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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.

World Wide Web Publishing as a Basis for Student Projects[1]

PAPER

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Students were set the task of publishing a set of pages on the World Wide Web to explain a chemical concept in detail. This was run as a ten week final year undergraduate project. The pages were written in simple Hypertext Markup Language, and students were encouraged to search for their own sources of material and to discover the best forms of presentation. The projects are consequently truly open ended, and require a much more structured approach than would a traditional dissertation. Web publishing is a valuable skill which will be of increasing interest to potential employers.

Introduction

Many scientists, and others, are currently interested in exploiting the potential offered by the World Wide Web (WWW)[2] as a means of disseminating material on a whole range of topics. In addition to conventional publications[3,4] meetings have taken place[5-6] to allow 'webmasters' to discuss the latest developments in this technology. The nature of chemistry is such that several specialised tools[7] have been developed in order to facilitate use of the WWW in this area. This may give the impression that in addition to needing specialised resources one has to be an expert in order to produce material for display. While this is true for web pages which include sophisticated features such as animations, more basic but satisfactory results can nevertheless be achieved with relatively simple techniques.

One such simple technique involves the use of hypertext. This is a well known concept,[8] and a number of specialised computer programs for producing hypertext documents have been available for some time. Essentially, certain items of text are designated as links to more detailed material, and a user can navigate backwards and forwards through these links at will. The term hypermedia is sometimes used to describe the extension of hypertext to include images. The WWW extends this concept by allowing the links to refer to other documents elsewhere on the web (i.e. on remote computers), whereas in simple hypertext they would only refer to other local material.

One reason for subsequently choosing tools developed for WWW document production to develop such documents using relatively simple hypertext was their ease of use, and consequent suitability for teaching to students. Relatively few commands need to be known before readable pages can be produced. Most of the software required is available free of charge for educational use, and the computer hardware requirements are quite modest. These considerations suggested the possibility of undergraduate projects which would be intellectually demanding, open ended and chemically relevant, and which would lead to the development of skills and expertise likely to be useful to some students. Such projects could meet the exacting standards required of final year research projects, and could provide a welcome broadening of the conventional range of topics.

Two projects of this type have been run to date. The first contains material on the industrial production of urea, the second on the more general topic of crystallography.

Educational Objectives

As in most undergraduate chemistry courses, students in the chemistry department at the University of Keele undertake project work rather than following scripted laboratory experiments in their final year. As far as possible, students choose their project from a number supplied by staff; choice is ensured by offering about 4 projects for every 3 required. Students may undertake two ten week projects or one twenty week project. Project work is carried out during four-hour sessions timetabled twice per week. There is a potential difficulty with projects which do not require laboratory work in that students may work additional hours without supervision as there are not the same safety concerns as for laboratory based projects. However, staff are expected to uphold the departmental policy of restricting project work to these hours as far as is practicable. Projects are set each year in the area of computational chemistry, but I was interested in broadening the scope of these to include some for which the outcomes were more likely to be of interest in chemical education than in chemical research.

The overall objective of the projects is described in a paragraph taken from the descriptions on which the students based their choice of project:

"The skills to be taught in this project include the planning and design of educational material, the use of an authoring tool, searching of information sources, and evaluation of the product at various stages. No prior experience of computational methods is required, as the authoring packages do not assume any previous experience. The extent to which the software is developed will depend on the length of project selected (i.e. 10 weeks or 20 weeks), but the shorter time should still be sufficient to allow the basic framework to be established."

As these projects are a part of the practical requirement they must allow the development of some practical skills over and above those of information retrieval which are required for a literature survey. They do this in several ways. First the construction of hypertext links places a more rigorous demand on logical presentation than does the preparation of a written document. There is also a need to produce a meaningful and aesthetically pleasing screen layout, and to consider the human-computer interaction. Furthermore the skills of using the relevant authoring tools in the production of WWW material are likely to be increasingly recognised as a skill which (at least some) potential employers may regard as being as valuable as the mastery of any single laboratory procedure.

Initially, one project on the industrial production of urea was offered to students. In view of the demand for this, two students were allocated by the Course Leader who asked to be provided with a second similar project. The subject for this was the broad area of crystallography. Projects are allocated to students by the Course Leader in order to maximise student choice. The student working on the crystallography project was reading dual honours in chemistry and computer science, and consequently had more experience and prior skill in this area than did his colleague.

Part of the brief for both projects was that they should produce material which would be of interest in the wider community, and the expectation was that they would be mounted on the WWW server when completed.

Methodology

The students were briefed to produce pages in Hypertext Markup Language (HTML)[9] using a simple text editor. The relatively small subset of commands summarised in Table 1 were used as the basis of the work. Students had free access to a scanner for the incorporation of photographic images and to Windows Paintbrush for the preparation of line drawings. The pages were viewed using the WWW browsers Mosaic or Netscape, depending on their availability on a particular computer.

Various hardware was used, depending on the availability of computers. The minimum platform was an IBM PC compatible 386SX with 2 Mb of memory and a 40 Mb hard disk. During the development stages it is not necessary to use a computer linked to the Internet; this is only required once the pages are more generally available on the WWW server.

Table 1: Minimum set of Hypertext Markup Language (HTML) Commands

Command	*Description*
<P>,</P>	Beginning and end of paragraph
<B>,</B>	Beginning and end of bold text
<Hn>,</Hn>	Beginning and end of header text (1 - n - 6)
<UL>,</UL>	Beginning and end of unnumbered list
<LI>	Item in list
<HTML>,</HTML>	Beginning and end of HTML document
<HEAD>,</HEAD>	Beginning and end of undisplayed document header
<BODY>,</BODY>	Beginning and end of displayed document body
<ADDRESS>,</ADDRESS>	Beginning and end of address of author
<A HREF="f1.html">,</A>	Beginning and end of hypertext link to document f1.html
<IMG SRC="f2.gif">	Display f2.gif as inline graphics image

A key reference[10] on the industrial production of urea was provided as a starting point for the student working on the urea project. The topic is not covered in the undergraduate course, and it provided an opportunity to introduce some industrially relevant material. The student concerned took advantage of this and made direct contact with industrial companies to obtain up to date information. The crystallography project was so potentially broad that selection of relevant material by the student formed an important stage of the work.

Results

The results of both projects may be viewed on the WWW.[11] A summary of the topics covered in the projects are given in Tables 2 and 3 respectively; no attempt is made here to show the relationships between each page since this can be quite complex with links forward backward and sideways. The crystallography pages introduce some additional features to the simple HTML commands listed in Table 1. Navigational

Table 2: Topics Covered in the Urea Project

Industrial production of urea†
The reactants
In the reactor
Formation of carbamate
Conversion of carbamate to urea
Effect of temperature on the conversion of carbamate†
Effect of pressure on the conversion of carbamate to urea†
Effect of excess components on the yield of urea†
A representation of the structure of urea†
Simplified flow diagram of the production of urea†
The recovery of unreacted reactants
"Once-through" type process†
Aminoethanol
Removal of urea
The formation of biuret†
The effect of temperature on the formation of biuret†
The effect of water on the formation of biuret†
The effect of atmosphere on the formation of urea†
How is urea sold in the UK?
The Kemira urea production plant, Rozemburg, Holland†
The port at Seaham†

† denotes a page which includes graphics

aids and icons give the user a far greater degree of flexibility in moving around. External links are included to other sites on the WWW, including the WWW Virtual Library Crystallography Site in Switzerland, as well as local links within a page. Commands are used to give greater control over the alignment of images, and to set the appearance of the background.

Figure 1 shows a typical page produced as part of the urea project, and Figure 2 the external links page of the crystallography project. Note the extensive use of icons in the latter.

Table 3: Topics Covered in the Crystallography Project

Introduction
Contents
Other sites for you to visit
An introduction to crystals
The unit cell
The seven crystal classes
Atomic coordinates
Lattices
Bravais lattices
Miller indices
Symmetry
Types of crystals
X-ray diffraction

Figure 1: Sample page for the urea project, showing hypertext links to other pages

Removal of Urea.

There are three main possibilities.

1. Temperature
2. Water
3. Nature of the atmosphere

UREA HOMEPAGE

Figure 2: The external links page from the crystallography project

Other sites for you to visit :

Assessment of Effectiveness

The fact that the initial project was oversubscribed demonstrates the potential demand for this type of project.

Both projects were successfully completed in that they produced WWW pages which could be successfully viewed using an appropriate browser. The final products were enthusiastically received by the members of staff who carried out the oral examinations of the projects. Both students involved had become proficient in writing HTML code. A different measure of success was obtained by monitoring the access statistics for any file on the WWW server. These show that the urea pages are accessed rather more frequently than the crystallography pages, and that the former are the most frequently visited pages on our departmental site. In a typical week around thirty accesses of the urea home page take place.

The formal assessment of the student's project work followed the procedures used for all projects. Unfortunately this did not involve direct viewing of the material; this does not fit into the assessment strategy used for other forms of project. Each student produces a written report which is assessed by the project supervisor and a second marker. The project supervisor also provides an assessment of performance during the project. Since the two projects described here took place in different semesters, the third element of assessment differed. The student undertaking the urea project gave a talk to staff and fellow students, while the student who completed the crystallography project was given an oral examination involving two members of staff. Both students performed well in all areas of assessment of these projects, which made a positive contribution to their overall degree results.

Transportability

As noted above, production of such resources requires very little cost apart from the provision of a computer. Even this can be eliminated by using a text browser on a central machine, but then the advantage of including graphics is lost.

The topics for such projects need to be chosen with care. The two described here were quite different, with one being covered in many undergraduate textbooks and the other one not appearing at all. For a future project the ideal subject might be one which is touched upon briefly at undergraduate level, but which requires a reasonable amount of subsequent searching of literature and other information sources. Further work in this area will involve production of a resource to accompany an undergraduate chemistry module. The starting point for this will be the current printed module outline, and the aim will be to have a coherent set of pages comprising both links to external material of relevance and material written locally.

The advantage of this type of project is that students are often able to develop their skills quickly, and can therefore concentrate on scientific and creative aspects. They are truly open ended, being limited only by students' imagination. On the other hand, it may be difficult to monitor students who are highly computer literate, and access to suitable computing equipment needs to be ensured.

Acknowledgment

Tim Morton and Aravind Velagapudi put a great deal of effort into the urea and crystallography projects respectively, ensuring success in both cases. I would also like to thank Kemira Ince Ltd for providing material on the production of urea.

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Introduction to the use of the chemical literature: an innovative library workbook

PAPER

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A library workbook for chemistry students is described. Workbooks have been integrated into degree programmes at several levels and are tailored to assist with location of information of direct relevance to the practical, essay and project work being undertaken during the programme. The workbooks are reviewed annually, with account being taken of new developments in databases, the printed material available and students' feedback forms.

Introduction

Training of chemists in information skills at other universities

There are a number of reported examples of library and information retrieval training courses for chemists in universities. The majority of these are in the USA where chemical information specialists and academic staff have integrated such training into undergraduate and postgraduate courses. A pioneer in this area is Wiggins,[1] who first introduced a Chemical Information Specialist Program in 1969. This programme, which is probably the most comprehensive in existence, leads to a Master in Library Science. The programme is designed for students with a first degree in chemistry and is run jointly between the Chemistry Department and the School of Library and Information Science. Wiggins has also developed a World Wide Web 'clearing house' for chemical information teaching resources.[2]

The American Chemical Society has laid down requirements for training undergraduate chemists in information skills,[3] and cases of integration of chemical information instruction are well documented.[4,5] New approaches include capitalising on the availability of the Internet.[6] In the UK notable examples are the work of Breuer,[7] who has developed a literature-searching exercise as part of the second-year undergraduate course at Lancaster University, and Bailey[8] who has developed an information 'treasure hunt' making extensive use of the Internet and BIDS as part of a module on communicating chemistry at Heriot-Watt University. A useful bibliography is presented by Carr[9] and a recent paper which lists many sources which could be included in library exercises is that by Matthews,[10] which in addition to the author's own experience, provides an up-to-date overview of reports of current teaching of chemical information skills in the USA.

Background to the UMIST library workbook

In 1992 UMIST was awarded funding from the Enterprise in Higher Education initiative for the improvement of library user education. A member of library staff was appointed who developed a generic library workbook after research which identified similar resources already in existence. The basic framework of the UMIST workbook was the same for all subjects, and was tailored to the needs of specific departments by library subject specialists and academic staff. The chemistry workbooks are printed documents of around 25 pages in length and comprised of a series of exercises which require students to make use of printed and electronic sources of information to answer specific questions concerned with chemistry. Descriptions of the sources are given and the methods of using them. The completed workbooks are returned to students, and make useful documents for future reference.

The Chemistry Department was particularly keen to adopt the workbook and integrate appropriate versions into courses at various stages at undergraduate and postgraduate level, as its introduction coincided with a time when courses were being reorganised and the need to train students in information skills was recognised.

Although the chemistry workbooks are assessed, the overall objective is to familiarise students with information sources available and promote efficient use of those sources. Completion of the workbooks requires use of the main and departmental libraries.

Structure of the UMIST library workbooks

All versions of the workbooks are divided into sections, each covering a different aspect of library use or information retrieval. These are described in more detail below. Each section of the workbook contains background information, a list of objectives and an estimate of the length of time it is expected that the section will take. The background information includes a description of the materials to be used for the exercises, for example for the reference books a description of the scope and coverage of the book (see Figure 1). For databases, users are guided through an example, showing how a search strategy should be compiled and the use of logical operators before the assessed search is embarked upon. Extra handouts, such as guidance in the use of printed *Chemical Abstracts* and *Beilstein CrossFire*, are provided to assist with use of more complex systems.

The workbook is in print form only at present, as this allows the students to take it with them to the appropriate part of the library. It is expected that it will remain in print form until the sources covered are all electronic.

There are three versions of the chemistry workbook in use at present. These are designed to equip students with the information skills they need at the most appropriate time during their course.

Figure 1: Examples of descriptions of reference books used in the Library Workbook.

(ML = Main Library, CL = Chemistry Library)

The Merck index. (ML 540.3/MER; CL 540.3/M14)

Useful for natural products, drugs and general organic compounds. Contains structure drawings, IUPAC names, physical properties and references to preparations. Trivial and systematic names can be looked up in the Cross Index of Names, formulae in the Formula Index.

Chemical research faculties: an international directory. (ML 540.7/AME; CL 540.6/A2)

Lists chemistry departments in universities from around the world, along with their staff members. There are name and chemical information indexes.

The workbooks

The first-year workbook

This is completed during the first week of the first semester, with nine hours allocated. The workbook forms one week of the Techniques course (which additionally comprises laboratory and computing skills).

