A SYSTEMATIC APPROACH FOR LONG-RANGE LABORATORY DEVELOPMENT

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Today, the rapidly changing state of technology and the almost daily introduction of new computational, electronic, and diagnostic hardware and software systems can make even the most modern laboratory facilities obsolete in a relatively short period of time. This phenomenon is further accelerated by the constantly changing nature of research and instructional focuses. Now, more than ever, it is essential to establish a systematic approach for long-range laboratory development that incorporates a modernization plan for equipment, instruments, and computational systems, but that will, at the same time, have minimal impact on operational budgets, personnel training, and space needs.

PLANNING FOR FUTURE NEEDS

It is not too difficult to identify and define what the state-of-the-art is at any given time. A more challenging task is to project the future direction of a particular field of science or discipline. Generally, the intermediate future direction is defined by those scientists and educators who are at the leading edge of technological and pedological research. There is also a repertory of literature available for most scientific disciplines, and there are periodicals that address the issues, e.g., *Chemical Engineering Education.*[1]

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Perhaps the most important factor during the "defining stage" is the views of industrial colleagues and their perception of future needs. This is analogous to "consumer input" and prepares students for what will be expected of them in an industrial setting. The input could come from both an industrial advisory committee and a group of alumni who have had industrial experience. There are also other sources, such as professional societies which have committees that deal with the future needs of a particular discipline.

Other considerations in the planning stage include the needs, the expertise, and the growth opportunities that may be available in a certain geographical location. For example, if a particular region is well suited for research in polymer science due to a concentration of polymer industry, research institutes, and available funding, then such a factor should be considered when establishing long-term developmental objectives.

It goes without saying that from the beginning the available expertise and interest of the faculty should be a determining factor in all of these considerations. Furthermore, any laboratory development plan should be in harmony with both the overall teaching focus of the department and the long-term plans of the college and university. Given the faculty interests and teaching goals, a lack of any particular expertise can be remedied through proper training courses offered by institutions, universities, and equipment manufacturers.

The level of available funding should not be a key factor at this stage. Once a solid plan is established, attention can then be given to the writing of laboratory development proposals for funding support, and priorities can be assigned to the various plan segments in order to address the funding limitations.

LONG-TERM GOALS AND OBJECTIVES

Setting specific goals and developing a periodic review plan should be accomplished with the help of an advisory committee. It should consist of senior members from both industry and academe in addition to alumni and a representative from the administrative component of the university. The committee's task should be to review objectives and make recommendations on the relevance and applicability of the overall program to industrial concerns and basic scientific principles. The committee should also review capital and maintenance costs and should assist in identifying potential sources of funding. Special attention should be given to the safety program, and a safety group should be appointed for routine laboratory inspections.

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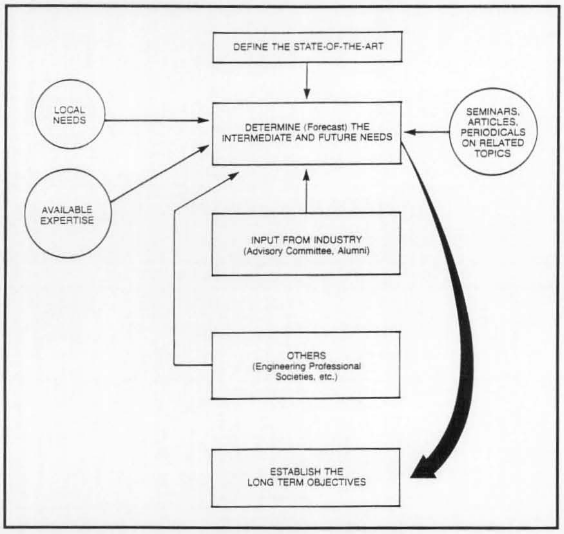

