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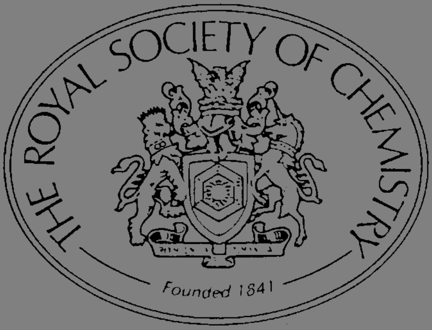

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The journal is aimed at those who teach chemistry in higher education. As a journal for all practising teachers of chemistry at this level it deals with any topic of practical relevance and use to those involved. It is a place to publish effective methods and ideas for the teaching and learning of chemistry and issues related to the effectiveness of teaching and learning. Contributions are particularly welcome if the subject matter can be applied widely and is concerned with encouraging active and independent learning, with increasing student motivation for learning, with helping them to become effective exploiters of their chemical knowledge and understanding, or with assessment. Contributions should be of clear practical interest to those who teach chemistry.

There are no hard and fast rules for subdividing manuscripts. However, an introduction should provide a clear statement of the relationship of what is described to previous work and opinion (and is likely to include some references to some aspects of educational theory), and also the overall purpose of the article (including, where appropriate, the educational objectives, intended learning outcomes and why these are not satisfactorily achieved by other approaches). Other sections may be equivalent to 'methods', 'results', and 'discussion' as used in conventional scientific papers; these sections would describe how the work was carried out, show or illustrate the outcomes (new teaching materials etc) which have been created, and critically evaluate how far the original objectives have been met. It is accepted that evaluation will rarely involve the use of rigorous control groups; but manuscripts should include a discussion of some appropriate method of evaluation leading to critical assessment of the effectiveness of the work described.

Contributors should make clear the extent to which the work described could be transported to other institutions. All contributions should be written in a language readily accessible to academic chemists of any specialism; technical language appropriate to educational research should be avoided or explained.

Four types of contribution may be submitted:

Reviews: these provide for practitioners an up-to-date survey of current methods or approaches to teaching and learning and also show how these relate to our understanding of student learning. They are normally written at the invitation of the Editorial Board, but suggestions for suitable topics are welcomed by the Editor. Reviews may deal either with a particular approach to teaching and learning (such as methods of assessment, contexts for developing team working, use of CAL), or with evidence concerning aspects of an effective learning experience.

Full Papers: these describe a specific method of or approach to teaching, or some teaching material which has been used by the author; papers should explain the educational objectives which led to the use of the method and indicate its potential usefulness in other institutions. Where appropriate, information about the availability of supporting material should be given.

Communications: these are brief accounts of work still undergoing evaluation and development, but of sufficient interest to merit publication because it is likely either to be widely adaptable by other institutions or to provoke widespread discussion.

Perspectives: these provide an opportunity for contributors to present a concise but in-depth analysis of a topic of general interest, with clear conclusions likely to be directly useful to other academics involved in teaching. Articles intended as a perspective should deal with a topic of immediate interest and relevance.

Letters: these are a medium for the expression of well argued views or opinions on any matter falling within the remit of Journal, including comments on and experience with previous publications.

All contributions, whether or not they were solicited, are rigorously reviewed. Referees are required to evaluate the quality of the arguments presented, and not to make subjective judgements involving their personal views of what constitutes good or effective teaching. Contributions are judged on:

(i) originality and quality of content;

(ii) the appropriateness of the length to the subject matter;

(iii) accessibility of supporting material.

Improving Students' Data Analysis Skills in the Laboratory

PAPER

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Basic courses in mathematics for chemists often do not allow students to practice analysing data within a true laboratory environment. This is a vital skill which students often find quite intimidating. This problem has been addressed by using the first session of the practical component of a physical chemistry module to perform a data analysis exercise with the assistance of staff and postgraduate demonstrators. Student reaction suggests that such an exercise is needed, and that more encouragement needs to be given in the use of technology to support laboratory data analysis.

Introduction

The emphasis within the physical chemistry laboratory is very much on producing quantitative results and assessing their reliability. It is well known that many students of chemistry currently have great difficulties with the mathematical aspects of the subject. In a previous study[1] I concluded that students in the physical chemistry laboratory experience difficulties as a result of their weak mathematical ability. Some of the principal difficulties experienced by students are:

- general lack of confidence in using numbers
- failure to appreciate orders of magnitude
- lack of ability in basic algebra
- failure to appreciate the importance of including units.

These problems arise despite the provision of basic mathematics courses including such topics as estimating the maximum probable error and elementary statistics[2].

These difficulties are exacerbated by the students' inexperience with technique which means that their experimental error is greater than it would be for an experienced scientist. Thus the whole problem of data quality and uncertainty analysis becomes an important issue, and this is an area which requires a degree of experience not often possessed by the average first year chemistry undergraduate. The introduction of pre-laboratory work may help to overcome these problems[3].

Much pre-laboratory work has concentrated on providing a knowledge-base which will help students to understand underlying theory behind a laboratory experiment[4,5]. A different approach was needed to overcome the problems which students experience with data analysis. It occurred to me that a single pre-laboratory experience could prepare students for a complete laboratory course. This approach has been tried before with some success[6]; in the study described here all students analysed the same set of data while their activities were carefully monitored by staff and demonstrators, with ample opportunity for discussions.

The main difference between such a session and the analysis of data generated from a real experiment is that the instructor retains more control over the quality of the data and thus identifies mistakes more quickly. Furthermore all problems associated with experimental technique are eliminated, thus allowing students to concentrate completely on data analysis. The tutor does not need to spend a large amount of time trying to identify an error in a single student's piece of work and so is free to have meaningful discussions with a large number of students. This enhances the learning of each student, and should reduce the time spent in looking for mistakes later in the course when students do move on to analyse their own data.

The introduction of modularisation required the revision of the second semester course on "Energy and Dynamics". This provided an opportunity to introduce an exercise which would allow students to go through a specimen (typical) calculation with support from a tutor in the expectation that this would develop the confidence and skill to enable them to do other calculations unassisted.

Data analysis exercise

The data analysis exercise was designed to form a part of the first session of a second semester course consisting of twelve 3-hour laboratory sessions. Typical student numbers in this laboratory are 35-40, with three postgraduate demonstrators and one member of academic staff in attendance. The other activities included use of the Chemistry Courseware Consortium software on Using Tables and Graphs[7] and the straight line[8], and viewing of the video showing the experimental arrangement[9]. Thus 60 – 90 min was available for the data analysis exercise.

Data for analysis was chosen using the following principles:

- It should be provided by an experiment which was conceptually simple enough for the students to be able to envisage how the data had been collected without actually doing the experiment;
- A demonstration (or good video presentation) of the procedure should be available;
- The experiment should not be included later in the course;
- In order to fit the available time the data manipulation should not involve calculus, but only the simple algebraic manipulations of addition, subtraction, multiplication, division, indices and logarithms.
- The data processing should involve the use of a straight line graph, since this is one of the most common features of data analysis in physical chemistry.

Using these principles, the experiment selected was one in which the equilibrium constant for the dissociation of dinitrogen tetroxide is measured at various temperatures in order to determine the standard enthalpy change for this reaction.

Prior to modularisation, this experiment had been used in the second year physical chemistry laboratory. It was abandoned because it is technically difficult to carry out so that most students obtained poor data. Since constraints of time limited the collection of data to three temperatures, students had difficulty analysing straight line graphs. Although the technique is difficult, the theory required for this experiment is covered in the first year physical chemistry module. Furthermore the reaction itself involves a clearly visible colour change which is shown on a video in the Basic Laboratory experiments series[9].

The actual data used was modified from that provided by Alberty and Silbey[10]. Their data is essentially error-free, and reasonable error was introduced in order to encourage students to explore ideas of uncertainty analysis.

Description of the experiment

The laboratory experiment involves filling a calibrated flask with nitrogen dioxide to reach atmospheric pressure, and weighing the amount of nitrogen dioxide (which is, of course, a mixture of NO_2 and N_2O_4). The measurement is made at three different temperatures. The variation in mass reflects the degree of dissociation of the nitrogen dioxide. The calculation of the equilibrium constant for the reaction and for the molecular mass of N_2O_4 (M_1) uses the value for standard atmospheric pressure (p^o) and experimental values as follows:

- the volume of the flask (V) which is calibrated by weighing it empty and full of water, and using the density of water to determine the volume;
- the mass of nitrogen dioxide (w) from the weight of the flask when evacuated and filled with nitrogen dioxide;
- atmospheric pressure (p);
- the temperature at which the flask is filled with nitrogen dioxide.

The calculation itself involves the following steps:

- calculation of the apparent molecular mass of the gas in the flask from equation 1;

$$M = \frac{w}{V}\,\frac{RT}{p} \qquad (1)$$

- calculation of the degree of dissociation (α) from equation 2

$$\alpha = \frac{M_1 - M}{M} \qquad (2)$$

The equilibrium constant is then obtained from equation 3.

$$K = \left(\frac{4\alpha^2}{1-\alpha^2}\right)\left(\frac{p}{p^o}\right) \qquad (3)$$

The calculation of $\Delta H^{\ominus}$ for the reaction involves determining the slope of a graph of lnK against 1/T.

Running the data analysis exercise

This exercise has now been run for two years. The data analysis exercise itself has not been changed, but in the second year, the arrangements for running it were modified: the class was split into groups each under the supervision of a specific demonstrator and the data analysis was undertaken in rotation, with the other activities described above. In both years peer group discussion was encouraged as long as it was relevant to the work.

Students were given a verbal outline of the exercise and a set of instructions for analysing the data. They were also asked to estimate an uncertainty on their final value of ($\Delta H^{\ominus}$. Although methods of uncertainty analysis are covered in an earlier Mathematics for Chemists module, they had not previously been expected to apply these methods in a real situation. The format allows extensive discussions with the students, so that it is possible to emphasise that the level of certainty cannot be known, but only estimated, and that several methods are available for determining this[11]. The value of discussing the uncertainty estimation for each experiment with a member of staff or a demonstrator is stressed. The whole aspect of uncertainty analysis is something which students have traditionally found difficult in physical chemistry, and this approach allows some indication of the need for further discussions at the appropriate time. No formal treatment of this subject is made in the first year, but it is covered in more depth subsequently. The aim here is to give students an appreciation of the importance of error analysis and to consider how it may be applied in each of the experiments met.

No guidance is given as to how students should produce the required graph, and this is another area where informal discussion can be beneficial. With only three sets of data, statistical analysis of the line of best fit is inappropriate and students have invariably drawn the graph by eye. This easily leads to a discussion of how the line was chosen, and how this reflects the error or uncertainty in the result. The choice of appropriate scale is another feature which leads to useful discussion.

Some students completed the exercise relatively quickly while others struggled to finish in the time available. The format used allows flexibility by allowing the instructor to help, for example by supplying selected missing values in order to allow a student to move to the next step. In this way, each student can be shown the whole process, and given the opportunity to generate the required graph and discuss it.

Feedback given to students

All students are required to complete the exercise to the approval of the demonstrator. This judgement is based on an evaluation of how well the student has addressed the data analysis, and whether they are judged competent at data manipulation. It is thus possible for an incomplete exercise to be judged satisfactory, which goes some way towards addressing the different speeds with which students work.

Once the data analysis exercise has been completed to the satisfaction of the staff member, the student is provided with a sample report for the experiment which includes a full analysis of the data.

The sample report is approximately 500 words plus the relevant graph and includes sections headed *Introduction*, *Experimental Method*, *Results*, *Calculations*, and *Conclusion*. It is intended to parallel the form of the report required for experiments which are actually performed in the laboratory during the rest of the module.

Evaluation of effectiveness

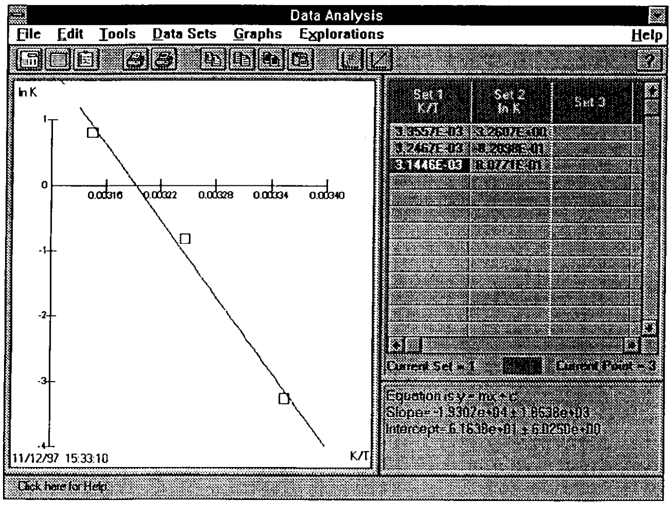
In the first year of operation the data analysis exercise ran with one large group while subsequently the class was divided as described earlier. There are merits to each approach; in the former less time is lost due to moving around, but in the latter additional supporting activities could be introduced, and students were under the supervision of an allotted demonstrator.

