INDUSTRIAL COLLABORATION IN THE CAPSTONE DESIGN COURSES: EXPERIENCES AT OKLAHOMA STATE UNIVERSITY

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Abstract

The undergraduate curriculum at Oklahoma State University (OSU) includes two required senior design courses: CHE 4124 (Chemical Engineering Design I) and CHE 4224 (Chemical Engineering Design II). These courses are offered once a year in the fall and spring semesters. There are two co-instructors in both classes. Starting in 1993, the authors have made significant modifications to the two design courses to increase student exposure to industrial work practices. These changes include use of industry sponsored design projects, equipment vendor seminars and shop tours, guest lectures, use of commercial design tools and references, and formal presentations by students to industry representatives. This paper describes our two most successful methods of integrating industry into the curriculum: 1) industrially sponsored design projects, and 2) a vendor design symposium series.

Introduction

The undergraduate curriculum at Oklahoma State University has a strong, traditional flavor with an emphasis on unit operations for commodity and continuous-stream processes. Many of our B.S. graduates choose employment in the oil and gas and petrochemical industries. Approximately two-thirds of our undergraduates go straight to industry, and the other third pursue graduate studies. Consequently, the curriculum must maintain a good balance of theory and practice.

The two-semester capstone design courses, CHE 4124 and 4224, are offered in the senior year and are required for all B.S. graduates. These courses are structured to integrate concepts from previous classes in a professional environment with a heavy emphasis on accepted engineering practices, oral and written communications, professional ethics, and process safety/risk management. The intent is to provide the seniors with an intense learning experience that transforms them from students to engineers. A key element in this transformation has been planned interaction between students and industrial practitioners.

A variety of methods have been employed to provide this interaction. These include use of industry sponsored design projects, equipment vendor seminars and shop tours, guest lectures, use of commercial design tools and references, and formal presentations by students to industry representatives. This paper describes our two most successful methods of integrating industry into the curriculum: 1) industrially sponsored design projects and 2) vendor design symposium series.

Industrially Sponsored Design Projects

When developed and administered correctly, an industrially sponsored design project provides a rich learning experience. Student motivation increases with "real-world" assignments. This translates into greater effort, better focus, and enhanced commitment to produce a "good solution." Many students relish the opportunity, albeit with some amount of trepidation, to see what they can do.

However, there are a number of potential pitfalls that must be addressed for the overall experience to be positive. A discussion of three key issues follows.

1) Development of the Problem Statement

Coordinating development of the problem statement with the industrial sponsor is a non-trivial task (for both the instructors and sponsor). There is a need for the instructor(s) to provide guidance and to help shape the problem statement. This typically requires a couple of iterations. We begin the process of creating the project statement a month or more prior to the project assignment date on the class schedule.

The inevitable questions that arise when working with an industrial sponsor for the first time are "What constitutes a good problem?" and "How do you want us to write it up?" With regard to the first question, we suggest considering a project, or part of an actual project, recently completed by the company. This minimizes the effort required to produce the solution, as the required data and many of the technical calculations are available in the project files. With regard to the second question, we provide a prior problem statement to use as an example or template.

Generally speaking, we prefer design problems that involve modification or expansion of existing processes rather than grassroots design of a new process. While synthesis is a critical skill, our courses emphasize process analysis and demonstration of engineering work practices in a comprehensive manner (transformation from student to engineer). Use of a process modification or expansion for the problem also allows discussion of the actual solution implemented by the sponsor. The opportunity for a student to compare his or her solution to what was actually done is one of the most valuable aspects of an industrially sponsored design project.

In many cases the sponsor will have proprietary process information that must be protected. The best approach is for the company to modify the rates, product qualities, kinetics, process description, product and utility prices, etc. in the problem statement to protect proprietary or sensitive information. The instructors need a general understanding of how the problem was modified but do not require knowledge of the proprietary information. We have had situations where the sponsor required everyone in the class to sign a secrecy agreement, but we encourage the use of problem statements that do not require this measure.

Over time many practicing engineers forget how much they learned in their first year or two on the job. Over-estimating the technical maturity of students can lead to overly complex problem statements that detract from the intended experience. Consequently, there may be a need to scale back the scope of the problem initially proposed by the sponsor. We have had few situations where the proposed project needed additional technical complexity.

