DEVELOPMENT OF THE DESIGN LABORATORY

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THE CHEMICAL ENGINEERING Design Laboratory was initiated as a senior course at Stevens Institute of Technology in 1968. It is a six-credit course and follows our course in process design. Both courses are related, giving the student a complete experience in chemical engineering design. In 1973 the philosophy and organization of the laboratory was described [1]. Since that time we have been developing a systematic approach to designing the systems and operating the laboratory which are described in this paper.

The design laboratory is an example of an experiential learning activity. In 1976 Harrisberger *et al*, [2] described the experiential learning process and evaluated several current programs. They grouped experiential learning activities into two classes: simulations and authentic involvement. "Simulations consist of contrived situations that are carefully designed to meet selected learning objectives and are under close faculty control. The Authentic Involvement activities expose the student to real situations with totally open-ended outcomes, although the faculty may influence the selection of the situations and set performance criteria to assure that positive learning objectives are met." Harrisberger *et al* further state that besides being open-ended the authentic involvement models involve ". . . unstructured activities, originating off campus . . . ." For simulations they identified the following models: the experimental laboratory, guided design, case studies, and games. For authentic involvement models they identified: internships, consulting, and clinics or design centers. According to Harrisberger *et al* all authentic involvement uses outside clients, which may be industrial firms, governmental agencies, civic organizations, institutions, or private individuals. It should not be necessary that an outside client generate projects. The essential feature of an authentic involvement activity is that it should be open-ended. Although most projects in the design laboratory have been originated on-campus by our faculty, the projects are open-ended and the operation of the laboratory is unstructured. Thus we believe that the design laboratory is an authentic involvement activity. Projects generated by the faculty have the advantage of promoting a greater involvement of the faculty in the course.

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COURSE OBJECTIVES

Several modifications in the content of the laboratory have been made since it began, but the main objective has always been to use the laboratory ". . . as a vehicle for teaching design. . . ." [1]. Also, ". . . an important objective of the design laboratory is that the student develop the skills required to reduce his design calculations to practice. . . ." [1]. As it has been pointed out, training in design is not only useful for those who undertake a career in design, but also for those who enter research and development and who will frequently be required to design their own experimental systems [1]. Early in the development of the course the collection and analysis of data was considered an additional objective of the course, but later it was decided that this is not a design objective.

Presently, the only data required is that which is necessary to demonstrate that the system operates as designed. Producing a working system is the main consideration. At the beginning it was recognized that, in addition to the design experience, the student obtained a complete experience, starting with project conception and ending with its implementation. Later, it was found that training to plan, execute, and complete an engineering task, specifically project management, was also necessary [3]. This particular aspect of the course, which is still being developed, is generally useful whether the engineering task be process development, process design, or project engineering.

DESIGN PROJECTS

The essential feature of an authentic involvement project is that it be open-ended, although Harrisberger *et al* stated that the project should originate off-campus, probably because in the course models they considered the projects were originated by off-campus clients. At Stevens most of the projects originate on-campus. Although the work may be done on- or off-campus, or in some combination, we prefer that the work be done on-campus so we can maintain better control over the projects and also so we can continuously observe and improve the learning process and environment. Sources of projects and examples of projects were given earlier [1]. More recent examples of projects are listed in Table 1. Several projects have been to design and construct experiments for other chemical engineering laboratories and for faculty research projects. In these cases a faculty member becomes the client. Several systems have been designed and built by the students over the years. The projects may involve the design of new systems or new subsystems for existing systems. Recently, completed projects have been expanded by designing control systems. An example of a subsystem was the addition of a carbon dioxide makeup system to an absorber. This required designing a sampling system to analyze the carbon dioxide in the exit gases from the absorber and a system for automatically feeding of makeup carbon dioxide.

