

THE DEVELOPMENT OF LABORATORY COURSES IN CHEMISTRY IN DEVELOPING COUNTRIES

M.H. Freemantle

Department of Chemistry, University of Jordan, Amman, Jordan

Abstract - This paper initially discusses four groups of problems which are common to many universities in developing countries. Certain principles which relate to teaching chemistry in the laboratory are then established. An attempt to apply these principles to tackle such problems is illustrated by reference to a laboratory based post-graduate course in chemical education and a second year undergraduate course in quantitative chemical analysis at the University of Jordan. The overall approach of using a postgraduate course to evaluate and develop undergraduate laboratory based courses is seen to be particularly appropriate for the chemistry departments of universities in developing countries since it not only provides a means of easing staffing problems with demonstrators who have been trained to be keen and competent teachers, but also it provides a means of reducing costs.

First of all I want to outline some problems that are associated with teaching chemistry in the laboratory and that are particularly acute, I suspect, in most developing countries. I then want to mention some principles that have formed the basis of my approach to teaching chemistry at the University of Jordan. The second part of this paper will be devoted to a description of an attempt to apply these principles and tackle some of these problems by means of a post-graduate chemical education course.

PROBLEMS

What follows can in no way be considered as a comprehensive treatment but is rather a general description of what I think are some of the more important problems that are encountered in laboratory teaching in developing countries. The problems that I want to consider fall into four groups.

1. Economic and logistical problems

The economic and logistical problems of running large laboratory classes are common, perhaps, to most countries which have universities and are especially troublesome in the universities of developing countries. In particular, the problems associated with large intakes of first year students are often acute. At the University of Jordan, for example, over 600 students attend first year chemistry courses. This number may well increase to 800 by next year. These students have to be accommodated in laboratories and lecture theatres. Money is needed to buy chemicals and equipment for their laboratory classes. The requirements of such large numbers of students can therefore put a severe strain on the shoe string budgets of chemistry departments. Associated with these problems are the problems of maintaining and servicing equipment and laboratories and providing adequate technical support for laboratory classes. Since these problems can be vast and sometimes insuperable, it is important to consider any means of reducing costs and improving the quality of the technical support that is available. For example, a close evaluation of many experiments with respect to cost often reveals that cheaper materials or smaller quantities of these materials and cheaper or simpler equipment can do the job just as well. But before we can do this we need to know the job that the experiment is supposed to be doing. If we want to reduce experimental costs therefore, we need a complete evaluation of the experiments. But how is such an evaluation going to be done and who is going to be willing to do it?

2. Problems of language and communication

Language and communication always present a problem when the medium of teaching and learning is a second language. I would say that the level of English of the majority of students entering first year chemistry courses at the University of Jordan is inadequate. The University, of course, makes every effort to rectify this problem through its own English courses for science students, but the problem is not entirely eliminated even by the time some students graduate. For example, the frequent use of a dictionary during lectures is common and I have often seen

textbooks of first year students which are translated from English into Arabic, word for word, line for line, page for page and so on. The translation is usually in pencil and squeezed between the lines of the text. The problem becomes even more acute in the laboratory where, if we are not careful, some students will finish an experiment whilst others are still struggling through the written instructions in an attempt to translate them. And sadly, it is often the students from poorer backgrounds whose English is poor. Lack of adequate English, I have found, often leads to lack of confidence and thus lack of the verbal communication necessary for teaching and learning in the laboratory. This lack of confidence is often made worse by the sight of awe inspiring professors or lecturers who cannot possibly, in the three hours per week of laboratory time allocated to the class, get to know individually and to any satisfactory extent the fifty or so students for which they are usually responsible.

The transition from school to university can be traumatic therefore, especially when a student finds that nobody at the university seems to be really bothered whether he or she sinks or swims. Faced with the daunting prospects of exposing their inadequate second language and also exposing their ignorance of chemistry, students often shrink away from the very help they need and resort to devious means to get through the course. This state of affairs is obviously unsatisfactory and inevitably leads on to questions about staffing and teaching.

