Integrating Practice into Engineering Education – The Role of Adjunct Faculty and Industrial Mentor Programs

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Abstract - Our Chemical Engineering Department offers classes that introduce creative product and process development and design. Students first are introduced to creative methods to implement projects that they carry through from conception through development to design. Concepts of fuzzy front end (FFE) options and basic economic principles are introduced leading to a concept developed by small groups into a feasible project.

A second course includes an option of (1) participating in an industrial program of four or more companies who mentor students in a semester-length program, (2) working the American Institute of Chemical Engineers (AIChE) annual student contest problem, or (3) a classroom and pilot plant-based design project mentored by two or more adjunct professors. Working in smaller groups of about three students allows active participation and leadership opportunities. Classes are offered to junior and senior year students.

Introduction

There are many challenges associated with integrating industrial practice into undergraduate engineering curriculum. However, one key element is exposure of the students to problems and personnel in “real world” situations. At the Washington University Chemical Engineering Department, we have developed two programs which emphasize integrating industrial practice through interaction with industrial personnel – either as adjunct faculty, or project mentors.

In the chemical engineering discipline, dramatic shifts have taken place in the past few years that place greater emphasis on the need for teaching product development to undergraduate Chemical Engineers in order to adequately prepare them for industrial practice. In the past, the emphasis has been on process design and development. This mismatch of industrial need and academic curricula is exacerbated by a decline in the number of students enrolling in this major. As part of a program to revitalize the Chemical Engineering (ChE) curriculum, two new courses have been developed with the help of an industrially experienced adjunct professor. These new courses, “New Product and Process Design” and “Product Development Methodologies” emphasize topics related to product development which are frequently missing from typical ChE curriculums – such as, creativity and innovation, design of experiments, Fermi problems, the Theory of Inventive Problem Solving, product based economics, and intellectual property.

As chemical engineers, however, there will always the need for process design and development skills. In the process area, we have introduced a variety of options for exposing students to industrial practice through product based design work and industrial mentoring.

In this senior level process design class, students are given the choice of (1) participating in an industrial program of four or more companies who mentor students in a semester-length program, (2) working the American Institute of Chemical Engineers (AIChE) annual student contest problem, or (3) a classroom and pilot plant-based design project mentored by two or more adjunct professors.

In this manuscript, the two new programs mentioned above are outlined and discussed. In both of the programs, the student feedback has been very positive. Integrating industrial practice into the curriculum does present a number of issues. However, through the use of industrially experience adjunct faculty and collaborating with local industry, the benefits to the students appear to significantly outweigh the difficulties.

Product Development in Chemical Engineering

Traditionally, the chemical engineering (ChE) curriculum at Washington University (WU) emphasized process oriented skills, as do most of the accredited ChE programs in the U.S. The focus of this approach to curriculum is to produce competent engineers for the chemical and petroleum industries. While this was a desirable outcome 25 years ago, it does not fully address the needs of today’s engineering students. In 1975, the majority of graduating students went into a chemical, petrochemical, and petroleum manufacturing business, and only about 1 in 6 went into a product oriented business. Recently, however, nearly half of the graduating seniors are going into a product-oriented business (Cussler, July 23 – 28, 2006

San Juan, PR
The change in employment is well illustrated by a recent article by Cussler and Wei (2003)

Furthermore, recent shifts in interest among students have created a major problem for ChE departments attempting to update their curricula. A recent ASEE survey summary states the following: “Another notable trend has been the steady decline of degrees earned in chemical engineering. Since 1999 they have decreased 11 percent at the bachelor's level and 17 percent at the master's level” (ASEE 2002). In most departments, shrinking enrollment means that there is little likelihood of hiring new professors with adequate background in product development.

In order to adequately address this shift in focus, we are in the midst of implementing a completely reorganized curriculum. As part of this effort, and in anticipation of the need for product development activities, we have already added two new senior level classes “New Product and Process Development” and “Product Development Methodologies”.

The objective of these courses is to improve the relevance of undergraduate chemical engineering curriculum to changes in industrial needs and expanding the educational opportunities for departments that would not otherwise be able to meet the needs of current and future students. The program has been designed to allow adjunct faculty with industrial experience and an expertise in product development to develop and teach these classes.

