This column provides examples of cases in which students have gained knowledge, insight, and experience in the practice of chemical engineering while in an industrial setting. Summer internships and co-op assignments typify such experiences; however, reports of more unusual cases are also welcome. Description of the analytical tools used and the skills developed during the project should be emphasized. These examples should stimulate innovative approaches for bringing real world tools and experiences back to campus for integration into the curriculum. Please submit manuscripts to Professor W. J. Koros, Chemical Engineering Department, University of Texas, Austin, Texas 78712.

A QUALITY-DRIVEN PROCESS DESIGN INTERNSHIP

R.M. Counce, J.M. Holmes, S.V. Edwards,[1] C.J. Perilloux,[2] R.A. Reimer[2]
University of Tennessee • Knoxville, TN

The course "Design Internship in Industrial Pollution Prevention" at The University of Tennessee (UT) is an honors capstone design course in which source reduction is incorporated into the design of industrial processes. It involves the participation and support of DuPont and is consistent with DuPont's commitment to environmental excellence, summarized by the following process design priorities: 1) The design of processes will emphasize technology selection such that all process materials are converted into useful products. For process materials that are unsuccessfully converted, the remaining design priorities will be 2) recovery and recycle of all materials, 3) any material that must be put into the environment will be in a form that is transparent to the environment, and 4) failing all of the above, material will be put into a form that is safe to handle, and it will be immobilized and securely stored in a controlled manner. Using that philosophy, internship projects in process design have completed studies on far-ranging topics.

The activity described here is honors experience in industrial process design where pollution prevention through basic flowsheet development and equipment selection is emphasized rather than conventional treatment of the effluent waste streams.[1] It is a 3-semester-hour course and is an alternative to the traditional senior capstone design course. The advisors have typically been full-time and emeritus chemical engineering faculty members, but faculty from other departments have also been extremely valuable in helping the students gain a suitable working knowledge of a subject that is commensurate with their educational background. DuPont currently provides internship opportunities, technical direction, and financial support, with cost sharing from UT. Concepts to promote effective team building and teamwork are provided by Quality Develop-

R.M. Counce *is Professor of Chemical Engineering at The University of Tennessee. He holds a PhD in chemical engineering from UT. Prior to coming to UT in 1981, he was at the Oak Ridge National Laboratory. He conducts research in separations, process design, and pollution prevention.*
J.J. Holmes *is Emeritus Professor of Chemical Engineering at the University of Tennessee. He holds a PhD in chemical engineering from UT. Prior to coming to UT, he worked in the chemical and nuclear industries.*
S.V. Edwards *is a Management Consultant with Quality Development Incorporated of Knoxville, TN, where she has been since 1992. She holds a BS in Psychology from the University of Tennessee, Martin. She was with IBM before coming to Quality Development Incorporated..*
C.J. Perilloux *is involved in research and development and new process commercialization for organic chemicals. He is currently at DuPont's Sabine River Laboratory in Orange, TX. He has a BS from Louisiana State University and a PhD from Rice, both in chemical engineering. He has been with DuPont since 1970.*
R.A. Reimer *is an Engineering Associate in DuPont's Orange, TX, nylon intermediates research organization. He holds a BSChE from the University of California at Berkeley and an MS in chemical engineering practice from M.I.T. He has been associated with DuPont since 1969.*

[1] *Quality Development Corporation, Knoxville, TN*
[2] *Sabine River Laboratory, E.I. du Pont de Nemours and Company, Orange, TX*

The type of activity described in this paper provides for involvement of university students and faculty in significant and challenging projects involving pollution prevention. This project and similar activities have been well received by the students; their enthusiasm, perseverance, and overall quality of work have been outstanding. . . . Participants . . . typically begin industrial careers soon after project completion, with a smaller number going to graduate school.

ment Incorporated (QDI).

The design internship proceeds through some typical steps of preliminary process synthesis and evaluation, summarized in Table 1. Faculty and industrial advisors provide the necessary conditions and support for a student-directed process design team to function effectively. Over the course of several projects, the students have demonstrated the ability to handle increasingly more complicated design tasks; insights on the elements necessary for successful student design teams are the focus of this paper.