Figure 1. *Defining intermediate and future needs.*

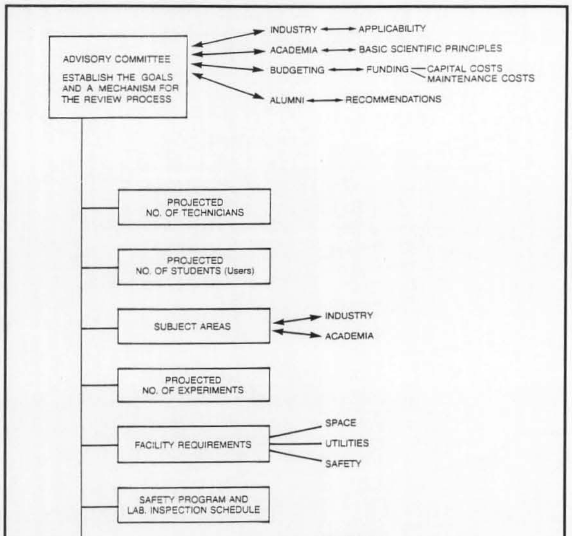

Figure 2.. *Long-term objectives*

The developmental plan should include a reasonable and realistic initial projection of what the needs will be for the ultimate number of technicians, students (users), experiments, laboratory inspection frequency, and facility requirements such as space, utilities, and safety features. The latter is particularly important if a building renovation or additional space is to be considered. The above issues should be carefully addressed and the final recommendations should be implemented without much additional change (except for changes recommended by the advisory committee during the periodic reviews). Figures 1 and 2 are summary charts showing the initial planning process.

SELECTION OF EXPERIMENTS

Certain laboratory experiments which demonstrate very basic scientific principles must be incorporated into the undergraduate laboratory program. The scale and degree of sophistication of these experiments should be determined by certain factors that will be described later in this section. The plan should also include an optional menu of experiments from which students can choose. These experiments can be designed and built on an in-house basis by one group of students and then modified and improved by subsequent groups of students. They should be viewed as temporary experiments—once they are developed and fully tested, they should be replaced or substantially modified to provide new and more challenging experiences for the students.

If economic factors permit, it is advantageous to obtain commercial-scale equipment in order to provide "real-life" experiences for the students. I recall how helpful such an experience was when, as a student at The Ohio State University, I worked with a commercial-size triple-effect evaporator. It took almost one-half of a day just to bring the unit to a steady-state condition. Then, when things did not go as planned, there was only so much that could be done through calculations and applications of theory.

Beyond that, as the technician in charge of the unit pointed out, one had to develop a "feel" for it—something that cannot be learned in school. Students should be exposed to at least one such experience in order to learn and appreciate the limitations and the range of applicability of theoretical principles. Figures 3 and 4 are summary charts of factors that should be considered in selecting laboratory experiments.

EQUIPMENT RESIDENCE TIME

Every effort should be made to assign a lifetime period to each experiment and its equipment. As the allocated period comes to an end, the experiment and its various pieces of equipment should be properly replaced or modified. This is the only way to keep a laboratory facility from becoming an obsolete collection of antiquated equipment.

Other considerations include such concerns as the long-term applications of an experiment, the number of individuals who can be involved in the experiment at any given time, the relevance of experiments to the department's instructional and research goals, the required frequency of updating, and the required supplies, initial costs, maintenance expenses, safety, and specialized needs. One individual should be designated as the person in charge of the experiment, and he or she should report to the advisory committee as needs arise regarding any of the above factors.

UNIT OPERATIONS VS. SPECIALIZED EXPERIMENTS

A recent article by Landau and Rosenberg[2] on the history of chemical engineering alludes to Arthur Little's concept of unit operations, *i.e.*, breaking all the chemical processes into a handful of building blocks or units. They say

> An engineer trained in unit operations could mix and match them as necessary. Such an engineer would be flexible and resourceful in his approach to problem solving...