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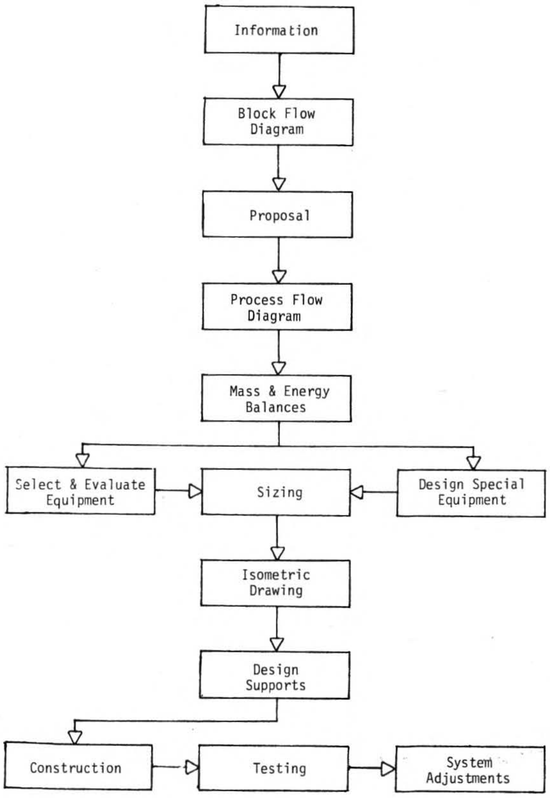

FIGURE 1. Phases of a design project.

TABLE 1
Selected Design Laboratory Projects

1. **Design of an automatic carbon dioxide makeup system for a gas absorber recycle stream.**
2. **Design of an adsorber for removing phenol from waste waters.**
3. **Design of a fermenter for producing cellulase enzyme.**
4. **Design of a distillation column using York-Twist packing.**
5. **Design of a sonochemical reactor for producing phenybutanol.**
6. **Design of an equilibrium flow cell for measuring the solubility of carbon dioxide in crude oil.**
7. **Design of an electrochemical reactor for reducing ketones.**
8. **Design of a packed bed catalytic reactor for producing methane from carbon dioxide and hydrogen.**
9. **Design of an artificial kidney with continuous removal of urea from dialyzate.**
10. **Design of a membrane process for stripping monomer from latex solutions.**

PROJECT STRUCTURE

The general structure of any project is shown in Figure 1. A team of three students selects a project from a list. We have experimented with team sizes of one to four and have found that three is optimum. Working alone is generally not beneficial for the student, and a team of four tends to be inefficient. Students prefer working with a group so they can readily discuss their project and test their ideas. After the project is selected, the project definition phase begins which first requires familiarization with the project.

At the beginning, references are usually provided. Additional information can be obtained from the literature, the faculty in general, industry, or any other source. As the student becomes familiar with the project he generates block flow diagrams to illustrate alternative designs, and he eventually writes a preliminary proposal to outline the scope of the project for the semester. Further refinement of the project goals is achieved by conducting an informal project review with at least two faculty members.

After the project has been defined, the design phase begins with the construction of a process flow diagram. The type of diagram we have found to be most useful is one that contains all the major equipment, valves, and instrumentation. Following this, mass and energy balances are made, and all the equipment appearing on the diagram are sized. Because flow system design appears in nearly all projects, the topic is taught in our process design course which precedes the design laboratory. Simultaneously, most equipment is selected from catalogs, evaluated, and ordered. If some equipment is not available commercially, it must be designed and fabricated. Because of the time required to fabricate special equipment, we make a considerable effort to find an alternative method which uses standard equipment. While waiting for the delivery of the major pieces of equipment, the piping system is designed by first laying out the equipment and then constructing an isometric drawing. At the same time, equipment and piping supports are also selected.

From his evaluations and tests he found that that particular thermometer was the most reliable. It was the experience of his company that equipment which looks the best is often the most reliable.

Accurate drawings are needed to reduce construction errors and to produce a reliable, aesthetically pleasing system. There appears to be a relationship between aesthetics and reliability, as pointed out by Hathaway [4]. At the beginning of his talk, Hathaway passed out several dial thermometers and asked the audience to select the best one. At the end of the talk he tallied the votes, and it was found that the thermometer which looked the best obtained the most votes. From his evaluations and tests he found that that particular thermometer was the most reliable. It was the experience of his company that equipment which looks the best is often the most reliable. Obtaining an acceptable drawing from students is rare. On a trial basis we have attempted using a draftsman, but this was only partially successful because of the cost and the number of drawings required in a short time. The next step will be to develop a computer-aided drafting program suitable for the course.

Finally, the implementation phase of the project is reached. It consists of construction, testing, troubleshooting, and the final adjustments necessary to produce a working system. This phase provides the necessary feedback for the student to gain confidence in his design procedures.