Our primary intent is not to provide a technical challenge, e.g. "Can you solve this?" Likewise, we don't want the majority of the effort to be devoted to mastering simulation software or struggling to get a simulation to converge. While the project is technical in nature, we are striving to provide a learning experience rather than a diagnostic experience. The final reports are weighted 50% technical and 50% communication.

The "ideal" industry sponsored design project accomplishes the following:

1) requires solution of non-trivial technical problem with as many of the following attributes as possible:
   a) process involves recycle and requires simulation software or spreadsheets to model
   b) key process parameters are controlled by thermodynamic or equilibrium properties
   c) multiple solutions are possible with opportunities for economical optimization
   d) application of unit operations or technology not generally covered in the CHE curriculum are required
   e) economic justification is required using criteria routinely employed by the sponsoring company
   f) elements of risk management (safety, health, & environment) are incorporated
2) provides a scope appropriate for a three person team over a period of four weeks
3) requires no more than one or two weeks to develop a viable base solution, so there is adequate time to perform some degree of optimization and generate a well-documented report
4) provides an opportunity to employ industry accepted work practices and equipment design methodologies
5) includes a minor element of uncertainty that pushes the student teams out of their comfort zones, but not to a degree that can prevent successful completion of the project
6) generates a sense of accomplishment and self-confidence in the students
7) includes results that been evaluated or implemented by the company that can be shared with the students when the final reports have been submitted

From 1993 to 2003, the crown jewel in the OSU curriculum was the Celanese Design Competition. This four-week design problem was assigned as the last of three design projects in the senior year. The problem was formulated by Celanese engineers who were OSU CHE alumni. The list of projects is presented in Table I. All involve modification, expansion, or evaluation of technologies associated with existing (at the time of the project) Celanese manufacturing units.

The Celanese project assignments were written in the form of inter-office memoranda. In addition to a charge memo from the Celanese business team to the student teams, the problem statement documentation typically contained a formal background memo with technical information about the process and references to relevant prior work in the literature. The Celanese engineers used a highly creative method of sharing detailed technical information – they provided a series of mock conversations with process and business experts responding to the obvious (and not so obvious) questions that the students would have or should have. The total amount of original documentation (not counting PFDs or other figures) provided by Celanese for each project was approximately 10 pages.

Table 1. Celanese Design Competition Projects at OSU

Year	Project Title
1993	Proposal to Add Preconcentrator Column to Ethylene Glycol Unit
1994	Options for Abatement of Hydrocarbon Vent to Atmosphere for Ethoxylates Unit
1995	Proposal to Install Ethylene Recovery Unit at the Clear Lake Plant
1996	New Butyl Acrylate Unit at the Clear Lake Plant, Disposition of Waste Streams
1997	PacRim VA Unit Optimization
1998	Optimization of Ethylene Glycol Unit
1999	Evaluation to Expand the Clear Lake Ethylene Oxide Production by 200 MM lb/yr
2000	New Butyl Acrylate Unit at the Clear Lake Plant, Disposition of Waste Streams
2001	Expansion of the Singapore Acetic Acid Unit: Raw Material Requirements
2002	Evaluation of BP's Iridium Based Acetic Acid Technology
2003	Ethylene Glycol Unit, Improved Reaction Process

The instructor(s) generated formal solutions for each project using spreadsheets, flowsheets, and calculations provided by the Celanese engineers. Copies of the solution were available for review by the students at the end of the project but were not distributed.

2) Commitment of the Industrial Sponsor

The Celanese Design Competition was started in 1993 as an initiative of senior corporate Celanese management with ties to OSU. The idea originated in a meeting with the OSU CHE Industrial Advisory Board in 1992. The author of the first problem was an OSU CHE alum with 15 years experience at Celanese's Clear Lake, Texas facility. Corporate management selected the individual. This top-down arrangement demonstrated clear corporate commitment to the effort. Establishing this level of commitment at the outset was instrumental in creating sufficient organizational momentum for continuation of the competition well after the original senior advocates retired or left Celanese.

The issue of corporate commitment is especially important to the company representative(s) working with the OSU faculty. The demands on the company collaborator(s) are spread across three time periods: 1) formulation of the problem, 2) consultation while the students are working on the problem, and 3) evaluation of the final written and oral reports. From start to end, there is a three- to four-month period where some level of interaction with OSU is required. An estimate of the time required to create and administer a project is provided in Table II.

The total estimated time requirement for the sponsor is 50 person-hours. This estimate only covers the sponsor's primary technical contact with the OSU faculty. No time has been included for others in the sponsoring company who may assist during all phases of the project.

