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INTEGRATING LABORATORY WORK WITH LECTURES

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Abstract - The purpose of teaching a laboratory course is to train the students in the techniques of observations and the methods of obtaining observational facts, besides illustrating the lecture materials. As it is nowadays, the lecture discussion is much concerned with microscopic concepts, hence the synchronization between laboratory and lectures becomes harder to attain. In a developing country, two factors have to be considered. One is the background of the students from secondary education, and the other is the role of the university. The lack of coherent operation between lecturers and laboratory staff, the unavailability of machine shops, and the large expense of imported chemicals, are obstructions towards the accomplishment of such integration. Besides, the fact that English is only the second language adds to the difficulties the students have to face, since most text books are in English. The problem of integration between laboratory and lectures becomes less severe in the upper division courses when there are fewer students in the class and the topics are more specific. It is proposed that students should learn through the practical work more than previously, and that experiments from the laboratory and every day examples should also be discussed in the lectures.

INTRODUCTION

I think I will have to modify the topic a little for it is quite broad, and with so many experienced and able chemical educators here, I don't think I can do very much with it. Rather, I shall talk about "Integrating laboratory work with lectures: The case of Thailand". As I go along, I will make some comparisons, whenever possible, to my own experiences as an undergraduate in the U.S.

As we all know, chemistry is more of an empirical science and hence observation is the means towards discoveries. Viewed from this aspect, a laboratory course should be a necessity in learning chemistry. It is hoped that from working on experiments, students may feel the wonder of chemistry and appreciate it, which in turn will inspire their curiosity and drives for understanding and explaining. The ideal way towards the appreciation of chemistry is probably letting the students pick out their own experiments according to the individual's interest, and to develop their own way of working under the supervision of the teaching staff. However, due to the lack of time, we cannot afford to let the students work on their own by trial and error. We have to train their mode of thinking, and teach them techniques of doing experiments efficiently as have been studied and formulated by other scientists. This is normally done through lectures. Ideally, laboratory work and lectures should feed-back to one another; lectures are necessary for efficiency in the laboratory, and observational facts from the laboratory are the starting point of the formulation of theories and predictions of related events. As it is nowadays, lectures have been placed as more important than the laboratory work in many aspects. At the least, to most students, lectures get more credit than laboratory per number of hours spent.

One of the main features of laboratory teaching is to demonstrate or illustrate the lecture materials. This notion has merits in its own way if the other purposes are not overlooked. It should be kept in mind that the characteristic of a laboratory course is training the students in the techniques of observations and methods of obtaining observable facts. And things would be even better if, by achieving this, we can demonstrate the lecture material as well. In general, the ideal aims of chemistry laboratory instruction can be summarized as follows:

1. Training the students towards the development of the habit of being observant.

2. Teaching the students the common techniques used in the chemistry laboratory.

3. Teaching the students the methods by which data can be handled and information retrieved.

4. Demonstrating and illustrating the lecture material.

5. Preparing the students for careers as professional chemists and researchers.

(However, we must not forget one more fact, that is, letting the students have fun and enjoy the experiments as well).

The problems in achieving these aims are more serious in the general chemistry course than in the upper divisions.

In Thailand, chemistry majors in most universities are required to complete the following courses in chemistry before graduation*. Using the example of Mahidol University they are:

2 courses in General Chemistry with laboratory**.

3-4 courses in Organic Chemistry (lecture).

2 courses in Organic Chemistry laboratory.

3-4 courses in Physical Chemistry (lecture).

2 courses in Physical Chemistry laboratory.

3 courses in Analytical Chemistry (lectures)

2 courses in Analytical Chemistry laboratory.

2 courses in Inorganic Chemistry (lecture).

1 course in Inorganic Chemistry laboratory.

1-2 courses in Biochemistry (lecture).

1-2 courses in Biochemistry laboratory.

2 courses in Industrial Chemistry (lecture)

1 course in selected additional topics in chemistry.

1 course in senior individual experimental project.