3. The problems of staffing

In the chemistry department at the University of Jordan most of the 15 academic staff are involved, in one way or another, in first year teaching. In addition there are 10 teaching assistants including graduate students. How can a mere handful of twenty or so people cope in any meaningful way with 600 to 800 first year students? The problem also applies to other classes. It is quite common to find 60 or so students in a second year class for example. The problem, as I see it, is not just one of finding adequate numbers of staff and demonstrators to ensure a healthy student to teacher ratio of say, 10 or 15 to 1, it is also a problem of finding or producing adequate numbers of staff and demonstrators who are sufficiently motivated to teach chemistry with at least some measure of competence and enthusiasm. If such people cannot be found then attempts should be made to produce them and this means producing keen and competent demonstrators. And where better a place to produce such demonstrators than within the chemistry department itself?

4. Course evaluation

Hand in hand with producing keen and competent demonstrators we must also ensure that the course itself is wholesome. To do this we need periodically, and if possible continually, to evaluate our courses not only with respect to cost as I have already mentioned but also with respect to developing and improving them. Once again the question is how can courses be evaluated and who is going to do it? Are we just going to rely on the occasional burst of enthusiasm from an odd professor or two? As we all know, in most universities there is little if no incentive in terms of career advancement for academic staff to devote more than the minimum amount of time and attention to their teaching.

FIVE PRINCIPLES

Before I outline our own attempts to overcome these four groups of problems I want to establish certain principles which seem useful and are basic to the approach which I shall later describe. The principles which have guided us in our efforts to teach chemistry and train demonstrators to teach, fall into five groups. The first concerns motivation.

1. If we are to generate any interest and competence in chemistry at all amongst students, we need teachers and demonstrators who not only put their hearts into teaching but also put their hearts into chemistry.

In other words we need people who are interested and competent in the chemistry they teach as well as their teaching. In my experience, one of the best ways of stimulating enthusiasm and developing competence in both teaching and chemistry is to work as a member of a team. Such a teaching team can include technicians as well as the demonstrators and professors. Ideally the team should meet at least once a week whilst the course is in operation to review the session of the previous week and to plan for the following sessions. Where appropriate they can also, before or during the course, work together in the laboratory checking out experiments.

2. The laboratory should be central to chemistry teaching and not an adjunct.

In my opinion, most, if not all, chemistry teaching and training of chemistry teachers or demonstrators should start, continue and finish in the laboratory. We should, of course, where appropriate, support such laboratory based teaching with talks, discussions and audiovisual aids. However, to my mind, there are no better visual aids than, for example, the pink of permanganate appearing or the needle of a voltmeter swinging round dramatically at the end-point of a titration that a student himself has performed. All teaching of chemistry should relate to or derive from the laboratory because that is where chemistry is

practised and that is where it takes place.

Unless the student-teacher-student cycle is to remain closed and therefore completely worthless from an economic point of view, there must be some spin-off of chemistry into the country to benefit its economy and the welfare of its people. That means that somewhere along the line there must be a spin-off of people trained and experienced in the practice of chemistry. Such experience and training can only be acquired in the laboratory. The third principle derives from this concept of practice.

3. Students at all levels should be confronted with the unknown as well as the known.

The practice of chemistry whether it be in industrial laboratories, analytical laboratories, teaching or research laboratories frequently involves the necessity of grappling with problems to which there are no immediate answers and sometimes no answers at all. Even when teaching chemistry at the lowest level students should, I think, not only be presented with the predigested, prepackaged chemistry of textbooks, lecture notes and known unknowns, they should also be presented with and encouraged to ask questions that are not immediately answerable without further experimentation or without exhaustive literature searching. And indeed, sometimes a five minute test tube experiment can replace five hours of literature searching. From the start we need to generate a spirit of enquiry amongst chemistry students and the best place to do this is in the laboratory. Laboratory experiments should lead to a discussion of the chemistry involved and where appropriate and possible questions and problems that arise should be answered through further experimentation. There is thus a need for short snappy experiments which can be readily adapted in one direction or another. And not infrequently students and teachers who do view their experiments as voyages of discovery will soon find themselves treading over ground which has not been trodden over for a long time, if at all. It is difficult to generate this spirit of enquiry and simulate such adventures on the blackboard, through a transparency or by means of cookbook chemistry.