In our experience, there have been typically two senior company engineers involved in the problem formulation phase. One had primary responsibility, and the second served as a sounding board/consultant. All technical communication between OSU and the sponsor went through the primary technical contact. Celanese typically sent a team of 2-4 company representatives to OSU at the end of the project to evaluate formal presentations by each of the student teams. Consequently, the total time invested by the company was probably 100+ person-hours per project.

Table 2. Estimated Time Requirements*

Task	Effort, person-hours Sponsor	Effort, person-hours Instructor
Problem Formulation (spread over 1+ month)		
Identify problem and set scope	4	2
Write-up problem statement	8	2
Generate initial solution	8	16
Project Administration* (spread over 4 weeks)		
Technical consultation (answer questions, clarify info in the problem statement, etc.)	4	24
Review progress reports	--	8
Refine solution	2	16
Project Evaluation* (spread over 3 days)		
Travel	8	--
Evaluate written reports	5	25
Evaluate oral reports	8	8
Awards dinner and student-sponsor mixer	3	3
Total (spread over 3- 4 months)	50	104

* Assumes 10 three-person student teams

While possible to reduce the total time commitment by the sponsor, it is very important that management of the sponsoring company is fully aware of the length and duration of the commitment. While many alums may be interested in participating on a collaborative design project, a lack of organizational commitment to the effort can doom the best of intentions.

The Celanese Design Competition is an example where support for the effort in the company was top-down. From an OSU perspective, the experience for the students and faculty could not have been better. We have also collaborated on industry sponsored design projects where the support for the effort in the company was bottom-up. That is, the idea was championed by alums who were staff engineers and had to garner support from management. While successful, this arrangement provides greater risk of “soft support” for the effort during periods of business disruption. Consequently, there is a need for the faculty to be more familiar with details of the process to insure the student experience is not affected.

3) Feedback

Managing feedback is important when introducing a third party, the project sponsor, into the classroom. The most important is the feedback from the company representatives to the student teams. Typically, each student has invested more than 80 hours working on the project, while keeping up with their other classes. Assuming the problem statement was crafted properly, all of the teams have generated a viable solution to the problem and are anxious to get the sponsor’s response to their work. This feedback occurs in two venues: at the end of the team’s oral presentation (specific to the team) and after all oral presentations have been completed at the awards dinner (general feedback directed to the entire class). Based on our experience, it is important that the company representatives maintain a positive, encouraging attitude in their remarks. Technical shortcomings can be addressed by the instructors at a later date. The most important contribution that the sponsor can make at this point is validation that the class has made the transformation to novice engineers. This message is invaluable in removing self-doubt at the end of the senior year and creating expectations of continued success as the students begin the next phase of their life in the workplace or in graduate school.

In addition to providing positive feedback to the students, it is also important the faculty and students provide positive feedback to the sponsor. The awards dinner provides the best opportunity to individually recognize the company representatives who participated in the project. We immediately followed up with formal letters of appreciation with copies to Celanese management. The OSU Public Information Office also prepared a press release describing the design competition with special recognition of Celanese for sponsoring the activity. The press release was distributed to the major daily newspapers in the state and the hometown newspaper of each member of the 1st, 2nd, and 3rd place teams selected by Celanese.

Chemical Engineering Design Symposium Series

The second major collaboration with industry involved the addition of a Vendor Design Symposium Series in 1995. The OSU main campus is located within 70 miles of Tulsa, OK. Almost all types of process equipment (e.g., pumps, compressors, shell-and-tube heat exchangers, air-cooled heat exchangers, distillation column internals, furnaces, flares, and complete skid-mounted processing units) are manufactured in Tulsa. Initially, vendor companies were invited to present a seminar on equipment design, specification, and troubleshooting. Besides providing multimedia presentations, most vendors also distributed literature (including handbooks in some cases), which the students find extremely useful on the job. Most companies also distributed equipment sizing software that the students are encouraged to use on class assignments and projects. Over time, the interaction with vendors migrated from campus presentations to site visits in Tulsa. The students enjoy the opportunity to see the equipment and interact with "experts" and discover that the concepts and methods presented in class are actually used in industry. As a side benefit, numerous students have secured jobs with vendor companies based on contacts they made during the design symposium presentations.