In some laboratory courses, a one-hour prelab. talk is given for each experiment. Laboratory directions are generally available and reports are required.

Due to the fact that the situations in general chemistry and in other chemistry courses are quite different, it would be appropriate to discuss them separately.

A General Chemistry Course

In this two-semester course, integration between laboratory and lectures is quite a problem, not to mention the other aims of teaching a laboratory course. In analyzing the problem, two important factors should be considered:

1. The Student. Up to this school year (1977-1978), most students from High School have not had enough training in chemistry laboratory. The experiments were usually demonstrated rather than carried out by the individuals. The problem became worse for schools in the rural areas where the qualified teaching staff and equipment were scarce. Besides, the lecture materials taught were mainly quantitative analysis and descriptive chemistry in a very old style of presentation. These students came to the university and attended the general chemistry

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* Students spend about 600 - 650 hours of laboratory work altogether.

** These two courses are taken with students of other disciplines such as pre-medicine, pre-dentistry, pre-pharmacy, physics and biology.

lectures with a puzzled mind, especially in the first semester when the emphasis is more on physical chemistry concepts such as thermodynamics, chemical kinetics, atomic structures and chemical bonding. In modern general chemistry lectures, students find most chemical concepts abstract with mathematical formulations, so they just accept the theories without much understanding, and almost forget the fact that chemistry is an empirical science. It probably does not occur to the majority of students that most of the laws have been formulated from observed facts. Together with the fact that the laboratory directions provide too much information about the experiments, the students' observing capability is not necessary at all in obtaining good results and high laboratory marks.

Only a decade ago when the lecture course dealt largely with descriptive and quantitative topics, the synchronization between lecture and laboratory was rather meaningful. Today with the modern concepts which have turned general chemistry into an introductory physical chemistry course and deals more with microscopic phenomena, synchronization of laboratory work and theory has become more difficult to attain, since the labs can only provide macroscopic realization. However, there has always been an effort to do so. Students get to work on one experiment on thermodynamics (such as heat of neutralization), one or two on both chemical kinetics and electrochemistry. The rest of the first semester is on determination of molecular weight, diffusion and effusion, and mostly quantitative analysis in the form of titrations. In the second semester, students work mainly on qualitative analysis such as finding the unknowns in solutions, analyses of cations and anions, and one or two experiments on organic and inorganic complexes. It is in this part that the integration between lecture material (which is now on introductory inorganic and organic chemistry) and lab work is more appreciated, and students get to develop their own observing nature.

It is to be noted that the situation concerning the students' background has been recently changed for the better. With the help of UNDP, a programme has been worked out in training the attitude of the students towards science as being empirical. Experiments are tried out first and students are trained to become more observant and to be able to collect and classify data in order to get the observable facts. From these facts, laws are formulated in the lectures. Only one instructor is required to both conduct the experiment and formulate the laws. In addition, modern concepts and new experimental techniques have been introduced. These students are, hopefully, more able to cope with the modern general chemistry course. However, they are rather weak in quantitative analysis, and some may take the extreme view of refusing to believe in any formulated reactions unless they have tried those out experimentally first.

2. The University Factor. There are problems concerning the co-operation between the lecturers and lab staff, the departmental budget, and the lack of mechanical workshops. Some lecturers do not feel that the history of scientific events is important, and the students can get the impression that most of the abstract laws and theories are merely the creation of the great human brains. In the case when the lecturers are not also the lab staff, the students may miss certain points and observations in the experiments. Integration may look satisfactory when the topics in the lectures and experiments are compared, but it is probably not from the student's point of view. Moreover, when the illustrations of most lecture topics are planned for the lab, less time will be available for each. One way of avoiding this difficulty is a "detailed" lab direction. However, it is probably so detailed that the students are told what and where and when to look for certain phenomena. Some lab directions even provide a fill-in-the-blank type of report for students to record in or a blank diagram to draw a curve.

