Vol. 4 No. 2 SEPTEMBER 2000 Pages 39–74 ISSN 1369–5614

ROYAL SOCIETY OF CHEMISTRY

UNIVERSITY CHEMISTRY EDUCATION

THE JOURNAL OF THE TERTIARY EDUCATION GROUP OF THE ROYAL SOCIETY OF CHEMISTRY

JOURNAL OF THE TERTIARY
EDUCATION GROUP OF THE ROYAL
SOCIETY OF CHEMISTRY
VOL 4 NO 2 SEPTEMBER 2000

UNIVERSITY CHEMISTRY EDUCATION

CONTENTS

PAPERS

COMMUNICATION

REVIEW

LETTERS

University Chemistry Education is published in April and September. It receives substantial financial support from Glaxo Wellcome plc, and is available free of charge to all members of the Education Division of the Royal Society of Chemistry who are over 29 and employed in institutions of higher education.

After the publication of Vol 4 (2) the Editorship of U. Chem. Ed is taken over by Professor Pat Bailey (Heriot Watt)
and
Dr Stephen Breuer (Lancaster)

Manuscripts to be considered for publication may be submitted to either of them.

Glaxo Wellcome support for this journal forms part of a continuing programme of charitable contributions which places emphasis on health care and scientific and medical education.

Designed and printed in the UK by York Publishing Services Ltd.

Editorial Policy for University Chemistry Education (U Chem Ed)

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.

The Use of a Computer-Assisted Personalized Approach in a Large-Enrolment General Chemistry Course

PAPER

Paul W. W. Hunter

Department of Chemistry, Michigan State University, Michigan 48824-1322, USA e-mail: hunter@msu.edu

The CAPA© system[1,2] (a computer-assisted personalized approach) has been used in general chemistry courses at Michigan State University since January 1993. This networked software system is a tool that enables instructors to write and distribute personalized problem sets, quizzes, and examinations for their students and includes an array of course management and statistical functions. Advantages of the system include

- Encouragement of a continual rather than sporadic effort by students in the learning process.
- Immediate feedback of a student's responses at any time.
- Individual problem sets for students that permit and encourage collaborative study.
- A shift in effort for instructors from grading and course management to teaching and course development.
- Support for the design and coding of both conceptual and algorithmic problems.
- A shift in role for the instructor from examiner to tutor and teacher.

Introduction

Michigan State University is a large public university with an undergraduate student population of approximately 32,250. Of these, about 8650 are in the freshman class. Almost all physical science, biological science, and engineering students are required to take at least one semester of chemistry – in most cases the 4-credit general chemistry course CEM 141. This results in an annual enrolment in CEM 141 in excess of 3000 students of which 2000 take the course in the Fall semester.

Students in CEM 141 have widely different backgrounds in chemistry and mathematics. Many, but by no means all, have experienced one year of chemistry in high school. Their mathematics backgrounds, often the more reliable predictor of success, vary from little or no knowledge of algebra to some experience with calculus. Enrolment in the course requires no prior knowledge of chemistry but does require at least concurrent enrolment in algebra I. The academic level of CEM 141 approximates that of A-level chemistry or a pre-degree general chemistry course in the UK. Chemistry, biochemistry, and chemical engineering majors do not take CEM 141.

Our intent in CEM 141 is to provide for the student a thorough basis in the fundamental properties and behaviour of matter that subsequently will be of some use to them in their major programme. The syllabus is fairly typical of traditional general chemistry courses in the US – the topics covered are listed in Table 1. Only 33% of the CEM 141 enrolment go on to take the second semester (CEM 142).

Chemistry 141 is taught by a traditional lecture-recitation method and the aim is to encourage conceptual understanding of the principles rather than to focus on the memorization of facts and the algorithmic solving of problems[3]. Thus the aim is to emphasise the higher order aspects of Bloom's taxonomy of educational objectives[4] and this is done as much as possible in the spirit of the lighting of a fire rather than the filling of a pail[5].

To achieve success, students need to develop two habits. The first and more important is a regular (preferably daily) active study of the material. The second, which helps a student enormously, is collaboration, cooperation, and discussion of the subject with other students[6,7]. In addition, students benefit from rapid formative feedback of their progress. Given the number of students involved (as many as 2000 per semester) these needs raised significant logistical concerns. One problem is that it is easy for students to get lost in the crowd and considerable care has to be taken to cater for the needs of the individual. For the instructors, the administration of examinations and problem sets can be almost overwhelming; the manual grading of the latter places an onerous burden on teaching assistants and it is impossible for them to provide results rapidly enough for effective feedback. A computer-based learning support system is the only realistic way to meet these demands.