MECHANICAL DESIGN

In addition to process design, a successful project also requires careful consideration of the mechanical aspects of the design, including fabrication techniques. Surprisingly, it is difficult to instill the importance of insuring that the various parts of an apparatus fit, are properly sealed and are securely supported. Instruction in these techniques must be provided in the course. Some of the required techniques are unique to a project while others are more general, such as piping. Since we keep the size of the systems as small as possible (to minimize the cost, the space required, and the time to assemble the system), small diameter tubing is adequate for the piping. For a number of years a local company has lectured, instructed, and demonstrated on the selection of fittings and valves and the assembling of flow systems with tubing. Since the introduction of these topics into the course, the reliability and aesthetics of the systems have improved considerably. Seal design, another generally useful topic needed for designing safe and reliable systems, will also be treated more systematically than it has.

PROJECT MANAGEMENT

Students, as well as professors, are hopeful that given enough time they will be able to do a better job. At the beginning not much consideration was given to the student's need to develop techniques of planning his operations to fit within a fixed time frame. Procrastination is always a problem, but most students have a strong desire to complete their projects and to do well. The design laboratory project is more complex than other activities which they have encountered up to this point in their careers. Also, they must coordinate their activities with other members of their team. Because students are inexperienced in planning and organizing their activities jointly, we have gradually developed project management techniques for the course. In this activity students are instructed to break up their project into tasks and to schedule their project for completion in fourteen weeks by computer using the critical path method. The Gantt chart is also utilized. Responsibility for each of the tasks is then assigned to each member of a three-man team.

Further control over a project is established by requiring each team to submit weekly progress reports where progress during the past week is described, problems are discussed, and plans for the following week are outlined. In addition to the weekly reports, extensive monthly reports and a final report are required. The monthly reports are cumulative, which means that the second monthly report uses the first monthly report as a base, making the necessary corrections, improvements and additions. The final report uses the second monthly report as a starting point. This procedure for writing reports is a very effective way of obtaining an acceptable final report.

LABORATORY OPERATION

The students are responsible for the execution of their project, and they are urged to seek help when needed. Except for the initial project review there are no other scheduled reviews. The coordinator is a consultant who suggests courses of action and sources of information, both internal and external. Occasionally, if it is perceived that a project is stagnating or that the project direction is not clear, as indicated by the weekly reports, the project team will be required to report orally to the course coordinator.

Teaching assistants are assigned to the course and are useful during the design phase of the project. Later, when equipment must be selected and evaluated, and during the mechanical design phase, teaching assistants are less effective. Teaching assistants are also used to control the flow of tools, to regulate the ordering of equipment and supplies, and to maintain laboratory safety and construction standards.

To make the laboratory function, a variety of mechanical skills is needed. It is unrealistic to expect that students will have all these skills, but they should understand the principles and limitations of each technique used in their project. Our goal is to limit the student's laboratory activity to assembling their system from components and to testing the completed system. Because of the large demands on our machine shop, we use our shop for only small jobs and utilize outside sources for major machining, welding, glass blowing, and other specialized skills. The students coordinate these activities, making all the arrangements, providing drawings, and filing requisitions for the work.

We do not rely entirely on a storeroom of equipment for projects. Ordering most of their equipment is considered part of the student's experience in the course. Various companies have donated equipment to the laboratory, helping to reduce the cost of operation. Funding for the laboratory has been provided by Institute funds and by general funds given to the department by industry. Occasionally, grants have been given directly to the laboratory. Last year we had a total of seven projects costing about $2000 per project.

On the final day of the course each team is required to demonstrate the workability of their project during an open house. This is an exciting day, and the results have been gratifying. Grading is determined by the degree of completion of each project, performance during the semester, and the quality of the reports.

CONCLUSIONS

There is no doubt about the value of the design laboratory in developing the ability and confidence of the students to translate their calculations into a working system and in giving them the satisfaction of obtaining a finished product. The design laboratory compliments our course in process design, giving the student a complete design experience. During the semester one can see considerable improvement in the ability of the student to apply his knowledge to a real situation, to make technical decisions, to overcome obstacles, and to manage a project. It is believed that the design laboratory experience shortens the time period required for a student to become a productive employee after he enters industry.

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