THE CHEMICAL ENGINEERING LABORATORY
AT JOHNS HOPKINS UNIVERSITY

by

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Introduction

Laboratories, once thought to be necessary evils in the engineering curriculum, are now more often considered one of the exciting parts of the program, independent of the lecture courses. During recent years, there has been much discussion of the proper role for the laboratory in the program. The objectives and the relative merits of various mechanical details of laboratory organization and operation have been discussed most intensively.

There are three extreme positions which one might adopt with respect to the goals and objectives of an undergraduate laboratory in Chemical Engineering. These are:

1. That the laboratory should be an adjunct to a lecture course and should serve as a forum for illustration of principles discussed and presented during the lecture;
2. That during the laboratory course, the student should be given some "feeling" for research and development techniques in engineering;
3. That the laboratory is best concerned with training students in the operation of equipment which he will be expected to operate or whose operation he will be expected to supervise later in his career.

In practice, these are not three separable ideas. Any laboratory course will inevitably involve some of each for almost every student. However, the attitude of the professor in charge of the course will influence the relative emphasis placed on each, the orientation of the course work, the experiments, and, hence, will largely determine the type of experience provided to the student and the ideas and talents gained from the program.

During the last decade the laboratory has developed largely as a separate and independent part of the curriculum and not as an adjunct to a lecture course. This is quite a different role for the laboratory from that in earlier engineering programs. While some laboratories must still serve as supports for lecture courses, there is ample need for those which operate completely independent of any one lecture course and draw on material from all. In these, the student may take a more active than a passive role.

Any attempt to use the laboratory as a means for training students in the operation of equipment can only be partially successful. Further it is difficult to justify such a training rather than educational function in a university. Since the time available for laboratory instruction is so limited, it is not possible to include more than a small fraction of the total possible items of equipment which are important in the chemical industries. Hence it seems more reasonable to consider that the education of students in research techniques in the broadest sense, that is, in methods for extracting information or of learning from physical systems to be the goal of this course. Such a goal is capable of realization in some measure.

Within broad limits, the exact experiment which the student is assigned in the laboratory is less important than the type of assignment which he is given. The student may learn how to approach a problem in the physical sense from virtually any of the classical unit operations experiments or from any of the engineering-science experiments in the transport processes. Thus the details of the laboratory operation and the relationship between student and instructor are important.

Some of the questions of importance in the operation of the laboratory are the following:

1. Whether students should work in teams or be assigned to experiments on an individual basis;
2. Whether students should be expected to do substantial amounts of set-up or maintenance on the equipment or whether they should approach an apparatus which is functioning correctly and is in excellent repair;
3. Whether detailed instructions should be given to the student or only minimal information provided on the objectives of their assignment;
4. Whether the equipment should, in general, be of pilot plant scale or whether very small, bench-scale apparatus is to be preferred.

The answers to these questions will largely determine the type of laboratory course given and the nature of the experience afforded to the student. There is, of course, another factor - the interest and competence of the professor in charge of the laboratory. This is of overriding importance in the success of the laboratory as an educational experience.

There are many different answers to these questions reflected in laboratory programs throughout the United States, each set functioning with certain advantages. The laboratory course, like the lecture program, reflects the interets and philosophies of the staff. Such differences exist and should be continued actively as a positive good associated with our educational system rather than to be tolerated passively but suspiciously.

However, so long as we have the freedom to orient our programs along lines representing our own interets, it follows that we must be prepared to assume the responsibility associated with this freedom, in this case, to communicate our ideas and activities to others in the profession. The purpose of this paper is to outline the system used in the undergraduate chemical engineering laboratory at The Johns Hopkins University, to indicate some of the features which are believed to be most attractive and to present some of the problems which exist.

The Laboratory Program at The Hopkins

The chemical engineering laboratory in the undergraduate program at The Hopkins is presented entirely in the senior year. The first semester is devoted to experiments in the engineering sciences and the second either to advanced experiments (or projects) or to experiments in the classical unit operations areas, depending on whether or not the student is going into graduate school.

The first semester "engineering science" experiments are varied in nature; most of them have been developed around one or a combination of the transport processes. The type of experiments available are illustrated by the following partial listing:

1. Gas flow through an orifice, venturi meter, and capillary meter measurement of velocity profile;
2. Gas flow through a packed bed;
3. A Joule-Thompson experiment;
4. Liquid flow through a capillary, variable head tank;
5. Gas flow (pressure drop versus velocity and bed height) in a fluidized bed;
6. Pressure drop versus velocity and bed height in a liquid fluidized bed;
7. Velocity profiles in the working section of a well-designed wind tunnel; measurement of the velocity decrement behind a rod oriented transverse to the mean flow; use of hot wire apparatus;
8. Heat transfer to and within a packed bed;
9. Heat transfer from a metal rod heated on one end - determination of surface coefficients as a function of position;
10. Heat transfer to a stirred liquid; control of the temperature in the pot by an electronic control instrumentation;
11. Heat transfer to a thermocouple; errors in temperature measurement;
12. Heat transfer from a heated cylinder oriented transverse to the mean flow in the wind tunnel;
13. Thermal diffusion in gases;
14. Mass transfer from the surface of a rod oriented transverse to the mean flow in the wind tunnel;
15. Diffusion through agar-agar gel with and without an imposed electric field.

Wherever possible, experiments are "rigged to involve more than one principle. For example, in the experiment listed as No. 4, the fluid is an oil which, on occasion in the past, has been initially loaded with "Thixin" making it thixotropic. The advantage to the educational experience of the student is, I think, considerable.