Table 1: Syllabus for CEM 141

- Classification of matter
- Formulas, equations, stoichiometry & the mole concept
- Types of reactions; redox and acids and bases; aqueous solutions
- Solution stoichiometry
- Energy and reactions; first law of thermodynamics
- Atomic structure; electronic configurations; periodicity
- Bonding and molecular structure
- States of matter, gases and solids
- Second law of thermodynamics; entropy and free energy
- Changes of state; phase diagrams
- Solutions
- Kinetics and equilibria
- Aqueous equilibria

There are many web-based educational tools available today that can be used in a variety of ways. Some merely assist in the management of traditional lecture courses, supplement the presentation of some of the material (for example, Authorware-based visualization[8]), provide question management and test construction (for example, Question Mark Designer[9]), or enable instructor-student conferencing on line (for example Alta Vista Forum[10] which has previously been used with considerable success in the Physics Department here at Michigan State University[11]). Other tools enable entire web-based courses for either local or distance learning (for example WebCT[12–14] –a development system that includes management and administration, material presentation, study guides, quiz and examination modules, online help, bulletin boards, chat rooms, and email).

The CAPA system described here proved to be the ideal solution for our students in CEM 141. This system is a specialized single component rather than a complete web-based program. It can be used in conjunction with other web-based tools, such as conferencing utilities or material presentation modules, to provide an entirely online program, or, as in our case, it can be used in conjunction with lectures and recitations in a more traditional course. The CAPA system is a sophisticated component[15] consisting of three parts: 'QUIZZER' is used to create questions and prepare personalized problem sets or examinations, 'GRADER' is used to record student responses and scores, and 'MANAGER' is used to create class reports and compile various statistical information. What distinguishes the CAPA system from many other computer-based generators of problem sets[16] is the variety and sophistication of question types that can be designed and coded. In addition to the more easily coded algorithm-based numerical questions[17] it is particularly well-suited to the design and coding of conceptual questions[18], with the inclusion of pictures, diagrams, and animations[19]. A key feature of the CAPA system is that it includes templates and tools which make it easy to generate hundreds (or thousands) of different questions from the same code[11,15]. Thus each coded question has many variants of which one is selected at random whenever that coded question is assigned. This ability to generate hundreds of similar random questions from a single code is essential in permitting open formative assessment problem sets[20].

A detailed description of the CAPA system is available elsewhere[1,2,11,18,21], and its use in a smaller enrolment chemistry course has also been described[22]. The system is under continual development and is available under licence from Michigan State University[23]. It is used in chemistry courses at several universities in North America (US and Canada) and to a larger extent in many physics departments.

The system used by our department is served by a Digital Alpha 433a workstation (433MHz) with 256MB RAM and two 9GB ultra-wide SCSI drives. Printing of the problem sets is done on an HP 8100 duplex laser printer. In this department, the CAPA system has been used in both semesters of general chemistry (CEM 141 & 142), in the first year laboratory classes and subsequent sophomore analytical and senior level analytical-physical laboratory classes, and in junior level physical chemistry courses for non-majors. Although this report concerns only the large-enrolment CEM 141 course, the benefits of the system in the encouragement of student activity and learning apply equally as well to classes of 20 as to classes of 2000 students.

Methods

Writing the Questions

The aim was to create a bank of coded questions from which an individual problem set of 10 would be distributed to each student during every week in which there was no examination. This is a total of eleven sets, or 110 questions. In any given week each student would receive the same set of coded questions, but the set would be unique to the student because of the random assignment of question variants.

The question bank now includes over 400 coded questions classified by topic. The questions are of four types and an example of each type is shown in Figure 1.

- TYPE I: Straightforward numerical questions that can be solved by the application of an algorithm or formula (which could be supplied by a friend or in an internet chat room). The inclusion of such questions in the question bank is useful because almost all the students benefit from practising such routine items. Furthermore these comparatively easy questions successfully encourage the poorer students in the class to try the more difficult ones, and the better students feel good about getting the answers correct quickly.
- TYPE II: More thought provoking numerical questions that require the student to think more deeply about the theory behind the calculation.
- TYPE III: Non-numeric questions that cannot be solved by applying an algorithm but are essentially tests of knowledge.
- TYPE IV: Problems testing conceptual understanding, often through the use of diagrams.

The Appendix provides descriptions of how large numbers of variants can be generated and randomly selected for each coded question.