First and second year students may be forgiven for believing that the chemistry they are presented with consists of watertight packages which just have to be signed, sealed and delivered. In fact, much of that chemistry is no more than the well known landmarks of unplotted territories riddled with jungles of loopholes, ambiguities and near impossibilities. So long as the chemistry is taught in and around the laboratory therefore, there is every opportunity to generate a spirit of enquiry at the very outset of university chemistry teaching.

The cycle of experiment leading to theory and questioning leading to further experimentation can only take place in laboratory based courses. If we pull this cycle apart and separate the theory and the practice or, as we often do, just pay lip service to the theory content of practical work, we risk tearing apart the very fabric of the science we are trying to teach.

4. Courses should be kept alive and fresh.

If we are to stimulate and maintain the interest in and enthusiasm for chemistry our courses must be kept alive and fresh. And if courses are to remain alive and fresh they must change regularly because if they do not they will become stale and boring. To keep courses alive and fresh there are two things we can do. First the teachers or teaching teams should be given every opportunity to get their teeth into a course and enjoy it but they should not be given an opportunity to become bored with it. Second, teachers should be encouraged to make a creative contribution to the course, for example, by introducing new experiments and material which they find interesting and exciting and by dropping and modifying experiments and material which they find uninteresting, with the proviso, of course, that any changes fall within the general aims of the course.

5. We should go to where the student is.

Finally, we should remember that at the beginning of any course, students will have a variety of backgrounds and a range of abilities. We can, if we like, sit on a lofty pedestal, dish out pearls of wisdom and expect students to rise to our level by their own efforts alone and gobble up these pearls. On the other hand we can go to where the student is and attempt to lift him up to the levels we expect. This requires tailoring our efforts and attention to the individual needs of each student not only with respect to his or her background and ability in chemistry but also, if a second language is used for teaching, with respect to his or her ability to communicate in that language. These needs are best satisfied by face to face contact with motivated and sympathetic teachers and demonstrators who are fluent in the two languages. In my opinion the best results are obtained if individual demonstrators are assigned to groups of ten or twelve students rather than be allowed, as frequently happens, to float around larger numbers of students. It is usual to find the widest range of backgrounds and abilities in first year and so it is here that the needs for individual guidance are greatest. Yet it is in first year that these needs are

least satisfied.

A POST-GRADUATE COURSE IN CHEMICAL EDUCATION

What follows is a description of a post-graduate chemical education course which was and is used as a vehicle for the evaluation of the experimental components of first and second year courses I have been involved with and also used as a vehicle for training demonstrators and technicians for these courses.

The overall aim of the course was to get post-graduate and final year students into the laboratory and practise the chemistry they would be teaching, and to practise it not like cooks following recipes but to practise it with critical awareness both from the technical point of view and from the pedagogical point of view. We wanted to expose these students to the problems their students might face when doing these experiments and also to the responsibilities and problems they would have to face up to as teachers. These students therefore worked through series of experiments, evaluated them and then reported on their work and evaluations both verbally and in writing. Finally they were given an opportunity to develop and improve these experiments.

The course lasts for one semester and involves 14 (plus or minus one) three hour sessions of which ten are spent in the laboratory and four devoted to reporting and discussion sessions. Normally between ten and sixteen students enrol for the course. These include post-graduate M.Sc. chemistry students and fourth year, that is final year, students in chemistry.

Let us assume that sixteen enrol for the course. These students are divided into four groups of four. Each group is assigned a different concept area. The concept areas are:

Stoichiometry

Energy

Rates

Equilibrium

The groups then work through experiments related to their concept areas for four weeks. After four weeks each group is assigned another concept area from the above list and the process is repeated so that during a course each concept area and therefore all the associated experiments are covered twice. After six weeks each group hands in a report on their first four week block of experiments and after ten weeks, they hand in another group report on the second block of experiments. Weeks nine, ten, eleven and twelve are devoted to talks and discussions. Finally, after the talks, the class returns to the laboratory where they are given a fairly free hand to develop and improve the experiments they have evaluated.

