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 interns and coop assignments typify such experiences; however, reports of more unusual cases are also welcome. Description of analytical tools used and the skills developed during the project should be emphasized. These examples should stimulate innovative approaches to bring 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.

THE M.I.T. PRACTICE SCHOOL

Intensive Practical Education in Chemical Engineering

BARRY S. JOHNSTON, THOMAS A. MEADOWCROFT,
ALEKSANDER J. FRANZ, T. ALAN HATTON
Massachusetts Institute of Technology
Cambridge, MA 02139

One of the most satisfying engineering activities is to apply an appropriate blend of theory, intuition, and experience to the solution of a practical problem. In general, engineers learn their theory and principles in the academic classrooms and laboratories; they cultivate practical intuition and experience on the job. Naturally enough, it may be asked if the academic training should also include some practical development as well. The new engineer could then approach a first job with some knowledge of how it "really works." To this end, there exists a variety of cooperative education and industrial internship programs.

In this article, we will describe a unique program of practical education at the graduate level. The David H. Koch School of Chemical Engineering Practice (the "Practice School") is administered by the Department of Chemical Engineering at M.I.T. Students who are admitted to the Practice School spend a semester working at off-campus industrial stations. The semester at the stations replaces the conventional Master's research thesis. Upon successful completion of the Practice School, plus two semesters of graduate lectures in Cambridge, students are awarded the degree of Master of Science in Chemical Engineering Practice.

The Practice School stations are maintained at host companies, which provide office facilities and student tuition and stipend support. Each station is staffed by a Director and an Assistant Director (both faculty of the Department residing year-round at the station) and a secretary from the host company.

Practice School students work within the company, on the company's problems, using the company's resources and equipment, but they are not company employees—they work for academic credit under the guidance of the station faculty. They are given a good deal of responsibility for planning and execution of the work, rather than perfunctorily performing a predefined set of steps. For the host company, the Practice School is like a small consulting firm, working for company clients within a format designed to accomplish a great deal in a short time.

A BRIEF HISTORY

The Practice School is seventy-seven years old, and its continuous operation has been interrupted only by the two World Wars. It came about through the initiative of M.I.T. alumnus A.D. Little and the support of Chemical Engineer-

Barry S. Johnston *has been Assistant Professor and Director of the Midland Station since 1992. He holds a PhD in chemical engineering from Northwestern University. Prior to coming to M.I.T., he worked in the chemical and nuclear industries.*
Thomas A. Meadowcroft *has been Assistant Professor and Director of the West Point Station since 1993. A Practice School graduate, he holds a PhD in chemical engineering from M.I.T., where his thesis was on distributed control systems.*
Aleksander J. Franz *was recently the Assistant Director of the Midland Station. A Practice School graduate, he is now a PhD student at the University of Michigan.*
T. Alan Hattan *is Chevron Professor and Director of the Practice School. He holds a PhD in chemical engineering from the University of Wisconsin. He conducts research in novel separation processes and interfacial phenomena.*

ing Director W. H. Walker. Little, remembering his formative years in industry, sought to have industrial experience made available to students on a regular basis. With funding from George Eastman of Kodak, five stations were set up at companies in the northeastern United States.

In the early years, each host company provided a laboratory and workshop for its station, but presently the Practice School maintains no laboratories, and the students' time is devoted entirely to company projects. What has not changed is the residence of M.I.T. faculty at the stations and the practical nature of the work.

There have been some thirty host companies for the stations over the years. There are currently two stations: the Midland Station at the Dow Chemical Company in Midland, Michigan, and the West Point Station at Merck Pharmaceutical Manufacturing Division in West Point, Pennsylvania. A comprehensive history of the Practice School and its contributions to chemical engineering is available in a monograph by Mattill.[1]

HOW IT WORKS

Either between or after two semesters of graduate lectures on campus, a class of five to eleven students spends one semester in Practice School. These students all have Bachelor's degrees (about half from M.I.T. and half from other schools), predominantly in chemical engineering. They stay eight weeks at one station, have one week off, and then go to the other station for another eight weeks. At the end of this schedule, each student will have worked on four technical projects, contributed to eight written reports, delivered at least four talks, and led at least one technical team.

In the months before the students arrive at a station, the resident faculty solicit project topics from the host company, and together they prepare projects, each designed to occupy a team of students for four weeks. They also identify the company resources that will be needed to support the project. For each project, the faculty write a Problem Statement expressing the client's ob-jectives and providing background information and a suggested strategy for the students. The students are divided into groups of two or three, and in each group a group leader is appointed.

A typical work calendar is shown in Figure 1. After an orientation to the company and the Practice School, each group receives a Problem Statement and is introduced to its client. By the end of the first week, each group submits a written Investigative Memorandum in which the students demonstrate their understanding of the problem, present relevant background information, and propose the method by which they intend to accomplish their objectives. The students must also exhibit a satisfactory understanding of the safety requirements of their project. In the associated Proposal Conference, one student from each group makes a formal oral presentation to the clients, faculty, and students. The Proposal Conference is a useful forum for review and modification of project plans.