This is precisely the way laboratory experiments should be selected. The experimental procedure should not be just a compilation of steps that have to be followed one-by-one, but rather should challenge the students to exercise their creativity and resourcefulness. Including several building-block experiments allows students to test the validity of different scientific concepts. As an example, the analogy among heat, mass, and momentum transfer can be illustrated with a set of similar experiments wherein students can creatively combine different transport mechanisms and compare the results.

LABORATORY TRAINING PERIOD

A student training period should precede any laboratory activity. It should encompass lectures and, if possible, a series of video and film presentations on topics such as safety, objectives of the experiment, use and handling of delicate and sophisticated instruments, report writing, and oral presentations of results, as well as other appropriate topics, all tailored to a specific laboratory (see Figure 5).

INDUSTRIAL SPONSORSHIP OF EXPERIMENTS

It is important to attract industrial sponsors, not only to fund and support an experiment but also to provide field data for direct comparisons with laboratory results. This gives students a sense of what

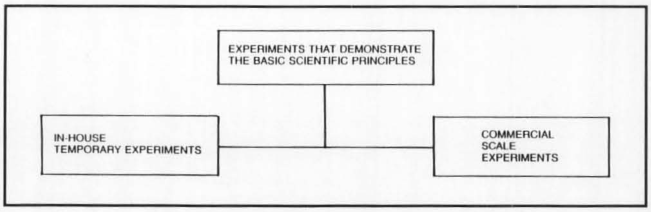

Figure 3. *Types of Experiments*

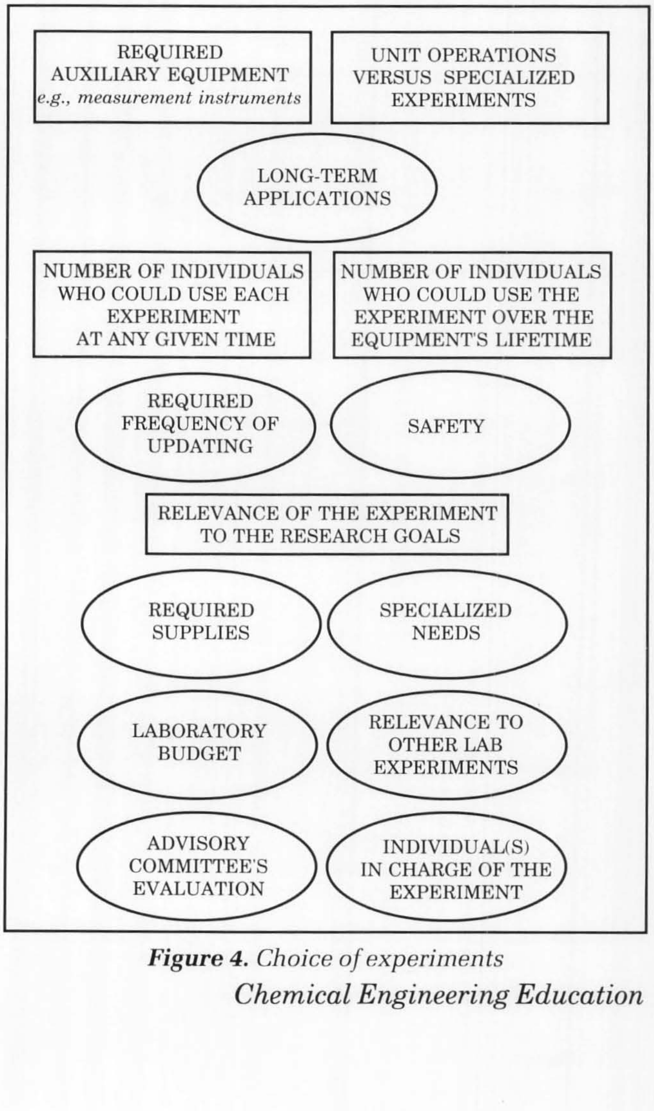

Figure 4. *Choice of experiments*

they can expect in the field so far as error tolerance and analysis are concerned. An individual from industry can be designated to work with the instructors, to give one or two lectures on his or her own experiences, and to suggest new ideas. In effect, the industrial partner would "adopt" an experiment.

