THE ROLE OF PRACTICAL WORK IN TEACHING PHYSICAL CHEMISTRY

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Changes in attitudes towards chemical education and changes in physical chemistry itself invite a re-examination of the role of practical work in the teaching of physical chemistry. Several functions of laboratory work in physical chemistry are readily recognized. First, it gives opportunity for the student to acquire manipulative skills and secondly provides experience in making observations in a critical manner. At the same time the student may gain knowledge of a variety of experimental techniques. But besides these bench-skills practical work offers opportunity to develop other abilities in the student. The reporting and interpretation of results, and the presentation of scientific work can all be put in a realistic context for the student. Nor do the functions of practical work end here. After some experience the student may take a larger part in the design of experiments. Then there is the possibility of some investigational studies or a small research project to consider. All of these are widely recognized as important features to be considered in the design of courses in practical physical chemistry, but the relative importance of these various functions changes as physical chemistry itself develops.

Considering a knowledge of techniques first it could be argued that there are some techniques (e.g. the use of vacuum lines) which are now so important in physical chemistry that every student should have some experience of them. On the other hand so many techniques are now employed in physical chemistry that an undergraduate course can cover only a fraction of them. Of the new instrumental techniques that are being introduced into chemistry we find increasingly that they are at the same time both more sophisticated and simpler. Very similar boxes with very similar knobs and meters replace different varieties of string and sealing wax. These developments have repercussions throughout chemistry. They change the position markedly in a physical chemistry teaching laboratory. Only twenty years ago the member of academic staff in charge of a physical chemistry laboratory could be familiar with the detailed construction of every piece of equipment, mechanical, electrical, optical or electronic. He could locate any fault that might arise and correct it. Frequently he expected students to develop the same attitude towards the instruments they used. But the introduction into the physical chemistry teaching laboratory of the mass spectrometer, the infra-red spectrometer, or even the packaged conductance bridge or direct-reading pH meter have changed all this. Indeed instrumentation is no longer confined to the physical laboratory. Increasingly, instrumental techniques are being employed in inorganic and organic teaching laboratories. It is likely in the future that the responsibility for the teaching of instrumental techniques will be confined less and less to the physical chemistry laboratory.

If we turn next to consider making observations in a critical manner we recognize there are also repercussions here as a result of increased instrumentation. Frequently the measurement consists of observing simultaneously or in succession pointers moving against scales and, furthermore, such movements are now frequently automatically recorded. One box of electronic equipment looks very much like another. How many instrumental techniques, purely as techniques, does a student need to meet? How many different kinds of scales and pointers does a student need to use?

Two other features of practical physical chemistry were mentioned earlier: the interpretation of results and the design of experiments. We recognize in real life that these are now to a considerable extent chair-and-desk activities. The interpretation of data may require a desk calculator or even access to a computer. At research level, design of experiment frequently calls for consultation with the mechanical workshop staff or the electronic engineer.

Important questions are raised from all of these points of view about the way in which undergraduate physical chemistry courses should reflect changes taking place in chemistry. Nevertheless, the role of practical physical chemistry cannot be fully examined by an anlysis in terms of manipulative skills, experimental techniques, the interpretation of results and the design of experiments. Practical physical chemistry has to be considered in the context of a course in physical chemistry as a whole. The objectives of a practical course depend on the overall objectives of a course in physical chemistry. These objectives are no doubt multiple and agreement on them would probably be hard to obtain. Nevertheless, there is probably wide support for a general objective of university education which in the words of the *Robbins Report on Higher Education in the U.K.** is 'to promote the general powers of the mind'. The committee held it a distinguishing characteristic of healthy higher education that even where it is concerned with practical techniques it imparts them on a plane of generality that makes possible their application to many problems.

Physical chemistry is, I suggest, rich in opportunities for the development of the powers of the mind. Students frequently find conceptual difficulties to be overcome and problems in applying principles. It is important for a student to recognize that there is an area of chemistry which employs precise concepts and which calls for thinking mathematically about chemistry. This does not refer merely to putting numbers into formulae or even to solving complicated equations, but rather to the formulation of a problem in mathematical terms and visualizing the physical implications of an equation or expression which comes out of the theory. Students of chemistry need to know the power, and limitations, of such a discipline in order to have a proper perspective in chemistry. Problems of formulation are tackled differently in different areas of the subject, e.g. quantum mechanics and