Using the System

Each week in which there is no examination, the course instructor selects from the bank of coded questions a set of 10 which are at an appropriate level for that stage of the course and which includes an appropriate mix of the four types of questions. This constitutes the *problem set* for the week. The CAPA system then creates a unique version of the problem set for each student and prints the student's name and other course information at the top. The problem set is made available both online through the web and as a printed copy at lectures at least a week before the deadline. The deadline for the submission of answers was chosen to be the Friday of each week at 8:00 am. The CAPA system provides for an unlimited number and duration of logins at any time of the day. Upon login, students can try the current set, participate in discussion online, look at the answers to previous problem sets, or access their record. When trying the current problem

Figure 1: The four basic types of question

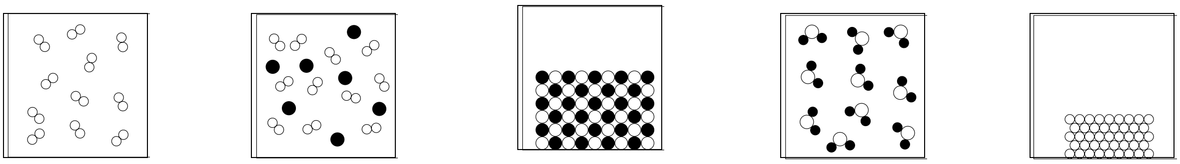
Type I What is the molar mass (atomic mass) of an element if 1.010 moles of atoms of the element have a mass of 119.897 grams?

Type II Suppose that the atomic mass unit (amu) had been defined as one-twentieth of the average mass of an atom of fluorine, instead of one-twelfth of the mass of an atom of carbon-12. What would the average atomic mass of magnesium be on this new scale? What would the value of Avogadro's number be using this new scale?

Type III Decide if the statements written are always true, sometimes true, or not true. Select A – always true, S – sometimes true, and N – not true. For example, if the first statement is always true, and the remaining questions are never true, enter ANNNNNN.

1 Compounds are molecules
2 A substance is pure matter
3 Elements exist as molecules
4 All molecules are diatomic
5 Molecules are made of atoms
6 Mercury is an element
7 Substances are either elements or compounds

Type IV Answer the following questions referring to the figures shown. The circles in the pictures represent atoms; different coloured circles represent different elements. Enter your answer as a series of five letters. For example, if the answer to all is A, then enter AAAAA.



A B C D E

Which figure represents a view, at the particulate level, of

1. Water vapour
2. A mixture of hydrogen and neon at room temperature
3. Nickel metal at room temperature
4. Chlorine gas
5. Crystalline sodium chloride

set they are expected to make mistakes and are allowed multiple attempts. The number of tries allowed for a question is a global or question-dependent variable set by the instructor (usually 10 or 15). The instant feedback and the opportunity to correct wrong answers immediately without penalty encourage the students to learn the principles of chemistry. The possibility of attaining a perfect score is highly motivating and students work hard to achieve it. The advantage of providing students with immediate knowledge of their progress is that they can do something about it, rather than waiting one or two weeks for the return of a manually-graded problem set, by which time it is too late.

The course is graded on a fixed and published scale. The accumulated score on the CAPA problem sets typically contributes 22% to the grade. The rest of the marks come from the recitation (8%), three mid-term exams (15% each) and the final exam (25%). Although the marks from the CAPA problem sets contribute to the total for the final grade, this summative component is intended primarily as a formative assessment tool– "a testing method without academic penalty that reveals shortcomings in students' understanding while allowing them to take responsibility for their own learning"[24].

Clearly the system relies on networked computer technology: students login to the server over the internet using a web browser, or telnet, and enter their responses remotely to verify their answers. The great majority of students (>80%) now use the web.

Results

Figure 2 shows the numbers of students for two Fall semesters (1998-1999) who obtained a given cumulative score from all 11 CAPA problem sets. It shows that approximately 25% of a typical course enrolment achieve a perfect score of 220. This reflects considerably greater effort than observed previously for manually-graded homework sets: 60% of students spent more (37%), or much more (23%), time doing CAPA problem sets compared to manually-graded assignments[22]. Figure 3 illustrates the hours during the day when students most frequently login to the system. The data show average figures over a three week period during mid-semester (weeks 5, 6, and 7) in the Fall of 1999 – a total of 113,233 logins. The most popular hours are from 7 to 11 in the evening with a maximum observed rate during this three-week period of 2395 logins/hour, a rate of more than one login per student per hour. Login rates increase as the deadlines approach.

Figure 4 shows the individual CAPA scores plotted against the final grade for the CEM 141 course in the Fall of 1998. It shows that it is rare for a student to obtain a grade of 3.0 or better without obtaining a CAPA score of at least 75% (165 marks). The CAPA results do not discriminate between the better students in the class; discrimination between the different grades results primarily from examinations. At grades of 2.5 and below, a few students obtain scores below 50%, though a similar number of students in these grades continue to score near-perfect scores. It is only in the failing grade (0.0)