At the beginning of the second semester, the students are divided into two groups. Those who do not plan to continue into a graduate program (or who will not be recommended for graduate school) are requested to do experiments of the classical "unit operations" type. For this purpose we provide a quite standard single-bubble-cap plate distillation column, a packed distillation column, a standard shell-and-tube heat exchanger, and other similar prosaic apparatus. We feel that, for such students, this type of experience is most desirable.

For those students who are going into graduate school, either of two options is open. They may do a special project, perhaps in association with the research activities of one of the members of the staff, or, if they so desire, they may elect to do several more advanced engineering science experiments. Among the latter are kinetics experiments, development of new experiments in areas not covered by the laboratory, experiments in instrumentation and control, etc. We hope that this division of effort will provide a laboratory experience which can be made nearly optimum for each student.

Students are assigned individually to experiments during both semesters, there is no formal "team system" involving a "group foreman". We recognize the argument that students must learn to work in teams - since that is the system used industrially - but we believe that the most satisfactory educational experience is not achieved in this way. It is true that for very large classes and large student-to-staff ratios, the team system could be the only practical way to operate. Hapily, the chemical engineering senior class at The Hopkins rarely exceeds 10-12 students and the professor in charge of the laboratory is normally provided with a graduate assistant to help in the operation of the program. With such numbers, students may easily be handled individually throughout the program.

A technichian is provided in the laboratory to maintain equipment in a satisfactory state of repair and operability. Students are expected to cope with routine maintenance problems as they arise during the laboratory period and to make such minor adjustments and corrections to equipment as may be required for their experiment. Major plumbing, electrical, and mechanical repairs and changes are normally provided, often under the supervision and direction of the student requesting the work.

Instructions to the student are purposely kept minimal. An objective is always clearly stated but methods for achieving the objective or objectives are never suggested. The student is expected to decide on procedures which will permit him to obtain the necessary data, to derive or find in the literature the equations or relationships which will be useful in calculating the results which are wanted, and to report these in some meaningful way. Report forms are never prescribed, their format and length depend entirely on the nature and extent of the information which the student wishes to describe.

The size of the equipment to be used by the students in the undergraduate laboratory must be determined by the objectives set for the laboratory by the professor in charge. If the operational problems associated with the actual industrial type equipment are to be illustrated, then the laboratory equipment must be large and must possess many of the characteristics of the corresponding industrial-scale items. However, the amount of material required for the operation of such large scale equipment, the time required for equilibration, the difficulties encountered by the students in understanding the principles of operation when faced with the complexities of manipulation, tend to militate against such large scale apparatus and dictate the use of smaller scale items.

Intermediate sized equipment possesses neither the characteristics of the large scale pilot or plant scale items which can be justified in terms of operational training nor does it provide the opportunity for learning and understanding basic principles provided by the very small scale units. Hence, we use small scale equipment, equipment operable by one man, which can be equilibrated in periods of less than one hour. The student is expected to study the principles involved rather than the mechanical details.

One further problem associated with the laboratory arises from the difference between laboratory and lecture courses. Unless the group is very large, the professor in charge of a class can almost continuously monitor the comprehension and receptiveness of the students. There is continual feedback from the student to the professor and those students who are confused by some facet of the work may so indicate immediately and the source of confusion can be discussed at that moment. Further, from quizzes and tests, the professor discovers those areas where comprehension is lacking, where more work must be done, or where he is failing to communicate effectively. Such information feedback is an important, although almost automatic and perhaps unconscious part, of any classroom structure.

While similar channels for information feedback do exist in laboratory courses, the impedance to information flow is very much greater. As a result, the professor cannot appraise the comprehension, contribution, and activities of any single student in the laboratory nearly as well. Grades in the laboratory are usually based on attendance, on report grades(usually from the graduate assistant), and on a final examination which may have little to do with the work actually done by the student during the year. A possible system for improving the flow of information from the student to the professor in charge of the laboratory involves enlisting the aid of the other members on the staff.

Assume that each member of the staff, except the professor in charge of the laboratory, meets with the members of the laboratory class individually for discussion of a problem(or several problems as the case may be) which the student has completed in the laboratory. The student would be expected to explain what his problem was, the work he(or his group) did, the conclusions reached, and the significance thereof. The professor could, by careful questioning determine the extent to which the student understands the work, its significance, and even the extent to which the student was responsible for the success or failure of the experiment. This system would have the educationally salubrious effect of forcing the student to report to someone qualified to judge but not directly familiar with the assigned task.

The professor in charge of the laboratory would then receive reports from the rest of the staff on each of the students. This report could be in the form of a grade based, for example, in equal parts on presentation by the student, comprehension of the work by the student, and the quality of the work actually done. Such a system is planned for the 1962-1963 academic year in the chemical engineering laboratory here at Hopkins.

Such a system does not result in a serious drain on the time or energy of the staff. With a student body of, for example, 30, each assigned to ten experiments during the semester, and a staff of five in addition to the professor in charge of the laboratory, this would necessitate four staff/student conferences of this sort per week per man. Since a half-hour is surely enough for such a discussion, this does not seem to be an excessive additional load. The gain to the program could be quite considerable.

Summary

In summary, the laboratory during the senior year in the undergraduate chemical engineering program at the Hopkins is thought to be one of the most important parts of the program. The course provides an opportunity for students to experience the problems encountered when information must be extracted from a portion of the physical world about us. They are required to obtain certain information from an existing piece of apparatus, information which must then be used in some meaningful way either as a source of new knowledge or a means of relating the behavior of one system to that of others. The laboratory is thought to be an educational experience and not part of the student's training in some topic or topics of "practical" significance.

Students are assigned to work and are examined individually. Staff are expected to teach, not just to supervise, students in the laboratory. Whenever necessary, the professor in charge of the laboratory calls upon the entire staff for assistance in the program, for all have an interest in its success.