*A committee under the chairmanship of Lord Robbins was appointed by the Prime Minister to examine higher education in the U.K. The report of the committee, published in 1963, examines at the beginning objectives of higher education. Four objectives which were recognized may be summarized as (i) instruction in skills suitable to play a part in the general division of labour, (ii) to promote the general powers of the mind, (iii) the advancement of learning and (iv) the transmission of a common culture and common standards of citizenship.

thermodynamics. The range of such an intellectual discipline is sufficiently wide to offer opportunities in promoting powers of the mind, to develop abilities which it may be expected will be transferable to wider areas of activity. Practical work, seen as an integral part of a physical chemistry course can play an important role here. Students frequently find difficulty in assimilating concepts encountered through reading or lectures. Often concepts and principles appear too abstract to be integrated into their own knowledge and understanding. Time and opportunity to apply such concepts and principles in situations with which they can become familiar are required. Practical work is able to provide just such an opportunity in an ideal way. The student is enabled to visualize the application of concepts and principles in a concrete situation which he has created himself. To take a simple example, a student might gain a better understanding of a concept such as that of a partial molar quantity by measuring and using such quantities in his laboratory work.

If practical physical chemistry is treated as an integral part of a physical chemistry course a wide range of concepts and principles can be met in laboratory situations. Two examples, one from the general area of thermodynamics and the other from spectroscopy, illustrate the point. The first example is an investigation of liquid–vapour equilibrium for a binary mixture by isothermal distillation under recycling conditions. Some concepts and principles which the student will meet are indicated below.

Liquid–vapour equilibrium for binary mixtures

Equilibrium	Raoult's law and Dalton's law
Steady state	Phase diagram
Partial pressures	Chemical potential
Mole fractions	Activities and activity coefficients
	Standard states

Needless to say the experiment also calls for certain manipulative skills. In fact successful results are probably a good indication of the development of good psychomotor skills. The second example from spectroscopy relates to the visible absorption spectrum of iodine and the bond dissociation energy. A value for the bond dissociation energy can be obtained quite readily from the spectrum. On the other hand, the opportunity can be taken to make a more thorough investigation involving the ideas listed below.

Visible absorption spectrum of iodine

Vibrational and electronic energies	Anharmonicity
Dissociation energies	Franck–Condon principle
Potential functions	Boltzmann law
Zeropoint energy	

Again the experiment calls for experimental skills and introduces a number of techniques. These range from photographic techniques, through techniques of spectroscopic measurements and calibration to the organization of material for computation.

Practical physical chemistry treated as an integral part of a physical chemistry course can provide coverage of the different areas of the subject, treat a wide range of the more difficult concepts and at the same time call for the development of a variety of experimental skills while introducing the student to a range of techniques.

The question arises: to what extent should practical work involve investigational studies, set experiments and projects? Investigational studies call for consideration at a time when incoming students are increasingly likely to have been involved in such an approach at school level. Among the advantages claimed for such an approach are that it provides a challenge to the student to tackle a problem. In the process of tackling the problem he learns and, more important, he learns how to learn. On the other hand, it is time-consuming for the student and demanding on the time of staff. It may be that the greatest value of such an approach is in introductory courses where a student is beginning to learn how a scientific enquiry is made. A set experiment, which is long enough to bring the student up against some conceptual problems, can still offer a challenge even though a laboratory manuscript is provided. Furthermore, it can call for the devising of simple techniques, planning of work, choosing a sequence of operations and organization of the student's time. Generally such a procedure is less time-demanding than an investigational approach and allows the student to meet in the laboratory more of the concepts of physical chemistry than he would otherwise be able to do. A student must increasingly learn to stand on his own feet. Nevertheless, there may well be advantages in including some investigational aspect, particularly in the first year, perhaps as laboratory tutorials or seminars. For certain work it may be helpful to bring together the group of students who may be working on a particular topic, for discussions at various stages in the development of the work. The laboratory seminar probably