Figure 2: CAPA Final Scores for CEM 141 Fall 1998 and Fall 1999

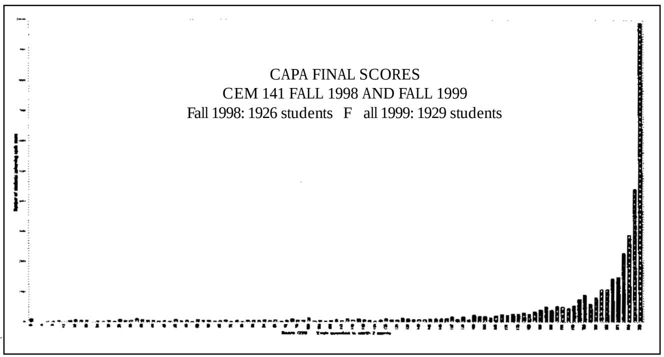


Figure 3: Distribution of logins over a 24 hour period

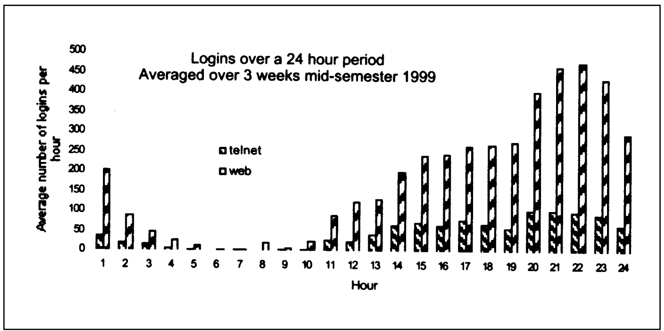


Figure 4: Correlation of Final CAPA scores and Final Grades

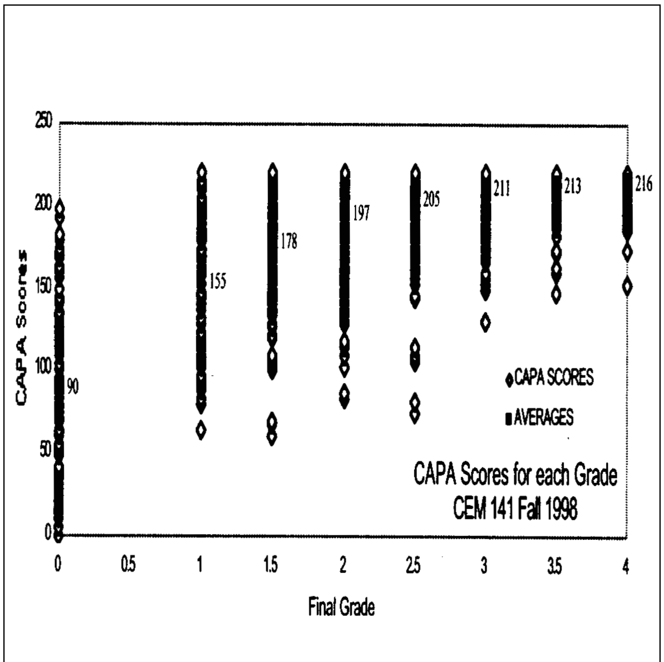


Figure 5: The range of degrees of difficulty for ten questions on a set

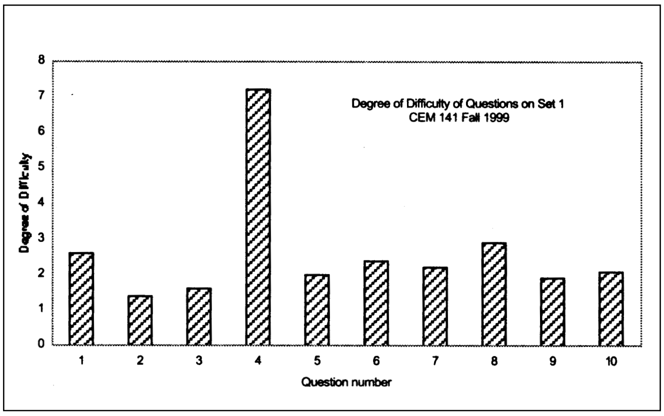
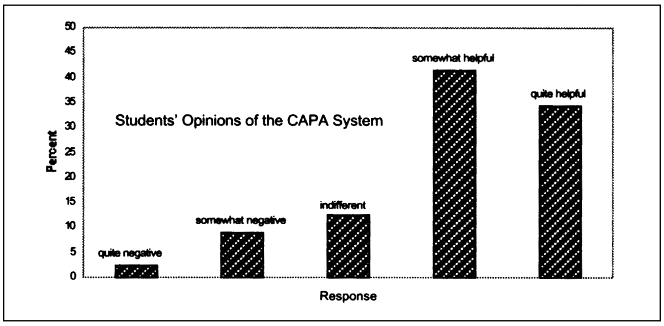


Figure 6: Students' opinions of the CAPA system



that the mean CAPA score falls below 50% (110), and even in this grade a number of students score nearly 90% in the CAPA tests. Thus, although there is a relationship between the *mean* CAPA score and the final grade, the lack of a tight relationship coupled with the high scores is good evidence that the CAPA problem sets encourage students across the ability range to engage actively with the subject throughout the course and that the CAPA problem sets are better characterised as incentive rather than assessment.