The first exercise addresses library catalogue use, essential to enable students to identify efficiently course books and additional reading material. It is also designed to help students become orientated in the library and be able to find the material they have identified using the on-line catalogue.

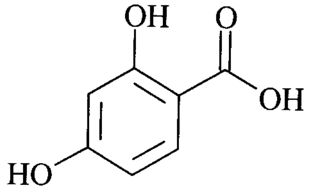
The second exercise involves answering a series of questions which require students to make use of reference and data books. The workbook gives examples of suitable books (see Figure 1), a brief description of their coverage and where they can be located in the libraries. Students do not have to use the books listed, but in their answers must quote the source. About ten questions are then presented, which include dictionary definitions, values for physical properties, safety information, determining research interests of departmental professors, the melting point of an organic compound and location of an IR spectrum in Aldrich (see Figure 2).

The final exercise in the first-year workbook is an introduction to the computerised databases which will be of use in the early part of the course. This exercise was introduced partly due to increased availability of databases and partly because of requests on feedback forms. The two databases covered at present are the *Chemical Safety Data Sheets* available as part of the BIDS-RSC service and the *Wilson Applied Science and Technology* database available on the local CD-ROM network (see Figure 3). Information is given about the subject coverage of the databases and how to use them. This is followed by exercises which ask the students to find hazards associated with working with specific chemicals and the type of topic set for essays.

Figure 2: First-year and MSc workbooks: questions from the reference books section

5. Find an infrared spectrum for β-resorcylic acid. You will have to start from its systematic name or empirical formula. If you don't know its systematic name, try looking up the formula in the formula index of Aldrich.

   What is the Aldrich spectrum number (page number and letter)?



6. What might happen to you if you are exposed to 1,3-dinitrobenzene?

Source:

Figure 3: First-year workbook: question in database usage section

Now try a search for articles on methane and the greenhouse effect. To begin a new search, press Esc, then select Enter a New Search.

- Indicate here your chosen search terms:
- How many references did you retrieve?
- Give a complete citation for one relevant article which is likely to be available at UMIST. You may want to use the following as a model:

  F. Pearce, Methane: the hidden greenhouse gas. New Scientist, 1989, 122, pp.37-41.

The second-year workbook

Undergraduate chemistry students at UMIST have to complete a more advanced workbook during the second semester of their second year, and they are allocated nine hours for its completion. This workbook builds on themes present in the first-year version, contains two sections, and is intended to prepare them for their third and/or final year. Second-year students go on either to the final year of the BSc course in Chemistry, or to the third year of the MChem course, or may go to a university abroad for a year or to an industrial placement either in the UK or abroad. In either their third year or their final year (or both) all students will carry out an individual or teamwork project involving chemistry research. The workbook is intended to prepare them for this activity.

The first section, location of material, is intended to enable students to identify different types of references they may encounter during the course of their research. Examples of typical references for a journal article, conference paper and chapter of a book are given to assist with this process. Then six references are presented and students are expected firstly to identify them correctly and then to locate these publications in the library. To add a personal touch, all the examples in this and the next section use UMIST chemistry department staff names or departmental research topics.

The second section covers use of indexes and abstracts, both printed and electronic. The first of four exercises covers printed *Chemical Abstracts* (there is no free at the point of use electronic version available at UMIST at present). Use of Author, Subject and Chemical Substance Indexes is included, as well as use of the Index Guide for identification of appropriate subject headings. The General Subject Index search exercise is shown in Figure 4.

Figure 4: Part of the advanced workbook text covering use of Chemical Abstracts

Imagine that you want to find information about uses of ZSM-5 zeolites for alkylation.

First, use the Index Guide for Chemical Abstracts for 1987-1991. Look up ZSM.

- What is the correct term to search for in the General Subject Index of Chemical Abstracts?

Now use the General Subject Index to find references.

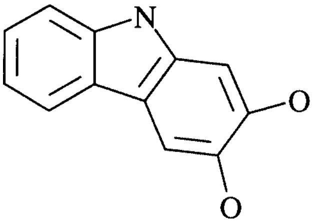
- Write down the full abstract number (including volume number) for a relevant patent (recognised by a P before the abstract number).

Now refer to the abstracts and look up the number you have identified.

- Give the title and bibliographic details for the patent.

Figure 5: Example used for a sub-structure search of the Beilstein CrossFire database

Use the database to find structures and substructures (a substructure is when you wish to find structures where additional substitution is allowed) of:



- How many compounds did you retrieve?
- Give an example of a structure that you found which is similar to the one drawn.
- Give one full bibliographic referece to a preparation of this compound:

The workbook then moves on to electronic databases, and covers the *Science Citation Index* and *Analytical Abstracts*, both available through BIDS. Again author and subject searching are covered. The final and most demanding exercise, to be introduced in 1998, is *Beilstein CrossFire*, available through the MIDAS service. This is included because it is the most important chemistry database which is available free at the point of use, and as it gives students the opportunity to gain experience of using a structure and property based database, also introducing the concept of sub-structure searching. One of the *CrossFire* exercises is given in Figure 5.

The MSc workbook

All taught-course chemistry MSc students have to complete a library workbook during the first two weeks of their UMIST course; there is no earmarked time for completion of the exercise. The workbook is an amalgamation of the first-year and second-year undergraduate versions already described. Although some of the exercises could be deemed rather elementary by some postgraduates who may have encountered similar library catalogues and databases before, it is hoped that they will recognise that the intention is to familiarise them with the UMIST libraries and the particular databases to which we have access. In addition, many of our MSc students are from overseas and some have had little experience of using computers and databases. The *Beilstein CrossFire* exercise mentioned above has just been completed in 1997 for the first time by these students.

A closely related library workbook has also been introduced for the MSc course of the Department of Instrumentation and Analytical Science at UMIST.

Updating the workbook

Literature and database searching is a rapidly developing area, so the library workbooks are necessarily dynamic in nature. They are reviewed every year and are updated with new examples where appropriate and to include new databases and information sources as they become available. In order not to increase the length unduly, as new material is included some older material is withdrawn. Students' comments obtained through evaluation forms are also reviewed at this stage.

Assessment

All the workbooks are assessed and contribute to the students' mark for the year. In 1994 when the workbooks were first introduced, the MSc version was not assessed. This resulted in very few students completing the workbook, whereas in the same year the assessed first-year workbook produced almost 100% submission.

Clearly it is impossible to prevent students working together while completing the exercises. Indeed, this is considered to be desirable, as long as the students go through the procedures together rather than simply copying answers. For the first- and second-year workbooks, students have a week allocated for completion of the workbooks and the marks awarded form part of the practical laboratory assessment (i.e. one sixth of the mark for the six-week techniques course).

For a number of the questions there is the possibility of more than one answer being correct. In particular, for the use of reference and data books exercises, the same properties and definitions can often be located in several sources, sometimes with different values given. As far as possible prior to marking all relevant books are checked, including those not specifically listed in the descriptions (see Figure 1), and marks are given for correct answers obtained from any suitable source (students are asked to specify in which book they found the answer to each question). In the section on database usage often there is no correct answer when students are asked to indicate the search strategy they have used. For these exercises students are expected to demonstrate an understanding of the concepts of use of logical operators, use of synonyms, truncation of words and sub-structure searching where appropriate. In cases where no thought has been given to these aspects, low marks are allocated.

Feedback

Each student is given a feedback form to complete, which invites comments on the clarity and length of the instructions, the usefulness or otherwise of the different sections, and to add additional comments. Students are also asked whether the workbook will help them to become more efficient in their use of the library. The feedback has been very favourable, a typical response being from the 1995 first-year group, where 71 out of 106 students completed the form. 50 thought they would be more efficient in their use of the library, four thought they would not and 16 were unsure. Comments on the feedback forms have led to inclusion of exercises on the use of databases in the first-year workbook (see above) and the possible inclusion of the use of the Internet in future versions (see later).

Future developments

As stated above, there are no immediate plans to enable the workbooks to be completed electronically. A number of the questions make use of printed sources of information and if the workbook had to be completed at a computer terminal this would involve extra work for the student in transcription of the questions and answers. The workbook does not lend itself to multiple choice questions and there is also the problem of the possibility of a number of different answers being correct for some of the exercises as mentioned above. The possibility of moving to electronic versions of the workbooks will be kept under review should appropriate technology become available which would enable more automated assessment.

In terms of the scope of the workbooks, a common recent request has been for coverage of material available through the Internet, and this may be included in the 1998 workbooks. As soon as a viable free at the point of use electronic version of *Chemical Abstracts* becomes available this will also be included.

Transportability

Exercises which make use of local library catalogues could form the basis of such exercises in any university, although account would have to be taken of the local catalogue system when writing instructions for use. Similarly, many of the databases used are available in most universities, although it may be preferred to tailor the examples to be of direct relevance to the material being studied by the students at the institution in question at that time.

Because many of the examples in the workbooks make use of reference and data books which are available in most good academic libraries, they could be used with little or no modification in many university chemistry courses.

It would also be straightforward to add new sections to the workbook as new resources become available or if universities have significantly different holdings.

Conclusion

The library workbook has been in place within UMIST's chemistry degree courses for four years, and has been well received by staff and students. The increasing emphasis on transferable skills and the developments in databases and information retrieval should ensure its continuation for the foreseeable future.

Acknowledgement

The authors would like to acknowledge the support of the Joule Library, UMIST, for help with production and development of the library workbooks for the Chemistry Department.

Summary of sources covered

Books

Luxon, *Hazards in the chemical laboratory.*
Sax, *Dangerous properties of industrial materials.*
Sigma-Aldrich library of chemical safety data.
CRC handbook of chemistry and physics.
Lange's handbook of chemistry.
Kaye and Laby, *Tables of physical and chemical constants.*
The Merck index.
Chemical research faculties: an international directory.
Dictionary of organic compounds.
Aldrich library of infrared spectra.
Handbook of data of organic compounds.
Tables of chemical kinetics.

Abstracts and databases

Wilson Applied Science and Technology Index (local CD-ROM network)
Chemical Abstracts (printed)
Beilstein CrossFire (through MIDAS)
Science Citation Index (through BIDS)
Analytical Abstracts (through BIDS)
Chemical Safety Datasheets (through BIDS)

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Copies of the workbooks are available by email as a word file from Helen Schofield.

Post-laboratory support using dedicated courseware

PAPER

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Post-laboratory courseware supporting inorganic chemistry experiments has been integrated into the curriculum at Liverpool John Moores University. It has three main objectives: (a) to instruct on the chemistry occurring in experiments, (b) to report authentic results directly from raw data and (c) to instruct on and test data-manipulation. On-line data-capture allows automatic processing and reporting of resultant information, facilitating efficient assessment of the experimental results of large student cohorts. The system replaces traditional written laboratory reporting. It produces an increase in student motivation, an increase in productivity in terms of reduced assessment workload, and provides a valuable teaching and learning resource. This paper describes the design, integration, uptake and evaluation of laboratory courseware support during the 1996/97 academic year.

Introduction

The need to equip chemistry students with essential laboratory skills is of fundamental importance in higher education. This is recognised universally, and is addressed by a number of initiatives using information technology to enhance the student learning experience in practical chemistry. For example, pre-laboratory initiatives aid the preparation for laboratory sessions[1] and simulation initiatives help to explore the effects of varying conditions within (virtual) experiments, when it is not feasible in the laboratory[2,3,4]. While post-laboratory initiatives do not enhance the student experience within a laboratory session, they are also important because students need to rationalise the results of their experimentation. These are generally communicated in the form of a report written for the purpose of assessment. However, experiments of a predominantly analytical nature do not require a detailed report to communicate findings. For example, the standardisation of a solution can be declared effectively in one line, with supporting data.

The problem with this is that a poor final result may reflect poor experimental technique or faulty data manipulation. It is a time-consuming task for a tutor to distinguish between these. However, such a distinction is necessary both to provide useful feedback for the student and to arrive at a fair mark.

The recent proliferation of networked computer terminals coupled with the availability of quality object-orientated programming languages such as Authorware Professional, makes it possible to use a computer to separate out these two aspects of practical work and to enhance the learning opportunities offered. This paper describes programs developed at Liverpool John Moores University (LJMU) which have been in use since 1995 and have saved staff time and proved popular with students[5-7].

Characteristics of dedicated post-lab courseware

Dedicated post-lab courseware has been written for laboratory experiments dealing with

- standardisation of solutions
- gravimetric determinations
- preparation and analysis of inorganic compounds/ complexes

Students obtain data in the laboratory and enter it directly into the computer. The post-lab courseware has the following characteristics

(a) Data conversion: As each datum is entered, it is automatically converted to an intermediate result. This process continues until final results are generated. The courseware shows the stepwise conversion of data to results and thus offers an opportunity for the student to learn the principles of data manipulation. This process is concluded by an invitation to comment on the results, using an in-built word processing facility. Thus data conversion and teaching are performed simultaneously.

(b) Assessment/feedback of laboratory performance: On display of each final result, the courseware generates a proportioned assessment mark based on a set of ideal results. Each is assigned an appropriate weight and a total assessment mark is displayed which reflects laboratory performance. The mark thus is not confused by possible problems with data manipulation.

(c) Assessment/feedback of data manipulative performance: It is of paramount importance that students are able to treat experimental data appropriately. This is tested thoroughly by requiring students to complete a set of calculations which mirror those in the work up of the raw data. The use of specimen data, selected randomly from a large bank, allows the courseware to match correct answers and give an automatic assessment. Each individual set of data (typically comprising 10 questions) is rarely delivered more than once. Furthermore, no limit is placed on how many attempts are made at each set. Credit is given where evidence of increased attainment is apparent. A final mark for data manipulation is thus generated independently of the work for laboratory performance.

(d) Storage and collation: On-line data capture is used to write selected information to the computer network. This commonly comprises data generated in the laboratory, results and conclusion derived therefrom, the number of specimen calculations executed correctly, computer generated assessment marks, student identity, date and time. For any given experiment, one single data file is generated (together with back-up files) containing the efforts of all participating students. This file (available only to the tutors) is imported into a template, producing a spreadsheet containing all laboratory data and assessment marks across the entire cohort (for example, see Table 1).

(e) Productivity and efficiency:The use of this courseware eliminates not only the need for students to construct written experimental reports, but also the need for tutor marking. The larger the class of students, the greater this efficiency gain, which, unlike any efficiency gain in terms of teaching and learning, is quantifiable (see 'Productivity issues'). Furthermore,feedback to students is immediate (irrespective of class size) and is linked directly with an underlying teaching element.