Overall Interest in Chemical Engineering

Numerous changes in the relationship between traditional engineering skills and industrial needs have resulted in a significant shift of student’s interests and educational goals. This shift has been so significant that some ChE educators have predicted the eminent demise of their fields (Wesselingh 2001). Traditional engineering disciplines like chemical engineering are struggling to deliver a curriculum which is stimulating to the students and of practical value to modern industry. Of particular note, traditional engineering curricula have neglected the shift towards team-based organizations and innovation skills (Wesselingh 2001). As a consequence, undergraduate chemical engineering studies have registered a drop in enrollment – from 8.5% of engineering students in 1999 to 7.4% in 2000 to 6.5% in 2001 and 6.0% in 2002 (ASEE 2001, ASEE 2002). A similar downward trend has been observed here at Washington University, as shown in Table 1.

While it may be true that some commodity chemical businesses are moving overseas, many high-tech fields still need the expertise offered by the chemical engineering discipline. Notable examples include biotechnology, fuel cell technology, nanotechnology, materials, biomass conversion, bioenergy (e.g., biohydrogen, bioethanol, methane), pollution abatement and treatment, and development of environmentally benign processes.

<table>
<thead>
<tr>
<th>Year</th>
<th>B.S. ChE Degrees Conferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999</td>
<td>42</td>
</tr>
<tr>
<td>1998</td>
<td>41</td>
</tr>
<tr>
<td>1997</td>
<td>49</td>
</tr>
<tr>
<td>1996</td>
<td>50</td>
</tr>
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The Application of Engineering Principles to Product-Oriented Industries

Using the context of product development to discuss the application of engineering principles has the potential to give the students true-to-life practice in what these principles really mean. If someone proposes a more concentrated version of an existing liquid product, discussion of viscosity may be appropriate. Likewise, basic chemistry and kinetics can be applied to improve product safety and shelf life. In some cases, students are amazed to find out how the phenomena they have studied interact with them on a daily basis – from catalytic converters to facial cleansers. The primary goal is to change the way the students see the world such that they interpret everyday events in terms of engineering principles. Too often, the engineering principles lay dormant in their knowledge base because they are applied only in the context of process equipment. Product development demonstrates the daily interactions we have with engineering principles in a very tangible, hands-on approach. It is our belief that this approach is both encouraging to the students and does in fact improve their engineering skills.

Cussler (2002) points out that in 1975 the majority of graduating students went into a commodity chemical manufacturing business and only about 1 in 6 went into a product oriented business. Recently, however, nearly half of the graduating seniors are going into a product-oriented business. “The commodity chemical industry is not the focus of most of our graduates, and product-oriented industries definitely are.” Is there such a difference between process and product oriented design? Cussler goes on to list differences between the traditional algorithm for process design and that of product design, as shown in Table 2.

<table>
<thead>
<tr>
<th>Process Development</th>
<th>Product Development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catalysts</td>
<td>Facial cleansers</td>
</tr>
<tr>
<td>Fuel cells</td>
<td>Bioethanol</td>
</tr>
<tr>
<td>Catalyst converters</td>
<td>Biohydrogen</td>
</tr>
<tr>
<td>Condensers</td>
<td>Methane</td>
</tr>
</tbody>
</table>

Clearly, while the principles are the same, the way we go about using them are quite different.

Furthermore, the dramatic drop in chemical engineering enrollment and the shift in industrial needs points to one logical conclusion: There should be more product development concepts taught in the undergraduate curriculum. Given these dramatic shifts, however, many
departments have been slow in adopting the new paradigm. One likely reason is that many departments do not have faculty with significant product development experience. Given that many professors themselves matriculated in a department with an emphasis on the previous paradigm, there aren’t as many experienced instructors as one would hope.

Table 2: A comparison of methodologies for process and product development.

<table>
<thead>
<tr>
<th>Process Design</th>
<th>Product Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. batch vs. continuous</td>
<td>1. customer need</td>
</tr>
<tr>
<td>2. input/output</td>
<td>2. idea generation</td>
</tr>
<tr>
<td>3. recycles</td>
<td>3. selection</td>
</tr>
<tr>
<td>4. separations/heat</td>
<td>4. manufacture</td>
</tr>
</tbody>
</table>

It is for this reason that the WU chemical engineering department turned to someone with industrial expertise to help in developing these courses. The lecturer for these courses graduated Washington University summa cum laude in 1996. He then went on to a successful career in product development with Procter & Gamble which included the invention and development of several new products with over $100 million in annual sales. He is currently an adjunct faculty member in the ChE department and the primary lecturer for these courses.

New Courses for Product Development with Industrially Experienced Faculty

As a result of this effort, we created two new senior level courses titled “New Product and Process Development” and “Product Development Methodologies”.