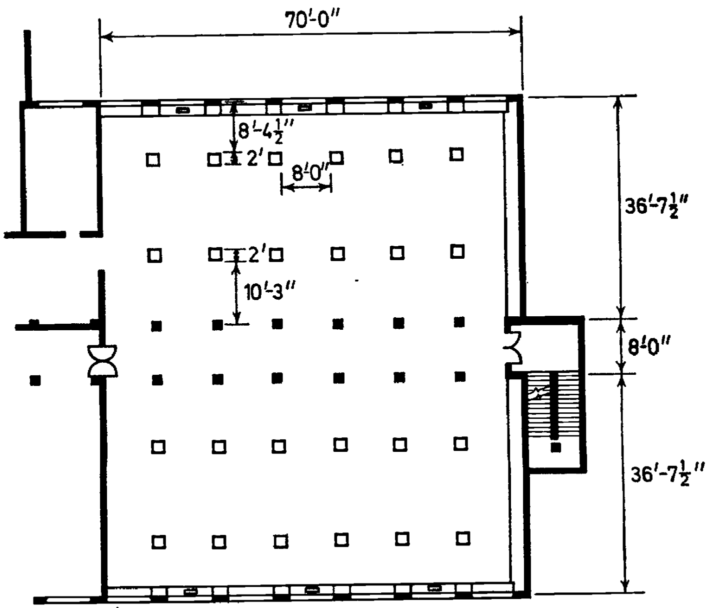

Figure 1. Plan of general purpose physical chemistry laboratory. (Dimensions are given in feet and inches.)

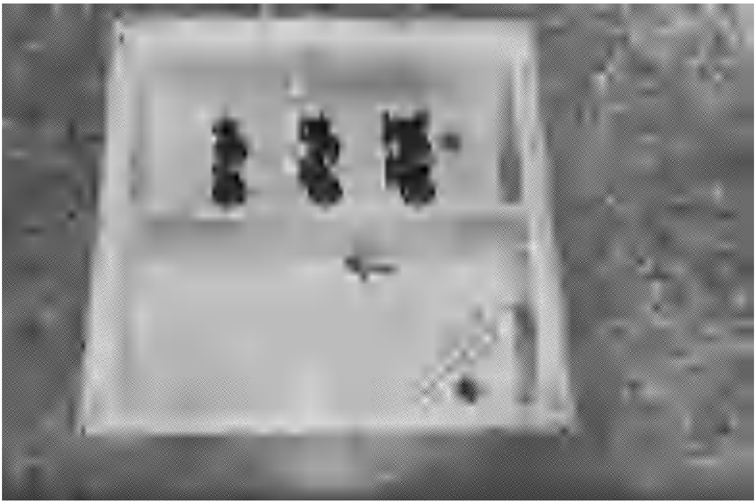

Figure 2. Removal of a cover plate gives access to water, gas, compressed air and to a drain. A sink unit may be located in position above the service unit.

Figure 3. Electricity is provided by units suspended from the ceiling which are readily removed when not required.

Figure 4. Arrangement for laboratory seminar on crystal structure.

Figure 5. A corner of the laboratory set out to provide for a general talk to a larger group, during laboratory work.

deserves more consideration particularly in the early stages of a university course. Towards the end of a university course when a student has a good knowledge of his subject there are advantages in a project extending perhaps over some weeks. The student is now in the position of planning his own work and playing an important part in deciding the direction in which to go in the light of his experimental results. There is good opportunity here for the student to develop his own powers. Experience suggests that the choice of project for the particular student and the level of guidance are important factors in developing a student's confidence in his ability to work with a degree of independence.

The introduction of new instrumental techniques, the use of laboratory seminars and the pursuit of projects all make demands on a physical chemistry laboratory. We at University College, London are fortunate enough to have moved recently into a new laboratory and I shall conclude with a brief account of the way we have attempted to meet demands on a physical chemistry laboratory, outlining some of the design features in the new laboratory. A major aim has been to provide flexibility in an attempt to meet present needs and future demands. An outline plan of the main general purpose laboratory is given in *Figure 1*. As shown, about half of the wall space has fixed benching which provides for such services as wash-up sinks, ovens etc. Two walk-in fume cupboards are also provided along one wall. There is no other fixed benching and the rest of the floor space may be used, as required, for any particular classes. Service units are provided at intervals of about three metres as shown in *Figure 1*.

On removing a cover-plate, access is given to water, gas, compressed air and to a drain as shown in *Figure 2*.

Sink units with gas and air points may be located in position by locating them on the floor when the cover is removed. Tables as required may then be placed in convenient positions about the sink units, and underbench units of cupboards or drawers are available as needed. Electricity is provided from above rather than from floor level. Units suspended from the ceiling as shown in *Figure 3* provide six standard 13 A outlets. The complete unit may be removed when not required.

Spaces are readily provided in the laboratory for seminars. *Figure 4* shows an arrangement for a laboratory seminar on an aspect of crystal structure.

It is readily possible for the lecturer to arrange to talk to larger groups. *Figure 5* shows a corner of the laboratory as used in a recent summer school.

The arrangement has also been found convenient for general talks to large groups in the early stages of a laboratory session. The desks can easily be moved away and laboratory benches set up as required.

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