(f) Authenticity of laboratory data: Before leaving each laboratory session, a slip listing the raw data must be completed and submitted. To eliminate any temptation to manufacture better quality data, these data must match that fed into the courseware. A 'data-sort' of the results spreadsheet (based on any data column), will reveal identical or suspicious entries.

Operation

Laboratory experiments supported by this courseware operate in the following stages.

(a) in the week prior to the laboratory session, students are obliged to complete a pre-laboratory courseware program dedicated to the experiment (described elsewhere[5]). Failure to perform this task satisfactorily leads to exclusion from the laboratory session. This decision is made on safety grounds because preparation for laboratory sessions is regarded as paramount. Due to the sophistication of the on-line data capture, a simple check can be made immediately before the session to identify and exclude unprepared students.

(b) the laboratory session is completed. Students submit data slips listing collected data and time taken to complete the experiment. The slips double as a satisfactory attendance record.

(c) up to one week after the experiment, students complete the corresponding post-laboratory courseware program, including a satisfactory attempt at the calculations section.

At the following session, the students obtain a confirmed mark for the previous experiment during an individual discussion with a tutor.

An example of a level one exercise - an acid base titration

Table 1 is an illustration of a typical spreadsheet (edited for clarity) generated by the post-laboratory courseware. The particular example is the standardisation of hydroxide against weighed amounts of potassium hydrogen phthalate (KPH).

The full spreadsheet includes data for three determinations, giving three molarity values and corresponding marks (not shown). The entries comprise a representative sample taken from a class of 55 students. The 'total mark' is an average of the 'laboratory mark' and the 'calculations mark', weighted 80% to the former. The laboratory marks are based on an actual molarity of 0.1000M NaOH, with a deduction of 5% for each 0.0001M unit distant from the actual value. The generation of such spreadsheets has the following advantages with respect to the written laboratory report:

- results and marks may be discussed with students at the beginning of each following session. This cannot be done using written reports due to the delay (typically one week at best) caused by marking. No delay exists using computer marking.
- the rapid feedback allows students to track and discuss any concerns relating to their overall performance as soon as any problems arise.
- laboratory performance and data manipulation is disentangled.
- marks are awarded which are objectively linked to the quality of data and data manipulation
- marking is accurate, and takes little time and effort, thus saving a considerable quantity of work.

An example of a Level 2 exercise

The laboratory work in this example involves the preparation of iron(II) oxalate dihydrate from iron(II) ammonium sulfate and excess oxalic acid.The formula of the compound is then derived by sequential titrations. First, a weighed amount of product is titrated against standard permanganate solution

Table 1: Spreadsheet for NaOH standardisation (edited)

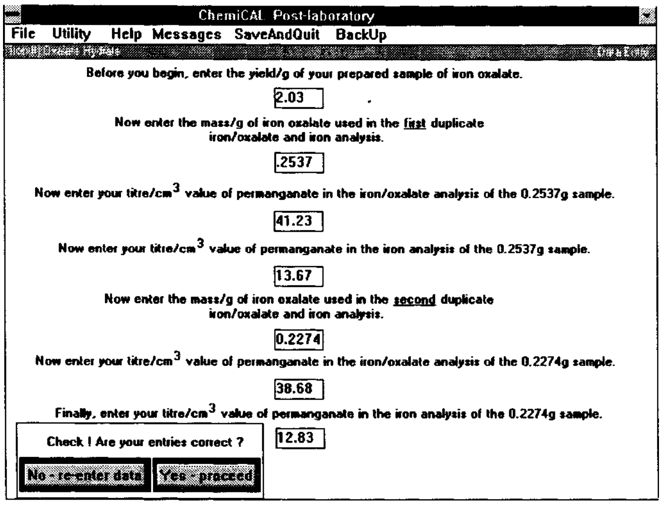
name	*date*	*mass/g KPH*	*titre/ml NaOH*	*[NaOH] mol l^{-1}*	*laboratory mark/%*	*calculations correct*	*calculations mark/%*	*total mark/%*
Average		.6445	31.83	0.09915	63	9	90	68
student1	2/11/97	.6571	32.20	0.09993	95	8	80	89
student2	4/11/97	.6536	32.21	0.09936	82	7	70	80
student3	4/11/97	.6264	31.21	0.09828	15	9	90	30
student4	5/11/97	.6311	31.14	0.09924	76	10	100	81
student5	5/11/97	.6543	32.38	0.09895	45	10	100	56

which oxidises both iron(II) and iron (III) and oxalate to carbon dioxide.The iron III is then reduced with zinc, and the resulting solution is retitrated with permananate to give a value for the oxidations of iron(II) only.The whole procedure is carried out in duplicate by using two different weighed samples of product.

Figure 1 shows the screen display on which students enter seven figures: the total yield from their original preparation, and (in duplicate) values for the mass of product titrated and the first and second titration value.

Figure 1: Initial screen for data input for preparation of iron oxalate

Note: this and other screenshots have been built sequentially by entering appropriate data.



Before you begin, enter the yield/g of your prepared sample of iron oxalate.

2.03

Now enter the mass/g of iron oxalate used in the first duplicate iron/oxalate and iron analysis.

.2537

Now enter your titre/cm^3 value of permanganate in the iron/oxalate analysis of the 0.2537g sample.

41.23

Now enter your titre/cm^3 value of permanganate in the iron analysis of the 0.2537g sample.

13.67

Now enter the mass/g of iron oxalate used in the second duplicate iron/oxalate and iron analysis.

0.2274

Now enter your titre/cm^3 value of permanganate in the iron/oxalate analysis of the 0.2274g sample.

38.68

Finally, enter your titre/cm^3 value of permanganate in the iron analysis of the 0.2274g sample.

12.83

Check ! Are your entries correct ?

The students then progress through six sections designed to reinforce the theory behind the experiment and to ensure that they understand the necessary calculations. These are as follows:

(a) Preparation: reinforces the chemistry involved in the preparation.

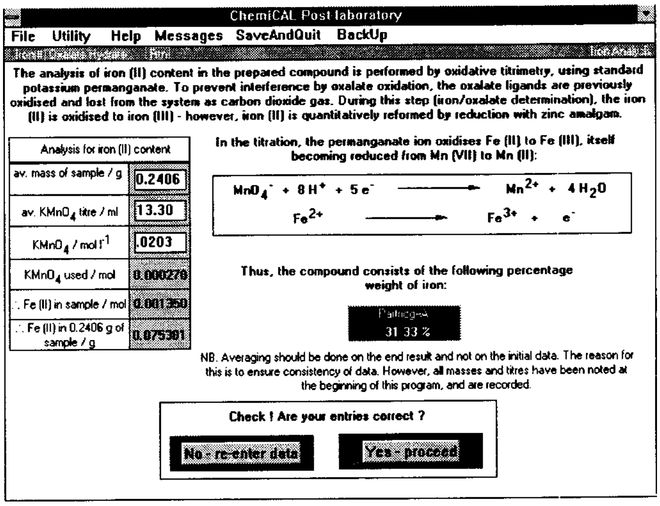
(b) Fe(II) Analysis: gives the respective half equations for the iron(II) permanganate reaction and requires the student to produce a stoichiometric equation (after 3 incorrect attempts the correct answer is supplied).As shown in Figure 2, the student then enters

- average mass of product analysed;
- average permanganate titre (for the second titration step);
- molarity of permanganate.

The program responds by indicating:

- moles of permanganate used,
- moles of iron(II) in sample,
- mass of iron(II) in sample, and
- the %mass of iron(II) in the product.

Figure 2: Calculation of the percentage mass of iron



The analysis of iron (II) content in the prepared compound is performed by oxidative titrimetry, using standard potassium permanganate. To prevent interference by oxalate oxidation, the oxalate ligands are previously oxidised and lost from the system as carbon dioxide gas. During this step (iron/oxalate determination), the iron (II) is oxidised to iron (III) - however, iron (II) is quantitatively reformed by reduction with zinc amalgam.

Analysis for iron (II) content	
av. mass of sample / g	0.2406
av. $KMnO_4$ titre / ml	13.30
$KMnO_4$ / mol l^{-1}	.0203
$KMnO_4$ used / mol	0.000270
∴ Fe (II) in sample / mol	0.001350
∴ Fe (II) in 0.2406 g of sample / g	0.075301

In the titration, the permanganate ion oxidises Fe (II) to Fe (III), itself becoming reduced from Mn (VII) to Mn (II):

$$MnO_4^- + 8H^+ + 5e^- \longrightarrow Mn^{2+} + 4H_2O$$
$$Fe^{2+} \longrightarrow Fe^{3+} + e^-$$

Thus, the compound consists of the following percentage weight of iron:

31 33 %

NB. Averaging should be done on the end result and not on the initial data. The reason for this is to ensure consistency of data. However, all masses and titres have been noted at the beginning of this program, and are recorded.

Check ! Are your entries correct ?

The path from data to result is thus outlined. The calculation is guaranteed correct and is automatically assigned an assessment mark by comparison with the ideal value[8] (see below).

(c) Oxalate analysis: this has a similar pathway to the iron analysis, yielding a final %mass of oxalate in the sample.

(d) Composition and %yield: the mass of iron(II) ammonium sulfate (used as the limiting reagent in the synthesis) is entered in this section. The program responds by indicating the %yield based on iron content. The results are summarised in tabular form, and a formula and %yield of the product is generated (Table 2):

Table 2: Courseware table showing results computed from laboratory data

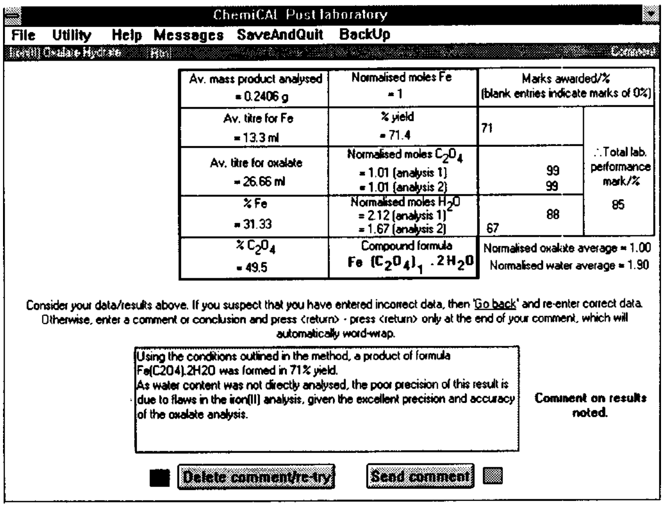
Mass of product analysed/g: 0.2406

	iron(II)	*oxalate*	*water*
mass/g	0.0754	0.1191	0.0461
mmoles	1.35	1.35	2.56
normalised	1	1.00	1.90

Product formula: $Fe(C_2O_4).2H_2O$ %yield: 71

(e) Comment: This section displays all data-input, results and corresponding marks (Figure 3).The marks are weighted as follows: %yield (20%), duplicate Fe(II) analysis (2x20%) and duplicate oxalate analysis (2x20%) - a corresponding "laboratory performance mark" is generated. A facility is incorporated to enter a conclusion, and to make a comment on the results. However, the laboratory performance mark may be moderated by the tutor.For example,the %yield mark is reduced if analysis shows that the product is of less than adequate purity. Similarly, marks assigned to analyses are increased if they show good precision in the case of poor accuracy, and vice versa. Such moderation is not easily addressed by computer code.

Figure 3: Final results from Iron II oxalate analysis



Av. mass product analysed = 0.2406 g	Normalised moles Fe = 1	Marks awarded/% (blank entries indicate marks of 0%)	
Av. titre for Fe = 13.3 ml	% yield = 71.4	71	∴Total lab. performance mark/% 85
Av. titre for oxalate = 26.66 ml	Normalised moles C_2O_4 = 1.01 (analysis 1) = 1.01 (analysis 2)	99 99	
% Fe = 31.33	Normalised moles H_2O = 2.12 (analysis 1) = 1.67 (analysis 2)	88 67	
% C_2O_4 = 49.5	Compound formula Fe $(C_2O_4)_1 .2H_2O$	Normalised oxalate average = 1.00 Normalised water average = 1.90	

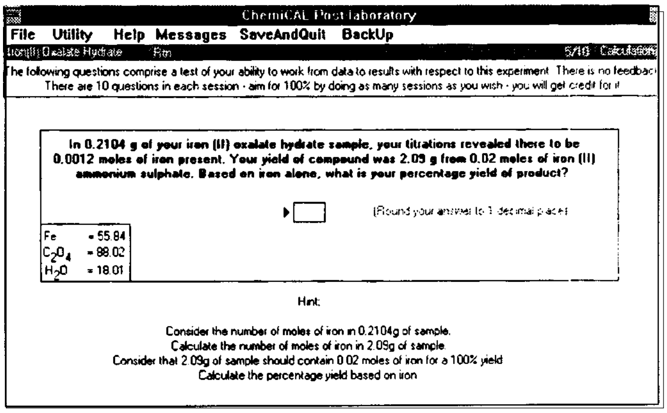
Consider your data/results above. If you suspect that you have entered incorrect data, then 'Go back' and re-enter correct data. Otherwise, enter a comment or conclusion and press <return> - press <return> only at the end of your comment, which will automatically word-wrap.

Using the conditions outlined in the method, a product of formula Fe(C2O4).2H2O was formed in 71% yield.
As water content was not directly analysed, the poor precision of this result is due to flaws in the iron(II) analysis, given the excellent precision and accuracy of the oxalate analysis.

Comment on results noted.

(f) Calculations: the student carries out a minimum of ten calculations based on specimen data selected at random from the bank held in the software (Figure 4). From this, the computer calculates a data manipulation mark which is reported instantly, and is incorporated in the final marks spreadsheet. Failure to score at least 50% in this section automatically leads to an overall failure mark for the experiment, irrespective of the quality of data.

Figure 4: A calculation based on specimen data



The following questions comprise a test of your ability to work from data to results with respect to this experiment There is no feedbac
There are 10 questions in each session - aim for 100% by doing as many sessions as you wish - you will get credit for it

In 0.2104 g of your iron (II) oxalate hydrate sample, your titrations revealed there to be 0.0012 moles of iron present. Your yield of compound was 2.09 g from 0.02 moles of iron (II) ammonium sulphate. Based on iron alone, what is your percentage yield of product?

