IN THE CURRICULUM

Through a Multidisciplinary Research Experience

JAMES A. NEWELL, STEPHANIE H. FARRELL, ROBERT P. HESKETH, AND C. STEWART SLATER
Rowan University • Glassboro, NJ

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] It is difficult, however, to work these topics into an already-overcrowded chemical engineering curriculum, which averages 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, homework problems and unit operations lab experiments usually do not give 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, only a small fraction of students are able to participate in these programs.

At the same time, industry reports 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 pedagogically valuable hands-on learning experiences[12-13] and technical communications.[14-16]

At Rowan University, all engineering students participate in engineering clinics in an eight-semester course sequence.[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 comprehensive properties of Kevlar, examining the performance of polymer fiber-wrapped concrete systems, advanced vegetable processing technology, metals purification, combustion, membrane separation processes, 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.

Although many of the projects are sponsored by industry, some projects have sponsorship from federal or state agencies, including the National Science Foundation, the Department of Energy, and the Environmental Protection Agency. Some projects are self-funded by the department to facilitate the seed research needed to attract corporate sponsorship for future projects.

THE CLINIC SEQUENCE

In 1992, local industrialist Henry M. Rowan made a $1 million donation to the then Glassboro State College in order

James A. Newell *is Associate Professor of Chemical Engineering at Rowan University. He serves as 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 received the 2001 Ray Fahien Award and the 1997 Dow Outstanding New Faculty Award in the north Midwest Region.*

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

Robert Hesketh *is 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-time 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 Chair of the Chemical Engineering Department at Rowan University. He is a two-time recipient of the Martin Award, and other awards include the Westinghouse, Carlson, and Dow. 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.

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 (with an average SAT score of 1260 and an average class rank of top 13%) have repeatedly verified the need for a quality undergraduate engineering school in the 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 so that it is large enough to provide specialization in separate and credible departments, yet small enough to permit a truly multidisciplinary curriculum in which project-based 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 loosely based on the medical school model,[17] students and faculty from all four engineering departments work side-by-side on laboratory experiments, real-world design projects, and research. The solution to engineering problems requires not only proficiency in the technical principles, but also, just as important, requires 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 eight-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. Detailed course descriptions are available on the Rowan University web site found at <engineering.rowan.edu>.

With a total of 32 faculty members across the four engineering disciplines participating in the clinic, the small student-to-faculty ratio facilitates a high level of faculty-student interaction. This proves valuable to both student learning and the success of the project. Typical teaching loads for Rowan University engineering faculty are two courses per semester plus project management for junior/senior clinic projects.

TYPICAL PROJECT LIFE

The life of a typical engineering clinic project starts well before the first day of the semester, and the preliminary work in defining a project and securing funding requires a substantial time investment by the faculty members. The initial contact between a professor and a scientist or engineer from a regional company often results from a connection made through a professional society meeting, a recruiting event, student internship, or a newspaper article about the university or company.

Representatives from the interested company are invited to the university for an informational visit. They are introduced to the unique nature of the engineering clinics and the particular advantages that the flexible nature of the clinic sequence offers their company. The representatives also receive a brief overview of the expertise and interests of the college faculty members, while the faculty learn about the engineering priorities of the company. After this visit, interested faculty members often visit the plant site.

The next stage is to match faculty interest with the operations of the company. Then further meetings are set up 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 between the company and the university. Normally, the time between the first contact and obtaining a defined and funded clinic project averages about one year.

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 select their project. They may choose to work on a project led by a faculty member in their discipline, or they may decide to select one outside of their discipline. On Wednesday afternoon, programs meet to place students in projects. In many cases, students from biology, chemistry, computer science,

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	Written Communication and Design	16-Week Multidisciplinary Design Projects and Oral Communication
Junior	Year-Long Multidisciplinary Industrial Research Projects	
Senior	Year-Long Multidisciplinary Industrial Research Projects	

and business are recruited on these projects. On Thursday of the first week of the semester, the projects begin.

Industrially-sponsored projects usually begin with a brief introduction by the professor followed by a steep learning curve by the students. They are required to read introductory material provided by the professor in order 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 the aspects of the project that are important to industry, that industry has very short deadlines, and that industrial sponsors expect to see experimental results. Students also see that these projects have a goal that will directly impact the operation of the plant.

> ***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.***

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. In cases where a system needs to be designed and fabricated, this stage may take longer. The students have informal meetings at least once a month with the industry representatives and weekly meetings with the project faculty. Formal presentations to the industry are given in the eighth and fourteenth week of the semester. At these meetings with industry representatives, students begin to realize the engineering clinic is not an ordinary class where they simply submit their unfinished homework and expect a grade. Instead, they see that industry expects results and solutions to the problems. This aspect of the project motivates students to work to achieve project outcomes as opposed to only working during the three-hour laboratory period that meets twice each week. It also prepares students for the accountability they will face in the real world, where projects are not constrained by class hours.

These projects also help the program address many of the "softer" skills required by ABET.[18] Students function in multidisciplinary teams, design and conduct experiments, learn about safety and environmental issues, analyze and interpret data, communicate through oral and written reports, and use modern engineering tools.

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 those with whom they had normal contact. For example, the students made arrangements with the art department to use its large kilns for an initial study. They met with faculty in the mathematics department to discuss experimental designs and interpretation of experimental data. They also arranged with the company for shipment of the fiber-wrap material.

