THE UNDERGRADUATE CHE LABORATORY*

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The laboratory workshop format consisted of a number of speakers each discussing a particular aspect of a laboratory. The papers presented can be classified in four categories: 1) the philosophy and objectives of the laboratory, 2) computer aided laboratory instruction, 3) types of laboratories and experiments, and 4) different approaches and instructional techniques. To assess the attitudes of laboratory instruction along with current and future trends in each of the above categories, a 10-page questionnaire was prepared and mailed to over 50 chemical engeneering departments (primarily those who had faculty members registered for this workshop) in the U. S. and Canada and to a significant number of industrial contacts.

I. PHILOSOPHY AND OBJECTIVES

The major results of the survey were discussed in the first paper of the session by H. S. Fogler. The consensus indicated that the most important goals of the laboratory were to

- Demonstrate or reinforce principles or phenomena discussed in class,
- Give the students practice in planning and interacting with the experiment,
- Develop the students' interest in experimentation,
- Develop a proficiency in technical report writing, and
- Expose the student to open-ended experiments of a research or design nature.

Information on the philosophies of the laboratory at various universities along with ideas about experiments which impart a sense of learning to the student and leave him with a sense of accomplishment were also summarized in this paper.

The results of one question, when averaged, showed the following allocation of the student's time currently spent on a given experiment.

15% of the time should be spent in preparation for the experiment
30% should be used for setting up and carrying out the experiment
25% should be spent on computation and analysis for the raw data
30% should be used for writing the report on the experiment.

Many felt that too little time was currently being spent on giving the students practice at planning and interacting with the experiment to learn the process of experimentation, i.e., the technical and managerial skills required to carry out effective experiments. In the future, it is hoped that most laboratories will provide the student with the opportunity to plan meaningful experiments and experimental programs in which the outcome is not known or is uncertain and in which one must allow for contingencies.

Also discussed in the first paper were a few techniques used at The University of Michigan to complement the standard laboratory exercises in order to increase the student's capabilities for planning effective experiments. In particular, the use of guided design instruction in the synthesis of experimental projects at the sophomore level has proven quite effective. Here, a group of 3-4 students (1) define and develop the need for an experiment which they would like to perform, (2) state the constraints on the experimental program (3) determine the key or critical measurements to be made, (4) suggest methods of processing and analyzing the data, (5) support alternate approaches to various segments of the project, (6) suggest possible outcomes and means of evaluating the effectiveness of the programs. Each group receives feedback from the instructor at various stages of the planning and then gives an oral presentation and defense to the other groups at the end of the semester.

Methods of implementing the open-ended approach laboratory were presented by R. Clift and O. M. Fuller. They described a ChE Laboratory course at McGill, in which a special format

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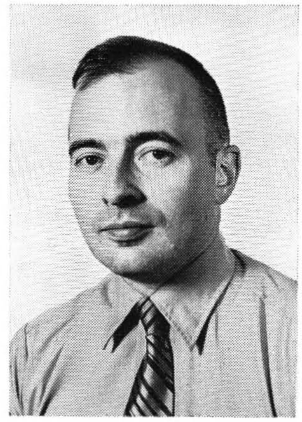

Shair

called the Evolutionary Laboratory has been developed in order to place emphasis on the process of experimentation itself. The distinctive features are specialization of the staff for optimal use of teaching personnel, and the conference period for rapid feedback and evaluation.

Work on each unit of apparatus is directed by an experiment controller (EC) who acts both as technical expert and teacher. The EC has sufficient freedom in planning so that he may, for example, direct a logically connected sequence of experiments rather than repetitive exercises. Following each laboratory exercise, the students have a conference with the EC which consists of an oral report, a teaching session, and an occasion for feedback on instructions and apparatus. The conferences permit flexible planning and evolutionary changes in the exercises. The teaching of experimentation requires, among other things, a description of the process in terms of observable behaviors and a methodology for planning experiments. For this purpose, the McGill program offers a description in terms of instructional objectives and an extension of PERT for planning.