Observation of the students during the exercise showed that many found it difficult even though no new mathematical techniques were being introduced, and full instructions for performing the calculations were provided. The format of the exercise encouraged the students to interact constructively with the demonstrators, and the quality of the questions they raised, and their response to guidance gave a strong indication that this was an effective learning experience.

This view was supported by postgraduate demonstrators during the reflective critical review at the end-of-module review.

Student opinion was canvassed by informal discussions with the students throughout the module. These confirmed that they viewed the exercise as a useful preparation for the analysis of their own data and allowed them to tackle this task with confidence. Compared with previous years the submission of experimental reports with correctly completed calculations was considerably improved.

Figure 1: Result of using the data analysis tool in this experiment



Set 1 K/T	Set 2 ln K	Set 3
3.3557E-03	3.2607E+00	
3.2467E-03	-8.2098E-01	
3.1446E-03	8.0771E-01	

Current Set = 1 Current Point = 3

Equation is y = mx + c
Slope= -1.9302e+04 ± 1.8538e+03
Intercept= 6.1638e+01 ± 6.0250e+00

Although I conclude that this exercise was of considerable benefit, I can see that improvements could be included in future years. One point we noted was that very few students even considered the possibility of plotting the graph using a computer. This suggests that this technique could usefully be incorporated into the exercise. There are many packages available for performing straight line plots and least squares fitting, including the Data Analysis Tool in the "Using Tables and Graphs" part of 'The Chemistry Tutor'[12] (see Figure 1).

The value of data analysis exercise might also be enhanced if combined with an appropriate post-lab after the experimental work as described by Johnstone et al [3]. At present some of this time is used for student oral presentations, and there is an opportunity to incorporate such work into the final timetabled session.

Availability

Copies of the data analysis exercise and the sample report described are available from the author on request.

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Independent Learning in an Introductory Module in Biological Chemistry: Use of Question Mark™ **Software to Provide an Assessment Tool and Tutorial Support**

PAPER

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In designing a new first year module in biological chemistry we aimed to eliminate lectures which we regard as a fairly ineffective way of imparting factual information and replace them with high quality handouts and a recommended text. Students were issued with a programme of structured study and assessment at the start of the module. Two hour tutorials were held weekly on questions/discussion topics previously given to students. This was the only formal (timetabled) contact between staff and students. Students worked their way through the subject material during 12 weeks and were assessed at fortnightly intervals using Question Mark™ software. This not only allowed us to monitor the progress of students but also imposed on them a structured programme of study. The results of the tests were available immediately to students and to staff. In the periods between tests, students had access to the computer laboratories to do practice questions. These questions all had feedback, so that if a student gave an incorrect answer an explanation could be given as to why it was incorrect. We found the QM software to be well suited to introductory chemistry – tests which are challenging and have considerable variety can be constructed. A survey of the students indicated that two thirds of the class thought that this style of learning was better or much better than lectures and none thought it was worse.

Introduction

We were asked to design a new module called 'Introduction to Biological Chemistry' which was to be studied by first year students embarking on Health Science courses.

The design of the module had to take into account not only the subject content and pedagogical approach but also cost effectiveness. For well-documented financial reasons[1] departments are increasingly under pressure to increase the efficiency of teaching. In our case this meant that the module had to be suitable as a foundation for a *range* of life science courses, without compromising the needs of students and the educational objectives of the individual programmes to which it contributes. Ideally, the module would also take account of the reduction of the number of academic staff and the pressure to reduce the use of valuable teaching accommodation.

Trigwell *et al* have studied the various strategies used by lecturers to improve learning by students in first year science courses[2]. At one extreme strategies were based on highly *teacher-focused* activities, where there was little or no interaction with students and where students had little or no responsibility for the teaching-learning situation. Typical of this approach was the provision of notes, perhaps with gaps which had to be completed by students, but where there was little freedom given to students to decide how *they* should take notes. The main intention of this approach was *information transmission*. At the other extreme, strategies involved highly *student-focused* activities, where students were very much more in control of and responsible for their own learning. An example of this approach is provided by White [3,4]. His innovative programme is unlikely to be viable in most UK institutions because of the high load on the teacher and the small enrolment.

Whatever approach is adopted, it is useful to take account of established theories about the way students learn. Some useful reviews dealing with this are available (for example[5,6]). As Boothroyd has pointed out[7], it is easier to acquire knowledge by independent learning than it is to acquire understanding and skills in applying knowledge; this leads to a powerful argument that a tutor's limited time is best spent in helping students with these more difficult aspects of the learning process. Furthermore, in a course where teachers concentrate on the acquisition of knowledge there is a risk of reinforcing the dualistic view of the world used by those in the first stage of intellectual development defined by Perry[8]. An introductory course needs to recognise that many students, being in this position, still expect teachers to be able to provide 'correct' answers to everything. Only when the 'language' of chemistry has been learned and a foundation established are students likely to proceed to the higher orders of reasoning described by Perry. However, at the beginning of most university chemistry courses there is undoubtedly a strong emphasis on the acquisition of factual knowledge and its simple processing.

A further complication for us was that we had to cater for a diverse client group of students with a range of educational backgrounds and wide disparity of chemical/scientific achievement. The traditional lecture approach did not seem to us to be a particularly efficient way of meeting the requirements of such an inhomogeneous body of students. An approach involving self-paced learning which lay somewhere between the two extremes described by Trigwell seemed to be more appropriate. This would also fulfil the requirements of reducing the contact hours for tutors and reducing the demand for teaching accommodation. Furthermore, previous experience with an introductory biochemistry module for physiotherapy students had shown that a structured programme of work based on detailed handouts and informal lecture/tutorial classes for students experiencing difficulty could work successfully[9,10]. The key to its success was regular computer-based testing which gave the students an incentive to keep up to date with their studies. We have developed and refined this approach in a number of ways and produced the module described here which was initially incorporated into a new degree programme in Clinical Science. This programme also included modules in introductory physics, anatomy and physiology in the first year.

Module content and teaching strategy

The aim of the module was to develop within students a knowledge and understanding of the chemical basis of life processes. The syllabus was loosely based on an introductory text on chemistry for the life sciences[11] and progressed from atomic structure and bonding through the topics: chemical reactions and kinetics, solution chemistry, organic compounds, carbohydrates, lipids, amino acids, proteins, enzymes and metabolism. There was no laboratory work. The emphasis throughout was on relating the chemistry to biological functions and to subjects such as physiology, nutrition and microbiology; it was not the intention to establish a foundation for the further study of chemistry and so the syllabus content was necessarily selective and illustrative rather than comprehensive.

The module was designed on the following principles:

- there were no lectures;
- the syllabus would be defined by eight handouts representing a unit of material; handouts would be provided at appropriate intervals throughout the 12 week module;
- the learning experience would be enhanced by stimulating self-assessment questions available on a computer network;
- tutorial support would be provided by a weekly compulsory two-hour class when the whole cohort (about 14 students) would meet to discuss sets of open ended problems which would be distributed seven days beforehand;
- additional structure would be provided to the learning environment by using fortnightly computer-based tests to assess preset goals;
- assessment would be based on the results of the computer-based tests representing coursework (60%) and an end of module examination (40%); (this division is required by course regulations).

Students who enrolled on the module met the tutors at induction, and the operation of the module was discussed. Students were arranged into groups of three as a basis for peer support. They were issued with a week by week timetable of events which showed when particular handout material was available and when self-assessment questions for the material would be loaded on to the computers. The fortnightly tests contained questions similar but not identical to these practice questions. The software allowed the tutor to monitor the progress of each student and could highlight areas of particular difficulty or indeed if they were not maintaining a reasonable study schedule. Records of each student's attempts at both the practice questions and the official tests were available to the tutors, but only the latter were retained for incorporation into the coursework mark. Students could access practice questions in the computing laboratories during sessions which were timetabled for two hours per week but were also available for access at other times. The questions were based mainly on the handout material, testing both acquisition of information and simple processing of this information. The programme provided comprehensive feedback, linked to individual responses of students, as well as individual scores.

During the two-hour weekly tutorial session students worked in their arranged peer groups on the open-ended problem and topic exercises. Examples of these are shown in Figure 1. They were designed to engage the student creatively with the material to provide opportunities for the tutor to explore with the students the wider implications of the subject. This type of interaction fits with Boothroyd's concept of using the tutor for 'higher order' aspects of learning[7]. It also gives an opportunity to discuss what type of response is required in the end of module examination.

The eight-unit handouts together are the equivalent of a small book of approximately 120 pages. Each unit consists of an outline, objectives of the unit, content, keyword list, set of discussion topics and problems, and some include self-assessment problems. The handouts were prepared from tutors' notes and diagrams by two (part-time) post-graduate students. They used the Pagemaker$^{\text{TM}}$ DTP package and Corel Draw$^{\text{TM}}$ for diagrams to create high quality colour-illustrated material. Reference to the introductory text book[11] was included for those students who needed further information.

The same postgraduate students also created the bank of about 400 computer-based questions (with feedback) using

Figure 1: Examples of problems and topics for discussion used in tutorials

Discussion topics:

1. What is a mole?
2. How are reaction rates measured, and how does the information gathered lead to a proposed mechanism?
3. What are the essential features of carbohydrates that suit them to their various biological functions?

Problems:

1. Identify the functional groups in (1) LSD (2) ATP
2. Draw the disaccharides of glucopyranose that are linked by the following glycosidic bonds:
   α-1,6-
   β-1,3-
   α-1,2-
   α,β-1,1'-
3. Rotation about the C-N bond of peptides is very difficult. From the table of bond lengths, what can you infer about the nature of the C-N bond?

the software package Question Mark Designer™ for Windows (QM).This is a dedicated assessment tool produced by Question Mark Computing[12] and is described in more detail in the next section. The tutors drafted questions, together with feedback, for each unit; the postgraduates transcribed these into QM format, including appropriate diagrams in Corel Draw. Selected questions were then reserved for the fortnightly tests, and the remainder were made available for practice when the students were studying the units. The questions were then set up on the server in a networked computer laboratory.

Other authors have used authoring packages such as Authorware Professional[13] and Toolbook[14] to produce CAL material to support the learning of chemistry.This material met only a small proportion of our needs and we had in any case decided that the availability of printed material gives the students much more flexibility to choose the time and place for their studies. This point is recognised by others who have pointed out that teaching material is not necessarily best delivered by computer (*eg* [15]). Although Authorware and Toolbook can be used to write assessments it takes much longer to master their intricacies compared to QM. Further advantages of the QM software are that it records student performances and an integral part of the software is the statistical analysis of responses. Also the QM company maintains an e-mail users group[16] which allows sharing of experience of assessment between different users.

Feedback and testing with QuestionMark Designer™

A brief review of QM software is given by Dempster[17]. We used windows version 3.10 which was installed on a local network. It is possible to deliver questions over the *Web*, but compared to the networked version there are two main disadvantages: certain types of question are not available and feedback cannot be given directly after a student makes a response to a question[18,19]. The QM software has been a key element in the success of our approach. In much assessment software, question formats are restricted to multiple choice questions (MCQ), which are not only difficult to create if they are to be effective but also are not appropriate for the assessment of all aspects we wished to test. In contrast, QM has a varied and interesting selection of question formats which are more easily applied to different types of problem over a wider range of the syllabus. As with other assessment software, students are given instant feedback on their response.Anyone who is familiar with Windows can quickly assimilate the QM software (both the question setter and the student); there is no need to learn any internal programming language. The editing of questions is easily carried out by tutors.

The types of question available in QM are illustrated in Figure 2. Once familiarity is gained with the different types of format, designing questions is a fairly rapid process. Essentially each type of question is provided as a visually attractive template into which the teacher inserts appropriate text, graphics or multimedia material. For example the *hot spot* question can incorporate multiple 'live' spots in a diagram (*eg* a graph, an equation, a figure, a chemical formula). When the student selects a particular *hot spot*, feedback which is specific to that spot can be given. The *selection* question presents multiple choices of answer (usually a one word answer) to each question asked. For certain types of question *supplementary questions* can be asked allowing the student's answer to be elaborated in greater detail. Feedback normally appears on-screen, superimposed on the question, immediately the student has given a response. However if the feedback is extensive or requires the use of rich text or graphics, an *explanation question* is usually the preferred route. This appears on the screen separately after the response has been given.

Figure 2: Question types

1. Multiple choice
2. Multiple response
3. Push button
4. Hot spot
5. Text match
6. Numeric
7. Selection
8. Explanation question

We chose to give as much feedback as possible when the students were attempting the practice questions. If a response was correct, it was marked with a tick; if it was wrong, an indication of the correct response(s) was given, together with an explanation. During the official tests, it was felt that some feedback would be helpful, so an indication of the correct response(s) was always shown (but no explanation was added).

The QM suite has three main components: **Designer, Presenter** and **Reporter**. **Designer** is the tool which provides templates for the different types of question. It also contains the control information which determines the type of feedback given to students, the sequence in which the questions are asked and whether the response options are shuffled. **Presenter** actually delivers the test to the student and provides the feedback. It has a passworded entry and can restrict the length of time available for the test. **Reporter** contains the answer files of individual students. It can be used to determine who was taking a particular test and when it was taken. It can be used to identify students who were experiencing difficulty. In addition **Reporter** carries out statistical analyses of responses to individual questions by students which gives the *facility* and *discrimination value* of questions. These can be used to 'weed out' inappropriate questions and to refine the test.