One of the many analytical features of the CAPA Manager is the determination of the degree of difficulty of a question equal to the ratio of the number of attempts to the number of successful responses. A typical range of degrees of difficulty is illustrated in Figure 5. An unusually high degree of difficulty has one of several causes: the question may involve material that was not, or has not yet been, discussed; the material may have been explained inadequately; the question may indeed be more difficult; or perhaps it is too easy for students to make random but incorrect guesses. Question 4 in Figure 5 generated considerably more attempts than other questions – almost certainly due to some early incorrect guessing. This question is a non-numeric TYPE III question (reproduced in Figure 1). Question 1 in Figure 5 is a simple numeric TYPE I problem with a slightly higher than average number of attempts; it asked for a calculation of a volume in cubic meters when length, width and height are all given in feet and inches. Invariably many students neglect to cube the conversion factor after calculating the volume in cubic feet or cubic inches. The value of the statistical and analytical functions of the CAPA Manager lies in the easy discovery of unrealised problem areas and possible misconceptions that students have of the subject matter.

Asked for their opinion of the CAPA system, students responded as illustrated in Figure 6 (mid-semester Fall 1999).

76% of the enrolment responded that the system was helpful, 13% were indifferent, and 11% were negative in their response.

The most common favourable written comments were "...helps me understand the material better.", "It makes me sit down and study the material.", "...forces me to keep up.", "...a way to make sure that I understand the key concepts.", "...doesn't punish you for getting the wrong answer.", "...can't think of a better way to submit homework for such a large group of students.", "...a great idea.", "...helps my grade.", "I prefer it to other forms of homework."

The few more negative comments were "CAPA questions should be more like those on the examinations.", "...tedious...frantic to find the answer rather than evaluating the problem.", "...doesn't prepare me for the examinations.", "...need more tries.", "CAPA stands for computer-assisted pain in the...but it encourages me to study the material.", "...takes too much time...one a week is too much."

In general, students' responses were overwhelmingly positive. Even those students who did not like doing the CAPA problems appreciated the satisfaction and reward of getting the answers correct.

Discussion

Student Study Patterns

The application of CAPA described here was intended to encourage the students to develop a regular study habit and to engage in co-operative discussions with other students. The number of logins and the overall CAPA scores show that the majority of students regarded the weekly tests as sufficiently important for them to work at them regularly–thus ensuring that the first objective was met. Furthermore informal feedback from the students revealed that during the most recent semester (Fall 1999) study groups have formed spontaneously in almost all the residence halls on campus. These study groups typically meet during the evenings once or twice each week. It seems likely that the students are encouraged to meet and study together because a favourable environment for collaborative work has been established[6,25]. As Ward and Bodner state: "*Students should never be rewarded because others fail. Nor should they fail because others succeed. It is possible to create an environment where students work together so that everyone who is willing to work can succeed*". In this case the co-operative environment is created by removing any competition to obtain the best grades (through the fixed grading scale and the opportunity for multiple attempts at each question) and by the varied style of question which encourages a range of intellectual activity.

Question Design

The question design is a key factor in determining whether the habit of regular study that is encouraged by the weekly problem sets actually results in effective learning. Thus the effectiveness of the CAPA system depends heavily upon the effort devoted to the design of questions and problems. This is perhaps more important for those students who are taking chemistry because they have to rather than because they want to. If a student's motivation is simply to get the correct answer, then the more the question compels the student to think and understand, instead of just using an algorithm or formula supplied by a friend or on an internet chat room, the more effective the question is in encouraging study. It is fairly easy to write and code questions that are straightforward algorithmic TYPE I problems and some of these are often useful–indeed they are included in our problem sets. However, as indicated in the Appendix, the CAPA system allows the generation of hundreds or thousands of variants of each coded question so that even with this most basic kind of question students cannot copy their answer from a friend, though they can often obtain the correct algorithm for calculating the answer in this way.

It is important to write TYPE II numerical questions that compel more thought by students. Figure 1 allows a comparison of this sort of question with a simple algorithmic TYPE I question on the same topic–the application of the mole concept. The TYPE II question, intended to be the more thought provoking, is in two parts; it requires consideration of how Avogadro's number is defined and what a mole is. As in the simple TYPE I equivalent, the question can be varied sufficiently to yield 2000 randomly different versions by randomly choosing the fraction, the first element, and the second element. When a problem has two required answers like this, it can be written as two separate but linked questions or as a single question requiring two answers, both of which must be correct. The increased thought provoked by this type of question is shown by the increased email traffic with instructors, increased student visits to the chemistry tutoring (help) room, increased postings on the student internet chat room, and the higher degree of difficulty revealed by item analysis: (Difficulty: TYPE I: 1.3; TYPE II: part 1: 3.0 and part 2: 3.2).

Non-numeric TYPE III questions designed to test knowledge are useful and are always included in our problem sets. Chemistry, at least to our freshman students, is a foreign language. As such, its vocabulary and syntax must be learned and practised–this is the lowest level, but a necessary one, in Bloom's hierarchy of educational objectives[4]. Non-numeric questions are included to encourage this learning.