In addition to comments on the laboratory received from industry on the questionnaire, information was gathered and presented by Drs. C. C. Zimmerman and D. N. Burdge of Marathon Oil Company who view the laboratory as a tool to increase the student's problem solving capabilities through experimentation. They reinforced earlier presentations suggesting that greater emphasis be given in the laboratory to problem definition and analysis and to experimental planning. This is to help insure that the student or employee may learn to decide which measurements will be meaningful and not to carry out unnecessary experiments whose results could have been obtained by other means, such as a combination of reasoning and calculation. They encouraged greater development of the student communication skills primarily through report writing but also through oral reports to the instructor. It is interesting to note that while only 50% of the universities returning the questionnaire stated that report writing was a major objective of the laboratory, *every* industrial reply suggested that improvement in the students report writing should receive major attention.

II. TYPES OF LABORATORIES AND EXPERIMENTS

F. H. Shair reported the survey results concerning the attitudes expressed by ChE faculties towards the laboratories in chemistry and physics which are required by students who enroll in the ChE curriculum. Generally the ChE faculty were satisfied, but certainly not enthusiastic about the chemistry laboratories. On the other hand, the ChE faculty generally expressed moderate dissatisfaction with the physics laboratories. Over half of the persons answering the questionnaire stated that they believed their required physics laboratories to be of little value in aiding their students in developing important laboratory techniques, in helping their students to analyze experimental error and uncertainty, in helping their students develop report writing, in helping their students develop oral presentations, and in helping their students formulate an experimental path aimed at obtaining desired answers with the least effort. The merits of the undergraduate laboratories developed by E. C. Stone and D. W. Skelton at Caltech discussed in some detail.

Professor Shair also described a ChE integrated concepts and laboratory course which has been given during the last five years at Caltech.

The fundamentals of ChE are emphasized along with both oral and written presentations. The laboratory experience involves open-ended projects which are also of interest to someone outside of Caltech. Recent experimental topics involved the internal combustion engine, the melting of icebergs, the spreading of oil slicks, the decay of ozone within buildings, transport across pulmonary membranes, and transport across artificial kidney membranes. Students participate in the planning as well as in the conducting of experiments. Several projects are in some stage of being published in the open literature. Exams are given in the form of scenarios. The most important aspect for course update and improvement involves the recycle of the top 10% of the class into teaching assistants during the following year.

Discussed by A. J. Perna were those results of the 10-page questionnaire relating to the Unit Operations Laboratory. A summary of the over thirty schools responding showed that:

- All had either conventional Unit Operations Laboratory or a Transport Laboratory;
- Laboratory experience ran the gamut from a three level approach (sophomore-junior-senior) to only a senior year (majority) course;
- Laboratories were primarily hardware rather than computer oriented;
- In general, laboratory experiments were a blend of pilot plant size and transport size;
- Integrated Lab-Theory courses were rare with only approximately 18% of the schools using this approach;
- All schools have experiments designed to cover the areas of Heat, Mass and Momentum Transport in their Unit Operations Laboratory, but some schools also have incorporated experiments in kinetics, thermo and process control and dynamics in the lab;
- In general the lab improvements have been in the areas of instrumentation, open-ended experimentation, and reduced workload.

One important factor which came out of the survey was that the laboratory has become an area for exposing the students to concepts not taught in the classroom and that it is an extension of his learning process and not completely integrated with the material presented in theory type courses.

R. D. Williams described a one hour chemical reaction engineering laboratory currently being used at The University of Arizona. In this laboratory the student is exposed to a number of different types of reactors used in homogeneous liquid phase reactions, in catalytic heterogeneous reactions and in non-catalytic heterogeneous reactions. A number of methods of data collection, ranging from direct sampling and titration or gas chromatography to direct temperature and pressure measurements, are illustrated in the course along with different methods of data analysis. The students could use these reactors to carry out reactions whose rate laws have been reported in the literature or to study reactions whose kinetics have not been reported.