An interim evaluation of the module

The new Clinical Science course has now been completed by two cohorts of students. There were 14 in the first intake and 13 in the second one. The majority of students entering the module had passed two or more subjects at GCE A-level (not necessarily including chemistry). The qualifications of other students included the BTEC National Diploma and the Irish Leaving Certificate.

Student feedback

All but one of the 14 students completed and returned an anonymous questionnaire at the end of the module.

From this we drew the following conclusions:

- two-thirds of the students thought this style of teaching was better or much better than lectures. None thought it was worse than lectures. All but one of the students were either satisfied or very satisfied with the module. The structure and organisation of the module was also favourably regarded by students.
- **all** students thought that practice questions with feedback and the regular tests helped their learning.
- students did not find the volume of work excessive (although there was a significant increase compared to lecture-based modules and on average students spent more than the nominal expected commitment of 13 hours per week).
- 71% of students said that they had received help from other members of the class whereas 57% said that they had given help to other students, showing that substantial peer assisted learning had occurred.

Student performance

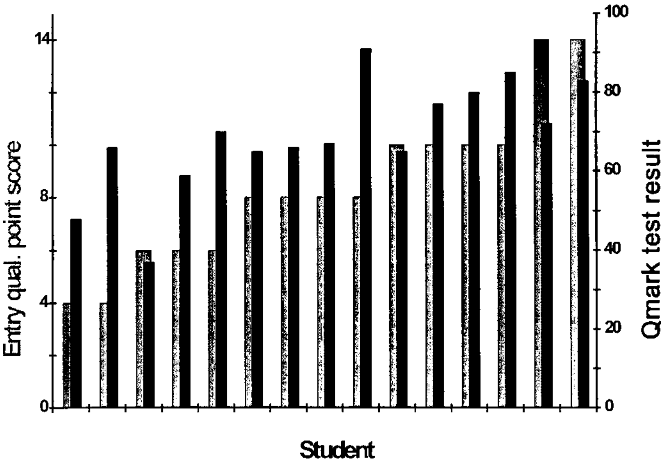
All students obtained a rather lower mark in the end-of-module examination than they did in the within-module tests, and the two marks showed only weak correlation. Given the immediacy and limited coverage of the within-module tests, this is not surprising, and we do not believe it invalidates either form of assessment.

The combined mark varied from 40% to over 80%, a mark distribution which compares favourably with other modules. The second cohort obtained a lower average mark than the first cohort and this was consistent with their relative performance in traditionally taught modules.

The end-of-module examination required the student to attempt four questions out of a possible six, three of which were essay style, and the remainder semi-structured. We noted that some of the students (particularly the BTEC entrants) seemed to find the formal examination more difficult; similar scores were achieved in the Introductory Physics examination.

We have compared the entrance qualifications of the students in the first cohort with their final mark (see Figure 3). The entrance qualification was obtained by adding the A-level point scores in biology and chemistry (when this had been taken) or by using recognised equivalent scores for entrants with other qualifications. Figure 3 shows that the students entered the course with a wide range of achievement. In general those with the weakest background showed the greatest relative improvement, and those with average backgrounds remained about the same. The two students with the highest entry qualifications had been advised to concentrate on other modules and this probably explained their relatively poor performance. From this analysis we concluded that the students with low entry scores benefited from the opportunity to work at their own pace, and that this helped to reduce the inhomogeneity of the group before they progressed to more advanced modules.

Figure 3: Comparison of QMark test results and point scores of entry qualifications in chemistry and biology



Tutors' input

A significant feature of this module is that the normal weekly contact time of six hours per week was reduced to two hours. This is a significant saving of staff time, and also reduces the pressure on teaching accommodation.

Our reflective evaluation of our contribution to the learning environment is based on our analysis of the amount of interaction with students and the quality of the discussion during the weekly classes. We concluded that our input (in two hours) was more effective than is possible in the six hours of a traditional lecture-based module, and we relate this to Boothroyd's point[7] that we were using our time to help the students with the higher order aspects of learning.

The key elements of the module have now been incorporated into two laboratory-based courses, year 2 of HND applied Biology and year 1 of BSc applied Biochemical Sciences for a total of 60 students. The attitude of these students has been very positive and their overall performance has been at least as good as previous cohorts. We are therefore satisfied that this module is appropriate for students with a range of backgrounds and that it serves the needs of a range of courses. We conclude that requiring students to take more responsibility for their learning in introductory courses provides a sound foundation for future study.

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Addressing Key Skills in the Chemistry Curriculum: Structured Learning Packages

PAPER

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An approach to addressing key (transferable) skills has been developed which builds on the chemistry background of students by means of realistic case studies sourced from the chemical industry. The development and format of the resulting *structured learning packages* are outlined. Early experiences in using these packages at two universities are described. Initial trials suggest that students can improve their understanding of chemical topics whilst developing skills in the principal areas of teamworking, communication, problem solving and information retrieval.

Introduction

Employers[1], professional bodies[2-4] and educators[5,6] continue to draw attention to the need for university degree courses to address the development of key skills alongside the subject-specific knowledge, understanding and skills of a particular discipline. This view has been emphasised further by the recent *Dearing Report* into higher education (HE) in the UK[7]. Despite the importance attached to these variously defined generic skills, there remains a perceived difficulty in finding time to introduce them adequately into an already overcrowded curriculum. One approach to resolving this problem is to teach the content itself in a way which simultaneously develops skills. This recognises that content *without* skills is limited in its value; professional chemists should be able to *extend*, *explain* and *exploit* their knowledge. There are powerful arguments in favour of this integrated approach and recent contributions have demonstrated how it might be achieved[8,9].

Recently, in the UK, the introduction of the M.Chem degree, and of modularisation, has created the space necessary for involving students in such skills based, reflective approaches to learning. We set out to develop resources to exploit this opportunity, with the specific aim to generate material which would:

- be based in chemistry;
- allow the development of key skills;
- encourage independent study;
- be sufficiently flexible to facilitate wide use.

We coined the description *structured learning packages* (SLPs) for these materials.

Characteristics of structured learning packages

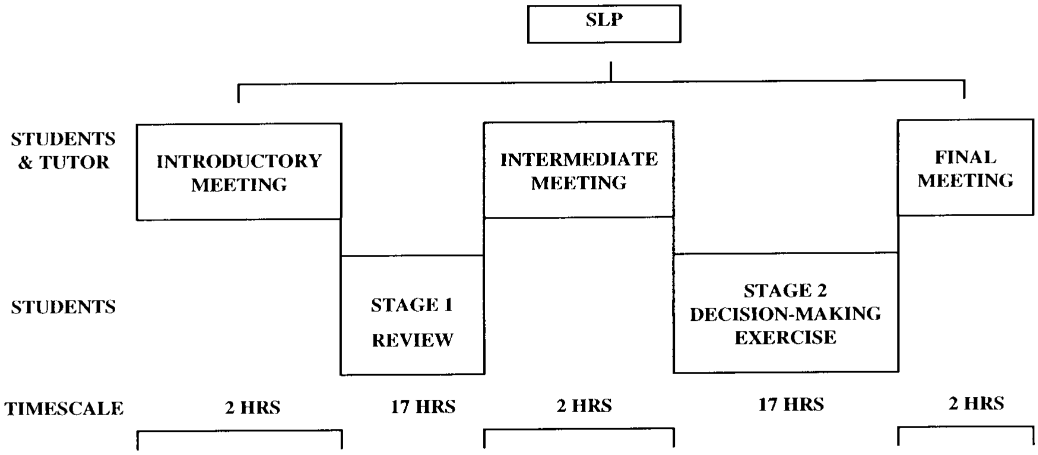
We established a consortium of academics from six universities[10] together with representatives from the chemical industry in order to discuss the style and content of the packages. In this way, we expected to maximise the suitability of the final product for use in a range of institutions whilst incorporating those skills most demanded by employers of professional chemists. From the initial discussions of this group, the following desirable characteristics for SLPs were identified.

- Each SLP should be based on a case study of industrial/ pharmaceutical chemistry to provide realism;
- A library of complementary SLPs were needed which covered a range of industrial scenarios;
- Each SLP should occupy 30–40 hours of student time (equivalent to 3–4 weeks of practical work in most courses);
- The chemistry involved should be suitable for third year BSc/MChem students
- Each SLP would be designed for use by classes of up to 25 students working in teams (2–5 teams of four or five students); larger cohorts could be accommodated by dividing them into two or more classes;
- In order to engage the interest of the whole class in the work of each team, each team should be assigned a complementary (but not identical) task within the same general topic;
- The tasks set to each team should bring out the importance of two aspects of teamwork: the value of dividing up a task and the value of 'sharpening up' ideas through team discussions;
- In addition to teamwork, each SLP should involve students in retrieving information, presenting written and oral reports, making decisions in a situation where more than one could be defended, and developing some commercial awareness;
- Most of the student time should be spent working independently of support from tutors, but sufficient support should be available to provide confidence;
- Student performance should be assessed.

The design of structured learning packages

The basic format of our SLPs (three plenary sessions separated by two periods of independent study) is shown in Figure 1.

Figure 1: The format of a structured learning package (SLP)



We judged that the inclusion of an intermediate plenary session, in addition to an opening and closing one, would provide sufficient input from a tutor to support the students' activity. This intermediate plenary allowed each package to be sub-divided into two distinct stages. Stage 1 was intended to be concerned primarily with information retrieval. We supposed that students would feel relatively confident in their ability to do this, and that this would encourage them to tackle Stage 2. This involves the much less familiar task (for students) of making decisions in a context where there is incomplete information, no uniquely correct solution, and when factors other than chemistry (such as costs, safety, and the environment) have to be taken into account.

The division of the exercise into two stages had other benefits:

- The initial input of information need only be sufficient to allow completion of Stage 1;
- The success of the information retrieval could be monitored and additional information provided, if necessary, in order to ensure that all groups had an adequate background to allow them to complete Stage 2;
- It enhances reflective learning since there are two opportunities for students to prepare written and oral reports on their work, and the intermediate plenary is used to provide feedback on the effectiveness of their efforts and guidance on how to improve their performance during Stage 2;
- The scope of the information gathered during Stage 1 is increased since all groups can be required to collect complementary data which is shared at the intermediate plenary; this sets up the possibility of using a single communal problem in Stage 2 introducing a useful degree of competition between the teams.

Choosing case study topics

To date, two SLPs have been prepared. One deals with the industrial manufacture of acetic (ethanoic) acid (see Table 1 for details). The other deals with the selection of a polyaromatic polymer compound for a specific use (see Table 2 for details). Both these topics meet the following criteria:

- We had the assured collaboration of an appropriate industrial consultant with considerable expertise in the field (BP Chemicals for the acetic acid study, and ICI for the polyaromatics study);
- Each topic is currently relevant and so illustrates the kind of things chemists actually do;
- The chemistry involved is simple, so that the students can concentrate on the development of skills in a context which is clearly chemical, but not so challenging as to dominate the learning experience;
- The students need to consider aspects of chemical engineering and technological economics, thus broadening their experience and illustrating the relationship between chemistry and other important disciplines;
- Most of the necessary information (at least for Stage 1) is in the public domain and can be found without reference to highly specialised or restricted publications;
- At least four complementary tasks can be identified for Stage 1 of each exercise (see Tables 1 and 2).

Experience with structured learning packages

We have used both exercises with students at Warwick and at York. The initial trial, as a course option, at Warwick involved a group of eight third year students working in two teams of four. The teams completed both SLPs within a four week period, two weeks being allocated to each one. At York the complete cohort of 65 third year BSc students completed a single SLP as part of the core curriculum. The students were divided into three classes. One class, comprising five teams, completed the Polyaromatics exercise and two classes, each of four teams, concurrently completed the Acetic Acid exercise. In order to trial the SLPs before the end of the year Stage 1 was completed over ten days, before the finals

Table 1: Student tasks in the Acetic Acid SLP.

Stage 1

Review two processes of acetic acid manufacture (from four). Apply a scheme for estimating chemical plant capital costs to the two processes. Compare the processes in terms of their complexity, raw materials, environmental impact etc.

Review the uses of, and global market for, acetic acid and derivatives. Review the nature of the costs, other than plant capital, which contribute to the 'factory gate' cost of an industrial chemical.

Prepare a talk and a written report to summarise findings.

Stage 2

Consider a number (four) of acetic acid plants, at locations throughout the world and based on the four different processes, and use the Stage 1 reports to arrive at a capital cost estimate for each.

Use additional cost information (raw material prices etc.) and a scheme for estimating some process costs to derive a production cost for acid at each plant.

Make use of this cost analysis, in addition to the accumulated information on the current and forecast world market for the acid and the raw materials to arrive at a decision regarding which single plant the company would be best advised to sell off in order to diversify into other areas.