The following information was provided to the vendors when invited to participate in the symposium series:

Goals: The goals of the OSU Chemical Engineering Design Symposium Series are:

1) reinforce the transition from theory to practice in the context of equipment selection, sizing, and specification; and
2) introduce the graduating engineer to the accepted practices and ethics used in working with vendors of chemical process equipment

Background: The Chemical Engineering Design Symposium Series is planned as an integral part of the two-semester sequence of capstone courses in the School of Chemical Engineering at Oklahoma State University. These two courses are intended to provide the students with experiences in integrating the fundamentals from previous course work in the engineering sciences, unit and rate operations, and chemical reaction engineering. This is usually carried out through a sequence of projects that include the conceptual design of processes, the development of process flow diagrams (and sometimes preliminary process and instrumentation diagrams), and specifications for major process equipment. The typical design project also involves an economic analysis based on purchased cost of equipment and estimated operating costs.

During the projects, the instructors review basic concepts of heat, mass, and momentum transport as applied to the selection and sizing of major process equipment, for example pumps, compressors, heat exchangers, etc. The major references for these topics are technical publications such as the *GPSA Engineering Data Book* and technical publications available from equipment vendors. However, the students do not have an opportunity to interact with vendors as part of the undergraduate experience, and the instructors are not in a position to speak on behalf of vendors. We would like to address this deficit by bringing vendors of major process equipment into the classroom and involving them in our undergraduate program through a series of design symposia.

Implementation: We envision the typical symposium to last approximately one-half day. The presentation and organization would be left to the equipment vendors, but hopefully would address the following issues:

What are the major factors in equipment selection?
What are the methods for equipment sizing and specification?
What is included in "purchased cost of equipment?"
How are utility requirements estimated?
What are typical delivery times?
What can the process engineer expect from the vendor?
What can the vendor expect from the process engineer?

The last two items are particularly important from our perspective. We also envision the seminar as a "hands on" experience for the students, so example problems would be appropriate and encouraged.

The instructors in Chemical Engineering Design I and II would work with the Symposium speakers to develop the content of a symposium or to present appropriate background information or lectures prior to a symposium, if required. Our intention is to maximize the interaction between the students and the representatives of major equipment vendors. We believe these interactions can add a new dimension to the background of our graduates and provide the vendors with the opportunity to introduce themselves to a group of individuals who represent potential future clients.
(end of information sheet provided to invited vendors).

Topics
The following topics have been covered since the first symposia in 1995. The organizations that have participated are also shown.

Centrifugal pumps (Durco/Flowserve)
Compressors (Dresser Rand/Hanover)
Shell-and-tube heat exchangers (Hughes-Anderson)
Air-cooled heat exchangers (GEA Rainey)
Distillation column internals (Nutter Engineering/Koch Engineering/Sulzer ChemTech)
Project management (ProQuip/Williams Cos./Linde BOC)
Environmental compliance and regulation (EPA)

Combustion systems engineering (John Zink/Zeeco)
Process instrumentation and control systems (Fisher/Vinson Process Controls)

The symposium presentations typically last 2 to 2½ hours and are scheduled during the 2-hour discussion section added in 1996 for this purpose. The venders generally organize their presentations along the lines described above. Some of the presenters provide sizing problems for the students to work prior to the symposium. Solutions are discussed in the presentation. The instructors participate by asking questions and requesting clarifications (there is a natural tendency for the vendors to use acronyms and jargon not familiar to the students). Student attendance is required at all symposia.

The following vendors also hosted tours of their manufacturing facilities in the Tulsa area. We typically schedule two visits in the same day, one before lunch and one after.

Dresser-Rand/Hanover (compressors)
Hughes-Anderson (shell-and-tube heat exchangers)
Nutter Engineering/Sulzer ChemTech (mass transfer equipment)
John Zink (combustion engineering equipment)
Zeeco (combustion engineering equipment)
Fractionation Research, Inc. (distillation)

Transportation is provided by the School of Chemical Engineering. Attendance is voluntary, since the trips last all day. In a class of 30 students, there are approximately five who have hard conflicts and are unable to attend.

Conclusions

Industrial participation has become a major component of our two-semester capstone design courses. From the instructors' standpoint, the most significant benefits have been:

1) student validation of the chemical engineering curriculum when they see and hear vendors and practicing engineers using the same terms and practices learned in class;
2) increased self-confidence of B.S. CHE graduates after completing an industrially sponsored design project (e.g. Celanese Design Competition);
3) increased appreciation/satisfaction of B.S. CHE graduates with their OSU CHE experience;
4) improved instructor knowledge of contemporary industry work practices.

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