TABLE 1
Typical Steps of Preliminary Process Synthesis and Evaluation

1. Project selection
2. Team selection
3. Project initiation
4. Feasiblity study
5. Narrowing the field of alternatives
6. Preliminary design report and presentation
7. Flowsheet development
8. Estimation of capital and operating costs
9. Selection of most promising alternative(s)
10. Final report and presentation

RECENT DESIGN TOPICS

In general, the projects are at the conceptual level and all students sign secrecy agreements. A background study is conducted to familiarize the students with the problem and to reveal alternative solutions. Screening is usually necessary to select alternatives for more in-depth study. Flowsheets for the selected approaches are developed and capital and operating costs are estimated. Recommendations are based on a matrix of considerations including economics and adherence to DuPont's waste-management criteria. A final report summarizing the various activities and recommendations is typically the primary deliverable. One project described below preceded DuPont's conceptual design activities and had the development of ASPEN process models as a deliverable.

Fall, 1991 • A team of six students reviewed DuPont's hydrogen cyanide recovery process and proposed improvements or alternative processes to minimize waste-treatment requirements. The project was coordinated by Dr. Ed Moss (DuPont Victoria Plant) and members of the HCN team, who met with the students for periodic reviews. Three alternatives to current production approaches were selected for in-depth study.

Spring, 1993 • A team of six students investigated various technologies for the removal and recovery of Cu and V from adipic acid process purges. The project advisor was Althea Haylett (DuPont Sabine River Laboratory), and UT advisors included Professor George K. Sweitzer (Chemistry Department). Potential technological approaches were screened, flowsheets were generated for three selected technologies, and capital and operating costs were estimated.

Spring, 1994 • A team of seven students focused on treatment options for biosolids from biological wastewater treatment. The project was sponsored by Dr. Charles Perilloux of the DuPont Sabine River Laboratory. The team examined state-of-the-art options for treatment of biosolids, including an innovative approach being studied by DuPont.

Spring, 1995 • A team of five students focused on alternative processes for recovery and control of gaseous process effluents from combined sources at the DuPont Chambers Works. This project was sponsored by Tom Scarfe of Specialty Chemicals. The team examined state-of-the-art options for the recovery and control of gaseous effluents, including NO_x, benzene, CO, O_2, and N_2.

Spring, 1995 • A second design team of five students focused on selection and evaluation of state-of-the-art options for the treatment of leachate from the Southeast Hazardous Waste Landfill at the Victoria Plant. This project was sponsored by E. B. Keough of the ESD-Gulf Regional Office. The team examined options for the treatment of hazardous leachate constituents, which were grouped as free HCN, complexed cyanides, free metal ions, ammonium ions, and organics. Three students from this team joined DuPont after graduation.

Spring, 1996 • Three teams of three students each focused on different approaches to the production of a marketable by-product from an aqueous/organic waste stream from adipic acid production facilities. All three approaches involved concentration of the recyclable organic material, reaction, and refining. The sponsor was Dr. Charles Perilloux of the Sabine River Laboratory. This project was unusual in that it was not at the conceptual design level and involved developing AS-

PEN flowsheets of the three routes and using the results as a basis for estimating the required capital investments. The deliverables consisted of a final report with details of the ASPEN process models and the capital investment, and executable copies of the models. A member of one of the design teams worked for DuPont at the Sabine River Laboratory during the summer following the project, polishing and optimizing each flowsheet for further evaluation.

Spring, 1996 • A second team of three students focused on alternative processes for recovery and control of gaseous NO_x from tank vent fumes at the Sabine River Works. The project was sponsored by Victor Kamantauskas of the Sabine River Works. The team examined state-of-the-art options for the recovery and control of dilute concentrations of gaseous NO_x. Flowsheets were developed for several destruction and recovery/recycle technologies using the FLOW program, a conceptual design simulation developed by the Oak Ridge National Laboratory.

CAPSTONE DESIGN EXPERIENCE

This project is one of only a few academic experiences involving a team rather than an individual effort. QDI is working with the UT faculty advisors to improve the link between the activities and resource utilization of individuals and teams and the desired results stated in a team's mission, vision, and values. The group's mission is spelled out in the design objectives and is developed in the early stages of the activity. The student's personal expectations and team expectations from Spring, 1996, were developed in the initial meeting and are presented in Table 2. The expectations were then translated into ground rules and project evaluations, presented in Table 3.

Students typically alternate weekly as group leaders and communicate frequently with their advisors. Three hours per week of scheduled group meetings (with their faculty advisors present is typical); these meetings begin with a warm-up activity, along with a review of the agenda and a determination of the appropriate time for each agenda item. The group leader acts as facilitator for the meeting, while other key roles are the time keeper (who keeps the meeting on schedule) and the recorder (who records the key discussion points and distributes the meeting record).