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One week later, another student from each group presents an oral Progress Report. By this time, significant progress is expected, and members of the audience often respond with valuable suggestions. With one week remaining, each group leader chairs an informal meeting of the group, the client, and the faculty in which the form and substance of the remaining work are negotiated and agreed upon. The project culminates in the writing of a Final Report (occasionally the size of a small Master's thesis) and the oral Final Presentation by the group leader. The faculty critique two preliminary versions of the report before accepting the final draft. A typical Final Report outline is shown in Figure 2.

The schedule is repeated for a second project, with new group assignments and leaders. At the conclusion of the two projects, the faculty give letter grades and evaluate each student with respect to technical ability, creativity, motivation and initiative, leadership, and communication skills.

Sun	Mon	Tue	Wed	Thu	Fri	Sat
Informal Dinner at Director's House	Company Orientation; Tours; Welcome Dinner	MIT Orientation; Students Meet with Clients		Slide Reviews	Proposal Conference; Investigative Memorandum Due	Canoeing
		Revised Investigative Memorandum Due	Group Leaders Meet with Director	Slide Reviews	Progress Report; Group Photo	Volleyball and Barbeque
				Informal Progress Report at Plants	First Draft of Final Report Due	Movie
		Second Draft of Report Due	Slide Reviews	Final Presentation	Assistant Director Conference; Final Report Due	Mackinac Island Trip!

Figure 1. *First-month Practice School calendar.*

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The students perform a similar evaluation of each other. For many it is the most thorough discussion of their strengths and weaknesses they have ever received. After a week's break, the students go to the next station for two more projects, following a similar schedule. Grading and evaluation at the second station are independent of that at the first.

The objectives of a Practice School project are deliberately ambitious. Students normally find they must work sixty to eighty hours a week. Careful planning of the work and effective organization of the group thus become crucial skills. Working in groups is often a new experience for the students. The group leader, in particular, can gain valuable experience in planning, allocating resources, encouraging the team, and making decisions. Each student has at least one turn as group leader.

The faculty attempt to keep abreast of the students' progress, challenge their thinking, supply information and suggestions, and direct them to resources. The students work as needed with a variety of host company personnel such as librarians, laboratory technicians, research scientists, technology specialists, computer experts, plant operators, and process engineers. Both faculty and students are bound by confidentiality agreements in their handling of the host company's information.

The students live in apartments that cost about as much as they would have to pay in Cambridge. To provide some diversion, the faculty arrange weekend activities that vary with the preferences of the individual class and can be as simple as dinner and a movie or as challenging as bicycling, cross-country skiing, or canoeing. During the weekend between projects there is time for an overnight trip to an area resort for skiing or sightseeing.

CASE HISTORIES

Consistent with the wide range of technologies and activities that fall within the province of chemical engineering, students in the Practice School may expect a diversity of work topics. The majority of projects involve an operating process, but the work may also include research, design, or simulation. Three case histories are described below, with the descriptions written to give a clear idea of the students' work while at the same time protecting the host company's proprietary information. Each of the projects was accomplished in four weeks, including written and oral communication of the results.

CASE 1: Refrigerated Separation

Figure 3 shows a continuous separation process. The column feed and overhead streams are cooled by a cascade refrigeration unit that provides coolant at two temperatures, the higher for the feed cooler and the lower for the condenser. The clients wanted to increase production at an upstream reactor and felt that the column and refrigeration unit were limiting.

The students began by determining the material and energy balances. They obtained flows, temperatures, and pressures from plant instrumentation and requested chemical analyses of several streams, using this information to develop and validate an ASPEN PLUS model of the process. A check of the column temperature profile suggested that little separation was being achieved in the upper portion of the column. After performing staging calculations, the students concluded that the reflux ratio could be reduced without affecting the overhead purity, as shown in Figure 4. This would reduce the load on the refrigeration system as well as increase column capacity.

The students then analyzed the operation of the refrigeration unit. They quantified the split of refrigeration capacity between the two sides of the cascade, showing that the overall capacity is increased as the cooling is diverted from the lower to the higher temperature side. The column staging calculations indicated that more feed cooling and less overhead condensing would not adversely affect the separation. Hence, they recommended operating conditions that increased both column and refrigeration capacity.

Beyond the immediate production increase from changes in operating conditions, the students also estimated the capacities of several heat exchangers, both within the refrigeration unit and associated with the column. From this they provided the clients with a list of equipment upgrades to allow further production increases. Furthermore, the students traced the service piping and recommended valve settings that would improve coolant distribution without requiring hardware modifications.