This type of relationship with industry can be mutually beneficial since (more often than not) new ideas can be tested more easily in a laboratory than in the field. Also, the loss-time associated with the testing of new ideas in the field, using commercial units, can be a prohibitive factor. Several years ago we experienced the benefit of this approach when we invited an industrial colleague to work with us on a design project that he had already supervised in the field. His comments and tips were most helpful to us. He indicated later that he had also learned from the students and that the design they suggested had certain advantages over the design his engineering staff had provided.

Another consideration is that smaller industries may not have access to a research center and might welcome a partnership with a university department. Figure 5 summarizes the above discussion.

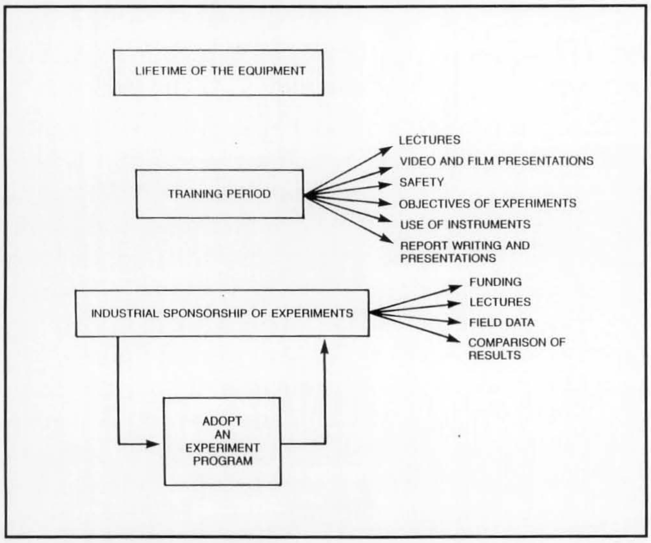

Figure 5. *Factors in selecting equipment*

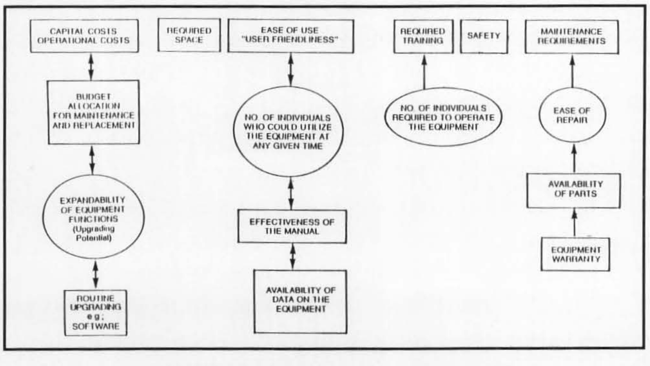

Figure 6. *Choice of equipment*

CHOICE OF EQUIPMENT

Obviously, the laboratory budget determines the type and quantity of equipment that can be purchased, its degree of sophistication, and the choice of supplies. Budget constraints also affect other factors, such as operational cost and maintenance of the equipment. In some cases, the initial capital cost may be affordable but the operational and maintenance costs may be prohibitive. In the planning stages it is of paramount importance to include a periodic maintenance budget and schedule for proper replacement of outdated or worn-out parts. Other factors such as ease of use, user-friendliness, and space requirements have to be evaluated very carefully before a decision is made on any piece of equipment.

As discussed earlier, the concept of unit operations applies to the choice of equipment as well. This means that the expandability of an equipment's functions, *i.e.*, the mix-and-match concept, and its upgrading potential should certainly be considered.