(Round your answer to 1 decimal place)

Fe = 55.84
C_2O_4 = 88.02
H_2O = 18.01

Hint:

Consider the number of moles of iron in 0.2104g of sample.
Calculate the number of moles of iron in 2.09g of sample.
Consider that 2.09g of sample should contain 0.02 moles of iron for a 100% yield
Calculate the percentage yield based on iron

The results from the entire cohort are loaded into a spreadsheet for the benefit of the tutor. Thus useful information relating to general performance with respect to particular parts of the experiment can be gained by a few clicks of the mouse button. For example, Figure 5 shows the variation in oxalate content of the product as determined across the cohort.As expected, the "% oxalate found" varies randomly about the actual value of 48.93%, with the class mean at 48.90%. However, in this example the iron(II) analysis was persistently low (Figure 6 - actual value 31.04%, class mean 28.58%), indicating a difficulty across the class or a problem with the experimental method. The conclusion is that insufficient care was taken in the transfer of iron(II) solution to another vessel after reduction with zinc. This problem, of course, may be averted with some good advice the next time the experiment is offered. This information could not have been gained from written reports, due to excessive effort required to collate and display the information.

Figure 5: Class results for oxalate analysis

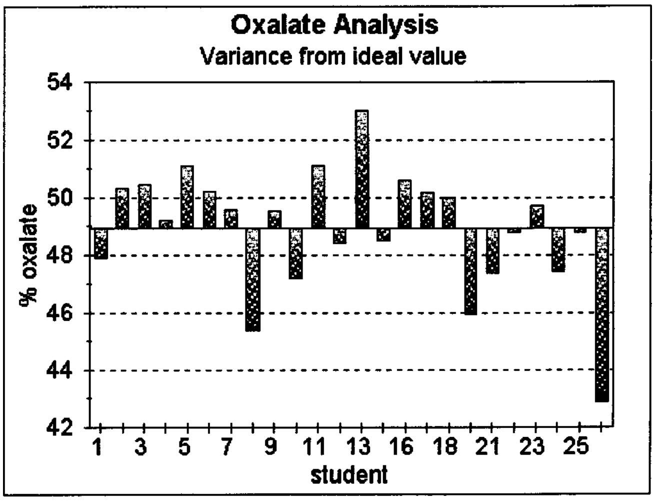
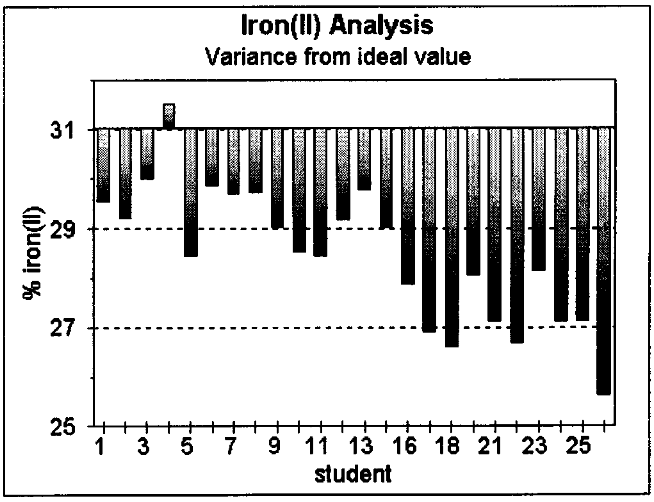


Figure 6: Class results from Iron II Analysis



Student motivation - A case study

This study is of level 1 students taking their first steps in university laboratory chemistry (table 3) and of level 2 students taking their final steps across a 2-year array of set self-contained experimentation (table 4).

Table 3: Details of post-laboratory courseware activity across a level 1 module

Expt	No of students	No calcns required (10/student/ expt)	No calcns attempted	Calcns per student	Hours in courseware	Courseware hours/ student
1	55	550	1561	28	60	1.1
2	55	550	1574	29	55	1.0
3	48	480	1221	25	40	0.8
4	45	450	1130	25	43	1.0
5	44	440	1049	24	62	1.4
6	41	410	1034	25	61	1.5
Avge	48	480	1262	26	54	1.1

Table 4: Details of post-laboratory courseware activity across a level 2 module

7	26	260	759	29	48	1.8
8	26	260	337	13	30	1.2
9	23	230	510	22	30	1.3
10	23	230	349	15	26	1.1
11	22	220	374	17	26	1.2
12	17	170	351	21	23	1.4
Avge	23	230	447	20	31	1.3

Note: all experiments are preparations followed by analyses.

Apart from laboratory techniques (addressed by pre-laboratory courseware[5]), one of the main concerns arising out of experimentation is the inability of students to identify and perform appropriate calculations correctly. One cause of the problem is that students dislike calculations. This, apparently, is not the case with the nature of courseware integration employed. Table 3 shows that, on average, level 1 students performed more than double the number of calculations than was required (26 calculations attempted per experiment when only 10 were required).

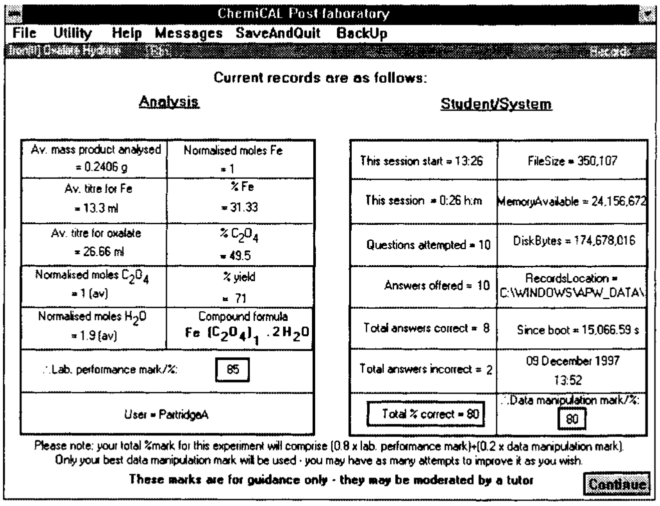
Level 2 students performed on average double the number of calculations required. Level 2 students may have found themselves to be more efficient at manipulating data possibly as a result of the effort they made at level 1. The figures also show that level 2 students, though attempting less calculations, spent more time using the courseware (1.3 hours per experiment) than level 1 students (1.1 hours per experiment). This can be attributed to the more complex nature of the chemistry. Clearly, the amount of effort put into the calculations at both levels is at least partly due to the reward offered for increased attainment.

Disadvantages of the system

The observed disadvantages are heavily outweighed by the advantages. The disadvantages (and their possible solutions) are:

- the system does not address written reporting. It is a matter of opinion whether this should be regarded as a disadvantage. There is no doubt that report writing is a key skill, but it does not follow that this is best developed through the writing up of all laboratory exercises. At LJMU, students experience a good balance of traditional and technological methods of laboratory reporting.
- the system does not allow work away from the university. This is an insurmountable problem, and particularly affects part-time day-release students, whose full timetable means that it is hard for them to spend 1-$1^1/_2$ hours during their day at a university computer terminal. Full-time students generally do not regard this as a problem - they feel the advantages of the system outweigh this restriction. Certainly, no student has ever elected to revert back to written reporting for the supported experiments (which they are entitled to do).
- network errors. Occasionally, data fails to store on the network, resulting in loss of assessment information. However, the situation may be retrieved by good practice at the terminal; students are advised to print the full record of each session (Figure 7), for the attention of a tutor in the event of system failure. In any event, students may save/back-up their work to floppy disk.

Figure 7: Final record of results and mark



Current records are as follows:

Analysis

Av. mass product analysed = 0.2406 g	Normalised moles Fe = 1
Av. titre for Fe = 13.3 ml	% Fe = 31.33
Av. titre for oxalate = 26.66 ml	% C_2O_4 = 49.5
Normalised moles C_2O_4 = 1 (av)	% yield = 71
Normalised moles H_2O = 1.9 (av)	Compound formula $Fe\ (C_2O_4)_1\ .2H_2O$
∴Lab. performance mark/%:	85
User = PartridgeA	

Student/System

This session start = 13:26	FileSize = 350,107
This session = 0:26 h:m	MemoryAvailable = 24,156,672
Questions attempted = 10	DiskBytes = 174,678,016
Answers offered = 10	RecordsLocation = C:\WINDOWS\APW_DATA\
Total answers correct = 8	Since boot = 15,066.59 s
Total answers incorrect = 2	09 December 1997 13:52
Total % correct = 80	∴Data manipulation mark/%: 80

Please note: your total %mark for this experiment will comprise (0.8 x lab. performance mark)+(0.2 x data manipulation mark).
Only your best data manipulation mark will be used - you may have as many attempts to improve it as you wish.

These marks are for guidance only - they may be moderated by a tutor

Productivity Issues

The use of this software relieves the tutor from the necessity of checking through data and calculations to provide useful feedback for students. The saving of time devoted to relatively low-level and unfruitful work demonstrates the potential value of the skillful use of courseware. This kind of gain in productivity and efficiency is seen as crucially important if the success of courseware is to be maximised [9,10]. Indeed, the main thrust behind the evolution of the system described in this paper centres on productivity, both with respect to the student learning experience and to academic duty.

Of course any gain in staff time is offset by the time taken to devleop the courseware. The courseware described here took approximately 35 hours of time to develop for each experiment. Allowing a modest 10 minutes to mark and provide adequate feedback on a student script, there is a net gain with only 210 scripts (for most people this is 3 years or less). This is a very simplified calculation. It ignores the costs of any subsequent updating of the software. But it also ignores the possibility of effective transportation across institutions which would reduce the costs dramatically. Furthermore, the benefits to the student must be taken into account: the system guarantees accurate marking of student effort, provides a valuable teaching resource for students to use and appears to increase motivation[11].

The courseware described in this paper runs under Windows (3.x or 95) over a main network. Its delivery does not require the presence of a tutor; students may use the courseware anytime during the opening hours of the university's learning resource centres (currently 9am - 11pm weekdays, and 9am - 5pm on Saturday and Sunday).

Invited demonstrations of courseware are welcome. Courseware is available for testing on request.

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Using Case Studies to Develop Key Skills in Chemists: A Preliminary Account

COMMUNICATION

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A series of case studies is being written with the aim of developing new and existing skills in chemists for employment. The development of the first of these case studies is described together with an overview of content and structure. Group work, tutor input (including assessment) and student skills profiling are discussed in more detail. These case studies are complementary to other skills based exercises and could be easily incorporated into other BSc Chemistry based courses. Preliminary observations made with Stage 2 Chemistry and PhD students indicate that these case studies can provide an enjoyable and effective means to skills development within a chemical context.

Introduction

A number of reports identify several key skills as being important to employers, but not well developed in recent graduates(e.g. 1-5). The recent report of the National Committee of Inquiry into Higher Education[6] specifically identifies the skills of communication, numeracy, use of information technology, and learning how to learn as "*necessary outcomes of all higher education programmes*". The report also envisages that students should be put "*at the centre of the process of teaching and learning*", and recommends that "*all institutions of higher education give high priority to developing and implementing learning and teaching strategies which focus on the promotion of students' learning.*"

Various strategies have been developed within the discipline of chemistry for achieving these aims. Some involve discipline related activities,[7] others may be discipline-independent.[8] Maskill and Race[9] have taken an approach which lies between these extremes. Our aim has been to identify a wider range of skills than those defined by Dearing,[6] and to address as many of them as possible within a series of case studies.

Case studies have a long history in business and management courses, and their potential value in chemistry courses has been recognised for many years(e.g. 10-13). A case study exercise is typically based on a real event which provides a context within which a decision has to be made. The aim of the exercise is to develop a mode of thinking, working and communicating, and this is best done by tackling a problem where there is no uniquely 'correct' answer. This paper is a preliminary account of the development and use of one such case study which is suitable for use in undergraduate chemistry or chemistry-related courses.

Identification of a suitable topic

We wished to develop a case study for use by final year BSc students which would require them to draw on their chemical knowledge, apply it in a context relevant to the environmental theme of their course, and provide a vehicle for them to practice a wide range of personal and professional skills. For practical reasons, the chosen study needed to be one for which we had ready access to a large amount of relevant data. In consultation with the Environment Agency (EA), we identified the case of the disused Wheal Jane tin mine in Cornwall. Briefly, the case is this.

In 1991, rising water levels in the disused tin mine resulted in the rupture of a plug in an underground adit causing millions of gallons of highly acidic water to be released into the neighbouring Carnon river and estuary. The underlying geology and acidic water meant that the discharge contained large concentrations of heavy metals which were of both short and long term environmental concern. A monitoring and treatment system therefore needed to be put in place that would satisfy both short and long term needs.

This makes a good case study because the possible solutions to the problem involve thinking more broadly than about chemistry alone, and the chemistry is relatively straight forward; furthermore the overall problem can be broken down into smaller tasks, so that none are overwhelmingly daunting. A complete solution involves research into various monitoring methods and treatment systems, calculations of a life expectancy for a treatment process, consideration of options for disposal and potential recovery of the metals concerned. This work involves a large amount of information retrieval from a variety of sources (including computer based searches and communication with companies), evaluation of information, familiarisation with new topics (e.g. legislation) and developing working equations for parameters that present difficulties in measurement (the volume of a metal precipitate in this case). Clearly, it is important that students have access to the information that is required. In the case of Wheal Jane, much of this is in the public domain. Other, specific numerical data has been provided by the Environment Agency, who also represent an invaluable general information source for students to make contact with at the outset.

Our initial analysis of the problem suggested both specific skills which should be addressed and activities through which they could be practised. These are listed in Table 1.[6]

Table 1: Summary of main skills and specific activities

Main skills	Specific activities
Group working	Discussions, minute taking, brainstorming, feeding back, division of tasks
Communication	Oral presentations of varying lengths and complexity to different audiences, report writing, inter-personal development
Critical thinking	Linking chemistry with other issues (cross-disciplinary thinking); evaluation of information
Independence	Individual judgement; taking responsibility for decision making,
Time management	Planning, prioritising and working to tight deadlines
Information retrieval	Collection and classification of information
Data treatment	Manipulation and evaluation of information,; undirected numerical and chemical analysis; computing skills
Commerce	Costing; evaluation of market forces
Legislation	Evaluation of Environmental law and EU directives

Procedure

The case study consists of four tasks which are tackled over a 5-10 week period by students working in groups of 4-6. The overall structure is shown in Figure 1.The 5 formal timetabled sessions are held at intervals of 1-2 weeks. Each session is led by a tutor.Since most of the session time is taken up with oral presentations and questions, the length of time required for each session tends to increase proportionally with the number of groups. For 2 - 3 groups most sessions are 1-1.5 hours.

The initial scenario is provided in the form of a newspaper article from a local newspaper.This not only introduces the project in a brief and understandable format, but also encourages students to begin to think about how they may present technical information to non-experts (see Session 5).