With the client's permission, the students supervised a plant trial to test their recommendations. Following the students' instructions, the plant achieved a record production rate while maintaining product specifications.

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Figure 2. *Table of Contents from a typical Final Report*

Company engineers subsequently incorporated the student's ASPEN PLUS model into a comprehensive model of the process, which has proved useful in further op-timization studies.

CASE 2: Reactive Batch Distillation

A product is made by sequential substitution at active sites

$$A - B_3 + 3C \rightarrow A - C_3 + 3B$$

The batch process is run in a steam-heated kettle, and volatile compounds are separated in an overhead still. After an initial distillation to remove by-product B, the kettle is run under vacuum to remove excess reactant C, which is then recycled to the kettle to begin the next batch. Sharply increased demand for the product necessitated a production increase. In addition, there were unacceptable variations in product consistency from batch to batch.

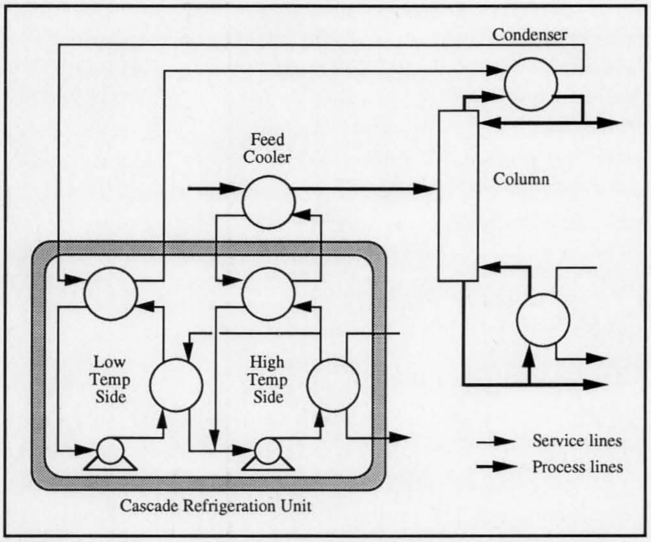

***Figure 3**. Process schematic of refrigerated separation.*

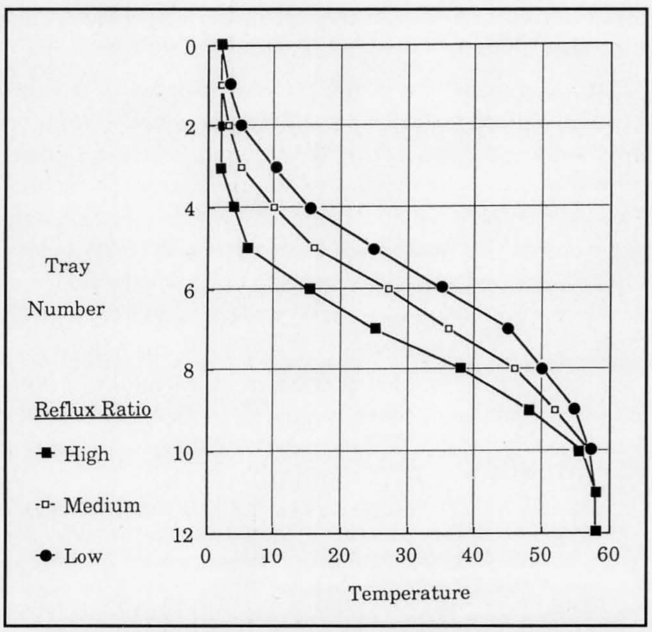

***Figure 4.** Variation of column temperature profile with reflux ratio*

The students approached the problem in three ways. One student began laboratory experiments to generate a consistent set of kinetic data; another attempted to model the batch distillation using BATCHFRAC software; and a third began reviewing the process operating data. It sometimes happens that an initial approach must be abandoned. In this project, the batch modeling was dropped and the students concentrated on process experimentation to effect improvements.

Chemical analyses allowed the unsteady material balance to be determined. The students discovered that by rearranging process steps, several non-productive steps could be omitted entirely. In particular, they could reduce the contamination of recovered reactant C with by-product B. They reached their conclusions from the scrutiny of process data coupled with basic stoichiometric calculations.

The students ran several trial batches in the process equipment to test their recommendations, which required some adjustment of sleep schedules to accommodate round-the-clock production. The simplified batch scheme increased the purity of recovered reactant C, which in turn improved product consistency from batch to batch. In addition, product yield increased. Hydraulic calculations indicated that the column pressure drop was significantly higher than expected. Subsequent examination of the column proved that the packing was crushed. The clients have realized significant production gains from the students' work. In addition, the students' kinetic data have proved useful to company engineers designing a new continuous process for the product.