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An alternative to the weekly laboratory in the form of a three-week intensive course was presented by G. B. Williams and J. H. Hand of The University of Michigan. In this course, which is offered at the end of each winter term, the student has essentially an entire day to complete the experiment and write his report. Consequently he is not under the usual pressure to get the experiment working and finished within as soon a time as possible in order to rapidly go on to other course assignments. In the intensive course there is adequate time to modify and experiment with the equipment, and also time to profit from routine difficulties and breakdowns of the equipment. While the faculty and students are equally enthusiastic about conducting the course in this manner, the only two serious drawbacks appear to be centered around finding housing for the students for only three weeks after the end of the term and the lab's interference with some summer jobs and summer school.

R. M. Hubbard presented a pilot plant oriented experiment which students undertake as a final experiment in the ChE laboratory at the University of Virginia. The experiment is multipurpose and forces students to work as a team to take data, make material balances on a process as soon as data are obtained, and to experience a continuous operation such as might be encountered later in industry. A small operating chemical plant produces hydrogen and carbon dioxide from the catalytic decomposition of a vaporized methanol-water mixture at 300°C and atmospheric pressure. The students operate the plant in shifts for most of a normal day and acquire enough data to carry out at least two complete material balances per shift.

III. COMPUTER AIDED LABORATORY INSTRUCTION

D. E. Seborg described the computer-aided student laboratory which he and D. G. Fisher have developed during the last five years at the University of Alberta. The computing facility includes an EAI 590 hybrid computing system plus an IBM 1800 digital computer which operates in a multi-programmed, time-shared mode and allows several research workers and student laboratory groups to have simultaneous, open-shop access to the real-time and background computing facilities. Typical real-time applications include control of pilot-plant processes, automation of analytical instruments, and student oriented experiments designed to demonstrate particular hardware and/or software features. It was stressed that when properly used, the computer can take over the time consuming routine tasks and let the student concentrate on the important, fundamental concepts of the experiment.

R. A. Schmitz described the on-line computing facility for undergraduate instruction which he has developed during the last three years at the University of Illinois. The system utilizes a time-sharing IBM 1800 computer in conjunction with an undergraduate process dynamics and control laboratory. The apparatus connected to the computer constitute simple closed-loop systems for studies of mathematical modeling and direct digital control. Students using the system must write a FORTRAN program to handle the collection of data, the sending of feedback signals and any calculations involved in the data processing. The system also provides for the connection of an EAI 580 analog computer to the digital machine so that the computer control of complex systems may be simulated. The facility is being employed in a required undergraduate course on process dynamics and control and in an undergraduate projects course.

IV. DIFFERENT APPROACHES AND INSTRUCTIONAL TECHNIQUES

An integrated theory-laboratory course approach was described by R. R. Furgason of the University of Idaho. The approach is to block out from four to six hours per week for a scheduled three credit course and have the class meet in a lecture mode for several weeks followed by one or two weeks of class devoted to laboratory experimentation. This allows the laboratory to be utilized whenever appropriate rather than on

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some fixed schedule. The main advantage is the excellent coordination between theoretical and experimental phases of the class with the laboratory neither leading or lagging the course. The disadvantage is primarily logistical in terms of class, manpower, and scheduling.

The integrated laboratory-lecture approach is being carried out on a much larger scale at Worcester Polytechnic Institute, where it encompasses the entire curriculum. Professor I. Zwiebel discussed the WPI project approach in which courses are viewed as elective tools to build the foundations for completing the students two major projects, which are the primary requirements for graduation along with a competency examination and a humanities minor. Many projects are inter-disciplinary in nature and require a team of students (e.g., a civil engineering-chemical engineering, etc.) each with his particular responsibility, working together to obtain a solution. Special projects, sponsored by a Sloan Foundation grant, run through about 1 1/3 calendar years during which time the student's time is divided equally along the following four segments of the project: preparing a proposal of the project plans, executing the plans, analyzing the results, and preparing written and oral reports. The WPI project approach offers a significant alternative to the conventional engineering programs.