Groups are provided with written instructions detailing the tasks to be completed before the next session. Students are expected to manage their own time during this period, though e-mail help is available to them. Each is expected to devote about 6 hours to each task, some of which will be working within the group and some performing individual tasks agreed by the group.

In sessions 2-4, the results of the tasks are presented in the form of both written reports and oral presentations of specified lengths.Time is also reserved for discussion and an introduction to the following task. The discussion is divided between time for questions relating directly to the task and for a summary of the skills used, together with an evaluation of the effectiveness of these. This allows students to reflect on the work they have done and how they did it, which together, is a crucial part of the learning process. For the fifth session, all the tasks are brought together so that the written report provides an integrated technical solution to the

Figure 1: General timetable for the case study*

Session 1(30-40 mins)	Overall aims of the case study are described Students are divided into groups Newspaper article and Task 1 are given out
Task 1 (approx 6 hours)	Initial review during which student teams • research methods for analysing metal concentrations in water; • investigate treatment systems; recognise need for short and long term solutions; consider cheap and rapid solutions.
Session 2 (1 - 1.5 hours)	Oral presentation of Task 1 and submission of written report Discussion leading to agreement on recommended treatment system (temporary storage of contaminated water in nearby tailings dam, precipitation of metals by addition of lime). Further information and task 2 given out.
Task 2 (approx 6 hours)	Students are encouraged to recognise that the size of the collection dam is crucial, and that the long-term solution requires disposal of the metal deposit. Student teams • estimate volume of dam (carefully defining assumptions made); • investigate methods of disposal of precipitate.
Session 3 (1-1.5 hours)	Oral presentation of Task 2 and submission of written report Further information is given and discussed; conclusion drawn; Task 3 given
Task 3 (approx 6 hours)	Use two realistic scenarios to evaluate the proposed treatment system. Student teams • develop chemical and numerical equations, and hence calculate volume of deposited metal; • consider the viability of commercial recovery of selected metals
Session 4 (1-1.5 hours)	Oral presentation of Task and submission of written report Further information is given and discussed; conclusion drawn; Task 4 given out
Task 4 (approx 6 hours)	Integration of information collected from each task and preparation of final reports and presentations. Student teams • consider quantitatively how to reduce metal concentrations to legal limits; • consider environmental factors which control metal concentrations; • agree on reports and presentations.
Session 5 (2-2.5 hours)	Formal oral presentation to experts§ (30 minutes) Oral presentation to non-experts (10 minutes) Submission of final written report§

*Times indicated are for 2 - 3 groups

§ This includes the oral presentation and written report for Task 4 problem. The final session also includes both a technical presentation and one for to a non-expert (e.g. a concerned local resident or a work colleague who is not familiar with the details of the study).

Group work

This case study has been designed for use with 4-6 students in a team each contributing ca. 30 hours (including group work). For each task, the aims are clearly defined but the methodology is left to the group. Therefore, groups need to address questions such as 'What information are we going to need to know/use?' and 'How are we going to use the information once we have got it ?' Individual responsibilities can then be allocated. We stipulate that all group meetings should be formally minuted and the minutes made available. Since most students have had little or no experience of this activity, some guidelines (including a rationale) are given during the first session. Each meeting should have a chair and secretary, and these roles rotate amongst the students during the course of the case study. Our objective was partly to provide students with useful experience, and partly to provide us with an indication of how effectively the responsibilities were shared. Feedback from the students shows that this was a popular innovation.

Tutor input

Time

Our aim in writing this material was that it should be widely disseminated. This required us to prepare case studies which could be implemented with a minimal amount of preparation by lecturers. Since some of the tasks cover topics outside mainstream chemistry, we have included some guideline information as lecturer's notes for each of the tasks. Figure 2 lists the contents of the complete package. Since we are aiming principally for a well balanced scientific approach from the students, rather than necessarily looking for a 'right' answer, we believe that a set of key points or guidelines is sufficient to enable tutors to carry out a meaningful assessment. Tutor time should be in the region of 12-15 hours, most of which is spent in assessing in-session presentations and fixed length reports.

Figure 2: Contents of case study documentation

- Introduction and overall objectives
- Recommendations for the case study delivery
- Tutor's notes on assessments
- Assessment forms
- Student's notes on assessments
- Student's notes on groupwork and minute taking
- Notes on student skills profiling
- Student skills profiling form
- Newspaper article and Site report
- Registration form for updates

For each of tasks 1-4:

- A description of the task
- Indicative solutions
- Help-mail
- Further considerations

Providing help

It is important to provide student support outside the timetabled sessions. Some students may understand the task at the first reading, others may either be uncertain as to what exactly is required or simply not know how to go about tackling it. To make efficient use of tutor's time, we have opted against formal help sessions in favour of an e-mail based system termed 'Help-mail'. For cases where general help is required, we have tried to anticipate key problem-areas associated with each task and written a standard hints page. For cases where more specific help is required, students must request clearly what information is required. Ambiguous requests are met with ambiguous replies! The use of the e-mail system in this way goes part way to focusing students' minds and serves to illustrate an important area of time management since a response by a tutor (however helpful) to a request may not always be immediate.

Assessment

Groups are assessed against well defined criteria (e.g. clarity of presentations and reports, whether the specified task has been addressed fully, use of visual aids, time keeping).

We have not included an individual assessment component though we believe this to be an important feature to be developed in the future. We are aware of difficulties in doing this. For example, the monitoring of individuals directly in groups is impractical and many other methods (e.g. peer assessment) can be unsatisfactory particularly when employed in isolation . We are currently reviewing individual assessment methods and are favouring a combination approach, involving, for example, peer assessment combined with an analysis of the minutes from meetings. Assessment of the latter should provide students with a driving force for ensuring that these are a true reflection of each individual's contribution to the group effort. In addition, we are now developing a CAL package for each case study and liaising with industry to determine their methods for individual assessment.

Skills Profiling

We have introduced a procedure for skills profiling whereby each student completes a *pro forma* before starting the exercise. This outlines various key skills subdivided into categories. Three levels are defined for each category and the student identifies their own level and justifies this with an example. Progress is monitored by repeating this self-assessment after completion of the case study. It is not expected that improvement is observed in all categories but rather that over a period of time, a general progression is achieved. Extracts from our profiling form are shown in Figure 3[14].

Figure 3: Extract from student skills profiling document[10]

SKILL	*LEVEL ONE*	*LEVEL TWO*	*LEVEL THREE*	*Indicate your current level.*	*Justify your selection with a specific example*
Team working					
Accepting responsibility within a team	Take responsibility within a team for investigating a single simple aspect of a task.	Take responsibility within a team for collating and disseminating information relevant to a task.	Take responsibility within a team for collating information and recommending a selected course of action.	1	*I went to the library and compiled a list of all of the journals that cover analytical chemistry*
Communication skills					
Presentations (2) (experts)	Explain a scientific concept to an ‘expert.	Deliver a scientific presentation using OHPs and answer questions directly related to the topic.	Deliver a multi media presentation of a scientific subject and answer a range of questions from experts.	2	*I have delivered a 10 minute summary of my final year project to my supervisor*
Data Manipulation & Information Technology					
Use of word processing, spreadsheets and graphics packages.	Use spreadsheets to create simple tables of data and plot graphs. Type and format short reports. Become familiar with graphics packages.	Perform complex mathematical functions within a spreadsheet. Prepare a full and complete report integrating a range of software.	Prepare a short ‘stand alone’ software presentation on a scientific problem.	1	*I write and format my laboratory reports in Microsoft Word. I can enter and plot simple x-y data in Excel, but I am unfamiliar with more complex manipulations. I have used chemdraw once for an assignment.*

Preliminary observations

Our Abandoned Mine case study has been tackled by one set of Stage 2 chemistry undergraduate students and one set of PhD students with presentations and report submissions taking place the following week. The undergraduate students received additional support in that, for 3 hours immediately following each timetabled session, a tutor running a laboratory class was available to deal with any problems which arose immediately. These sessions were useful in this initial trial in that they provided a useful means for obtaining rapid feedback on whether the appropriate level of guidance had been provided. The PhD students managed satisfactorily without this additional support; we believe that this better promotes independence, and in considering the long term, should be unnecessary for undergraduates. The observations from both groups are otherwise quite similar. Generally, students researched the information well and presented detailed and comprehensive accounts. In several cases, students had clearly spent more than of the recommended time in order to produce a high quality presentation or report. While this is not a criticism of the students *per se*, it serves to illustrate that it can be difficult within an academic setting, and with our current format, to ensure that fixed time constraints are kept to. Areas where students performed less well include justifications for answers, descriptions of assumptions made and quantitative considerations of opposing factors. Statements such as “*Several factors would need to be considered ….*” and “*Method X could never be used because it is expensive*” were common and indicate a superficial coverage rather than a detailed and balanced investigation. Our observations therefore suggest that students tend to approach tasks quite literally and tend to avoid considerations unless they are explicitly requested. For example, they include assumptions in a calculation only when instructed to do so. Students respond well to structured assignments probably because this is what they are most familiar with. In the work place less structured tasks are commonplace and students would benefit from more experience of them.

Concluding comments

It took 5 months to bring this case study to its present state of completion, with one of us working on it virtually full-time. Considerable time is involved in compiling all of the necessary information and in updating the tasks and format as a result of the first trial.

The production of a document that makes the study accessible to a range of tutors has also been a major consumer of time. However, we believe that our experience will enable us to extend the range of case studies relatively quickly. We draw attention to the following key features of our case study, which we believe will add significantly to their success.

• Minute keeping	a means to enhance the effectiveness of group work and the assessment thereof
• Help-mail	a method of improving tutorial support using e-mail
• Skills profiling	a way to identify skills level and development
• Oral presentations to experts and non-experts	aimed at promoting the importance of disseminating information to a wide audience
• Reflection	explicit requirement that students reflect on what and how they learned adds to learning-effectiveness.

Feedback from students has been positive. They welcome the chance to use their chemistry in a more applied context and appreciate the opportunity to develop both new and existing skills. We therefore conclude that this study (and others to be developed) will complement other available activities(e.g. 7-9). We welcome enquiries about availability.

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Teaching, Learning, and Computing

A REVIEW

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Introduction

Chemistry teachers want to improve their students' learning. They have been encouraged in this desire by the Dearing Report[1] which stresses the need for students to 'learn to learn'. Teaching with the aid of computers is often vaunted as a way to improve students' learning. This review argues that in order to use computers to improve students' learning, it is necessary to apply the work that people have already done on understanding how students learn. In the previous issue of this journal, Johnstone's review[2] discussed the process which goes on in students' minds when they learn. Here, I wish to review the work on learning with a view to its application to the use of computers in teaching chemistry.

In the first section, I discuss how students learn in general terms; in the second, I deal with research on learning in Chemistry; and in the final section, I show how this work has been applied to computers in teaching.

How do students learn?

General points

An understanding of how students learn can help teachers to devise effective strategies for teaching. This requires that research into the learning process is made accessible. Books such as those edited by Entwistle[3] or Bigge and Shermis[4] aim to show how such theory can be applied to real situations. Borg's critical review of the educational research literature[5] has useful sections on recommended reading. The excellent books by Laurillard[6] and Ramsden[7] are particularly accessible to the practising teacher.

A central strand in much of this literature concerns the development of students' views of knowledge. This strand is founded in the work of people like Piaget, Bruner, and perhaps most pertinently to higher education, Perry (whose model is summarised for chemists in[8]; an illustrated account of how his model affects students can be found in[9]). Such views of student development see the aim of education as moving students from a simple to a more complex position. In the first state, students tend to see facts as absolute, accept the view of authority uncritically, think of knowledge as a collection of facts to learn, and believe that all questions have a single right answer. The aim is to help them to espouse a more relativistic view of knowledge, find out for themselves, see how evidence can be interpreted in different ways, and construct integrating models into which such interpretations can be fitted. These writers emphasise that to facilitate such development, students need to be supported at the appropriate level: a student who strongly believes that there is one right answer will find an exercise which shows a multiplicity of possible interpretations confusing and unhelpful.

Constructivism

Constructivism is a theory about how students learn, and has at its centre the idea that knowledge is not transmitted intact from teacher to student, but is actively constructed in the mind of the learner. The origins of constructivism lie in the work of Piaget and Ausubel in the 1960s, but more recent works[10-16] are more useful for practical applications to university chemistry education; Bodner's paper[17] has precisely this as its focus.

According to constructivists, the most important single factor influencing learning is what the learner already knows. The teacher needs to be aware that this prior knowledge will have a profound influence on the way students construct new knowledge, and needs to take account of this in planning the delivery of new ideas. Furthermore, because students bring different prior knowledge and expectations to new experiences, they will learn different things from the same experience.

To summarise the implications of constructivist theory rather starkly:

- Education in chemistry needs to help students to understand how chemical knowledge is created/discovered.
- When there is conflict between students' existing (possibly mistaken) ideas and those being presented by the teacher, students will have problems. Teachers need to recognise when this occurs, and provide effective support.
- True learning only occurs when students create their own understanding; but teachers are needed to create the environment in which this can happen.
- Learning is not the simple transmission of facts from teacher to student, but a continuous and active process on both sides.

One aspect of how students' pre-existing ideas influence what they learn is discussed by Edmundson and Novak.[18] Students have different views of how 'facts' come to be known (epistemology), and this affects their learning strategies. Students who firmly believe that there are accessible 'right answers' to all reasonable questions are more likely to try to learn by memorising facts; those who think that 'facts' are constructed by social processes are more likely to try to understand the material being presented.

Context, motivation, and learning strategies

Students' learning strategies are affected by many other factors besides their epistemology.

Students approach learning in different ways, and their approach to a particular course or activity exercise is affected by its context and by their motivation.To help students learn in the strongest sense, teachers of chemistry will want to encourage them to try to understand the material at a deep level.

Ausubel[19] identified a difference between 'meaningful' and 'rote' learning; he maintained that students' motivation was an important factor for inducing meaningful learning. This is similar to (but not the same as) the difference between 'deep' and 'surface' learning, which is discussed in the works edited by Marton *et al*[20] and Schmeck.[21] In a chapter of the latter collection, Entwistle identifies three possible approaches:[22]

- a surface approach, where the students' aim is to simply reproduce the material necessary to complete their course;
- a deep approach, where the students' aim is to reach a personal understanding of the material; and
- a strategic approach, where the students' aim is to be successful by whatever means are necessary.

Obviously, these approaches tend to lead to different learning strategies and hence different outcomes. A surface approach leads to rote learning; a deep approach can lead to the student examining evidence and relating it to their ideas in a constructive way;and a student with a strategic approach will use whichever strategy they perceive will result in the best marks. The strategies students use affect what they learn: rote learning at best results in a substantial knowledge of factual information, but a deep approach can result in a deep level of understanding.