During the first course, “New Product and Process Development”, the first half of the semester is based on individual work including numerous opportunities for students to create and evaluate concepts for new products. The second half of the semester is a team-based project with an emphasis on the development of a creative idea into a product concept and prototype.

The basic goal of the course is to introduce students to issues encountered in the concept definition portion of new product development - issues that generally occur before traditional chemical engineering gets involved. Topics include technical creativity, intellectual property, the Theory of Inventive Problem Solving (TIPS), an introduction to design of experiments (DOE), Fermi problems, the impact of consumers, project economics and profitability projections. Whereas most courses define problems for the students to solve, this course allows the students to define the problem for themselves.

The second product development course, Product Development Methodologies (ChE 452) is also based on these fundamental topics, but emphasizes application of the techniques and a variety of case studies that illustrate how product development methodologies can be used to solve real-life problems.

These case studies focus on examples of technical, engineering problems which have been solved using creative methods. For example, it is a little known fact that Albert Einstein invented a refrigerator with no moving parts. At the time, mechanical failures led to deaths (due to release of hazardous refrigerants). Einstein’s approach fixed the problem through a creative application of physical principles which removed the likelihood of mechanical failure. Unfortunately for Einstein, modern refrigerants like Freon were developed around the same time which quickly gained wide acceptance among consumers (Silverman, 2001). Another example would be the use of MnO2 and Mn2O3 catalysts coating the radiators of cars to decrease atmospheric pollution. In this very creative approach, engineers have developed a way to reduce toxic pollutants by cleaning ambient air in a way that is more efficient and cost effective than via traditional catalytic converters alone (Tullo, 2002).

For both classes, the coursework culminates in a final project. The overall intent of the projects is to present students with complex problems, challenge them to come up with solutions via creative thinking, cooperative learning and teamwork; and then evaluate the final outcome including economic assessments, environmental impact, intellectual property assessments, and any other aspects important to their particular product.

Based on the results to date, all of our new classes with a product development focus have been very well received. For example, results from a survey in spring 2003 show that 85% rated product development topics significantly more interesting and useful versus other engineering classes; 69% said they learned significantly more during this class vs. other engineering classes; and 62% said they liked the class significantly better overall vs. other engineering classes. (Choices included “significantly more or better”, “slightly more or better”, “slightly less or worse”, and “significantly less or worse.”) Free response answers suggest that the appeal of the classes is at least partly due to the practical and industrial focus of the instructor, including the many “real-life” examples.

The Chemical Engineering Department at Washington University has recognized the success of these elective courses. Starting during the 2004/2005 school year, “New Product and Process Development” will become a required class for all chemical engineering undergraduate students. This move demonstrates the confidence of the department, as well as the commitment to product development as an essential part of chemical engineering.

Mentoring in Process Development and Design

In the process area, we have introduced a variety of options for exposing students to industrial practice through produce based design work and industrial mentoring.

In this senior level process design class, students are given the choice of (1) participating in an industrial program
of four or more companies who mentor students in a semester-length program, (2) working the AIChE annual student contest problem, or (3) a classroom and pilot plant-based design project mentored by two or more adjunct professors.

The intent of the senior design course is to provide a unique design experience for students. These include applying knowledge, designing and conducting experiments, designing systems to meet specific needs, identifying, formulating and solving industrial problems, and to learning to communicate effectively. Students work in groups of 2 to 3 per project. At the end of the semester, an oral presentation is given and a written report is submitted by each team of students.

1). Industrial Mentoring Program

Another option available to students in the process design areas is to choose a semester project that is supervised by industrial practitioners using real-life problems. This program is monitored by regular professors and industrially experienced adjunct professors.

These industrial projects are important to the respective corporate participants and are generally related to current process development and design problems. In order to heighten the authenticity of this experience, interested students are chosen for the projects through interviews with the companies.

As a complementary benefit to these corporations, their young engineers gain experience supervising and interacting with students. The company engineers plan weekly duties and give feedback to students as the projects progress.

The most difficult step in initiating a program of this type is, of course, finding industrial contacts and opportunities with mutual interest in working with students. Corporate representatives have been successfully identified by contacting major companies in the immediate area. Local corporations involved in this program include Mallinckrodt, Monsanto EnviroChem, EHV-Weidmann, Solutia, and Conoco Phillips Woodriver Refinery. Interaction with these companies allowed both the personnel and students to interact with each other and learn from the experiences. In some cases, it has even resulted in offers of employment. In order to be successful, a program of this type must present some benefits to the corporation – either in identifying potential employment candidates, and/or producing useful technical results. So far, we have been relatively successful in this area, as evidence by our retention of corporations through several years of continuous participation in the program.