This project provided considerable opportunities for the students to work with epoxides, 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 their 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 work project. In addition to the engineering expertise the students acquired through this work, they gained familiarity with Food and Drug Administration 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. At these meetings, students gave oral presentations on their progress. Then the industrial representatives, faculty, and students had brainstorming and discussion sessions in which the project was refocused and fine-tuned. 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 belonging to the company is operated at West Deptford, which is less than ten miles from the university. This close proximity facilitates the numerous interactions and projects that we have with Johnson Matthey. The company has sponsored three 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.

At the refinery, precious metals such as Pt, Pd, and Rh are purified from feed streams containing many unwanted metal species. These feed streams are made up of spent catalysts from which precious metals are recovered and recycled to feed streams from mines. In the refinery there 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.

A grant from the National Science Foundation's Division for Undergraduate Education helped support the membrane-related equipment costs necessary to undertake this project.[19] These funds enabled the college to expose students to the latest membrane-process technology, which helped secure industrial funding for subsequent projects in this area.

The impact of these projects on students has resulted in the following outcomes:

- *Understanding of the economics of high value-added chemicals.*
- *Design, fabrication and operation of new and innovative technologies.*
- *Examination of scale-up from laboratory scale at Rowan to pilot-plant scale in both West Deptford and Sonning, England.*
- *Experience with direct interaction of students with plant operators, chemists, engineers and managers.*

ACKNOWLEDGMENTS

The authors would like to thank the sponsors of the projects described in this paper, including Fyfe, Inc., Johnson Matthey, Inc., and Campbell's Soup. Partial support for the membrane-related laboratory project was provided by the National Science Foundation Division for Undergraduate Education through grant DUE-9850535.

REFERENCES

1. Nelson, R.D., R. Davies, and K. Jacob, "Teach 'Em Particle Technology," *Chem. Eng. Ed.*, **29**(12), 12 (1995)
2. Todd, P., R. Harrison, Jr., and E.H. Dunlop, "Teaching Biochemical Separations to Engineers," *Chem. Eng. Ed.*, **30**(4), 286 (1996)
3. Occhiogrosso, R.N., and B. Rana, "The Chemical Engineering Curriculum-1994," *Chem. Eng. Ed.*, **30**(3), 184 (1996)
4. Robinson, K.K., and J.S. Dranoff, "A Laboratory Experiment that Enhances Environmental Awareness," *Chem. Eng. Ed.*, **30**(2), 98 (1996)
5. Sinclair, J.L., "CFD Case Studies in Fluid-Particle Flow," *Chem. Eng. Ed.*, **32**(2), 108 (1998)
6. Carlson, E.D., and A.P. Gast, "Animal Guts as Ideal Reactors: An Open-Ended Project for a Course in Kinetics and Reactor Design," *Chem. Eng. Ed.*, **32**(1), 24 (1998)
7. Buonopane, R.A., "Engineering Education for the 21st Century: Listen to Industry!," *Chem. Eng. Ed.*, **31**(3), 166 (1997)
8. Bhavnani, S.H., and M.D. Aldridge, "Teamwork Across Disciplinary Borders: A Bridge Between the College and the Workplace," *J. Eng. Ed.*, **89**(1), 13 (2000)
9. Borchardt, J.K., "Navigating the New Workplace," *Graduating Eng.*, **17**(3), 22 (1996)
10. King, R.H., T.E. Parker, T.P. Grover, J.P. Gosnick, and N.T. Middleton, "A Multidisciplinary Engineering Laboratory Course," *J. Eng. Ed.*, **88**(3), 311 (1999)
11. Barr, R.E., P.S. Schmidt, T.J. Krueger, and C.Y. Twu, "An Introduction to Engineering Through an Integrated Reverse Engineering and Design Graphics Project," *J. Eng. Ed.*, **89**(4), 413 (2000)
12. Heshmat, A.A., and A. Firasat, "Hands-on Experience: An Integrated Part of Engineering Curriculum Reform," *J. Eng. Ed.*, **85**(4), 327 (1996)
13. Schmalzel, J., A.J. Marchese, and R. Hesketh, "What's Brewing in the Engineering Clinic?" *Hewlett Packard Eng. Educator*, **2**(1), 6 (1998)
14. Newell, J.A., D.K. Ludlow, and P.K. Sternberg, "Progressive Development of Oral and Written Communication Skills Across an Integrated Laboratory Sequence," *Chem. Eng. Ed.*, **31**(2), 116 (1997)
15. Van Orden, N., "Is Writing an Effective Way to Learn Chemical Concepts?" *J. Chem. Ed.*, **67**(7), 583 (1990)
16. Fricke, A.C., "From the Classroom to the Workplace: Motivating Students to Learn in Industry," *Chem. Eng. Ed.*, **33**(1), 84 (1999)
17. Newell, J.A., A.J. Marchese, R.P. Ramachandran, B. Sukumaran, and R. Harvey, "Multidisciplinary Design and Communication: A Pedagogical Vision," *The Int. J. Eng. Ed.*, **15**(5), 376 (1999)
18. *ABET Engineering Criteria 2000*
19. Slater, C.S., K. Jahan, S. Farrell, R.P. Hesketh, and K.D. Dahm, "Using Membrane Process Experiments in a Project-Oriented Environment," *Proceedings of the 2000 ASE Annual Conference*, Session 1526, St. Louis, MO. (2000) ❑