High-quality learning requires a deep approach.[23] Most students employ a strategic approach: they will switch between a deep and a surface approach according to what they think will be most effective. (This is a very sensible approach; and indeed, the students who enter a chemistry department will have been selected by the education system to be those who are adept at picking the most effective approach.)

The key factors affecting students' approach to learning are their previous experience (as argued by constructivists), the style of learning they have previously employed, their perceptions of the activity, and its context.[24, 25]

Students' motivation to learn is also important, but does not necessarily determine whether they employ a deep or a surface approach. Aspects of students' motivation to learn can be classified as either intrinsic (*e.g.* wanting to know for its own sake) or extrinsic (*e.g.* wanting to learn what is on an exam syllabus).[26, 27] There is also a third class, called 'amotivational' learning, which covers the situation where students do things (like attending lectures) without any conscious belief that this will help them learn anything.[28, 29] It is hard to design a course to address students' intrinsic motivations, but university teachers have a great degree of control in respect of extrinsic motivations (they decide what is in the exam) and in respect of amotivational approaches (they decide what goes on in lectures and workshops).

In designing a teaching method which encourages students to employ a deep approach to learning, a number of factors should be considered. According to Ramsden,[24, 25] key features which facilitate a deep approach are:

- The activity should be perceived by the students as interesting and relevant. (It is almost always worth explaining the relevance of new material or activities in several different ways).
- Students should have a choice over their study methods; the more autonomy over their learning they have, the more likely they are to try to understand, rather than simply follow instructions.
- The workload should not be excessive; if there is too much to consider in a deep way, students are forced to use a surface approach .
- Students should not be anxious about the exercise.(This can be especially important when considering the use of computers, since computers can themselves be a potent source of anxieties.)
- Students should not feel threatened by the exercise in any way. (The assessment procedure is often seen as a threat, as discussed further later.)

Other authors have suggested the following additional features:

- Students should be actively involved in the exercise.[30]
- Students should interact with each other; peer learning can be very powerful.[30, 31]
- Students should have/take time to reflect on the exercise afterwards, to consider what they have learned, how they learned it, and how it fits with what else they know.[30]
- The context of the exercise should be similar to that where the subject material is relevant; there is evidence[32] that there is little transference of understanding from one context to another - a familiar phenomenon to chemistry teachers facing the 'modularisation' of a course!

No single teaching method or activity can hope to cover all these points effectively. Laurillard[6] and Ramsden[7] both maintain that no single teaching method can create an environment in which students adopt a deep approach to learning. A range of teaching styles is valuable. Different students will be attracted by and learn most effectively from different teaching styles.

Assessment

Assessment is a key factor affecting students' learning: students will try to learn what they think will be assessed. Useful discussions of assessment can be found in the books by Rowntree,[33] Kempa,[34] and Brown *et al*.[35, 36]

The purposes of assessment are generally agreed to be:

- to provide feedback for the student in order to reinforce their learning;
- to provide feedback to the teacher about the students' level of knowledge (summative assessment) and to indicate where further work is required;
- to act as a focus for an activity and motivation for the student.

Assessment defines the *de facto* curriculum.[33,37] Ramsden[25] explains further that assessment is the most important factor in improving teaching and learning, because most students do what they think will get them marks. The style and scope of assessment will determine the learning approach of the student, as discussed above: assessment of factual recall and the ability to solve simple 'algorithmic' problems leads to a surface approach to learning.

Elton[37] has argued that traditional examinations are unreliable because they assess little beyond factual recall and simple application of techniques to familiar problems. Bowden *et al*[38] showed that students can do well in such examinations while lacking understanding of basic concepts which are required for their later learning. Assessment can be an almost random process - Longmore and McRae[39] claim to find no significant difference between conventional examination marking and awarding marks on the basis of how far the script travels when all the papers are thrown down the stairs.

To be effective and reliable, assessment must be humane, and not perceived by the students as a threat. Most importantly, the students should be explicitly aware that the assessment not only covers the subject matter, but also rewards them for their understanding (and not merely rote learning).

Computers can be used to help in assessment. At a trivial level, word processors can help to ease the burden of marking by rendering all students' writing legible. Computers can also be used to present and automatically mark questions to students. Often such questions take the form of multiple-choice questions; there is, of course, a danger that students will infer from such an assessment that they need to memorise a set of discrete, testable facts - precisely the opposite of the deep approach discussed so far.[33]

Chemistry

General points

Some efforts have been made to apply educational research specifically to chemistry. Notably, Johnstone has applied an information-processing model of learning to chemical education.[40-5] Finster[46] has applied Perry's model of intellectual development to the design of a General Chemistry course. Garafalo and LoPresti[47] used educational research to devise an entire integrated science curriculum for freshmen. At a school level, Herron has applied educational philosophy and research, especially that of Piaget, and has written guidelines on how this can best be done.[48, 49]

At a smaller scale, many studies have focused on students' concepts and their inter-relation (their cognitive structure). Kempa and Nicholls[50] found that problem-solving ability above the algorithm level depends on the strength of concept-interlinking in students' minds. They also found that students' ability was dependent on context, such that individual students can do well in some areas and badly in others. Others[51-54] have found that when students' chemical concepts are examined by means of 'concept mapping' or similar exercises, large gaps in their understanding are revealed. They have also found that students have particular trouble relating chemical concepts to new contexts. This is in line with the general findings discussed in the previous section.

Much of the above work echoes general educational research. Chemistry is an experimental subject; this raises particular points which are perhaps not obviously covered by general principles.

Experimental work

Much has been written about the aims of laboratory work [55-58]. The skills and competencies required of chemists include familiarity with laboratory techniques, experimental design, data interpretation, summarising research findings and scientific report-writing. The main purpose of laboratory work is to provide students with the necessary technical skills; it is often hoped it will help to equip them with the other skills, and to reinforce the content of other parts of the course.

Effective laboratory work is difficult to plan. Laboratory experiments take up a great deal of staff, demonstrator and student time; the chemicals, equipment and laboratories are expensive and hazardous; results are unreliable because students are inexperienced. To reduce these problems, experiments carried out in teaching laboratories are usually very well researched, and the instructions given to the students are very prescriptive. As Garratt[59] points out, using such 'recipe labs' is an effective strategy for maximising both the quantity of practical experience gained by the students and the quality of their results. Such laboratory work is widespread[60] and there is good evidence that students learn technical skills from it.[41]

However, in a 'recipe lab' the practical becomes a demonstration, rather than a real experiment. Verdonk[61] coined the term 'bookification' to describe this move from 'fact-making' to 'fact-learning': instead of learning how to experiment, how to describe and how to explain, the students learn experiments, descriptions and explanations. Another drawback to such laboratory work is that students are all working towards the same answer and so can copy results from each other. Furthermore 'recipe labs' do not provide opportunities to learn about experimental design, investigation and critical analysis of results, and sources of error.[40,62] Hofstein[63] found no simple relationship between students' experiences in the laboratory and their learning. This is not surprising, given that students usually follow their instructions line-by-line without thinking about what they are doing[41] and only notice effects they have been told to observe.[64] Edmundson and Novak[18] found that most students gained little insight into the key science concepts involved in laboratory work. Johnstone *et al*[43,65] have discussed how overloading of students' working memory is a common cause of such problems.

Hofstein[63] asserts that, in order to remedy these failings, it is necessary to address factors such as the attitude of the staff, demonstrators and students, the aims of the experiments, the context in which the experiments are set, and the level of students' understanding. There are three overlapping ways in which this can be done: laboratory work can be made more open-ended; 'recipe' laboratory work can be carefully designed to mitigate its limitations; laboratory work can be supplemented with other teaching methods to cover its shortcomings.

A widely-employed method for giving student chemists practice in designing and carrying out experiments and interpreting data for themselves is the research project. This is an "*important component in the education of a professional chemist*".[66] Ryder *et al*[67] report that tutors responsible for projects believe that they provide a unique opportunity to experience the actual practices of scientific research, which could not be achieved through other teaching contexts; they saw the project as an apprenticeship which introduces students to the culture of science. Analysis of the student view[68] showed that students do indeed gain valuable insight into the culture of science, but that peer support is needed to avoid students "*switching off [during] the boring bits*", and that students are inclined to worry excessively about not obtaining good results.

Project work is normally restricted to the final year of an undergraduate course. However, it is possible to make other laboratory work less recipe-based. For example, Johnstone[69] argues that tutors can design laboratory work to encourage the students to take more responsibility for their learning, without the need for much change in the amount of time or resources required. Laboratory worksheets can be improved.[70] It is possible to make laboratory work less recipe-driven. For instance, Merritt *et al*[71] found that one effective way of giving students practice in experimental design is to require them to prepare a plan of their experiment beforehand, and to encourage discussion. Verdonk[61] describes an investigation of ester synthesis designed to provide the students with some insight into the process of scientific research.

Johnstone *et al*[72] describe the results of a laboratory course which was designed to maximise the opportunity for the students to understand their work. The main features were the use of 'pre-labs' to give the students practice in the technical skills required and make the purpose of the exercise clear, and the minimisation of the amount of extraneous information presented. This resulted in a significant increase in the number of students who reported feeling able to concentrate on the chemistry involved. However, this work also showed that there is still considerable scope for providing more effective links between theory and practice.

Some of the limitations of recipe-driven laboratory work may be overcome by supplementing them with non-laboratory-based work. For instance, paper-based exercises can be used to teach critical skills (*e.g.* [42]) and experimental design (*e.g.* [73]), and whole courses have been designed to foster the development of such critical skills.[74] Another method of providing an effective link between laboratory work and theory is a carefully designed computer simulation exercise.[75]

Computers

In the last decade or so there have been many efforts to encourage the use of computers in teaching: most notably the Computers in Teaching Initiative[76] and the Teaching and Learning Technology Programme.[77-80] Two important reports on higher education published in this period (the MacFarlane Report[81] and the Dearing Report[1]) both prescribe the increased use of computers in teaching in the future.

There are many different ways in which computers can be used for teaching. They provide the following valuable features:

- hypertext, where text is presented with highlighted words, which when clicked provide further text, thus giving students an easy way to follow their own chosen route through a collection of information;[82]
- multimedia, where text is supplemented with high-quality graphics, animation, and sometimes sound;
- rapid feedback on answers to questions posed by the computer;
- Intelligent Tutoring Systems, which aim to provide complete artificial replacements for human tutors;
- computer-mediated communication, which can facilitate and enhance communication between teacher(s) and student(s), and between students;
- laboratory automation;
- simulations.

Many computer programs used for teaching combine two or more of the features described above. Examples in Chemistry include ChemiCAL[83] and the Chemistry Courseware Consortium's packages.[78, 84] Journals such as *Active Learning* and *Software Reviews, Journal of the CTI Centre for Chemistry* contain numerous other examples.

These features mean that computers allow new approaches to teaching to be developed. This automatically creates a potential benefit: as discussed above, a multiplicity of teaching methods can be very effective in promoting deep learning. However, any teaching method can be misused, and the use of computers has many unique potential problems. How can a tutor, keen to enhance their students' learning by use of computers, decide whether the benefits will outweigh the problems?

Are computers effective?

The Dearing Report maintains that "*the innovative exploitation of Communications and Information Technology holds out much promise for improving the quality, flexibility and effectiveness of higher education*"[1] (Chapter 13).

Computer-based material could be used to cope with increased student numbers. As Appendix 2 to the Dearing Report discusses, if resource-based learning is employed widely, the cost per course (in terms of staff time) need not increase as dramatically with increased student numbers as it would with more traditional course structures. For this to be achieved, the resource materials must be very well-designed, and capable of supporting a student working independently. It is worth noting that the benefits of this type apply mainly when resources are developed elsewhere and customised by a tutor for their own course. Developing one's own resource materials requires a large number of staff hours per hour of student learning time.

Decreasing the ratio of staff teaching hours to student hours of learning does not in itself show that using computers in teaching is worthwhile. The MacFarlane Report[81] found that:

"no general and comprehensive study exists which treats in detail the costs and benefits of applying innovation and using educational technology in higher education" (p. 80).

There is, however, some evidence that computer-based teaching has a beneficial effect. Kulik *et al*[85-87] report that computer-based teaching gives a small but significant improvement in examination marks, and reduces the time required by the student to cover the same subject area to around 70%. However, the examinations in the studies which show these effects predominantly assess factual knowledge, rather than understanding. It is perhaps unsurprising that students absorb facts more efficiently when working at their own pace with computers than with lecturers.

The most common general finding in this area is that there is no significant difference in students' learning from different teaching media, including computer-assisted teaching. Russell[88] has collected around 250 research reports, summaries, and papers which support this view. In a specific chemical example, the comparison of a self-paced multimedia package with a conventional lecture course showed no significant difference in the test results of the two groups.[89]

So it is not possible to say in general whether a computer-based teaching exercise is effective or not; it will be necessary to examine it in its particular context.

How can we tell if an exercise is effective?

Obviously, for a computer-based exercise to work at all, the software and hardware involved must be useable. Whether or not the exercise is effective or not will depend on factors beyond the software itself. The educational principles discussed in the first section are a useful guide here: the exercise should build on what the students already know, and the context and assessment should be carefully designed in order to encourage the students to adopt a deep approach to the exercise.

Moyse[90] and Laurillard[6] have shown that deep learning is favoured if students engage with a computer exercise using 'structural' or 'formal' thought, where they have a model of what is going on and can apply their knowledge from other areas. If, on the other hand, they work only at a more 'functional' or 'operational' level, where they have only a fixed set of rules which they apply without understanding the basis for the rules, they tend to adopt a surface approach. Engaging in such structural or formal thought gives a greater scope for understanding, and makes it much easier for students to see the application of what they have learned to new contexts.

Jonassen[91] applying constructivist principles, argue that the computer should not be used as a mere conveyor of information (as is common). Instead, it should be employed as a tool to facilitate the construction of understanding by transcending mental limitations (such as finite working memory), and students should be given authentic tasks to carry out.

Perhaps the most useful way to examine the utility of a computer-based exercise is to apply the framework for the effective use of technology in teaching in higher education set out by Laurillard.[6] This framework is summarised in Figure 1. It is designed to encompass all aspects of the academic learning process, and encourage a deep approach to learning. Laurillard calls this model a conversational framework, because it stresses the importance of interaction between the student and the teacher.