Conceptual TYPE IV problems are often pictorial although they need not be–the ability to imagine the behaviour of matter at the particulate level implies an understanding of how and why things happen.

Overall View of the CAPA System

The use of the CAPA system in General Chemistry at Michigan State University has been a very positive experience. From the student's view, the immediate feedback, the possibility of retrying the problem if necessary, and the impact that success makes on his/her grade, all contribute to the positive feeling about the program. It has increased the amount of time and energy devoted to chemistry by the students and it has encouraged them to collaborate in their learning. The system requires an active study of the material–the fact that each student has a unique problem set requires each student to solve their own set while allowing co-operation and discussion between students. Students have to become responsible for their own learning and they are motivated by the fact that they can indeed ultimately get all the questions correct with no penalty for the number of their attempts. The weekly required completion of a problem set of ten questions keeps the student on track and up-to-date.

From an instructor's point of view the increased study done by the students, and the timeliness and regularity of their study, is rewarding. Furthermore it is now possible to monitor the progress of individual students and provide early warning of possible problems and potential failure on an up-to-the-minute basis.

Acknowledgements

The CAPA system has since its inception been developed under the leadership of Ed Kashy in the Department of Physics and Astronomy and the National Superconducting Laboratory at MSU. The work of Wendy Whitford and Steve Poulios of the General Chemistry Office in the day-to-day operation of CAPA is invaluable, as is the support of Guy Albertelli and Felicia Berryman, system coordinators of CAPA at MSU. This paper was presented in part at a conference at Michigan State University February 1999[26].

References

1. Kashy E Sherrill BM Tsai Y Thaler D Weinshank D Engelmann M and Morrissey DJ 1993 CAPA, An Integrated Computer-Assisted Personalized Assignment System *Amer. J. Physics* 61 1124–1130
2. http://capa2.nscl.msu.edu/homepage/
3. Nakhleh MB and Mitchell RC 1993 Concept Learning versus Problem Solving *J.Chem.Ed.* 70 190–193
4. Pritchett N 1999 *Effective Question Design, in Computer-Assisted Assessment in Higher Education* (eds. S Brown, P Race, and J Bull) (Kogan Page, London)
5. "Education is not the filling of a pail, but the lighting of a fire" William Butler Yeats (1865–1939)
6. Cooper MM 1995 Cooperative Learning, an Approach for Large-enrollment Classes *J. Chem. Ed.* 72 162–164
7. Kogut LS 1997 Using Cooperative Learning to Enhance Performance in General Chemistry *J.Chem.Ed.* 74 720–722
8. Galloway GL and Hunter PWW http://www.falconsoftware.com/Chemistry/ChemBonding/cbond.html
9. http://www.qmark.com
10. AltaVista Forum, Digital Equipment Corporation http://altavista.software.digital.com/index.htm
11. Kashy E Thoennessen M Tsai Y Davis NE and Wolfe SL 1998 Using Networked Tools to Promote Student Success in Large Classes *J. Engineering Educ.* 87 385–390
12. http://www.webct.com
13. Goldberg MW and Salari S June 1997 Current Practices in Web-based Course Development http://www.webct.com/library/full_paper.html
14. Goldberg MW 1999 WebCT White Paper http://www.webct.com/library/whitepaper.html
15. MSUCL-1133 Cyclotron Laboratory Document, Michigan State University 1999
16. Bowen CW 1998 Item Design Considerations for Computer-based Testing of Student Learning in Chemistry *J.Chem.Ed.* 75 1172–1175 and references therein
17. Hall PG 1998 Production of Numerical Chemical Problems using a Spreadsheet *J.Chem.Ed.* 75 243–245
18. Kashy E,Gaff SJ Pawley NH Stretch WL Wolfe SL Morrissey DJ and Tsai Y 1995 Conceptual Questions in Computer-Assisted Assignments *Amer. J. Physics* 63 1000–1005
19. Ashkenazi G 2000 *Integrating Personalized Simulation in CAPA problems CAPA as an Asynchronous-Learning-Network Tool* Michigan State University February 18
20. Thelwall M 1999 Open-Access Randomly Generated Tests: Assessment to Drive Learning, in *Computer-Assisted Assessment in Higher Education* (eds. S Brown, P Race, and J Bull) (Kogan Page, London)
21. Thoennessen M and Harrison M 1996 Computer-Assisted Assignments in a large Physics Class *Computers and Education* 27 141–147
22. Morrissey DJ Kashy E and Tsai I 1995 Using Computer-Assisted Personalized Assignments for Freshman Chemistry *J. Chem. Ed.* 72 141–146
23. http://capa2.nscl.msu.edu/licenses.html
24. Sly L and Rennie LJ 1999 Computer Managed Learning as an aid to Formative Assessment in Higher Education, in *Computer-Assisted Assessment in Higher Education* (eds. S Brown, P Race, and J Bull) (Kogan Page, London)
25. Ward RJ and Bodner GM 1993 How Lecture Can Undermine the Motivation of Our Students *J.Chem.Ed.* 70 198–199
26. Hunter PWW 1999 *Issues in a 2000-student Chemistry Course CAPA as an Asynchronous-Learning-Network Teaching Tool* Michigan State University February 27
27. Readers interested are encouraged to contact the author for the code for questions illustrated in this paper. Readers may also visit http://capa2.nscl.msu.edu/homepage/VariousProblems.html to try a problem set in chemistry