The meeting concludes with setting an expected agenda for the next meeting and confirming its date, time, and location. A few supplemental faculty lectures are presented; the typical role of the faculty advisor is one of consultant, reviewer, and coach. The students contribute a great deal of time to successful conclusion of these projects, similar to the time required in a typical engineering capstone design experience.

Team Building • Effective team building begins with analysis of the critical elements of the project; this analysis then leads to clearly defined objectives, deliverables, and quality measures that translate into task assignments and priorities. The design internship evolves by incorporation of a total quality approach to definition and accomplishment of the team goals, summarized in Table 4. The faculty advisor works on creating a win/win relationship with the team members and on promoting planning, organization, and record keeping for effective project performance.

Project Selection • Discussions within DuPont begin several weeks in advance of the project's initiation, with the faculty advisors typically involved in the final selection of the project. The selection criteria are based on their educational benefits, their value to DuPont, and on the possibility of being completed in one semester. One or more DuPont personnel volunteer to function as industrial advisors for the students.

Group Membership Selection • The students are typically selected based on their academic achievements and on completion of an informal interview. Providing equal opportunity for all chemical engineering students who have appropriate prerequisite course work is an important consideration.

Project Initiation • Various formats for project initiation

TABLE 2
Personal and Team Expections (1996 Teams)

Personal Expectations

- *Better knowledge of what industrial activity will involve*
- *Working with a group on a long-term project*
- *Gaining practical engineering experience*
- *Gaining experience at working in groups*
- *Exposure to formal project encountered in "real" world*
- *Opportunity to bring personal learning to actual design*
- *Seeing a design project from initial idea to final state*
- *Overall design experience*
- *Ownership; having control over a project*
- *Seeing if this is a desirable graduate-school area of study*

Team Expectations

- *Cooperation and commitment to a common goal*
- *General interest in design task*
- *Being able to take initiative and to complete tasks*
- *Organization; communication*
- *Getting along with others*
- *Team members doing their jobs; not having to do other's jobs*
- *Having a leader, not a Mother Goose*
- *Working with a diversity of people*
- *Actually solving a problem (not guessing at its solution)*

TABLE 3
Student-Developed Ground Rules and Evaluation Criteria for 1996 Teams

Ground Rules

- *Attendance at group meetings by all team members*
- *Participants must display professionalism*
- *Individuals should advise group if there are problems*
- *Equal participation of all members (cross checking)*
- *Members should not let dominant personalities dictate*
- *There should be scheduling of flexible long-term goals*
- *Scheduling so that everyone can contribute*
- *There should be freedom for anyone to voice concerns*
- *Members should be willing to have an open mind and to address concerns without anger*
- *Mistakes should be minimized by getting group input*

Evaluation Criteria

- *Achieving design objectives*
- *Usefulness of work (quality)*
- *Timeliness (meeting deadlines)*
- *Effective use of individual time input to project*
- *Producing a valuable product*
- *Ongoing group evaluation*

TABLE 4
A Total Quality Approach to Definition and Accomplishment of Team Goals

1. Objective setting and deployment based on the needs and expectations of stakeholders (typically customers, employees, investors, suppliers, and communities.
2. Explicit connection between tasks (methods) and objectives (results).
3. Results-oriented meeting planning and record keeping.
4. Win/win agreements between individuals and team advisors, including role expectations and **S**pecific, **M**easurable, **A**greed, **R**ealistic, and **T**ime-phased (SMART) goals.
5. Process and results measurement for feedback.
6. Acquiring, updating, and maintaining the knowledge acquired in linking the activities and resource utilization of individuals and teams with the desired results.

have been used. In earlier projects, the initiation occurred at a production site where the facility was toured; later projects have been initiated on campus, sometimes with a visit from the corporate sponsor. In the initiation discussion, expectations for individuals and teams are established and project ground rules and evaluation criteria are set. This activity is facilitated by the faculty advisor, but input is provided only by the team members.

Information generated by the students at the initiation of the 1996 internship is presented in Tables 2 and 3. The intent of the facilitator in this activity is to create a win/win situation for all involved.

Information on the project design objectives is provided, as available, in the initiation meeting. Sometimes alternative designs are suggested at these meetings and supporting information is provided, as available; still other alternative designs are developed by the students later in the study.

The supporting information may include desired product purity, relevant reaction rates and yields, reaction and phase equilibria information, by-product formation data, operating- and pilot-plant data, and safety and toxicity information. Usually, more supporting information is available for some alternatives than for others.