This is harmful to the building up of the capability of observing, and to an awareness of the wonder of the scientific mind. Observation in this manner is subjective according to the directions. Some students even feel discouraged to think further if their observations are different from those pointed out in the directions. (In Thailand, the students' sense of exploration can be somewhat held back by the old tradition that obedience is considered a virtue). They may think their observations are wrong and simply ignore them. Whether those observations are wrong or not is not the point, as long as the students get interested enough to learn why they are so, instead of simply ignoring them. I remember going into an undergraduate lab at Caltech once when I was a graduate student there. I saw a big sign on the wall saying "When all else fails, please follow the directions". Now this kind of attitude can cause lots of troubles in the laboratory, it is still probably better than a following direction word-by-word routine which may bore the students continually.

The lab directions for the general chemistry course are usually in Thai, and probably translated from English or American versions. The UNESCO source book (vol. I) has only recently become available and has not been tried out yet.

Due to the limited budget and unavailability of chemicals, some experiments can never be attempted. Besides, one of the major problems is the lack of glass-blowing and mechanical workshops. At Mahidol University a glass-blowing shop has been set up with the help of the German Government, and is now servicing not only Mahidol teaching and research laboratories, but those of the other universities as well. The mechanical workshop has been considered as part of a future plan. The other important problem is that of qualified technicians for the workshop. When all the workshops can be run at full capacity, many more pieces of simple equipment (which can be expensive if ordered from abroad in large numbers) will be easily and cheaply made, which may open several new paths to more useful experiments.

In Thailand, a Committee for the Development of the General Chemistry Course has been set up for over a year. They have been working on writing a general chemistry text in the native language. It is hoped to standardize the level of teaching and learning in all universities and colleges. Once the text-writing is finished, work on an experiment source book will be undertaken. The theme will emphasize the integration between the lecture and the practical work, and the availability of local materials. In this case, a survey of the materials in each region of the country will have to be carried out locally. This may solve the problem of the expense of imported chemicals. Besides, the students can learn about the nature of resources available in certain parts of the country.

The Upper Division Courses

After a year or two, students have become acquainted with the learning system in the university and have developed stronger background in both theories and lab skills. Moreover, the courses of later years are more specific in certain areas of chemistry. With fewer students in each lab session (e.g. about 25 in comparison to 60 - 100 in a general chemistry course), more sophisticated instruments are also available. The synchronization between lecture and lab work can be more of a reality.

Due to the lack of text books, the lab directions have to be handed out. They are usually in English (for general chemistry it is in Thai) and are divided into sections on theory, experimental procedure, and questions. The students may have to look up further information from the references given. A written report in English is required for each experiment done. For this reason, a good knowledge of the English language is necessary for a successful student. In comparison to the general chemistry lab directions, those for the upper-division courses are much more concise and of less detail. The students are supposed to plan the laboratory work ahead and make their own extra observations. However, due to the lack of time, the students usually find that they are mostly busy following the experimental procedure and recording data, and have little or no time to do their own extra observations.

Typically, a chemistry major in the third and fourth years finds himself spending 3 - 4 afternoons in the laboratory per week, besides all the mornings in lecture classes. Most of his time is spent on the lab work, including writing up reports (which can be quite time-consuming). The lecture materials are not treated so well in comparison. In this way, the student is busy with the routine and detailed work and does not appreciate the inter-relationships between lectures and lab as he should. When he does, he probably feels that lecture materials help the lab work rather than vice versa, for the scope of lectures is much wider than the purpose of each experiment in the lab. Usually, the inter-relations are felt more strongly for analytical chemistry than for the other subjects. The point that should also be noticed is the lack of integration among the various fields of chemistry. When a student works on an organic experiment, he is usually concerned only with organic phenomena. It does not occur to him that physical chemistry is playing an important role in the lab techniques such as phase separation, distillation, etc. It would be helpful if this concept of integration could be pointed out in the lectures.

In the final semester when the student spends his time doing his individual experimental project, he will have a chance to develop his thinking, planning and observing capability. Hopefully, the training in the laboratories in the preceding three years will show up in his habits of working, more or less.