Many sophisticated instruments require training before they can be used to their full potential. In many cases, training courses are offered either by the manufacturers, through symposia, or university short-courses. Examples of such instruments are Laser Doppler Velocimeter (LDV) systems, different imaging systems, and Scanning Electron Microscope (SEM) systems. As the level of sophistication of measurement instruments increases, the issue of training becomes an even more important factor. It can be addressed in a number of ways. For example, the author has proposed the establishment of a research and training center for diagnostics, imaging, and visualization techniques[3] by forming a consortium of several Ohio universities and industry. This would enable students, technicians, faculty, and industry researchers to use the available facilities throughout the state and to obtain training in certain highly specialized laboratories. Figure 6 is a summary chart of this section and includes some additional factors which may be important, depending upon the type of equipment in question.

One consideration in acquiring a relatively expensive piece of equipment or instrumentation system is whether or not the equipment should be purchased or leased. Obviously, the critical factor in such a decision is the availability of required capital and whether or not it would be economically advantageous to purchase the equipment. This evaluation should consider the estimated number of years that the equipment can be used, based on the manufacturer's data, as well as projected laboratory growth and long-term goals. There are other factors tailored to specific pieces of equipment that cannot be generalized, such as the general maintenance requirements versus a lease-plan maintenance agreement, projected frequency of upgrading of the software system, and the depreciated value of the equipment after a certain period.

CONCLUDING REMARKS

Any long-term laboratory development project should be based on a methodical and systematic plan to ensure its proper development. Many factors have been described in this paper, but not all of them are applicable to all cases. Different laboratories may require vastly different approaches at the planning stage. The intent of the paper has been to provide some general guidelines for the planning and management of instructional laboratories. Several of the guidelines are applicable to almost all cases. They are

- Establishment of an advisory committee to review the objectives and plans and to make recommendations regarding the future needs of the facility.
- Establishment of a channel for direct input from industrial colleagues and alumni.
- Long-term projections of the laboratory needs with regard to the number and types of experiments, equipment, technicians, and student users.
- Establishment of a periodic review process to evaluate the progress and development of the facility, to assess the laboratory needs, and to ascertain the necessity of making modifications in the original plan.
- Development of plans for proper replacement or upgrading of both software and hardware after a designated period of time.
- Establishment of a maintenance plan for the upkeep of equipment and instruments.
- Development of a complete training and safety program for all individuals who use the facility.

It is not often that a complete new laboratory is built from the ground up. More often than not, an existing laboratory has to be renovated and updated. The criteria discussed in this paper are applicable in either case. Additionally, there are many textbooks[4-7] that provide a survey of experimental methods, experiment planning, instrument selection, accuracy and economy, analysis of data, and report writing.

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ChE ***book review***

ELECTROCHEMICAL ENGINEERING PRINCIPLES

by Geoffrey Prentice: Prentice Hall, Englewood Cliffs, NJ 07632 (1991)

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This book is an introductory-level textbook on electrochemical engineering that could be used in a senior-level undergraduate course or in a first-year graduate-level course. The book contains nine chapters and seven appendices and is 296 pages long.

The nine chapters are entitled: Introduction, Basic Concepts, Thermodynamics, Phase Equilibrium, Electrode Kinetics, Ionic Mass Transport, Modeling and Simulation, Experimental Methods, and Applications. The seven appendices are entitled: Conversion Factors, Standard Electrode Potentials, Equivalent Conductances, Activity Coefficients of Electrolytes at 25°C, Mass Transport Correlations, Computer Program for a One-Dimensional Cell, and Computer Program for a Two-Dimensional L-cell. A solutions manual is available for the problems given in the text, and the computer programs given in the last two appendices can be obtained in electronic form from the author.

The first chapter is short but points out the importance of electrochemical engineering in terms of the amount spent annually ($28 billion in 1986 dollars) on products such as aluminum, which are produced by electrochemical methods, and in terms of the annual cost of corrosion (approximately $200 billion in 1991 dollars).

The second chapter presents basic concepts that are needed in the study of electrochemical systems. The author reviews electrochemical cell conventions, Faraday's laws, the concepts of current and voltage efficiencies, ion conduction, and transference numbers. Unfortunately, the author does not cite the