The framework requires interaction at two levels: that of actions, and that of descriptions. Interaction at the level of actions concerns direct, experiential learning: actions on the world and their result. Interaction at the level of descriptions concerns adaptation and reflection: conversation about the world. An example of an activity which concerns the level of actions might be carrying out a preparation of an azo dye and seeing the vivid colour; at the level of descriptions, it would be considering the molecular orbitals, energy levels and photons which give rise to the effect. Laurillard uses the term 'intrinsic feedback' for the information the student can obtain at the level of actions, and 'extrinsic feedback' for information at the level of descriptions. Obviously, computers could conceivably be used to supply feedback of both types.

To learn in an academic sense, conversation (interaction) must occur at both levels. It is possible for students to learn even when such conversation is not fully supported by the teaching method employed. For instance, the role of the 'action-in-the-world' component could be played by considering reported or thought experiments; or the 'discussion-about-the-world' could take place solely in the mind of the student. However, providing support for all aspects of the framework encourages and facilitates deep learning.

A teaching exercise can be examined to see how it supports the activities of the Laurillard model: does it allow conversation between teacher and student at the level of descriptions (numbers 1 to 4 in the figure) *and* at the level of actions (numbers 6 to 9 in the figure)? Few single teaching methods address all aspects of the framework, so it is often valuable to combine complementary methods. Thus it is unlikely that an exercise which relies solely on a student working alone at a piece of software will support all of the elements necessary for deep learning; but it can be very effective to use a piece of software in conjunction with less technological teaching methods.

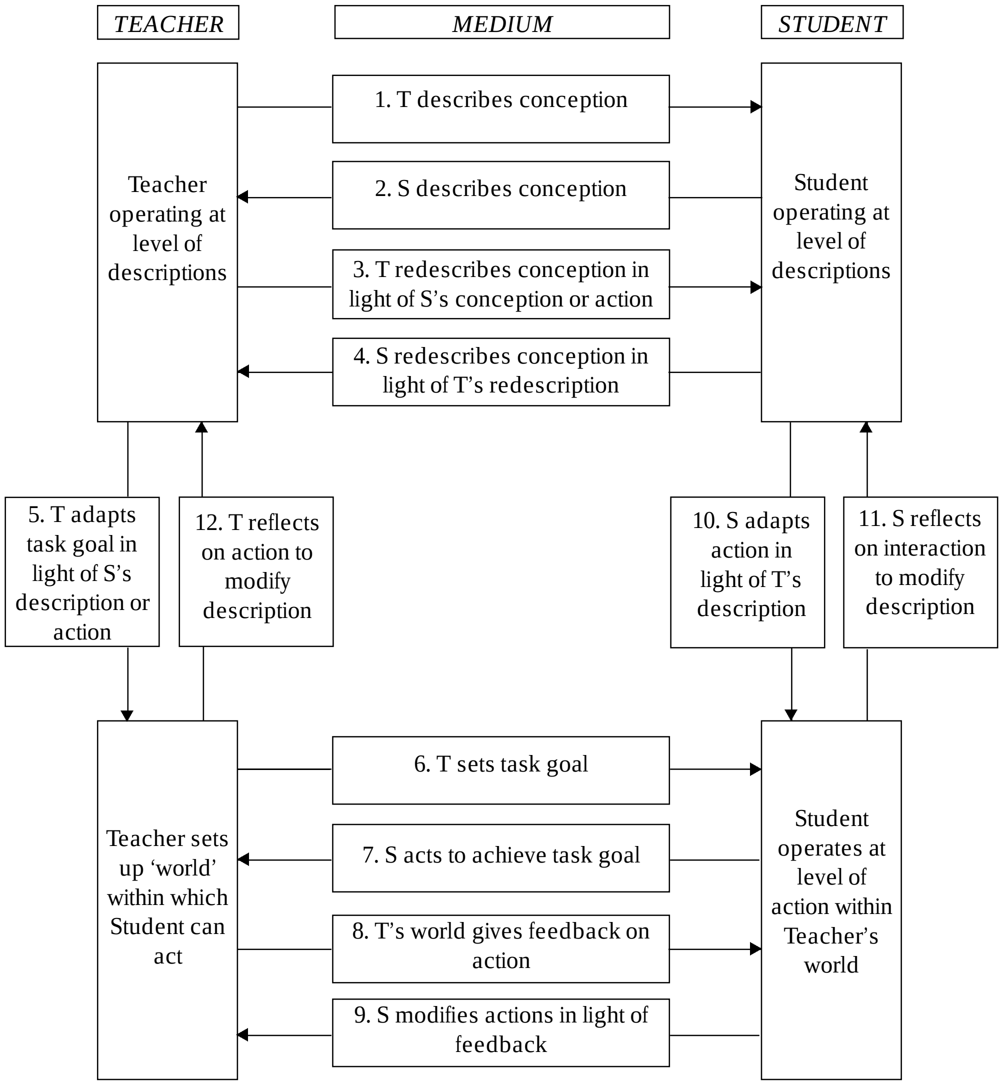
Conclusion

Computers are most effective when they offer a unique way of meeting a clearly identified educational need.

Existing courses are rarely perfect. Laurillard's framework and the work discussed in the first section of this review can help to identify defects; and few courses now take place without some form of evaluation taking place. Once identified, weaknesses can be addressed. Computers do not necessarily provide the best way to do this - but sometimes they do. Draper[92] calls this 'niche-based success'.

The effectiveness of a computer-based exercise lies mainly in the broader context - how the activities of the Laurillard framework are supported. Almost always, other forms of teaching will be required to facilitate students' deep learning.

Figure 1: Laurillard's conversational framework. Adapted from ref 6, *p*. 103.



Introducing computers to a course can often result in a boost to students' learning: there can be a novelty effect; and, less trivially, most chemistry teachers who introduce change do so after considering the purpose of the course, and how best to achieve it. The 'niche-based' approach, where an identified weakness in an existing course is addressed by the most appropriate method is the most reliable way to use computers to promote students' learning *powerfully*.

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Inducing People to Think

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Listening to people describing their methods for and ideas about teaching and learning chemistry, and discussing these ideas into the small hours is almost always stimulating. I have been fortunate in the number of opportunities I have had to do this over the last few months. In presenting here my reflections on these discussions, I make no claim for originality. They are other people's ideas, and I hope to be forgiven for not giving the sources of all my quotations.

Why Teach Chemistry?

"It is the whole business of the university teacher to induce people to think".[1]

Of course, Haldane understood that thinking requires having something to think about, so that, as far as chemists are concerned the induction of thought involves creating opportunities to learn how to think about chemistry. We could paraphrase this by saying that our job as teachers of chemistry is to empower our students to think like scientists. This means a great deal more than knowing chemical facts.

Johnstone[2] has proposed that understanding chemistry involves recognising a triangle of components; at the apices of the triangle are the macroscopic (phenomena which are open to the senses), the sub-microscopic (the use of diagrams, pictures, etc. to represent phenomena at a molecular level), and the symbolic (the use of chemical and algebraic equations to represent or describe a phenomenon). Johnstone suggests that professional chemists move easily between the apices of the triangle, and even within the triangle, to select an appropriate way of dealing with a particular situation.

Many people apparently share a concern that traditional teaching deals primarily with the macroscopic and the symbolic aspects of chemistry. There is a view, backed by some supporting evidence, that understanding (and examination performance) can be improved when conscious attempts are used to introduce the sub-microscopic. The use of pictorial representations to aid visualisation at a molecular level does not help all individuals equally. However, using and creating models (visual or conceptual) is a key feature of 'thinking like a scientist', and many students have difficulty coming to terms with the idea that most of what we 'know' about chemistry is really a model which usefully represents reality.

Real scientists realise that most of our models are ephemeral:

"Half of what you have been taught is wrong - and furthermore we do not know which half."

"Everything we believe in now will be disproved in four years."

Even if these quotations exaggerate the uncertainty of 'knowledge', they illustrate that another key feature of thinking like a scientist is the ability to consistently review and adjust our models. It is a Piagetian idea of knowledge that we develop schemes and these lead us to have expectations. If our expectations are met there is no need to change our schemes; "*the proof of the pudding is in the eating*". Sometimes our expectations are not met; "*the exception proves the rule*". In both of these sayings 'proof' has the old fashioned meaning of 'testing' and the rule or scheme must be changed if it does not stand up to the test. So learning involves developing flexible and creative minds which allow students to respond to experience and to change their schemes of knowledge.

Students learn in different ways, and they start their university courses with different expectations. To take account of this, effective teaching involves using a variety of methods.

"A key feature of effective learning is to select the teaching methods which suit the needs of the student."

One need of all students is to overcome barriers to effective learning.

Barriers to Learning

There are many reasons for students finding chemistry difficult to learn. For example, when we teach we have to make assumptions about what our students know. We know (or ought to know) what these assumptions are, but we rarely analyse them in detail for ourselves, and we even more rarely make them explicitly clear to our students. Very often the assumptions we make (explicitly or implicitly) are wrong - for a whole variety of reasons: we may not know what students are supposed to have learned from their previous courses; we know that none of them have learned everything that was expected of them; students may think they know more than they do; and our students' 'knowledge' is often undermined by their misconceptions.

We can easily understand why we make wrong assumptions. For example, changes in the school curriculum are not always understood in detail by universities; in the UK how many university teachers can honestly say that they know what is in the A level or Scottish Higher courses? Even if we know the content which is covered by the syllabus, we know that no student scores 100% in any examination based on that syllabus (and the majority of our students get a substantially lower mark):

"The verb 'to cover' and the noun 'information' are responsible for much mischief."

Another common complaint is that students forget so much. The problem may be one of not learning rather than of learning and forgetting (Figure 1). So our students know less than we often expect or assume, and do not understand all that they know.

Unfortunately, it is not just lecturers who overlook the fact that students do not actually know everything that they have 'covered'. Students themselves are likely to make the same mistake. Consequently they may mentally switch off when a topic is revisited and so lose the opportunity to develop their understanding. Probably a worse problem is that new information is incorporated into an unsound framework of existing knowledge: students (like the rest of us) understand incompletely, and frequently with misconceptions (Figure 2). Effective learning involves making connections between different pieces of information. This making of connections includes, but goes beyond, the process of 'chunking'.[3] Students are bound to have difficulty (and to develop new misconceptions) when they are faced with trying to build new ideas into a faulty framework of knowledge, and when they and their teachers make different connections between parts of this framework. So we should think carefully about our assumptions, and those of our students. We would also do well to remember that many students, especially early in their course, see chemistry in the light of a dualist thinker (everything is right or wrong).[4] We need to steer them away from this, and not be afraid to have high expectations.

"A pupil from whom nothing is demanded which he cannot do will not achieve all he can."

Understanding Student Difficulties

Students are helped to overcome their problems with learning if they have a clear understanding of what is expected of them, what goals we set for them, and what goals they set for themselves. These may not be as clear as they are in some walks of life:

"in any sport both the rules and the scoring system are clearly defined; in universities our attempts to be all things to all people prevent us from defining either the rules of the game or the scoring system; this is a recipe for confusion."

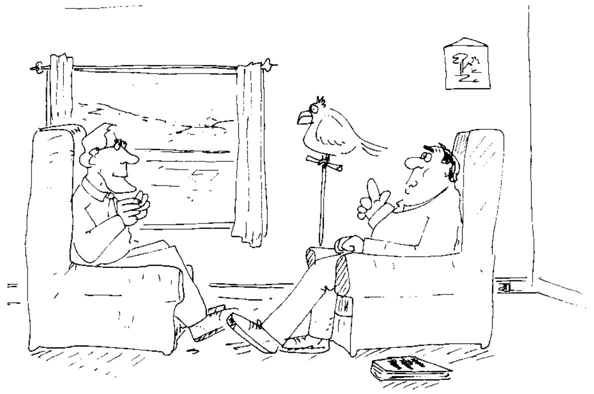
I have been offered many definitions of goals (including, of course, the quotation with which I began this paper). Here is a selection:

"Students need factual knowledge, technical skills, critical judgement, and a capacity for discovery."

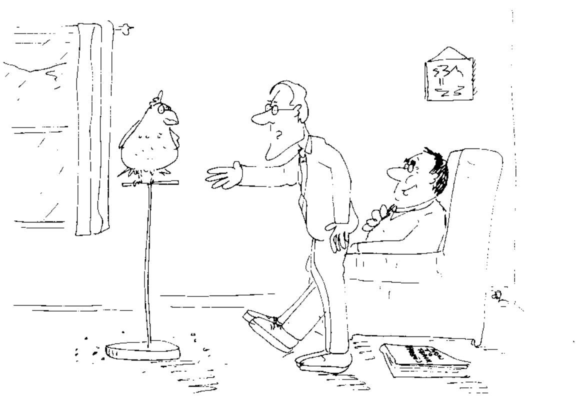
"We need to empower students to believe in themselves; if we do too much for them they become disempowered."

"Chemists need to develop the skills of algorithmic reasoning, conceptual understanding, scientific thinking, and

Figure 1: I taught my parrot to talk



I can't hear it saying anything



I said I taught it; I didn't say it learned anything.

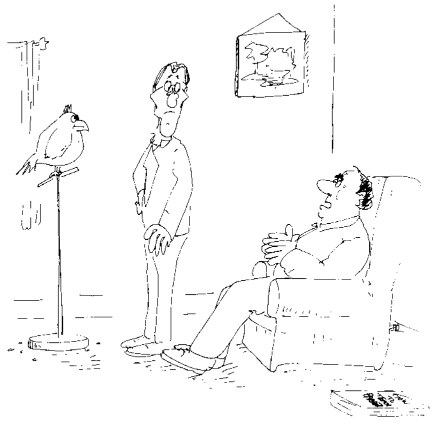


Figure 2:

a positive attitude to science."

"I want my students to know enough to know that they can learn more on their own; nobody poured knowledge into my head, and I don't expect to be able to pour it into someone else's."

"In order to replace their misconceptions, I need to know what those misconceptions are."

"Students need both instrumental understanding (knowing a rule and how to use it) and relational understanding (knowing what you want to do and why you want to do it)"

All of these suggest that our teaching objectives go far beyond that of content - though of course all of them include (explicitly or implicitly) the notion that content or knowledge is an essential component of learning chemistry. The key to achieving other objectives involves changing the mix of learning opportunities which our students experience in their programme of study. Planning an effective mix of learning opportunities means taking into account three factors.

First, we need to know what the student brings to his or her learning. An informal survey has shown that an overwhelming majority of academics want students with curiosity, a strong work ethic, competence in maths, and a willingness to learn for themselves. 'Knowing chemical facts', 'having lab skills', and 'knowing other sciences' all came way down the list. We don't always get what we would like, and it is worth considering what real (rather than ideal) students actually bring to their studies.