Develop a strategy for selling the plant as a going concern.

Prepare a talk and a written report to present and justify your decision and explain your strategy.

Table 2: Student tasks in the Polyaromatics SLP.

Stage 1

Review the area of polyaromatic engineering polymers with emphasis on establishing structure-property relationships for this class of polymers.

Use the structure-property relationships to explain the choice of three polymers from the list provided which would be suitable for the prescribed application (e.g. for dialysis membranes in food technology and desalination).

Outline a route for producing each candidate polymer considering the source of monomers, processing, environmental and processing hazards.

Review the nature of the key costs involved in producing polyaromatics. Analyse the potential market for the polymer including its size and the nature of competitor materials.

Prepare a talk and a written report to summarise findings.

Stage 2

Consider all the Stage 1 applications and apply a scheme to cost out the production and processing of the candidate polymers.

Use the cost information to choose an optimum polymer for each application based on the best compromise of performance and cost.

By consideration of the costs of each of these polymers and the information on the markets available in each application (and taking account of the ability of one polymer to meet more than one of the applications), choose a single polymer to go into production.

Develop a strategy to sell the new polymer into the target application/s and suggest other areas where it may find uses.

Prepare a talk and a written report to present and justify your decision and explain your strategy.

examination; three weeks later Stage 2 was introduced with an additional short plenary session, immediately following the finals examination.

In Warwick and in York, the introductory plenary session was used to emphasise the importance of key skills and the opportunities to develop these through the SLP.This was done by involving the student teams (as pre-selected by the tutor) in short periods of brain-storming followed by tutor-led class discussion. The following sequence of discussion was used:

- 'What do you understand by key skills?' (leading to agreement that these can be grouped into the four categories of skills identified for purposes of the SLP: communication, teamwork, problem solving, information retrieval).
- 'Identify good things and bad things about the way your team just worked in arriving at a conclusion, and about teamwork in general' (leading to complementary pairs of observations e.g. 'one person dominates' vs. 'everyone is encouraged to contribute' and 'there are personality clashes' vs. 'focus on the task in hand – be professional' etc.)
- Students then individually completed a skills profile form based on the expanded range of personal skills described by Gibbs *et al.*[11].
- Teams discussed individual profiles and summarised a combined profile for their team with a short presentation.
- Written details of the tasks to be completed before the next plenary session were then distributed and explained. Lists of learning outcomes were also distributed (Tables 3 and 4).
- The arrangements for a 'Help' service (available via email) and the requirement for team meeting minutes were explained. These features operated in a similar manner to that described for similar exercises[9].

The intermediate plenary session can be used for some, or all, of the following purposes:

Table 3: Learning outcomes (key skills)

On completing this course, you should be able to:

- list the key skills you regard as important in employment and describe how the case study helped to illustrate this:
- describe how your own key skills allowed you to contribute to the exercise and how you will use this experience to improve your performance:
- give examples of good and bad practice in the areas of communication, teamworking, problem solving and information retrieval.

Table 4: Learning outcomes (chemistry)

On completing this course, you should be able to:

- use examples from the case study to illustrate the role of technology, raw materials and markets in industrial strategy;
- use examples from the case study to demonstrate the differences between small scale laboratory synthesis and large-scale commercial processes:
- describe the influence of environmental and safety concerns on the operation of industrial processes.

- Each team delivers an oral presentation in which they must all participate. We have used talks of 10 minutes duration (with four or five teams presenting) though more time can be allowed in a smaller class.
- Each team can be given the responsibility for chairing the presentation and leading the questioning of another.
- At the conclusion of the presentations, a feedback and discussion session along the lines of 'what makes a good/bad presentation?' is appropriate.
- Assuming that written reports have been handed in and assessed in advance of this meeting, they can be returned together with copies of all other reports needed for the communal decision-making exercise in Stage 2. The opportunity to compare all the reports, side by side, in this way can be exploited in a 'what makes a good/bad written report?' review session.
- The tutor can ensure that the teams have sufficient accurate information to proceed with Stage 2 and introduce the requirements for this second part of the exercise.
- Comments on the operation of the 'Help' service and/or the style of team meeting minutes might also be relevant.

The final meeting creates opportunities for:

- The second oral presentation, this time presenting a persuasive justification of the decision the team have reached.
- The various suggestions from the teams can make for a lively discussion session. There is a useful role for an industrial expert in leading these discussions.
- Further feedback on skills can be provided either to prepare for tackling a second exercise or summarising the role of key skills and their relevance to the future course/career activities which the students face.

Assessment

We have used the brain-storming sessions on oral and written presentation to arrive at marking schemes which are presented to the students and used subsequently to assess their presentations. This concept of negotiating a mark scheme with students has been previously applied by Wallace[12]. The content of the oral and written reports provided suitable evidence for assessing the proficiency of the teams in information retrieval and their level of acuity in problem solving. Assigning a mark to teamworking was approached through assessing the continuity and coherence of the presentations, the degree to which the teams demonstrate good teamwork when responding to questions, and the quality and content of the minutes of team meetings. This procedure arrives at overall *team* marks. Deriving *individual* marks from these is more problematical.

We have chosen peer assessment as a route to individual marks. The team was given its team mark after each stage of the exercise. Their instruction was then to multiply the mark by the number of members in the team and to agree on a division of those marks between them. On one occasion, this was done with the proviso that no individual could get more than 1.2 times the team mark. Both marking systems were accompanied by a clear grievance procedure and the additional proviso that the course tutors had the final say in any dispute. In order to help police this system we made reference to the minutes of team meetings.

We chose to weight the marks for the exercise 40:60 between Stage 1 and Stage 2. In other words, more credit given to the latter part of the exercise when teams have had the advantage of learning from their first attempts during Stage 1.

Discussion

The exercises were run at Warwick and York with the participation of five tutors, with one of us (NL) in both places. Our subsequent analysis of the effectiveness of the exercises has led to a consensus view on a number of issues which contribute to the success of exercises of this type.

In order for students to get the maximum benefit, it is crucial to remind them (and ourselves!) that the main goal of these exercises is to develop key skills. We have found it important to temper the 'over-conscientious' nature of students towards the chemistry content. In particular, we stress the importance of introducing the unfamiliar nature of problems of this kind, where there is incomplete information, no uniquely correct solution, and a range of unfamiliar and complex factors. We emphasise to students that making judgements to a strict time or financial deadline, and on the basis of incomplete information is a crucial aspect of many real situations.

The 'Help' service was not heavily used during the exercises perhaps as a result of our suggestion that injudicious use of the service might be penalised. However, an effective 'Help' service is crucial, partly to ensure that the teams can complete the exercise, and partly to act as a database of papers and other data which teams might have genuine difficulty in obtaining during the exercise.

The intermediate plenary session can prove very intensive due to the combined pressures of listening to all the talks, giving feedback on talks and written reports, reviewing teamworking, giving a technical resume of Stage 1 and preparing the ground for Stage 2. Indeed, in anything other than a very small class, it is not possible to do all these things effectively in a single two-hour session. The division of this session into two, as practised at York, has much to recommend it, especially for a large class.

At York, we benefited from having a representative from the collaborating industrial companies at the final sessions. This galvanised the teams during their presentations and catalysed a lively concluding discussion. Given the generality of factors such as costs, safety, legislation, contract law, environment and market strategies to the full range of chemical industries, we suggest that an industrial expert can make a similarly valuable contribution to the running of the exercises regardless of their actual affiliation.

The use of all the Stage 1 reports to provide information for the communal decision-making exercise of Stage 2 not only allowed the bigger task to be tackled within the timescale of Stage 2 but had the added advantage of drawing attention to flaws in the original reports. A comment such as '…this reaction, from report 3, was not given a reference…' suggests that this process drew attention to the difference between 'writing a report' and 'writing a report *which can be used*'. The decision to give all teams the same problem in Stage 2 appeared to introduce a stimulating edge of competitiveness into the final presentations. No single outcome was universally selected in either SLP and so the teams did not have to listen to repetitive arguments. This may be due to the judicious design of open-ended exercises, to the prejudices the teams develop during Stage 1, or to a combination of these factors.

We noted considerable improvements in team performance over the course of the exercise.This was particularly evident when comparing the oral and written reports produced in Stages 1 and 2. We take this as an encouraging sign of the effectiveness of the feedback and guidance provided at the intermediate session/s. Students also become notably more comfortable with the concept that decisions have to be based on incomplete data in Stage 2, rather than attempting to accumulate all the data, as might typically be their approach during Stage 1.

The peer assessment only occasionally produced any variation of the *individual* marks from the *team* mark. When this happened there was a tendency to give very high marks to the above-average contributors. We felt some moderation was required in these cases. In general, the peer marking was effective in identifying the non-contributors, with other team members usually getting close to the team mark. We have some evidence that peer marking can result in above-average marks for some individuals who, from the plenaries, appeared to be making a below-average contribution. We think this is an important observation since it reminds us that the tutors may underestimate significant behind-the-scenes contributions made by some individuals who do not shine in public.

Tutor input

Even with short reports (typically, we have imposed a six-side limit on written reports and 10 minute limit on oral presentations), the time involved in assessment is appreciable and rises in proportion with the number of teams. Also, it is highly beneficial to run the exercises with two tutors, largely for purposes of second marking of oral and written reports. In these circumstances, we estimate that a class of 25 students (in 5 teams) requires a total of *ca*. 15 hours commitment from the course tutor (including six contact hours) and *ca*. 12 hours from a second tutor, including the plenary sessions, assessment and preparation. This is a similar time commitment to demonstrating and marking a typical laboratory course with, we feel, the tutor's input providing a higher level of intellectual stimulation than is usually provided in the lab. Additionally, the SLP requires no technical support, junior demonstrator or technician time associated with a practical course.

Student feedback

Running the exercises with a small group, as in Warwick, and with the benefit of two tutors, allowed for considerable interaction with individuals. This resulted in interactive and enjoyable plenary sessions with the teams often engaging in lively debate about the decisions their 'rivals' had taken. The feedback from students was extremely positive. Of the seven who returned the post-exercise questionnaire, six 'strongly agreed' with the statement 'I would recommend others to attend a similar course' and the other respondent 'agreed'. Further comments provided an endorsement of the style and content of the exercises:

'I did this course because I thought it would be a doss! In fact, it was hard work but the time just flew by.'

'I wish more of my courses had been like this.'

'I learned more chemistry in this course than I did in almost all of my others.'

At York, in spite of the large class size, the plenary sessions were still encouragingly interactive and lively with good levels of participation in the brainstorm sessions. We noted the same conspicuous improvement in performance between the stages of the SLP, as at Warwick, and the larger class-size seemed to enhance the experience of giving oral presentations.

Twenty-three students completed a questionnaire at the end of the course. (This return of ca. 35% is in line with other course questionnaires.) Fifteen of the 23 students completed the boxes inviting free responses and 13 of those comments were critical of the timing of the exercise. Similar verbal comments were also received. In future it will be possible to arrange the exercise at a more appropriate time. The discontent with the timing has almost certainly adversely affected the students' perception of the value of the course. Some evidence for this comes from the response to Question 1 (' How valuable is an exercise of this type?'). Students were asked to rate their answer on a scale of 5 (high) to 1 (low). The numbers of responses were as follows:

Score	5	4	3	2	1
No. of responses	3	5	2	6	7

Seven of the fifteen students who rated their score at 3 or less also gave written comments. All of these comments were strongly critical of the timing of the exercise and were often accompanied by remarks such as that made by a student who gave Q 1 a score of 1:

'the exercise should take place early in the third year, or even the second year'

Our conclusion that the student response to questions is not an accurate reflection of the value of the exercise is confirmed by our analysis of Question 2. This question asked students to score (on the same scale of 5 to 1) whether the exercise had helped them to improve or develop six specified skills. Table 5 shows the six questions, together with the average of the scores assigned by all 23 students and also the average assigned by the seven students who gave a score of 1 to Question 1. The latter scores are remarkably high considering that these students indicated that the exercise had little or no value. This analysis, together with the written comments, provides a strong indication that a number of students had effectively answered Question 1 as if it were 'did you enjoy this exercise?', and that they had responded negatively to this largely due to the timing issue. Furthermore, we believe that the timing issue also led to a number of students responding less favourably to Question 2 than they might otherwise have done. We base this on Clow's observation[13] that students' perception of the value of a whole exercise can be greatly affected by their dislike of one particular aspect. More directly, we had a series of semi-structured discussions with a number of individuals and groups of students at a social function held to mark the end of the course. Feedback obtained in this way was generally much more positive even when we targeted students who had clearly demonstrated their discontent throughout the exercise.

Our discussions have revealed that many students do recognise the importance of key skills and realise that the ability to demonstrate having developed and used them is crucial to their future careers. We conclude that the kind of exercise described here provides a substantial contribution to this process whilst also introducing important elements of additional chemistry. We are now in the process of making our own exercises available, upon request, as fully-documented materials with complete tutor's notes and recommendations which expand upon many of the issues raised here.