2). The AIChE Competition

One option available in this area is to compete in the AIChE annual student contest problem. This problem is generally an industrially relevant process design challenge that has to be completed within 30 days in order to meet contest guidelines. The course associated with this competition is a senior level process design course. As such, the competition is integrated into the curriculum as coursework and class time is used to discuss various issues and techniques. Unlike some class work, of course, the degree of mentoring and assistance must fall within the guidelines of the competition.

Using guidance and mentoring from regular professors and industrially experienced adjunct professions, the students have been very successful. In fact, with this model we have had students place in the competition at the national level in 2001 (first place for design), 2002 (first place in design and three safety categories), and 2003 (one safety award).

In addition to the typical benefits associated with developing and practicing the skills necessary for this competition, the students also consider the competition a significant individual accomplishment.

3). Pilot Plant Based Design Project - Mentored by Adjunct Faculty

A third option was investigating areas of bioenergy generation by converting corn to ethanol in association with the recently developed ethanol pilot plant facility of Southern Illinois University at Edwardsville (SIU-E). SIU-E has a new pilot unit to run commercial tests on ethanol production. In this program, process simulations and evaluations were performed using HYSYS and AspenPlus simulation software. The overall purpose of this program was to encourage industry to invest in biomass ethanol production with increased confidence, based on pilot-scale and analytical results generated through commercial tests. Washington University adjunct professors were specifically invited to participate in order to provide process modeling and practical technical expertise.

For the students, visiting the pilot unit offered valuable experiences by allowing them to interact with working equipment. During this exercise, four industrially experience adjunct professors advised the students with analytical modeling techniques. Adjuncts also interfaced with equipment vendors to scale up and choose appropriate equipment based on the results from student projects. The interaction between adjunct and vendors was facilitated by existing industrial relationships and prior work with vendors.

In this way students gained valuable knowledge about a working manufacturing process within an environment similar to an industrial facility. Furthermore, the students were allowed to contribute to and advance the technology under development, which encourages not only learning, but also confidence and enthusiasm.

So far, feedback from students involved in all three of these programs has been very positive. Of course, not all experiences were the same student and the choice of which of the options the students pursued had a significant impact into the topics the students investigated as well as the degree of industrial exposure. In some cases, the options were limited by the number of participating corporations. However, almost all the students were able to pursue the option of their choice. Future plans include identifying and developing
relationships with more local companies, contacts, and projects that cover areas of emerging technologies such as biotechnology, nanotechnology, electronic materials, and others.

Summary

The new approaches to teaching product development and process design with an emphasis on industrial exposure have helped to adapt to changing needs of students, expand the experience of the teaching faculty, establish a viable interaction between industry and academia, expand the capabilities of the university, and provide real experiences to students. This type of exposure to industrial relevant topics and real-life problems had not commonly included in earlier courses. These projects demonstrate to student how objectives are accomplished and how ideas are put into practice in an industrial setting.

In all of these programs the student feedback has been very positive. As such we believe integrating industrial practice into the curriculum is a valuable option for many undergraduate institutions. Through the use of industrially experience adjunct faculty and collaborating with local industry, the benefits to the students significantly outweigh the challenges.

Biographical Sketches

Muthanna H. Al-Dahhan is professor and co-director of the Chemical Reaction Engineering Laboratory (CREL). His research interests are in the fields of chemical reaction engineering related to multiphase reactor systems, mass transfer in multiphase reactors, bioreactors, and bioprocess engineering. He received a Doctoral degree from Washington University, an M.S. from Oregon State University, and a B.Sc. from the University of Baghdad. He has six years of industrial experience before joining Washington University in 1994. He has published over 100 peer-reviewed papers and presented over 250 presentations at national and international conferences. He has many funded projects and supervises a number of graduate and undergraduate students and postdoctoral fellows on various projects. Recently, Muthanna has spearheaded the effort to contact and develop industrial relationships between Washington University and local industry, with an emphasis on undergraduate student programs.

Nick Nissing graduated summa cum laude from Washington University with a degree in chemical engineering. He then worked at Procter & Gamble where he was a prolific inventor with numerous U.S. and foreign patents. His inventions have been applied to successful new products with annual sales in excess of $100 million. Nick Nissing is currently the president of Luminosity, LLC, a consulting firm focused on invention, innovation, and intellectual property. He is also an adjunct faculty member at Washington University, an independent inventor, and patent agent.

References