For each block of experiments each member of the group is assigned one of the following roles:

Group leader

Laboratory coordinator

Editor

Chairman

The group leader is generally a post-graduate student and it is customary for the student to retain this role throughout the course. The other responsibilities are changed after the first block of experiments so that each member of the group, apart from the group leader, assumes two roles during the course.

The job of the group leader is to lead and coordinate the activities of the group and liaise with myself. I have a meeting with all the group leaders and sometimes the technician once a week. At this meeting, the group leaders report on the previous week's experiments and then we discuss the work and plan for the following week. The group leaders collect all the worksheets and handouts from me and distribute them as necessary.

The laboratory coordinator has to liaise with the technician and ensure that all reagents and equipment are available and ready for the group's activities. He or she has to work closely with the technician checking solutions and sometimes, if there is a heavy load, help the technician prepare and test the solutions. Careful planning and preparation is stressed. Time in the laboratory is a valuable and scarce resource especially for those students who will eventually teach in schools with no or only very limited laboratory facilities. I therefore emphasise that the group must be ready, in every way, to start work immediately they enter the laboratory and they are then expected to work for the full three hours.

Each group has to present two reports. The reports are divided into four sections:

Introduction, aims and purposes

Description of experiments, results and problems that arose

Evaluation

Development and improvements

Every member of the group writes one of the four sections with the editor generally writing the introduction. The editor collects the other written sections from the group, discusses their work with them and ensures that the report forms a cohesive whole and is presented to me on time.

The talks follow a similar pattern with each member of the group talking for about fifteen minutes on one of the four sections covered in the report. The students are encouraged to use visual aids and simple demonstrations where appropriate. After the four short talks the group then faces questions by other members of the class and finally I give my assessment of their performance both individually and as a group. The chairman of the talks is a member of another group. He or she has to introduce the group, and each member of the group and then he or she has to ensure that the talks and subsequent discussions run smoothly.

Having considered the structure and operation of the course let us now turn our attention to the actual evaluation of experiments and also consider one of the main problems that arise when teaching in the laboratory. In order to help students evaluate the experiments they are offered certain guidelines in the form of questions. These are shown in the Table. Of course, in the time that is available in one course, it is not possible to apply all these questions to each experiment. Nevertheless, if the same experiments are used over a number of chemical education courses most of these questions can be answered in one way or another.

TABLE. Evaluation of Experiments

1. Cost and availability

- what are the costs and availability of the equipment and chemicals?
- are cheaper or simpler alternatives to these materials and this equipment available?

2. Laboratory

- should students work in pairs, singly or in groups or should this experiment be used as a demonstration?
- are there any dangers or hazards associated with this experiment and if so what precautions should be taken?
- how easily is the experiment prepared and made available?

3. Background

- what background reading and what preparation are necessary for this experiment?
- how should students be briefed?
- could this experiment be linked to other experiments?

4. Suitability, aims and benefits

- how would students benefit from the experiment both conceptually and in terms of techniques and skills or in other words what are the possible aims of the experiment?
- what is the degree of difficulty of this experiment both conceptually and in terms of manipulative skills required?
- is there a high probability of obtaining meaningful results from inexperienced hands?
- what courses is it suitable for?
- what are the alternatives to this experiment?

5. Procedure

- do the written instructions or worksheets require amendment, clarification or other improvements?

6. Flexibility

- since we regard each experiment as a vehicle for teaching chemistry how adaptable and flexible is it?
- is it short and snappy and capable of ready extension and variation or not?
- how could this experiment be developed and improved?