Design Objectives • An important Project Initiation activity is the development of design objectives. The purpose of establishing such objectives is to clearly spell out the level of effort, the expected resources, and the description and timing of expected deliverables. It is important that the design team and its advisors have a common vision as to the design objectives.

Due to limited travel budgets and minimal travel time available to the students, the current project initiation generally occurs on campus. When the students visit their sponsor later in this activity, they are more knowledgeable about the project and perhaps gain more from their visit than they would otherwise.

It is typical for the students to visit and present a briefing at the conclusion of their feasibility study or later in this activity when flowsheeting is complete and capital and operating costs are known. Attendance generally includes industrial and faculty advisors as well as interested industrial personnel.

Feasibility Study • The feasibility study provides information on the appropriate design alternatives. It ensures that students have the necessary information to make their own decisions as to appropriate technology. A computer search of the literature greatly expedites this phase of the project.

There is often extensive communication between the students and their industrial project advisors via e-mail, fax messages, and telephone conferences; video conferences are more expensive, but are still lower in cost than personal visits. The combination of faxed documents, speaker phones, and conference calling provides a low-cost and effective means of communication between a number of people at different sites.

At the conclusion of the feasibility study, the students present and discuss their findings with the corporate sponsor. These are important discussions for ensuring that the objectives of the design study are being met and that all feasible options are identified.

The design internship proceeds through some typical steps of preliminary process synthesis and evaluation, . . . Faculty and industrial advisors provide the necessary conditions and support for a student-directed process design team to function effectively. Over the course of several projects, the students have demonstrated an ability to handle increasingly more complicated design tasks.

Narrowing the Field • At the conclusion of the feasibility study the alternatives are screened to ensure that the most appropriate options are considered further. The students are encouraged to develop screening criteria that properly emphasize DuPont's hierarchy of waste management priorities. At this phase in the project, material and energy balance flowsheets have not yet been developed and no capital and operating costs have been determined. The results of this screening step are typically presented to the corporate sponsor simultaneously with feasibility discussions.

Preliminary Design Report and Presentation • The results of the feasibility study and the alternative screening step are provided through oral and written reports. The written report spreads the report writing tasks over a greater portion of the semester than would be the case if only a final report were required. Essentially all of the material in the preliminary report will become part of the final report. The preliminary report and all sensitive communications may be treated as confidential. For some projects, students and faculty sign a secrecy agreement with DuPont.

Flowsheet Development • Identifying waste streams in the early stages of process design is expedited by considering waste streams to be either intrinsic or extrinsic. Intrinsic waste streams are those that are inherent to the process configuration, while extrinsic waste streams are associated with the operation of the process.[2] Some waste streams can be identified from macroscopic material balances, but identification of other waste streams may be difficult at an early stage of process development. Identification of intrinsic wastes may, at times, require experimental data; identification of extrinsic wastes usually requires experience. A great deal of the nature and the input-output structure of alternative flowsheets[3] may be found from examining the reaction step. Information on some waste streams requires discussions with knowledgeable DuPont personnel in order to get a total view of the wastes generated in an operating process.

Development of appropriate mass and energy balances is a critical component of process synthesis and evaluation. Regardless of the computer tool employed, approximate hand calculations are a critical first step in the development of mass and energy balances. Approximate balances, typically using spreadsheets, tend to be appropriate for the more "preliminary" process synthesis activities, although advanced process simulators, such as ASPEN, may be timesaving devices for difficult problems such as coupled mass and energy balances. The FLOW conceptual process design simulator, developed at the Oak Ridge National Laboratory,[4] is very useful for incorporating the type of information typically available at the conceptual design level into simulation of mass and energy balances and estimation of capital and operating costs. For post-conceptual process synthesis, the rigorous material and energy balance capability of flowsheet simulators, such as ASPEN, may be required as a deliverable.

The window for creativity in these activities comes after the students understand the process and its constraints and are formulating or evaluating their flowsheets. The semi-structured brainstorming activities of the flowsheet formulation phase may take a considerable amount of time, but are critical for the opportunity they offer for creativity.

Estimation of Capital and Operating Costs • For preliminary estimates of fixed-capital investment by anyone other than an expert, the factored approach has generally proven reliable and is usually the method selected. In this method of cost estimating, the purchased cost of the major equipment items is estimated and the total fixed-capital investment is estimated by applying a multiplier (Lang factor) to the purchased cost of the major equipment items.[5] When time for this activity has been compressed, an approach based on a method by Zevnik and Buchanan[6] has been used; this method must be carefully applied, however, and calibration of the procedure using actual cost data is recommended. Specific operating cost information, product cost, and raw material costs are consistent with those used within DuPont.