CASE 3: Quantitative Risk Assessment of a Storage Facility

A volatile and flammable chemical is stored in a refrigerated tank. The tank is protected from overpressure by rupture disks, but the clients were concerned that the protection might be inadequate, especially in case of fire.

The students examined the equipment and the safety procedures. They constructed fault trees leading to a BLEVE (boiling liquid/expanding vapor explosion) or a UVCE (unconfined vapor cloud explosion). They made heavy use of the literature, as well as interviewing plant safety organizations. From these sources they assigned probability values to the steps in the fault trees and thus derived the overall probability of each incident.

The students found and applied correlations for damage from projectiles, blast waves, and thermal radiation. They deployed the PHAST code to calculate the dispersion of the chemical in an atmospheric release and thus estimated the consequential damage to the plant and to the surrounding community.

Having specified the paths by which incidents could occur, the students identified several improvements to operating procedures and safety equipment. They designed a new pressure-relief system, using an in-house code. Heat transfer calculations led to recommendations for the number and placement of water deluge nozzles. From their risk assessment, they could express quantitatively the benefit to be gained from implementing each recommendation. The estimated probability of incident was reduced by two orders of magnitude. The final report was abstracted for inclusion in the host company's process safety guidelines.

THE BENEFITS

The Practice School is an educational program operated for the benefit of the students, but it can only continue if the host company feels that its money is being well spent. For the company, the Practice School provides teams of talented engineers who can mount energetic attacks on important tasks. During their relatively short stay in Practice School, students are undistracted by the multiple duties and concerns of regular employees and are able to direct undivided attention to the problem at hand. The focus and intensity of the students' efforts is often inspiring to company employees.

What the students lack in practical engineering experience, they sometimes make up for by a fresh approach to problems. Often the solution to a problem is found in the creative assembly of company resources. The students do make original contributions, and occasionally they demonstrate new techniques of analysis which are then picked up by the company. Company personnel who devote a few hours a day in supporting the student group can see their investment produce a significant amount of accomplished work.

Clients are generally pleased with the quantity and quality of the work. Responses to surveys in recent years indicate that 90% of the clients would like to have another Practice School project. Many prospective clients, however, fear that the students will require too much of their time, and this possibility is especially troublesome for oversubscribed production supervisors whose plants are running lean on personnel. While the short duration of a project is appealing to some clients, others have requested that projects be longer, or that less time be spent in writing and presentations.

Students attending Practice School may experience an unprecedented level of professional involvement. The host companies offer them important tasks; decisions will be made and money spent, based on their work. Students are excited to find that their efforts have resulted in significant cost savings or production increases; they acquire the confidence which follows the accomplishment of a demanding task. From observing other groups, they appreciate the variety of activities and applications of engineering.

While knowledge from academic classrooms is offered as separate subjects, a Practice School project is likely to require that this separately acquired knowledge be integrated. Thus the reactor performance may be limited by the heat exchanger area, and the distillation column fails because of reboiler piping. Furthermore, what the homework problems normally gave as background information now has to be obtained or estimated. The students must quickly assimilate and deploy procedures and software that may be new to them. Since different companies may use different tools for similar purposes, the students must adapt to what is available at each station.

The students benefit from working with experienced engineers and scientists at the host companies. This can give them a deeper understanding of particular technical concepts, practical details of equipment operation, shortcut design and estimation techniques, or a sense of what constitutes reasonable and realistic industrial practice. Experienced engineers can illustrate how problems are best approached and what to watch out for. The students may also observe the sorts of jobs available in industry, which may influence their own career decisions. In addition, the students have more access to faculty guidance than in the typical campus lecture course.

Finally, the students are able to improve their communication skills. Reports are not only written, but they also must be revised. The faculty are concerned with content and presentation, questioning the choice of verb as well as the accuracy of the energy balance. Each student's oral presentation is evaluated for delivery as well as for composition. Before each talk there is a faculty review of the visual aids, to assess both the organization and the clarity of the material. The Informal Progress Report offers a chance to improve meeting skills. Working in groups, the students gain practical knowledge of interpersonal relationships, sometimes under stressful circumstances. The experience of being a group leader is particularly motivating to previously shy or reserved students.

CONCLUSION

The intensity of the Practice School would be impractical to maintain for more than a short time—students can find the experience exhausting. Each group has written and revised two documents and prepared three oral presentations each month; they have often had to adjust sleep schedules to follow production runs; they have met and listened and read and discussed and debated and calculated and defended until they want no more.

Appreciation of the benefits seems to grow with time. Practice School graduates have been particularly strong in their subsequent support of the program and the Department.[2] Students later tell us that through the Practice School they gained a sense of how much can be accomplished, how decisions can be made from incomplete and contradictory information, how scarce resources can best be allocated, and how new information can quickly be assimilated.

The Practice School does not pretend to be the only way to learn; however we are confident that its contribution to chemical engineering education is unique and valuable.

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