When we actually get into the laboratory with the chemical education students, we do not try to analyse, classify, list or specify aims and objectives of each experiment in any sort of formal or systematic manner. Rather, we talk about chemistry. For example, there are one or two experiments we use, which just entail dropping a piece of metal into a test-tube containing acid or water. These experiments are in Volume Two of the Sourcebook. When we watch those bubbles of hydrogen coming off we do not think about specific objectives. Instead we ask questions and try to experiment further. For example, is there any difference in the reactivity of magnesium and zinc? This is easy to demonstrate. What happens if we use other acids? Is heat evolved, that is, is the reaction exothermic? We can then demonstrate that a drop or two of Cu^{2+} will catalyse the reaction between zinc and HCl. What about other catalysts? Another related experiment which we have up our sleeves demonstrates quickly and simply the corrosive and catalytic effects of NaCl on the reaction between Mg and water. Is the rate of reaction dependent on acid or salt concentrations? Can we demonstrate this? What about the metal and the rate of reaction? We are now into surface chemistry and heterogeneous kinetics - an almost impossible field to explore in this context. We can then delve into reaction mechanisms and likewise find that almost impossible to penetrate. If we want to, we can turn our attention to analytical chemistry. How can we analyse the product MgCl_2 in the presence of excess acid and very soon we are onto solubility products, common ion effects, salt effects, Debye Hückel theory not to speak of acids, bases and indicator theory. We can then try to adapt or extend the experiment to demonstrate any one of these concepts depending on the spirit, the interest and the mood of the group at that particular moment. And all this, from a simple, inexpensive, five minute, test-tube experiment. This is what I mean by the teaching and learning potential of an experiment and the exploration of its chemistry.

I stated that one of the aims of the course is to expose future teachers to the problems that students and teachers face in the laboratory. One of the problems that frequently confront students and all of us when teaching in the laboratory is the problem of an experiment failing to work or failing to provide meaningful results. How can we systematically approach this problem and teach teachers to approach it? Experiments in the teaching laboratory normally go wrong for one or more of four reasons.

First of all, an experiment may not work because the reagents have been prepared incorrectly. For example, a 0.01M solution may be provided instead of a 0.1M solution. Second, an experiment may not work because the equipment does not work or is faulty. These causes, although obvious when stated, are frequently overlooked and the student often wrongly told to go away and try again. If this happens too often the student may soon give up and fake the results or copy them from someone else. However, the incorrect operation of the experiment is indeed one reason for an experiment going wrong. This may not only be due to a student failing to read the instructions correctly or for failing to understand them. It may also be due to faulty or ambiguous instructions. The fourth reason for an experiment going wrong may be the experiment itself. The experiment may be intrinsically weak or insufficiently tested. It may, for example, not work near a window or a door but may well work elsewhere. All these things have to be discovered. And not surprisingly, one of the first things that students do discover in the chemical education course is the high frequency of experimental failure even when well tested first year experiments are performed by post-graduate students.

Finally, I want to mention briefly the evaluation of students in the chemical education course. Students are told at the outset of the course that if they complete the course they will pass. Since there are no examinations, tests or quizzes, students are expected to attend all the sessions and complete all their assignments. A chemical education course has run each semester for the three years of the six semesters that I have been at the University of Jordan. The attendance record for these courses has been consistently one hundred per cent with only one notable exception. The student concerned could not attend the course one week because he was kidnapped - in Beirut. Fortunately he was released in time to attend the course the following week. Assessment is based therefore on attendance and also on the performance of the group as well as the performance of each individual. Thus, if one member of the group fails to pull his or her weight the whole group suffers. In arriving at a final grade for each student I consider, in addition to the performance of the individuals and groups in the laboratory, their performance in the talks and also their reports.

THE END PRODUCT

How can all this be applied to teaching chemistry to first and second year students in the laboratory? The application is best illustrated by reference to a second year course in quantitative chemical analysis (Ref. 1) for which I was responsible and which runs twice a year.

Between forty and sixty students regularly enrol for this course and each semester an average of three graduate students were assigned to assist me. They were always products of the chemical education course and since I had slanted many of the experiments in that course towards quantitative chemical analysis these graduates were quite familiar with most of the experiments performed in the analytical course.