Selection of Most Promising Alternative(s) • Selection of the most promising alternatives occurs when capital and operating estimates have been completed. Again, the students are encouraged to develop criteria that properly emphasize DuPont's hierarchy of waste management options as well as cost and other considerations.

Final Report and Presentation • The final design report from this activity is a business confidential document. As mentioned earlier, students typically sign a "limited term" secrecy agreement with DuPont. The agreement to hold findings of these projects and related information secret is important if the students need access to proprietary information in order to provide a useful study. The final report is reviewed first by the university advisors, and after their comments are addressed, it is reviewed a second time by both university and DuPont project advisors. A final oral report is also made by the student design team at the conclusion of the project.

PATH FORWARD

The essential elements of the design internship described in this paper are functioning successfully. There is both an opportunity and a need to improve the adherence to project milestones and for improving the cycle of review-feedback-revision in the various phases of the project. Responsibility for planning and execution of the internship rests on the students. An important expectation is that the concluding design report be of professional quality; the internship does not conclude without achieving this goal. Improving the operating procedures that refine the existing activity without reducing it to an academic exercise is likely to be a continuing goal.

CONCLUSIONS

The type of activity described in this paper provides for involvement of university students and faculty in significant and challenging projects involving pollution prevention. Several important steps ensuring successful student design internships are:

1. *The projects should involve worthwhile activities directly related to the student's prior chemical engineering courses.*
2. *The design objectives and ground rules should be clear and mutually acceptable.*
3. *Faculty and industrial advisors should provide effective review and suggestions on an ongoing basis. Suggestions based on the advisor's prior design experiences are of substantial value to the students.*
4. *Report writing and review should begin early in the activity. Much of the report should be semi-complete at the time of the preliminary review. All work, including basic assumptions, process and equipment selection, material balances, design calculations, computer programs/results, and economic evaluations should be included in the final report.*
5. *Cost elements should be similar to those used by the corporate sponsor and should reflect current economic conditions. Ground rules for economic estimations should be included in the Design Objectives.*
6. *The design report should be of similar quality to one expected of a commercial engineering design firm.*
7. *Students are usually required to use computer simulation systems during the projects. The importance of sound judgment in accepting simulation results cannot be overemphasized. When credible solutions are achieved, the very extensive advantages of these systems become apparent.*

The successful completion of projects such as these supplements corporate design activities, particularly when emerging technologies are involved. This project and similar activities have been well received by the students; their enthusiasm, perseverance, and overall quality of work have been outstanding and sincerely appreciated by their advisors and sponsors. Participants in these activities typically begin industrial careers soon after project completion, with a smaller number going to graduate school.

ACKNOWLEDGMENTS

This activity was supported by a grant from E. I. du Pont de Nemours and Company.

REFERENCES

1. Counce, R.M., J.M. Holmes, E.R. Moss, R.A. Reimer, and L.D. Pesce, "DuPont Design Internship in Pollution Prevention," *Chem. Eng. Ed.,* **28**(2), 116 (1994): Counce, R.M., J.M. Holmes, and R.A. Riemer, "An Honors Capstone Design Experience in Chemical Engineering," 5th Pollution Prevention Topical Conference (held in conjunction with the AIChE 1994 Summer National Meeting) Denver, Colorado (1994): *Advances in Capstone Education (Fostering Industrial Partnerships),* Brigham Young University, Provo, Utah (1994)
2. Berglund, R.L., and C.T. Lawson, "Preventing Pollution in the CPI," *Chem. Eng.,* **120** (1991)
3. Douglas, J.M., "Process Synthesis for Waste Minimization," *Ind. Eng. Chem. Res.,* **31**, 238 (1992)
4. Ferrada, J.J., J.W. Nehls, Jr., T.D. Welch, and J.L. Giardina, "Modeling a Novel Glass Immobilization Waste Treatment Process Using Flow," 1996 AIChE Spring National Meeting, New Orleans, Louisiana (1996)
5. Peters, M.S., and K.D. Timmerhaus, *Plant Design and Economic Analysis for Chemical Engineers,* 4th ed., McGraw-Hill, New York, NY (1991)
6. Zevnik, F.C., and R.L. Buchanan, "Generalized Correlation of Process Investment," *Chem. Eng. Prog.,* **70** (1963) ❐