Appendix A Question Design and Coding

As described in the body of the paper, we characterise questions as one of four basic types:

- TYPE I Straightforward algorithmic
- TYPE II Thought provoking numeric
- TYPE III Non-numeric tests of knowledge
- TYPE IV Conceptual

Random and choose functions for numeric or string variables allow great flexibility in the design of questions[27]. A general strategy, for example, is:

/LET indx = random(1,4,1) //chooses a random value for indx from 1 to 4 in integer steps

/LET diatomic = choose (indx, "hydrogen", "chlorine", "nitrogen", "oxygen")

In principle it is the application of these functions that makes it easy to generate a great many individual questions from the same stem.

The code for a type I question, such as that shown in Figure 1, includes ranges of numbers from which other numbers are calculated. In all such cases the numbers are varied so that each student is provided with a numerical problem quite different from others in the class. For example, in the question illustrated in Figure 1, the value 1.010 is chosen at random from a range of 85 possible values and the number 119.897 is chosen from a range of 25 values. For a Type II question such as that shown in Figure 1, many versions can be generated by varying the identity of the two elements shown in the example as fluorine and magnesium. Other Type II questions do not involve the use of strings. An example is

Consider the reaction of nitric oxide NO with oxygen O_2 *to form nitrogen dioxide* NO_2*:*

$$2NO(g) + O_2(g) \text{ Æ } 2NO_2(g)$$

Suppose that a 3.0 liter vessel contains NO gas at 3.0 atm pressure. Suppose that a second vessel, 4.0 liters in volume, contains O_2 *at 2.0 atm pressure. Now suppose that the two vessels are connected by a pipe of negligible volume and the two gases mix and react to form as much* NO_2 *as possible. Assume that the gases behave ideally and that the temperature is the same at the end as at the beginning. What is the pressure inside the apparatus at the end of the reaction?*

This question requires a clear understanding of the principles involved. It invariably causes some anguish amongst students, requiring as it does not only their understanding of the relationship between the relative number of moles of a gas and its partial pressure but also their recall of the principles of stoichiometry and limiting reactants. The degree of difficulty (Fall 1999) was 5.8–the highest on the set. Algorithms can be written for the solution to numerical questions such as this (they are coded in the question). However, they are sufficiently complex to discourage their formulation by students.

In general, the sharing of algorithms by students may be circumvented by coding a sufficient number of random permutations of the question–altering the question stem, the variable to be evaluated, as well as the random values assigned to other variables – so that no single algorithm is available. For example, if a question tests the stoichiometry of a reaction then one of a series of similar but sufficiently different reactions can be chosen at random.

Other requirements and features are also coded in the questions, for example: the accuracy and precision required in the answer, the number of tries allowed on the question, the point value for the question, a hint provided if the student's first (or other number assigned by the instructor) response is incorrect, and an explanation of the answer made available after the closing date. These and other features of the code and the formatting of the problem sets using LaTeX are described in the CAPA User's Manual[15].

Type III non-numeric questions such as that illustrated in Figure 1 invariably involve a mapping function that scrambles sets of variables based upon a randomly generated seed, thus ensuring that a large number of individual questions can be created from the same stem.

A Type IV pictorial problem is illustrated in Figure 1. It provides views at the particulate level of substances and mixtures in different states and the student is required to match the pictures with the appropriate description. The CAPA system facilitates the coding of questions such as these. In this question, the five diagrams are chosen from eleven possible, the names of the substances involved are chosen at random, and the order of the pictures and questions is randomly mapped–giving rise to hundreds of quite different versions of the question. The task for the instructor is only to draw a sufficient number of pictures and write a sufficient number of possible examples to match. The incorporation of figures and diagrams as eps files in CAPA questions is straightforward – some other examples are shown on the CAPA web site[27].