Most of the instructors for upper division courses are rather young and have obtained their education abroad. They always try to catch up with what is going on in developed countries and forget the fact that their students are struggling along with difficulty. The students do not read the textbooks or understand the lab directions, which are in English, as quickly and easily as their teachers do. The instructors often get disappointed and disillusioned when the time for evaluation comes. They wonder "we have taught these students everything that is taught in the U.S. or England or Australia, but why do they know so little?" Well, I suppose there is no time for digesting what they have to swallow. Teaching is hard (harder than doing research as most scientists would know) for we are dealing with people, and people are not as logical as we want them to be all the time.

I remember how much I enjoyed working in the laboratory courses at Berkeley when I was an undergraduate. I will mention in particular the Physical Chemistry laboratory. Two three-credited laboratory courses in Physical Chemistry were required. In the first semester we had to choose some experiments from the various topics offered. As I remember, there were about five or six experiments altogether, so we had a lot of time to work on each, to be able to think about it, to observe phenomena, and to make further studies. Then we took an oral exam for each experiment with the Teaching Assistant. In the second course, we did fewer of the offered topics and spent quite a while on a project chosen by the individual. We had to make up a problem and design the experiment ourselves. Most of the time we were on our own, with the Professor and Teaching Assistants available for consultation if required. I chose to work on the viscosity of binary mixtures; I was interested in this property for I had never done any practical work on this topic and I wanted to learn. The equipment used was simple, very simple indeed (and cheap too), only a viscometer and a thermostat were needed. I had time to play with the equipment enough to learn everything about it; I could build and design the whole equipment myself. Furthermore, I had enough time to observe the miscibility behaviour of the mixture at various compositions and it turned out so interesting that I extended my project to learn more about the miscibility phenomena.

I found after the heavy literature search that only two papers reported the same phenomena, by a Hungarian chemist about thirty to forty years earlier. I remembered how sorry I felt when the term came to the end because I had so many ideas to work on the problem but there was no time to finish them. When I handed in my report to the Professor, he told me to go ahead with the project and we would publish it. This, however, did not come to reality for I got involved with other course work later on. What I want to point out here is that I used simple equipment but I had time to think and I had fun.

Another point I wish to mention here is the "old" equipment I used in the undergraduate lab. I remember an old DU-spectrophotometer for kinetics work in the Physical Chemistry laboratory. It was so unsophisticated and so old that I could not believe the university still kept it. Thinking in retrospect, I appreciate that instrument which really showed me how a spectrophotometer worked. All I had to do was to lift the cover of the box and I could quickly learn the principles and operations.

Nowadays as a teacher, I ask my students about their instruments, which are by all means much more efficient than my own, and I find that to these students, the instruments are just "black boxes". Higher efficiency, however, means more complicated components, both optically and electronically, which makes everything look impossible to understand. So for developing countries, we probably do not have to worry about keeping up with the latest models available in the market. The students can still learn a great deal about the instrument and how it can be applied to the study of chemical phenomena from the old, low resolution one.

The unsolved problem concerning instruments, be they old or modern, that developing countries such as Thailand face, is the maintenance of such equipment. It is due to the inadequacy of skilled technicians who can take care of the instruments when things, even little things, go wrong. As we all know, money cannot buy everything; we may have the money for repairing the equipment, but no one comes for it.

In conclusion, I propose that laboratory courses should be given more importance than they have been. One of the emphases must be on the techniques and arts of doing experiments, starting from being clean and tidy. Otherwise, when the tests do not work, we cannot tell whether the defect is real or it is because of our being sloppy and careless. It should also be brought to the students' notice that under the same conditions, science must be reproducible. I think most laboratory work these days has a close relationship to the lecture material, but somehow the students miss the relationship. The need for integration can be brought to the students' attention by the lecturers and the lab staff in the early phase of the course, with the hope that they may look for it themselves later on. The lecturers can help to solve this problem if they can discuss relevant lab experiments whenever possible in lectures, and use more realistic examples which may remind the students that laws and concepts actually work to a large extent in reality.