Table 5: Average student response to questions

Rate how well the group exercise gave you the opportunity to:	*Mean score* (all 23 respondents)	*Mean score* (7 students scoring 1 for Qu. 1)
(i) improve your ability to think creatively	3.1	2.4
(ii) improve your ability to retrieve information	2.5	2.0
(iii) develop your time management and planning skills	2.8	2.6
(iv) improve your report writing skills	2.7	2.7
(v) improve your presentation skills	3.4	3.1
(vi) develop team-working skills	3.2	3.0

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Computer Simulations: Creating Opportunities for Science Writing

COMMUNICATION

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A computer simulation allowed second-year students to carry out a simulated investigation of factors affecting the rate of an enzyme-catalysed reaction and to write a report on this in the style of sections of a scientific paper.

The simulated investigation allowed students to generate data of sufficient quantity and quality to justify the requirement that their report should be in the style of a real paper.

Examination of the student reports reveals a number of weaknesses in the students' understanding of what makes for good professional writing.

We conclude that students need careful guidance if they are to get the maximum benefit from this opportunity.

Introduction

Most laboratory work carried out by chemistry students, at least during the first year of a degree course, consists of what Meester and Maskill[1] refer to as 'controlled' experiments which involve following recipes. There are many advantages in this approach. It allows the students to concentrate on laboratory technique[2], it maximises safety, and it helps to maximise not only the number of procedures which a student experiences, but also the number from which they obtain useful and interpretable results. This last point is crucial to the development of the student's confidence in a range of procedures.

The recipe approach has the disadvantage that it provides no opportunity for students to design investigations. It has been suggested that computer simulations can provide one way of filling this gap[3,4]. Of a number of computer simulations which we have written[4,5], enzymeLAB was specifically designed to enable students to design a simulated investigation of the characteristics of a newly isolated enzyme. This simulation allows students to study the effect of the key variables of pH, enzyme concentration, substrate concentration and inhibitor concentration on the rate of an enzyme-catalysed reaction. The speed with which data can be simulated by the computer means that an investigation which would take an experienced researcher many days to complete can be completed within two or three hours. The simulated experimental error is at a level which a competent experimentalist would expect.

A student report which included this large amount of raw data would create an unacceptable marking load on a conscientious tutor. We therefore made a virtue out of necessity by requiring students to summarise their data in the form of sections of a scientific paper. This preliminary account of our assessment of the outcome of the writing exercise leads us to conclude that the potential benefits to the students are considerable. We also suggest ways in which others wishing to adopt this or a similar exercise for their own students could avoid some of the shortcomings we identified.

The computer simulation

The simulation used for this work deals with the kinetics of an enzyme-catalysed reaction. The original version was created by Garratt and Groves[6], for use by second year students studying biochemistry. It has since been updated to a Windows version[7]. The program, known as enzymeLAB, provides each new user with different simulated but realistic characteristics of an enzyme which obeys Michaelis Menten kinetics, is sensitive to pH, and is inhibited by azide (widely used to prevent bacterial growth on columns). We are preparing a detailed paper describing our evaluation of this simulation as a tool for teaching experimental design and this will include details of the simulation package and the way we use it.

The program provides relevant information which a real experimenter would acquire during the purification of a new enzyme. This information includes:

- the range of reaction rates which can be satisfactorily determined by the assay system;
- the fact that the enzyme is inhibited by azide;
- the rate of reaction observed at pH 7 using 1 mg of enzyme and substrate at 20 mmol dm^{-3}.

The aims of the investigation are described to the student as follows:

'The questions you are likely to be asking yourself are:

i) what is the optimum pH for the enzyme?
ii) what effect does pH have on K_M and V_{max}?
iii) does azide inhibit substrate binding, the catalytic process, or both?
iv) what is the dissociation constant for the enzyme-azide complex?
v) how precise are your measurements of rates?

There is no single correct procedure to adopt to answer these questions and you must work out your own preferred strategy.'

The student task is focused by the requirement for a report which includes a summary, a results section, and a discussion section. Additional guidance given to the students is shown in Figure 1. No further formal guidance on report writing was provided specifically in conjunction with this exercise.

Figure 1: Instructions on the preparation of the enzymeLAB report.

You should present your results in the style of fragments of a paper from a scientific journal. If you are not sure what this means, look at a few papers in a journal like *Biochemical Journal, Journal of Biological Chemistry*, or *Biochimica Biophysica Acta.*

You should write the following sections:

Summary

This must consist of numbered statements giving your conclusions.

The first of these should be:

1. A new … ase (ref. no …), isolated from B. *yorkii* has been characterised.

Results

You may present your data in three figures or three tables or two of one and one of the other. No more than a total of three will be accepted. You may use up to three different symbols on any figure (e.g.●, ■, ◆) to represent different sets of data. All figures and tables must be numbered, have a short informative title and may have a brief legend.

You should write a brief description of your results which conveys useful information without the need to refer to the figures and tables.

Discussion

Write a concise paragraph about the effect of pH on the enzyme and another about the inhibition of the enzyme by azide. Each paragraph may include results of calculations and any interpretations of your data.

With the task defined, and after a formal class designed to help students to develop an effective strategy for carrying out their investigation, the students are allowed access to the computer.The software is available on networked computers in three classrooms across the campus, two of which are open 24 hours a day. Students are expected to spend about three hours working at the terminal. They have a free hand to choose conditions under which measurements of the rate of reaction are to be obtained. As already indicated, there are four variables: the pH of the assay system, the concentration of substrate (S) and inhibitor (I) in the assay system, and the volume of enzyme solution (of known concentration) to add to the assay system.

Having selected a set of variables, the student clicks the ‘run experiment’ button, and the computer calculates a value for the rate of reaction under these conditions. Before displaying the value, the computer adds a random error with a standard deviation of 5% of the calculated value. This ensures that displayed values of the rate (v) have a realistic experimental error.

Data can easily be transported to a spreadsheet of the student’s choice, so that it can be manipulated and presented in graphical or tabular form.

The structure of the student report, given in Figure 1, is justified as follows:

An *Abstract* of numbered points is specified in order to encourage students to focus clearly on what they regard as the main conclusions of their study; only a few professional journals insist on this style of abstract, but in our view it is an appropriate one for this exercise.

Neither an ‘*Introduction*’ nor a ‘*Methods*’ section are required because this exercise does not provide a context in which students can realistically practice this important skill.

The *Results* section limits the number of graphs and tables to a maximum of three because the important information can be presented clearly and concisely in three graphs.

The *Discussion* section is intended to encourage the students to interpret their data constructively.

The student reports

This analysis is based on our evaluation of the 16 reports handed in for assessment by a cohort of biochemistry students who carried out this exercise in the summer term of their second year.

Student abstract

On the whole the students showed poor judgement both in selecting and expressing the information which they included in their abstracts.Two points which we would expect to find in an abstract are the fact that the enzyme obeys Michaelis Menten kinetics, and a value for the specific activity of the enzyme. Only two students mentioned the former, and one of these and one other gave a value for the specific activity. Six other students quoted values for V_{max}, and this could be regarded as a different word meaning specific activity. However, only three of these students specified that the value quoted had been obtained at the optimum pH, and none gave appropriate units.

Seven students made a clear statement about the effect of pH on K_M and V_{max}, and thirteen on the type of inhibition observed.

Many (but not all) students showed a lack of appreciation of appropriate language. Examples of specific sentences given are:

‘The inhibitor (azide) does not work by binding to the substrate’.

cf ‘Azide is a competitive inhibitor of this enzyme’.

‘K_M and V_{max} were measured’. (No values were given.)

cf ‘The enzyme has an optimum activity at pH 7 where K_M = 1.14 mM and V_{max} = 2.59 μmol min^{-1}’. (Note that this sentence is faulty in that it is meaningless to give a value for v_{max} without specifying the amount of enzyme used.)

Student results

One student offered as a table a list of all the data obtained. One would expect this in a laboratory notebook, but not in a paper.

Seven students chose to show the effect of pH on K_M and V_{max} as a table. Five submitted a graph of substrate concentration *vs* rate of reaction at three well chosen values of pH (Figure 2 is an example).Three submitted an equivalent graph, but first transformed the data to a linear form (1/S, vs 1/v, v vs v/S, etc.) (Figure 3 is an example).The effect of the inhibitor was shown as a graph by all students; ten submitted

Figure 2: Plot to illustrate the effect of pH on initial rate of reaction

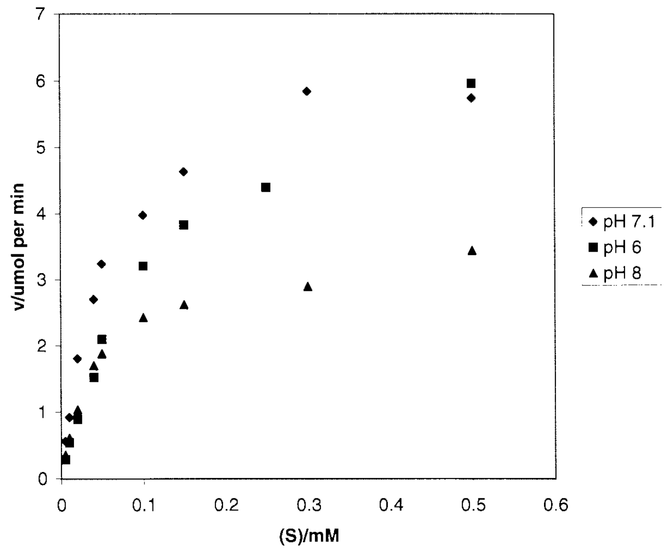
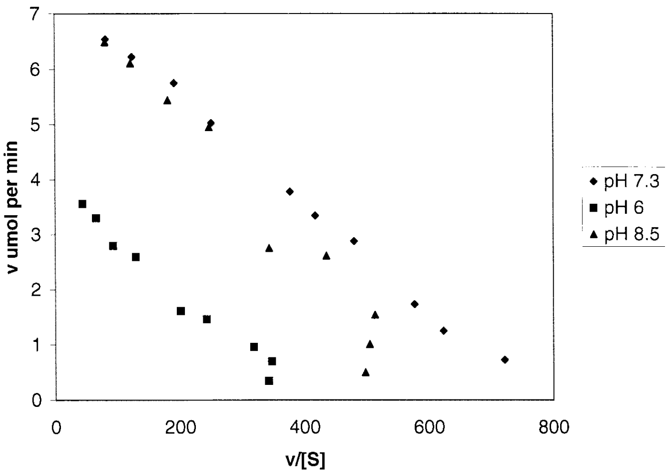


Figure 3: Graph to show the effect of pH on Vmax and Km values



plots of untransformed data and six showed data transformed to give a linear plot. In our view the linear plot is, in both cases, the preferred way of presenting results because changes in slope and intercept are qualitatively immediately apparent to the eye and also because the graphs give a visual impression of the quality of the data from which the parameters K_M and V_{max} are determined. Tables are acceptable even though the implications of the tabulated values are less easy to comprehend at a glance; tables are probably the preferred way of presenting data if students wish to present more than three sets. A graph of the untransformed data is the worst option because it is almost impossible to compare quantitatively by eye the two key parameters to be determined from hyperbolic curves (see Figure 2) – namely the maximum rate and the concentrations giving the half-maximal rate.

Other criticisms could be made of the way lines were drawn (or sometimes not drawn) on graphs to indicate a relationship between x and y, and of the quality of legends. We make no comment on these aspects of report writing, since they probably do not differ from observations of reports on recipe labs.

Student discussion

This section showed the students' lack of experience with presentation and interpretation of data. It offered the opportunity to give a fairly detailed interpretation of the effect of pH on enzyme activity. The students were specifically asked to distinguish between an effect on K_M and V_{max}, and this can be interpreted as demonstrating an effect on substrate binding or on bond rearrangement (catalysis). Some tutors might hope that an estimate of the pK of the loss of activity might lead to a discussion of possible groups in the active site which might have such a pK. No students went into all these details.

The data obtained from using the inhibitor can be used to calculate a value for the dissociation constant for the enzyme inhibitor complete. Only three students took this step.

Student style

We noted many examples of unprofessional style and of the inclusion of inappropriate information. These illustrate the students' lack of experience with presentation of scientific data. Some examples are included in the section on Student Abstract. An example of a sentence which is both stylistically unprofessional and which was inappropriately placed in a Results section is

'In all the experiments it was decided that a volume of 10 μl of enzyme solution would produce sensible results'.

In many reports the working of unprofessional use of titles for figures needed improvement. For example, many students submitted titles such as those given in Figures 2 and 3, or

Fig 1: Graph to show the effect of pH on enzyme activity.

or

Fig 2: Plot to illustrate the effect of azide inhibitor on initial rate of reaction

cf Fig 1: pH profile of enzyme reference no. PR/86–340-100

Discussion

The characteristics of reports which we illustrated in the previous section have led us to three main conclusions. First, the experience of writing reports on laboratory work based on recipes is of only limited value in learning how to interpret and present data to a scientific reader. Second, computer simulations can provide data of a quantity and quality to create realistic exercises in writing a scientific paper. Third, students need careful guidance and feed-back if they are to take maximum advantage of the opportunity. Strictly speaking, our conclusions apply only to the small group of students in this study, but we believe they are more general.