J. O. Maloney and G. M. Kortman of the University of Kansas presented material on two instructional laboratory units. The first was concerned with an experiment in unsteady-state-cooling, while the second unit treated the determination of binary vapor-liquid equilibrium data using an Othmer still. Especially developed for inexperienced instructors, each unit contains sufficient material that the instructor, after reading it and doing the experiment once or twice, would have adequate control of the experiment and would be able to estimate the validity of student results. Each unit provides the following information: equipment description, experimental procedure, extensive data, calculations, computer programs, error analysis, and suggestions for modification of the experiment to achieve variety.

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The educational objectives of the experiment are to expose the student to the concepts of process modeling and experimental determination of model parameters . . .

correlation reprinted by Himmelblau and Bischoff (1968). Since doing so would not serve any particular purpose in light of the educational objectives of the experiment, we have not attempted to confirm the negligibility of adsorption other than to note the absence of long tails on the impulse response curves.

DISCUSSION

The students are given two 3-hour laboratory periods to complete the experiment. In the first period they go through the entire experiment without actually using the radiotracer. Under this format they each get a chance to become familiar with the equipment and injection procedure without the worry of spills or other hazards. Also during the first 3-hour session they are instructed in fundamentals of radiation detection, particularly as related to Geiger-Mueller characteristics, and in radiation safety. In the second 3-hour period the actual runs are made, but the injections and tracer handling are not done by the students, who merely observe. The runs themselves are not particularly time-consuming, so that each student has sufficient time to carry out the necessary calculations and to seek individual instruction on any aspect of the experiment.

The participating students appeared to get a great deal out of the experiment; the only strong objection was to the necessity of calculating moments graphically from analog output, a requirement which will be eliminated in the future when digital output equipment becomes available. A potential problem with an experiment of this sort being given on a junior level is that the students may have to accept on faith the utility of much of what they are doing. This did not appear to be a matter of concern to the students, however, possibly due in part to the fact that they had been introduced to elementary concepts of modeling (and in particular to the dynamic response of a first-order process) in a previous course. The experiment also served to make related material subsequently encountered in senior courses on reactor design and process dynamics and control a great deal more meaningful to those who participated in it.

Once the basic procedure for a stimulus-response experiment of this type has been established, it is a relatively easy matter to study a variety of flow systems using the same technique. We are currently making provisions for the following experiments:

1. Flow and dispersion in packed columns.
2. Flow in obstructed tubes
3. Detection of stagnancy and channeling
4. Residence time distribution of stirred tanks in series
5. Variation of RTD with stirring rate in a single stirred tank—determination of mixing efficiency.
6. Impulse responses of laminar flow systems.

Our present plan is to include one of these experiments (probably the one on the packed column) in the laboratory course, either in addition to or instead of the empty tube experiment, and to use the others as senior projects.□

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D. J. Graves discussed the use of audio-visual packages in the preparation phase of the laboratory experiment. The student prepared modules used to describe complex pieces of equipment, measurements points, flow paths, and complex procedures. At the University of Pennsylvania the audio-visual modules have reduced laboratory time and allowed students to continue to work on project experiments after previous groups have graduated. Two sample audio-visual modules were shown to illustrate their use with typical experiments.

The entire proceedings of the laboratory workshop are to be published and can be obtained by sending a check for $10.00 payable to The University of Michigan to Professor H. Scott Fogler, Department of Chemical Engineering, The University of Michigan, Ann Arbor, Michigan 48104. The price of the bound proceedings, which will be available after May 1, 1973, was established by the ASEE ChE Division in order to minimize any loss of funds from printing costs.