We probably know quite a lot about their level of knowledge (or ignorance), something about their misconceptions, and only a little about their aspirations. Ignorance and misconception are not quite the same; there are several different ways of saying *"getting the right answer shows that you know how to get the right answer, not that you understand why it is right."* Aspirations can greatly affect student learning. Surveys and tests are sometimes used in an attempt to assess conceptual knowledge and attitude in advance of a course (e.g.[5]); I wonder whether their increased use might lead to more carefully planned programmes of study.

The second factor affecting the effectiveness of a programme relates to the context in which information is presented. Good responses from students (both in enthusiasm and in learning) are claimed by those who have tried 'topic-based learning' or 'thematic teaching' (you can find a lot of chemistry in topics such as 'what can we do about global warming?' or 'is it economically and environmentally profitable to produce ethanol from biomass?').

The third factor to be considered in planning a learning programme is the style of learning offered. The fashionable words are 'problem-based learning', 'student-centred learning' and 'active learning':

"Knowledge is not passively received, but actively built up."

A Student-centred Approach to Active Learning

There are several perceived advantages and disadvantages of shifting the balance of a traditional lecture-based chemistry course to a more student-centred approach which encourages active learning. One disadvantage is that it takes longer to deliver the same amount of factual content in this way. The counter-argument, for which there is some supporting evidence, is that students have a better understanding of (and therefore remember better) a greater proportion of the smaller amount covered. From this it is easy to argue that 'less means more' - less material is covered, but more (not just a greater proportion) is retained and applied. This is only part of the advantage, since one of the aims of a student-centred approach to teaching is to help them to develop other skills - and especially the skills of learning to learn independently.

Another significant problem for academics (which ought not to be seen as a disadvantage) is that student-centred learning involves shifting the tutor's role from that of 'authority' towards that of 'facilitator' or 'manager of learning'. The loss of control which this implies can be difficult to adapt to. The positive side is that it allows the tutor to pay more attention to the higher levels of competence. Table 1 shows six levels of competence based on Bloom's taxonomy of cognitive levels.[6]

Table 1: Levels of Competence (Based on Bloom's Taxonomy)

Knowledge:	able to identify and define the concept.
Comprehension:	able to apply the concept when instructed.
Application:	able to apply the concept appropriately without instruction.
aNalysis:	able to dissect a problem and apply the appropriate concepts.
Synthesis	able to combine concepts in new and appropriate ways to give new/useful knowledge.
Evaluation	able to analyse a problem in multiple ways and to identify the relative strengths and weaknesses of each approach.

One way of moving towards student-centred learning is to adopt a problem-based approach 'Problem' is an ill-defined word and its meaning in this context needs to be carefully thought through. I like this definition:

"Problem solving is what you do when you don't know what do, otherwise it is not a problem".[7]

Table 2: Characteristics of Good Problems

- engage interest
- Require decision and judgement
- Need full group participation
- Open-ended or controversial
- Connected to prior knowledge
- Incorporate content objectives

Some characteristics of a good problem, based on a paper by Duch[8] are given in Table 2. Such problems may be extensive, such as those based on a historical sequence of published papers,[9,10] or may be quite short. Here is an excellent example of a short, thought provoking, question:

'Consider two beakers of pure water at different temperatures. How do their pH values compare? Which is more acidic? More basic? Explain.'[11]

Other questions might be based on the interpretation of a graph or figure, the creation of a pictorial representation of a piece of symbolism (such as an equation), the need to define what information is needed to answer a question.

A key feature of good problems is that they encourage students to talk to each other, and to stimulate each other to reflect on their answers. Both verbalisation and reflection are valuable aspects of the learning process. The former is an excellent way of exposing and clarifying concepts; peer-group discussions can be extremely effective, providing that there is sufficient tutor-interaction to ensure that the entire peer group is not led down a blind alley. Reflection is an important step in making connections between different topics and in assimilating new knowledge into an existing framework.

There is a strong case for giving students more careful preparation for and feedback from different learning experiences. In the laboratory context this means well-designed pre-labs and post-labs. At their best these are quite different from an instruction to 'read your lab manual' or the marking of a report. Pre-labs and post-labs have (or can have) parallels in any other style of teaching - lectures, classes, seminars, workshops, tutorials, or anything else.

A cautionary conclusion

Edmund Burke is reputed to have said

"to innovate is not to reform."

Do we want innovation, or do we want reform? We should be trying to introduce something better, and not all innovation does this. We need clear objectives. 'Inducing people to think' is a useful start. By inducing our students to think we would expect that they would make better connections between aspects of their chemical knowledge, and this would lead to better understanding, and to better ability to use knowledge to make judgements and to solve open-ended problems. Thinking students would also develop the personal skills needed to work effectively with others. It would be good to dispel the image of an extrovert chemist as being

"someone who looks at ***your*** *shoes when talking to you."*

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Mystery Molecules or What's in a Name?

from Harold B. White, III
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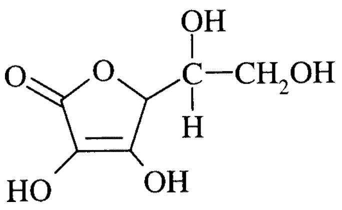
Reading Tina Overton's paper "creating critical chemists" [1] suggested to me that readers might be interested in a strategy I use to try to do this.

I teach biochemistry to a group of about 35 second year students at Delaware[2]. The subject depends on basic concepts in general and organic chemistry. Despite my students' exposure to courses in those areas, a frustratingly large number seem to have difficulty applying useful concepts to unknown structures, a problem not helped by their seeming inability to remember what they once knew. For several years now as a way to reconstruct their forgotten knowledge and build confidence from fragments retained by different students, I have begun most classes by drawing the structure of a relevant "mystery molecule" on the board. This initiates a short game that lasts several minutes. A typical dialogue with the class might be:

Professor *Can anyone identify this molecule?*



Student A (Hesitantly) *I'm not sure, but it might be glucose.*

Professor *What makes you think it might be glucose?*

Student A *Well, it has six carbons and sort of looks like a sugar.*

Professor *Is there any reason that it might not be glucose?*

Student B *I don't think glucose has a double bond.*

Professor *Notice the substituents. What is a double bond between two hydroxyl groups called?*
(No student response.)
(Circling the functional group)
Has anyone heard of an enediol?
What other observations do you have?

Student C *I thought glucose had a six-membered, rather than a five-membered ring, and I didn't think it was a lactone?*

Professor *Does everybody know what a lactone is?*
Can you come to the board and show what you mean?

Student C (At the board.) *Lactones are cyclic esters.*

Professor *Thank you. Let me see a show of hands.*
How many of you think this molecule is glucose?
(No hands go up.)

Professor *How many of you think that molecule is not glucose?*
(Less than half of the class raise their hands.)

Professor *How many of you are not sure?*
(The majority raise their hands.)

Professor *Given this structural representation, how would you go about identifying this molecule?*

Student D *I'd figure out the atomic formula and look it up in the Merck Index.*
(Within a minute or so, the molecule is identified as ascorbic acid, but the game is not over.)

Professor *Ascorbic acid, Hmmm, I don't see a carboxyl group. Why do you think it is called an acid?*
Puzzlement prevails but upon reflection some student will usually ask, "*Does it have a dissociable hydrogen?*"

Professor *Good. How might you decide which one?*
(Pointing to hydrogen bonded to carbon.)
Would this proton be dissociable?

Student E *No.*

Professor *Why not?*
(And so on until someone shows that one of the protons on the enediol is likely to be acidic.)

Professor *Another name for ascorbic acid is vitamin C. Why is vitamin C important in your body?*

Student F *I thought it was supposed to be an antioxidant?*

Professor *Chemically, what does that mean? Is that the same as a reducing agent?*

Student F *I think so. It gets oxidized to dehydroascorbic acid.*

Professor *Can anyone suggest a structure for dehydroascorbic acid?*

As can be seen, this game can be continued further and be played with any molecule. Equations also work. Sometimes, when answers are not forthcoming, the questions can be turned back to the students to discuss in groups or look up before the next class. The effect is that after several classes, many students start thinking about molecules as more than something with a structure and name to memorise. It helps to create critical chemists[1]. By seeing a variety of principles applied to different molecules in a context, students begin to gain confidence that they possess some relevant understanding and can apply general principles without knowing the name. They can appreciate the "*difference between knowing the name of something and knowing something,*" a lesson Richard Feynman learned early on about birds (and other things) from his father[3]. To reinforce that I value this type of thinking and understanding, I often include a mystery-molecule question on my examinations and ask students to predict or rationalise its chemical properties. Such an approach fits in nicely with the problem-based learning approach used in my course[4] and the constructivist ideas of how people learn[5].

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Reflecting on learning

From Jane Tomlinson,
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In the last issue of University Chemistry Education four articles in particular (those by Garratt, Overton, Bailey, and Kee and Ryder) described different strategies for encouraging students to engage actively in the learning process and develop various skills needed by professional chemists. Strangely, none of the authors referred to the importance of encouraging their students to engage in reflection on what they had learned and the way they had learned it.

Most teachers understand the value of reflection with reference to more traditional teaching: the student who reflects on mistakes and on feedback on a piece of marked tutorial work learns more than the student who forgets the entire exercise the moment the work is handed in. However, where teaching is intended to lead to the development of skills, the need for reflection can be overlooked. Learners are often provided with an opportunity to experience a situation which requires the use of specific skills, without actually being given the opportunity to reflect on how they performed, and what they have learnt. This may actually be counter-productive, since it may reduce confidence by exposing the learner's lack of skill, without helping the learner to develop that skill, or bringing to light other positive qualities which can be developed further.

The value of reflecting on a learning experience was brought home to me at a Project Improve workshop run by Maskill and Race, where participants were introduced to some of the materials developed by them as part of their FDTL funded project.The exercises focused on communication skills in a variety of contexts. Maskill and Race emphasised that the exercises they have developed include an explicit component of reflection by the learner on what and how they have learned. For example, in one exercise all participants were provided with a single piece of information about a fictitious public health problem; once all the information had been shared between the group, conclusions could be drawn. Drawing the correct conclusion was of secondary importance. The most valuable learning opportunity was the subsequent discussion, which ranged over issues such as the group dynamics, the influence of the seating arrangements, and how we had organised the information as it was revealed. Maskill and Race very effectively demonstrated that it was the process of reflecting on the exercise that enabled the participants to learn from their experience, and identify ways in which we could improve on our performance when next faced with such a situation.

Reflection can and does take place even without being explicitly designed into a teaching exercise by a teacher.This may be particularly likely when new materials or teaching strategies are being used because there is pressure on the teacher to evaluate the effectiveness of innovations. The evaluation process, involving feedback from students, may encourage exactly that reflection which plays a valuable role in the learning process.

Reflection may also be involved during activities involving group work, especially in those examples I referred to above taken from University Chemistry Education where group work is followed by plenary discussion sessions involving learners and teachers.

I therefore accept that a degree of reflection is frequently a natural part of most learning opportunities. My point is that it is too important a part of the learning experience to be left to chance, and should be explicitly included in discussions of teaching.

Laboratory work does not interest students

From Professor Alex Johnstone,
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I recently attended a meeting of university lecturers in chemistry on the subject of 'New Approaches to Undergraduate Laboratory Work'. We discussed various ways of increasing the effectiveness of this aspect of the curriculum. But we spent little time thinking about the students' view of laboratory work. The importance of this was forcibly made to me as a result of my involvement with the training of probationary university staff.

Last term I ran three courses and workshops on 'Teaching and Learning in Laboratories' which were attended by a mixture of Chemists, Physicists, Biologists and Engineers. As a preliminary part of the 'warm up' discussion, I asked each group to indicate if they had enjoyed their undergraduate experience in laboratories. Of the 50 young lecturers, only two admitted to having enjoyed their time in undergraduate labs (and these two were not chemists!).

When questioned further about how they were going to square this with inflicting the same experiences on the next generation of undergraduates, there was much disquiet. There were the usual mutterings about *"Science is practical and so they must do practical work"* or *"It is good for them"* or *"How else will they obtain research skills"*.

This was a good curtain raiser for the later parts of the course and forced us to question the experiences we had undergone and think about how things could be better. We ranged over the demands of the conventional labs in terms of time pressure, in ways students have of 'easing the pain' and boredom and in their dodges to make teachers believe that they were learning.

All of this points up the need for rethinking what goes on in labs. Nobody was suggesting that there should be no labs, but there was a genuine concern that in order to make this extremely costly form of teaching and learning effective and educational we need to maintain the interest and enthusiasm of the students. My unscientific 'survey' suggests that we are not even doing this for the most academically minded students who end up as university lecturers. How do you suppose the rest of them feel?

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Preparation of hard copy

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   A word count (excluding references, tables, legends etc) should be included at the end of the document.

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   Text should be typed in 12pt Times Roman (or similar), on single-sided A4 paper with 1" margins, double-spaced, unjustified, ranged left and not hyphenated.

   Always use an appropriate mix of upper and lower case letters: do not type words in uppercase letters either in the text or in headings (see 6). **Bold** or *italic* text and not upper case letters should be used for emphasis.

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   Tables and figures should be numbered consecutively as referred to in the text (use a separate sequence of numbers for tables and for figures). Each should have an informative title and may have a legend. Each table and figure must be provided on a separate page, and not incorporated into the text.

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   Equations should be written into the text using the word processing programme, either as normal text or using the programme's equation facility.

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   – an abstract of not more than 200 words.

5. Wherever possible articles should be subsectioned with headings, subheadings and sub-sub-headings. Do *not* go lower than sub-sub-headings. Sections should not be numbered. Headings should be no more than 40 characters in length and subheadings and sub-sub-headings no more than 30.

   The introduction should set the context for the work to be described, include references to previous related work, and outline the educational objectives.

   Suggestions about other sections are made in "Editorial Policy".

   A concluding section (which need not be headed conclusion) will include an evaluation of the extent to which educational objectives have been met. A subjective evaluation may be acceptable.

   All references must be designated by a number in enclosed parentheses.

   Footnotes should not be used, but important additional information may be referenced, and included in the reference list.

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   Reference numbers should be followed by a period rather than being placed within parentheses and are placed flush with the margin.

   References exceeding one line should *not* be indented.

   The list of references should be typed double-spaced using the bibliographic style shown below.

   Titles of articles in journals should be included.

   Books and special publications:

   - Perry WG 1979 *Forms of intellectual and ethical development in college years: a scheme* (Holt, Rinehart and Winston, New York)
   - McCloskey M 1983, in: *Mental models* (eds. D Gentner and AL Stevens) (Lawrence Erlbaum, New Jersey)

   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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