We suggest two possible difficulties which students may have faced. First, few, if any of them, had significant experience of reading primary literature and it seems unlikely that many took up the suggestion (Figure 1) that they look at some journals. Second, they are heavily conditioned by their experience of writing reports on recipe-based laboratory work. The style and language they used suggested that most were concerned to describe what was important to them while they were collecting data. Insofar as they thought of their reader, they seemed to have in mind a tutor who was aware of the expected outcome of the investigation and not an independent scientist who was fresh to the work. In a sense the students were required to engage in a role-play, but the role was too unfamiliar for them to play effectively, and they were insufficiently engaged in the task they had been set.

Discussions with colleagues confirm our impression that many students have serious difficulties when they come to write reports or dissertations based on project work. Yet the writing of such reports is a key skill for professional scientists and is a useful model for many other forms of writing. It is therefore useful to provide more opportunities to practice this writing style than is given by a final year project report or literature review. As we show here, computer simulations of investigations can provide data of a quantity and quality to create realistic model data for presentation in the style of a professional paper. However, students will only obtain maximum advantage if they engage seriously in the role-play which is required. This requires that they understand both what the role is and why they will benefit from playing it. Furthermore, they need time for critical reflection on constructive feedback on their report.

Our analysis of this exercise will help us, and we hope others, to improve the quality of the guidance and feedback for students so that they can take better advantage of the experience of writing a report based on a simulated investigation.

EnzymeLAB and other computer-based simulations are available via the Internet[5].

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The Teaching of Basic Chemistry to University Foundation Students

PERSPECTIVES

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Introduction

With the massive expansion in higher education in the UK has come not only greater numbers but a wider range of backgrounds, which for degree courses include: GNVQ, Access courses (through FE colleges) and non-traditional A-level subject combinations. For pre-degree courses, the entry qualifications of students are even wider, with many mature students claiming little or no previous science background.

Such a wide spectrum of entry qualifications means that fewer assumptions can be made in introductory courses; some students entering university in 1997 would have been loosely described as 'middle band' school pupils ten years ago, and this complicates any pedagogic action which seeks to improve the chance of their success. Nevertheless, in order to maintain the present flow of students into higher education, the needs of this group must be urgently addressed. We suggest that there are three main areas which reduce achievement by foundation students. The first is calculations, the second is that of language and the third is student motivation. Here we give examples of each of these drawn from our own studies.

Calculations involving concentrations

Calculations involving solution concentrations, often limited to 1:1 reactant ratio only[1], are first introduced to many students in GCSE chemistry (GCSE balanced science students may never experience these calculations[2]). Typical examination questions, presumably designed to be helpful to the student, lead the student through the calculation in many stages[3] such as:

- working out the molecular mass of a reactant;
- calculating its amount;
- finding its concentration;
- writing a balanced equation;
- working out the equivalent amount of a second reactant (using the stoichiometry);
- determining an average titre and eventually;
- finding the concentration of the second reactant.

We find that many students continue to solve problems in this manner (a 'linear' approach) when they arrive at university. We analysed the calculations submitted by a cohort of 70 first year students after a practical in which they were required to standardise a solution of potassium permanganate, using a standard solution of iron ammonium sulphate which they had prepared themselves. Few calculations were correct; 69% of solutions were incorrect in one or more major respects and recalculation and resubmission was required. In the vast majority of these deficient solutions, students adopted the linear approach, but missed out certain key steps in the calculation. Seemingly oblivious to their error, they carried on and inevitably arrived at the wrong answer.

Correct calculations involving the use of the linear method requires the student to hold in his or her memory the steps in the calculation *in a fixed order*. The student also has to remember the correct procedure for each step in the calculation. One explanation of the difficulties encountered is that the 'working memory' space[4] required for these operations may not be readily available to weaker students. Certainly, the common '*missed step*' type of errors suggest this. For this reason, we have experimented with replacing the linear approach with fewer steps which involve one set of substitutions[5,6]. This approach was adopted very reluctantly, and mainly in the throes of desperation after repeated tutorials (albeit with larger groups than we would like) produced a disappointing level of success which we had never previously experienced in HE. Using the *'substitution method'* produced fewer mistakes and perhaps confirmed what many good school teachers already knew – that fewer steps (with or without full understanding) yields success and confidence, and that success produces a 'feedback loop' in which students are more likely to appreciate alternative strategies in the future.

Watch your language! – language and the mature student

It is popularly believed that science is a purely logical subject, in which language is used consistently and clearly. Several examples, discussed below, illustrate that this is not always true.

Our first example is of the topic *acids*. In ten commonly used textbooks examined by the authors, acids are defined in two distinct ways, as illustrated by this quotation from the highly acclaimed textbook by Kask and Rawn[7]:

"Some substances produce H^+ ions when dissolved in water. Such substances are called *acids*." Then three lines later, "For example, when gaseous hydrogen chloride, HCl, is dissolved in water, it forms *hydrochloric acid*. (Our italics).

This paragraph defines acids as substances which react with water producing H^+, and also as the solutions that are produced when acids react with water! Several more confident mature students have pointed out this and similar apparent contradictions, and we conclude that even *'straightforward* *definitions*' may seem illogical to the more searching mature student.

In the case of acids, the apparent illogical position has arisen because the products of the reaction of acids with water were known long before the acids themselves, and such products have been known as acids (*'sour tasting'*) for centuries. In school, these definitions/descriptions (and more elaborate ones) about acids are developed separately over time, and are seen as a progression in the complexity of the theoretical base. On the other hand, the mature student who has no previous experience of the subject will be exposed to both definitions *simultaneously*, and the more seriously the issue is examined, the more confused he or she may become. In summary, the *intelligent response* of many able mature students may bring with it problems which are of minimal importance to students who have absorbed the *'culture'* and language of the science through the longer (traditional) school route.

The second example concerning language concerns the topic of oxidation and reduction, where we believe that attempts to simplify the issues can actually lead to more confusion. For example, standard electrode potentials are often used to answer this type of question: 'Can zinc react with copper(II) ions?' The question is often stated in this brief form, but strictly it makes little sense because it does not inform the student of the proposed products of the reaction. Intelligent students are quickly thrashing about searching in forbidding looking tables of half-reactions for possible products, each of which is associated with different electrode potentials. The more complete question 'Can zinc react with copper(II) ions to produce zinc(II) ions and copper metal', although rarely stated in this way, makes the task more explicit, and is less confusing.

These two examples serve to highlight that careful consideration of language and context is important in HE. This has been well studied in schools[8]. For example, the polysemous nature of common words (e.g. matter, pure, scale) has been considered by Tateson[9].

Motivation

It is a false assumption that students in higher education are always highly motivated. One feature that distinguishes high performing students from low performing students is that the former are much more able and willing to work on their own. This point has been raised in a CNAA review[10]; this was hardly worthy of discussion in the past, which dramatically illustrates how the intake into higher education has changed over the last ten years.

For financial reasons, higher education cannot mimic the level of individual attention that students receive in school. Nor is this educationally desirable, since the ability to work independently is usually regarded as one of the qualitative distinctions (other than intellectual difficulty of work) between school (or FE) and HE. Indeed, we *regard it as axiomatic that whatever strategy is employed in HE, even foundation students cannot be allowed to remain passive partners in learning.*

One of the most difficult tasks facing any teacher is to persuade students to take responsibility for their own learning[11]. We also recognise that one of the most important criteria in establishing student motivation, is a recognition on the behalf of a student that the work to be completed in a course is *relevant to their specialist degree scheme*. Accordingly, it is important that the lecturer conveys the reasons for such relevance to the students from the first lecture. In our survey of foundation-level students taken in 1997, over 86% of students described chemistry as 'useful' or 'very useful' in relation to their chosen degree. This degree of unanimity was surprising, though comforting !

Educational research is now providing pedagogically useful information on the motivation and needs of HE students. In the past, motivation was regarded as a fixed characteristic inherent in students, but we now appreciate that motivation is partly determined by encouragement and a belief that they (the student) *'are able to succeed with reasonable effort'*[12]. The effect of such studies is to emphasise that, provided the course has been tailored to the needs of the student, each objective within the course should become a *'can do'* (and not a *'can't do'*) obstacle. Foundation courses also have the advantage that differentiation is less important at this stage in the degree scheme, and assessments reflect this.

What are the problems? The most obvious one, supported by previous experience, is that weak students do not always seem able to discipline themselves to use the support material. Another difficulty of a very different kind is that the lack of individual interaction with students in a large group (supported, in all probability by an inadequate number of tutorials) reduces the opportunity for the teacher to find out, at first-hand, *'what the student understands by certain terms - as opposed to what we would like them to understand'* [13]. *Central to this strategy is the process of defining scientific terms and their relationship to the previous stock of ideas acquired by the student. This is no trivial task.*

Foundation chemistry at Glamorgan

Teaching on foundation courses has forced us to remodel our ideas of university teaching. Some of the ideas we use have been imported from educational research designed for schools. Many of our conclusions are based upon experience. This experience has led us to adopt the following principles in designing our one-semester foundation chemistry course at Glamorgan;

- using the lectures for the explanation of key points only, with no 'content overloading' and giving only one example of each problem;
- making exact references to an open-learning text *dedicated to the requirements of the course*;
- convincing students that the support material is *an extension* of the lecture and not an optional extra;
- making students aware of the need to amplify their experience of the subject by studying named numerical and chemically based questions in their own time;
- assessing by several multiple-choice tests and coupled with one or two sets of (more challenging) homework problems;

- realising that *how* one teaches is as important as *what* one teaches.

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Skills Development and Practical Work in Chemistry

PERSPECTIVES

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"Chemistry is an experimental science and its development and application demand a high standard of experimental work."[1] This, and many similar statements, can be found littering chemical and education literature. It is difficult to argue against this general thesis when it comes to the pursuit and pursuance of chemistry. Dall'alba[2] extends the idea and asserts that an important factor in higher education *teaching* is to initiate students into what it is like to be a practitioner of their subject. However, nowadays only a minority of chemistry graduates make direct use of their chemical knowledge and skills in their work. This is detailed in a recent report[3], and it seems likely that many students in chemistry may have no intention of pursuing chemistry as a career. Unless this is the case in future, it is hard to see how the number of university chemistry departments can be sustained or justified. Under these circumstances we suggest that it is inappropriate to design a programme that is specifically and solely directed to the training of the professional chemist.

We do not wish to challenge the widespread assumption that laboratory work is an essential feature of a university course, but we do wish to raise explicitly the question 'What is laboratory work for?' In other words what are the objectives, what are the outcomes? It is no longer sufficient to suppose that the objective is just to train the professional scientist in laboratory skills. No-one expects all students of literature to become professional writers or poets; similarly we must not continue to operate on the assumption that all chemistry students will become professional scientists.

Another powerful reason for asking what laboratory work is for is that it is an expensive activity. Laboratories are costly to build and equip; academic and technical staffing, instruments and consumables are a drain on resources. Furthermore, restrictions imposed by safety legislation on the use and disposal of chemicals have probably had a major effect on practical work, particularly in the less well endowed institutions. In consequence, a Royal Society of Chemistry report[4] concludes that "the restrictions on resources and the time allocated to practical work are causing a decline in the extent of practical work and the standards achieved". With the decreasing resources available for teaching, we can only address any such decline in standards by ensuring that maximum benefit is obtained from laboratory work, and this means being quite clear about our objectives.

Skills

Those responsible for the design of undergraduate chemistry courses are understandably concerned to meet the criteria set by validation bodies who define minimum standards required for professional recognition. These bodies often specify a minimum number of hours to be spent in the laboratory. There is a danger that this leads to a (hidden) assumption that competence follows automatically from experience, without there being any need for an assessment of skills. This emphasis on time spent, rather than quality of experience, means that even when a course is considered from the narrow perspective of professional training, it can be argued that it does not address this aim effectively. The development of the ideas and approaches to science and scientific investigation is what really matters. It does not necessarily follow that an extensive experience in a well equipped laboratory will achieve this end.

The questions we need to ask are 'what skills should be developed in students, which of these skills are traditionally developed in the laboratory and can any of these be effectively developed outside the expensive laboratory environment?'. Probably no two people could agree precisely on a definition of these skills, but most lists would probably include:

- manipulation
- observation
- data collection
- processing and analysis of data
- interpretation of observations
- problem solving
- team work
- experiment design
- communication and presentation
- laboratory know-how

With respect to this list, we suggest that there are two key limitations to laboratory work as currently practised in most degree courses. First there is the lack of active participation in experiment design. How often does the material supplied to students read like a recipe and how often is treated like a recipe by the student? The result is that most teachers of chemistry have been faced in the laboratory with such questions as 'Is this right?' while a student proffers a white powder. The reaction to the enquiry 'What is it?' is often 'Well it's, er, this' as the student points to the middle of a narrative purporting to represent part of a laboratory handbook. There are many tales of exchanges such as this; sadly they are often interpreted as the fault of the student failing to 'read ahead'. We should ask whether some of the responsibility lies with us, the course organisers. A parallel argument arises if a train is consistently late by twenty minutes each day; it might be that the timetable, rather than the train, that requires attention. So, perhaps there is something seriously awry with the design of practical work which often does not encourage students to develop an appreciation of the process by which our understanding of chemistry progresses.