Each week there was a three hour laboratory session and two lectures. I used the first lecture session to brief the students for the coming laboratory session and to discuss and pull apart the chemistry involved in the analyses. In addition, I presented to them and worked through study guides which were centred on the analyses. During the laboratory sessions the students performed standard analyses and supplementary exercises and then further explored the chemistry of these analyses by performing variations on them. The second lecture each week was used to review the laboratory work and discuss the chemistry in the light of their experiments. One or two students from each group of 12 or 15 were expected to report very briefly on their work.

In the laboratory, each demonstrator was assigned a group of about 15 students. They were completely responsible for this group and were expected to work very closely with them, briefing them individually or in groups. They provided the individual attention and support using Arabic, English or both as necessary. Where appropriate, they could pull the group aside to a blackboard for discussions and short reports and in addition they could introduce their own variations or extensions to the experiments as they thought fit. The three demonstrators, the technician and myself worked as a team. In particular, we met once a week to review, discuss and plan and if necessary to check things out in the laboratory.

CONCLUSIONS

What are the fruits of this approach? Three major benefits may be seen to result.

1. This approach provides a means of teaching large numbers of students in small groups with teams of motivated and trained demonstrators who can provide the individual supervision required.
2. The approach provides a means of evaluating and developing the components of almost any undergraduate laboratory based course.
3. The approach provides a means of reducing costs both by using graduate or final year students as teachers and also through the cost evaluation of the experiments.

This approach is particularly appropriate in developing countries where the problems of language, large student numbers and costs are often acute. The process of training demonstrators and technicians and the process of course evaluation and development can roll over continually if a suitable post-graduate course is integrated into the departmental teaching programme. The strategy of using one course to develop another course, if used effectively, has potential and offers tremendous rewards and advantages to student and teachers alike. Although universally applicable, many developing countries in particular have golden opportunities to adopt this approach whilst their universities are still in the formative stage.

I now want to make one final recommendation. In my opinion, the single biggest problem in chemistry teaching in tertiary education is, and always has been, the reluctance of most teachers, from full professors downwards, to take off their jackets, put on their white laboratory coats, and lead students into the front line of chemistry, which is the laboratory, and get their hands dirty. There are many reasons and excuses for this and a lot of leadership from behind, but unless we, the world's leading experts in chemistry teaching, can lead our students and colleagues into the laboratory and work alongside them on the chemistry we expect the students to perform, chemistry teaching will remain the disaster area it is and always has been. We can only excite interest and enthusiasm and therefore competence in chemistry if we go hand in hand with students and if possible our colleagues into the laboratory and demonstrate that, in the front line, chemistry, although hard work and difficult, can be an exhilarating and exciting experience. Unless we believe and can demonstrate that the chemistry we teach is enjoyable and fun, we might as well forget the rest and give up.

I therefore recommend that we do not take these sourcebooks back to our respective countries and make our colleagues work through them. I recommend that we not only read through the

sourcebooks but also, if we have not already done so, work through the experiments ourselves, with whoever cares to join us, and examine their teaching and learning potential. Only then should we think about getting together again for further discussions. I was very heartened to learn at this Congress that in the Middle East region for example Dr. Zayzafoon of the University of Damascus has already set the ball rolling, by encouraging his colleagues to work through Volume II experiments with him. I hope that others will now follow this fine example.

Finally, I should like to acknowledge my indebtedness to Professor E.C. Watton of Macquarie University. I have been at the University of Jordan for over three years now. For almost two of those three years Professor Watton and I worked very closely together on several projects and indeed during our association at the University we shared responsibility for the chemical education courses. Much of what I have described therefore, is a result of our combined efforts and thinking. Whilst I have been at the University of Jordan, I have been privileged to have the freedom to teach several courses in the way that I thought best, without interference and with complete institutional support. Such opportunities can be rare and in my case they were due to the support and cooperation of Professor Shibli Bayyuk to whom I have a lot to be thankful for. I should also like to compliment Professors Cole and Watts and Dr. Kingston for the organization of what I consider to be an invaluable congress and who, together with the British Council made my trip here possible.

REFERENCE

1. This course is, in part, described in an article entitled 'The reason why', M.H. Freemantle, E.C. Watton, and G. Ala Eddein, Educ. Chem. 13, 143 (1976).