The second limitation we suggest is that time available for developing manipulative skills is not always well used. In a recent analysis, based on work by Maskill and Meester[5], we have concluded that, on average, a first year student in a chemistry course of a typical English university performs over fifty titrations. Even though the contexts for each of these is different, it cannot be a valuable learning experience to carry out such an extensive repetition of this relatively simple manipulation.

For maximum effect, skills need to be progressively developed as the student moves through an undergraduate course. In many courses each laboratory experience may be valuable and worthy in its own right. However, the next session (or even the next semester) in the laboratory may not take into account the extent of skills developed in the earlier sessions. Indeed, even today, it is not usual to find laboratory programmes analysed, let alone designed, in a context of progressive skills development. To move in the direction of a skills driven programme is not only central to quality student progress, but will result in a more efficient use of the laboratory resource.

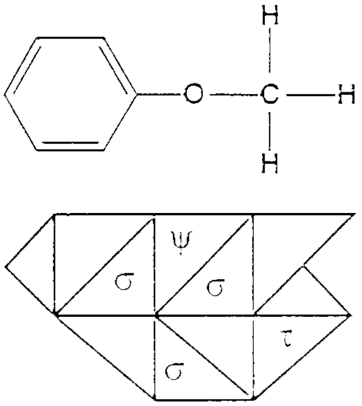
In the past, too little consideration has been given to where learning in the laboratory is effective and where it is weak. The advent of electronic media (and, in particular, the CD-Rom) has helped bring the development of skills to the fore, and encouraged a consideration of which practical skills can be developed (at least to some extent) outside the laboratory. As with all learning experiences, an evaluation of outcomes is a more useful parameter than the amount of time allocated.

Recipe laboratories

Students following a recipe are not ‘doing an experiment’, but ‘carrying out an exercise’. The problem is in the way that ‘recipes’ are used. Often the student reads through the notes line by line, mechanically carrying out the manipulations, with no real thought as to why certain actions are taken and how they fit into the overall outcome. ‘Recipe experiments’ can be criticised for making limited intellectual demands on the students, who often seem to go through the motions of laboratory activity with their minds in neutral. However, in the research laboratory, workers often use recipes[6]. The difference is that here the user of the recipe is the person who wrote it. The literature search, the ensuing discussions, the design of the experiment, the estimation of quantities, are all necessary inputs to the development of the recipe that the researcher takes into the laboratory. In most undergraduate work, these stages are missing. However, it is clear that the first year student does not have the experience to cope simultaneously with too many different aspects of practical at once, and so the process must be simplified somehow. The question is how best to do this. It may help to introduce the analogy of learning to drive a car. Imagine a driving instructor announcing to a pupil ‘today we will learn gear changing; you can overlook the need to steer, accelerate, brake, watch your mirrors, while we concentrate on gear changing’. We know that all the skills need to be developed together and gradually. The good instructor achieves this without leaving out anything crucial, and without losing the motivation of the learner.

So how is it that experienced drivers are able to drive safely and at the same time do other things like talk to passengers, admire the scenery, and listen to the radio? The answer lies in the concept of ‘working space’ expounded by Johnstone[7]. According to this principle it is only possible to process or work with a limited number of pieces of information (usually six to eight) at the same time. Experienced practitioners overcome this limitation by gathering all the steps in gear changing under one activity, a process known as ‘chunking’. In this way, changing gear is a single activity. Chemists use the same process in (for example) recognising methoxybenzene (Figure 1a). The chemist immediately recognises two components, the methoxy group and the phenyl group. To the uninitiated, the picture is of fourteen lines and five symbols (three of which are the same), too many separate items of information to take in. Figure 1b also comprises fourteen lines and five symbols. Try asking a chemist and a non-chemist to write down from memory both Figure 1a and 1b after a moment’s viewing!

Figure 1



Johnstone’s analysis has had significant impact on the learning of chemistry, but it is arguably in the laboratory these lessons need to be heeded most. The first year student enters the laboratory cold except for perhaps a short discourse on ‘safety rules’. The inputs of information are huge: location of chemicals and identification of the particular materials needed to begin the prescribed work, recognition of equipment and its handling, instrumentation, safety requirements etc. It should not be surprising that most students are unable to give much intellectual effort to the theory behind the laboratory activity or to experimental design. Indeed, the ability to plough through a ‘recipe experiment’ line by line could be regarded as a major achievement in such circumstances.

There are some simple things that can be done to reduce the ‘clutter’ and ease the student into unfamiliar surroundings. For example, provide each student with simple drawings or photographs of the equipment to be used. A plan of the laboratory with the location of all the chemicals and equipment would help avoid many of the ‘Where is it?’ questions that typically occupy much of a demonstrator’s time in the early part of a laboratory session. It is simply not fair to expect the new student to spot a Hirsch funnel at twenty paces! The layout and presentation of practical 'instructions' can, in many cases, be improved. The narrative 'recipe' presentation leads to a focus on the immediate manipulation and to a loss of the overall plan and logic of the experiment. We have found that an overall perspective is greatly helped by dividing the experiment into logical stages and presenting it to the student as a flow chart. The student works with the flow chart on the bench and a single sheet that summarises the instructions for a particular stage on the flow chart. This system has helped students to pinpoint exactly where they are in the experiment[8].

To work successfully in the laboratory, the student must master a range of manipulative skills and instrumental techniques. There is a temptation to introduce the student to a portfolio of techniques early in the course. Whilst there may be a logic in this approach, it has the dual disadvantage of delaying the introduction of the student to the excitement of investigative chemistry, and of risking that techniques developed early in the course have been forgotten when they are required later. A more satisfying approach might be to develop a small number of techniques that can be used in a simple investigation, then introducing more techniques to be used in another investigation and so on. The bonus for the student is that there is a feeling of being able to do real investigative work at an early stage rather than having a long apprenticeship in learning how to use the tools. Even so, students find the provision of video reminders of the techniques valuable[9].

Skills analysis

In an attempt to limit the demands on the student (and the poor learning experience that ensues if demands are unreasonable), we have collected and developed twenty-two laboratory activities which span a wide range of chemistry[10]. These tried and tested activities are intended to be representative and not comprehensive and are directed toward the early part of an undergraduate chemistry programme. Each activity has been analysed from the standpoint of skills, rather than of content, and the activities have been ordered according to demand for increasing skills (both in level and sophistication). This approach takes due regard of the entry behaviour of the student and acts as a focus for defined outcomes.

Our series of activities is not intended to prescribe a programme and it would be entirely appropriate to select individual activities and slot them into an existing course. However, the series illustrates the possibility of developing a programme that covers a range of chemistry and allows students to develop a coherent portfolio of laboratory skills. A different analysis of the required skills would necessitate a different programme. However, the main point is that by starting with desired outcomes, and selecting and developing activities that collectively achieve the desired outcomes, there is much less risk of omitting the development of important skills and of the unnecessary over-emphasis of others.

Each activity which has been included in our pack includes a Student Guide. These notes have been written in several styles, one of which is the 'flow chart style' outlined earlier. The Student Guide is accompanied by a Demonstrator Guide for the teacher. These notes include detailed safety information, specific comments on the processes and comments on the questions included in the Student Guide. There are also suggestions for pre-lab activities. The importance of pre-labs has been stressed[11]. Pre-lab is not simply telling students that they should read through the notes before the next session. Pre-labs should involve student's active participation, and can compensate for the features generally missing from the 'recipe' type activity (e.g. problem identification, solution strategy and experiment design). An often neglected area is the post-lab session which is always valuable and is essential for those activities that involve a team approach when individual members work on different aspects of a problem (see, for example, [12]).

Analysis of skills used in an activity is never simple. There is a hierarchy based on intellectual and on manipulative demands and within this specific skills require careful definition. The only effective way of defining a skill is by detailing exactly what the student is able to *do* once that skill has been acquired. An outcome that states 'be able to interpret an infrared spectrum' is too vague. (What kind of spectrum: gas or liquid (or mull), absorption or reflectance, what frequency range, group frequencies or normal modes etc?). To be useful, outcomes need to be written in terms of the behavioural objective. However, even a superficial attempt to analyse activities for skills can lead to useful indicators. Identification of over- and under-emphasis of particular skills and subsequent fine-tuning of the practical programme can result in an increased efficiency in the use of laboratory time. It is particularly worth considering which skills can be acquired (at least in part) outside the laboratory. Experiment design can be seen in this context[6] and it would not be unreasonable to suggest that all of the skills in the earlier list (with the exception of manipulation and laboratory know how) can be developed to some extent outside the laboratory. The continuing improvement of the quality of multimedia software makes this approach increasingly fruitful.

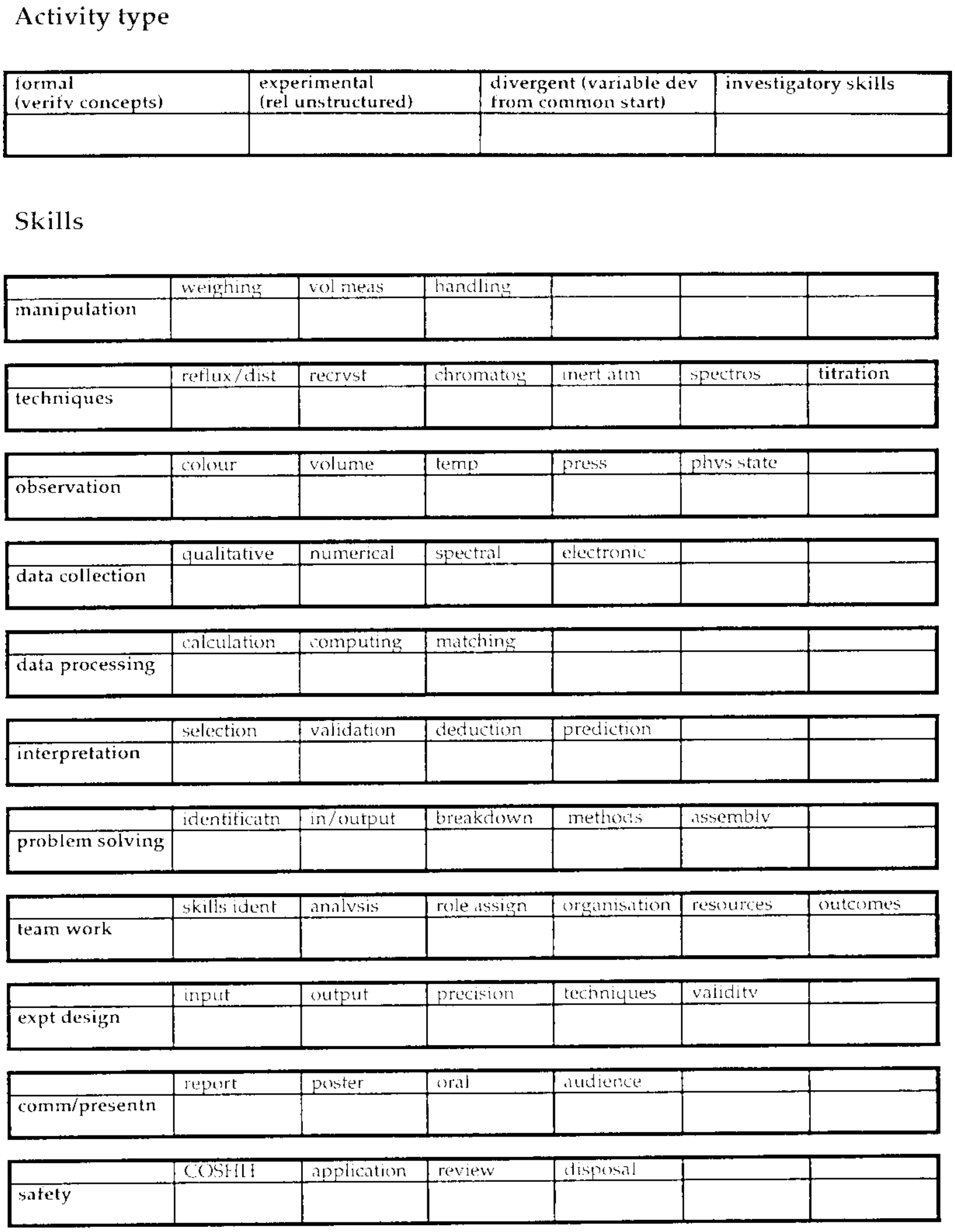
Our analysis of skills is based on one proposed by Kirchner and Meester[13]. Each activity has been allocated to one of the four general categories they proposed:

- the academic or formal laboratory which employs didactic methods to verify and illustrate laws and concepts;
- the experimental laboratory in which exercises are open-ended and relatively unstructured;
- the divergent laboratory which offers tasks with an initial, standard, structured component which may be developed in a number of different ways;
- the investigatory skills-teaching laboratory in which the procedures of investigation are the principal subjects of study.

(It is possible to change the category of some of the activities by using a different style of notes or by changing to the information supplied to the students.)

The skills analysis system has been distilled onto a single form (Figure 2). The major skills categories have been subdivided into their different facets. For example, team work can include problem identification and analysis (skills which could also be placed under problem solving). Team work skills also include identification of the personal skills required to solve a problem, selection of the team on the basis of the members strengths (and weaknesses), development of a strategy, assignment of roles to team members based on individual strengths, organisation of the team operation (time-scales, reporting, redirection etc), evaluation and optimisation of resources and development and communication of outcomes. Each of these categories can be further sub-analysed and so it is for all skill categories. We have tried to limit the analysis of each activity to a level that is quick and easy to carry out yet carries sufficient information to provide a useful

Figure 2: Skills analysis form



Activity type

formal (verify concepts)	experimental (rel unstructured)	divergent (variable dev from common start)	investigatory skills

Skills

	weighing	vol meas	handling			
manipulation						

	reflux/dist	recryst	chromatog	inert atm	spectros	**titration**
techniques						

	colour	volume	temp	press	phys state	
observation						

	qualitative	numerical	spectral	electronic		
data collection						

	calculation	computing	matching			
data processing						

	selection	validation	deduction	prediction		
interpretation						

	identificatn	in/output	breakdown	methods	assembly	
problem solving						

	skills ident	analysis	role assign	organisation	resources	outcomes
team work						

	input	output	precision	techniques	validity	
expt design						

	report	poster	oral	audience		
comm/presentn						

	COSHH	application	review	disposal		
safety						

The form as it stands apparently gives equal weighting to each box. Some boxes should have greater prominence than others and this can be incorporated by a simple system of requiring greater numbers of entries. With an electronic system, differential weighting can be easily incorporated.

input to the complete package of course skills. The analysis form is not unique and an amended version may be more useful for particular programmes.We have found that a quick and simple way of using the form is to reproduce it on a transparent sheet. By overlaying the completed sheets for the practical programme it is easy to see which categories may be being over-developed and which neglected.

Based on our experience, we propose the following set of guidelines for the design of laboratory courses in chemistry:

- review carefully and take into account the range of unfamiliar ideas and concepts faced by first year students starting laboratory work (many of which may be scarcely relevant to chemical understanding, but which can affect a student's ability to engage with the chemistry);
- design the laboratory course so that a range of skills is introduced in a logical sequence as a coherent package;
- introduce the opportunity for real investigations very early in the course;
- introduce pre and post laboratory sessions which actively engage the students.

Acknowledgements

We thank the Cutter bequest of *The Royal Society of Chemistry* for the financial support for the project which enabled us to collect and develop our portfolio of activities, and we are grateful to the many colleagues who have provided valuable discussions and ideas.

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Letters

Chemical games to improve communication skills

from Ray Wallace* and Bob Murray
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In his letter in the April issue of *University Chemistry Education* White[1], highlighted his use of a mystery molecule game to encourage students to apply useful concepts to unknown structures. Business games[2] are well developed in education as a means of increasing student participation and active thinking, denying them the passive role they so often adopt. Games are adept at reinforcing or revising simple principles, particularly with new undergraduates where an additional aim is to cement group dynamics. Such a situation exists, for example, in the Open University's ST240 Residential School which lasts for only three days, and where many students have to learn quickly in an unfamiliar laboratory situation. One of us has described[3] a series of experiments which have a significant games element, which requires groups to interact strongly, and are used prior to the main laboratory work. Some games can be quite sophisticated, for example, the elegant *Hwuche Hwuche bark*, devised by Bailey[4], which he describes as a business game with real chemical problems ending in student presentations.

One game that we have used is *'The Element Game'*, which does require some basic knowledge of elemental properties. 'Before you meet your group,write the names of selected elements onto post-its or pieces of paper that can be sellotaped onto peoples' backs. Get your group into teams of five or six and firmly attach the element name to each person without their seeing its identity.The rest of the team have to convey the identity of the element by non-verbal means!'

Although its use is predominantly in the form of an ice-breaker, when students come together for the first time, it does allow the organiser to gain some useful information about the state of knowledge of students prior to embarking on a course in, say, inorganic chemistry, as well as their ability for lateral thinking. There are obvious variations on the game to fit with other branches of chemistry (using organic structures, analytical techniques etc.)

Comments on the use of games would be appreciated to reinforce or contradict our view that games do have a useful role to play in developing key skills, and a positive attitude to learning.

Information about other games will be published in due course.

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Problems with small numbers

From Dr R Greaves, Department of Chemistry, University of York, York, YO10 5DD

While I was demonstrating in an undergraduate practical I was presented with the following apparent paradox.The student correctly pointed out that the solubility product of $Fe(OH)_3$ is $2 \infty 10^{-39}$. In pure aqueous solution the concentration of hydroxide ions is 10^{-7} mol dm^{-3} (from the ionic product of water).This would mean that $[Fe^{3+}]$ is equal to $2 \infty 10^{-18}$ mol dm^{-3} in a saturated solution. The student further pointed out that in 1 µl of solution this would correspond to 1.2 ions of Fe^{3+}. It had occurred to the student that this would mean that 0.5 µl of this solution would therefore either contain 0 or 1 ion of Fe^{3+}. With a single Fe^{3+} ion in 0.5 µl the solubility product would be exceeded! The student asked me to confirm his conclusion that the $Fe(OH)_3$ would precipitate so that it is impossible to obtain a solution of 0.5 µl of $Fe(OH)_3$. I thought it more likely that the absence of a nucleation site would prevent precipitation, so that the result would be a super-saturated solution. Was I right? Or is there some other theory which explains why normal laws of chemistry do not apply to very small numbers? There must be other similar examples. I feel that students would learn something useful about chemistry by thinking about them. But how do we give such apparent paradoxes a meaning?

Titration formulae – a universal approach

From P. Glaister, Department of Mathematics, P.O. Box 220, University of Reading, Reading, RG6 6AX
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When considering the determination of a titration formula relating the volume of added base to hydrogen ion concentration it is usual to consider four different types of titration, namely strong acid/strong base, strong acid/weak base, etc., as separate cases (e.g. [1,2,3,4]). However, the concepts of 'strong' and 'weak' acids and bases are limiting cases in a continuum, and therefore this definition of four types of titration is rather arbitrary. It may be that university students find it easier to understand four limiting cases rather than a single general case, but it is important that they appreciate that these are indeed limiting cases of a continuum of titrations, and that all four cases are governed by a universal formula relating $[H^+]$ to the volume of titrant.

For monoprotic acids and bases the universal formula can readily be derived from the following equations:

$$K_a = \frac{[H^+]\,[A^-]}{[HA]} \tag{1}$$

$$K_b = \frac{[B^+]\,[OH^-]}{[BOH]} \tag{2}$$

$$[H^+] + [B^+] = [OH^-] + [A^-] \tag{3}$$

$$[A^-] + [HA] = \frac{C_aV_a}{V_a + V_b} \tag{4}$$

$$[B^+] + [BOH] = \frac{C_bV_b}{V_a + V_b} \tag{5}$$

$$[H^+]\,[OH^-] = K_w \tag{6}$$

where K_a, C_a and V_a denote the dissociation constant, the concentration and the volume of acid HA, respectively, and similarly for the base BOH, and where K_w is the ionic product of water. Combining equations (1)-(6) gives the following formula

$$Vb = \frac{V_a(K_w / K_b + [H^+])\,((1+[H^+] / K_a)\,(K_w - [H^+]^2) + C_a[H^+])}{(1 + [H^+] / K_a)\,(C_b[H^+]^2 + (K_w / K_b + [H^+])\,([H^+]^2 - K_w))} \tag{7}$$

This universal formula gives the volume

of added base V_b (or acid V_a) for a given hydrogen ion concentration $[H^+]$. Alternatively, by rearrangement it can be used to calculate $[H^+]$ for any value of C_a and C_b.

In the limiting case of a weak acid $K_a << 1$, so that the term $1/K_a >> 1$ in the formula. For the limiting case of a strong acid $K_a >> 1$, so that the term $1/K_a << 1$ in the formula. Similar remarks apply to the base, and applying these limiting cases in equation (7) gives the separate cases that are usually quoted. For example, for the limiting case of a strong acid/strong base titration we have $1/K_a << 1$ and $1/K_b << 1$, and hence equation (7) becomes

$$V_b = V_a \frac{(K_w - [H^+]^2 + C_a [H^+])}{(C_b[H^+] + [H^+]^2 - K_w)} \qquad (8)$$

Note that equation (8) can be rearranged to give the quadratic equation

$$[H^+]^2 \frac{(C_a V_a - C_b V_b)}{(V_a + V_b)} [H^+] - K_w = 0$$

Given that $K_w << 1$ and that $[H^+] = \sqrt{K_w}$ when $V_b = C_aV_a/C_b$, the positive root of the quadratic equation approximates to

$$\frac{C_aV_a - C_bV_b}{V_a + V_b} \quad \text{for } V_b < \frac{C_aV_a}{C_b}$$

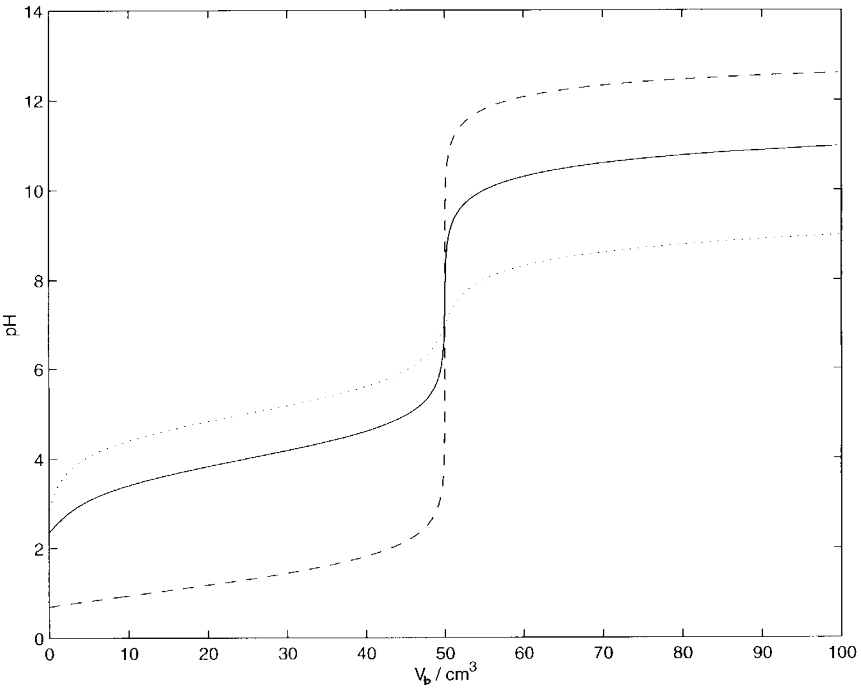
and to

$$\frac{K_w}{(C_bV_b - C_aV_a) / (V_a + V_b)} \quad \text{for } V_b > \frac{C_aV_a}{C_b}$$

These expressions are in agreement with the result obtained by calculating $[H^+]$ as the number of moles of excess acid $C_aV_a - C_bV_b$ divided by the total solution volume $V_a + V_b$, or the result obtained by calculating $[OH^-]$ as the number of moles of excess base $C_bV_b - C_aV_a$ divided by the total solution volume $V_a + V_b$, and then using $[H^+] = K_w/[OH^-]$.). Similarly, for the limiting case of a weak acid/strong base titration we have $1/K_a >> 1$ and $1/K_b << 1$, and hence equation (7) becomes

$$V_b = \frac{V_a((1 + [H^+] / K_a) (K_w - [H^+]^2 + C_a [H^+])}{(1+[H^+] / K_a) (C_b[H^+] + [H^+]^2 - K_w)} \qquad (9)$$

Figure 1: Titration curves for different values of K_a and K_b



(Note that equation (9) can be rearranged as a cubic equation.)

The other two limiting cases follow in a similar way.

For a given pH, $[H^+] = 10^{-pH}$ can be calculated, and hence the corresponding added volume of base V_b can be determined from equation (7).

The pH can then be plotted against V_b (or V_a) with pH on the vertical axis in the usual way. The Figure shows three specific examples of titration curve obtained in this way.

I suggest that students benefit from meeting one or more of the limiting cases first, preferably through examples, and including the simplest case of strong acid/ strong base in the usual way. A universal approach can then be considered as outlined above. Similar results are possible for polyprotic cases.

I suggest this approach is of pedagogical value, especially for the theoretical prediction of different titration curves. In particular, for any value of $[H^+]$ the volume of titrant (acid or base) can be calculated, and $[H^+]$ can be calculated for any value of C_a or C_b. This can provide the student with a better insight in the rather sophisticated topic of different titrations, as well as checking experimental results against the theory.

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   Journal articles:

   - Finster DC 1989 Developmental instruction I *J. Chem. Ed.* **66** 659-661
   - Johnstone AH and Letton KM 1990 Investigating undergraduate laboratory work *Educ. Chem.* **27** 9-11

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