Preparing for the Chemistry Laboratory: An Internet Presentation and Assessment Tool

PAPER

George M. McKelvy

School of Chemistry and Biochemistry, Georgia Institute of Technology, Atlanta, Georgia, 30332-0400, USA
e-mail George.McKelvy@chemistry.gatech.edu

Video recordings have been made to prepare students for 43 different laboratory exercises carried out by students taking the first semester course in Introductory Chemistry. Each exercise-specific video includes an introduction describing the purpose of the exercise, details of the laboratory procedures involved, and representative calculations. Each video is packaged with a pre-laboratory quiz and the whole package is made available to students over the web using the WebCT system. The preparation of the package is technically simple (needing no specialised skills), easy to update, and inexpensive to produce (relative to the usage it gets). Both students and Teaching Assistants have been found to benefit from their usage of these packages.

Introduction

The value of laboratory courses in chemistry has been questioned on the grounds of both cost and effective learning for more than 20 years[1]. The first published attempts to improve student learning appear to have involved improvements to the structure of laboratory manuals and the way in which laboratory work is presented to the students[2]. However, Pickering describes pre-lab quizzes or pre-lab talks as "the classical way to prepare students [for laboratory work]"[3], thus implying that the importance of proper preparation was well recognised by 1987. One example of a pre-lab quiz was described by Kolodney and Bayly[4]. Merritt et al[5] introduced a requirement that students prepared themselves actively by submitting an 'experimental plan' for the instructor to evaluate before they carry out laboratory work. By 1997 Johnstone[6] argued that there is "*no point in putting a student into a laboratory without mental preparation*", and that "*the nature of the preparation has to be as carefully thought out as the course itself*". Clow[7] has presented the virtues of computer-based pre-labs, of which one example has been published by Nicholls[8]. Others have experimented with the use of videos. For example Joesten produced videotapes for students to use for pre-laboratory instruction, but subsequently dropped the programme because of the constraints on students' time[9]. Rest has produced a series of high quality videos of a range of common laboratory techniques, and these are published as videodiscs[10]. The advantage of this technology is that it is possible to define and select any desired sequence using a bar chart reader, and according to Rest[11] the video discs are widely used throughout the UK as an adjunct to laboratory work. In at least one case, clips from these videos have been incorporated into packages designed to support the teaching of a first year laboratory course in physical chemistry[12]. These packages are delivered by CD-ROM and incorporate theory, worked examples, and a computer-marked test.

Students at Georgia Institute of Technology are no different from others in that they need to be mentally prepared for their laboratory work. Two particular aspects of the first year semester course on Introductory Chemistry do not apply to most examples of pre-lab work quoted above, and merited special thought. One is that the number of students is in excess of 1400 during fall semester and the laboratory instruction is spread over a 15-week period. During the semester, each of the 1400+ students completes 21 of the 43 exercises in the laboratory manual. Each student attends one three-hour lab session in each week of the semester giving a total of 13 sessions. In order to fit this number of students into the laboratory, they are allocated to one of 75 separate sessions held each week so that the number of students present at any time is 20 – 24 (there are three different lab sessions on each of five days, and these run in five separate laboratories, giving a total of 75 sessions). The students are supported by one graduate Teaching Assistant (TA) in each session. The second unusual aspect of the course is that at least half of the TAs who teach the course are not native to the USA and their first language is not American English. Many of these TAs may have never previously carried out, or even come across, the particular laboratory exercises on this course and therefore need training.

It seemed that a web-based package would be the most efficient way to deliver material suitable for both training TAs and also preparing a very large class of students. Analysis of the needs of both groups of learners suggested that an effective pre-lab experience for each different laboratory exercise would

- explain the purpose of the exercise and review background theory
- demonstrate the procedures to be used
- provide help with the calculations
- provide feedback for the users on their level of preparedness
- provide access for the students to the instructor so that they could raise queries.

The WebCT system seemed to provide the specification necessary to deliver all these aspects of pre-lab work. WebCT is a commercially available product which “offers colleges and universities a total solution across the learning enterprise by (a) providing faculty with the best tools for building online curricula; (b) connecting students with an integrated Web-based learning environment; and (c) supplying publishers an ideal platform on which to provide the richest variety of content”[13]. The Georgia Institute of Technology holds a site licence for this package, so that it was immediately available.

Methods

The material was planned to exploit the availability of two servers at the disposal of the faculty. There was a WebCT server to create, host and archive campus courses and a Real™ video server to host and archive html and real data for multi-bandwidth streaming. Fifteen three-hour laboratory sessions are scheduled each week and one site for each was placed on the WebCT server. Each of the sites is a copy of one template which has been archived for use as a backup. These sites are maintained by a departmental ‘web master’ and include the ‘Instructor’s Home Pages’ which is a hyperlink to the Chemistry Department server and the individual instructor’s materials (including biography, current research, publications, course syllabi, homework assignments, old examinations). The student also has access to a link to the glossary from the currently used textbook[14] and to an image database with images scanned from the textbook to serve as visual references (provided with permission of the publisher). The use of bulletin board tools allows students or the instructor to ask questions or to speculate on techniques and calculations. Useful as these resources are, the main part of the pre-lab package is accessed via ‘On-line Pre-labs’ which provides a path within WebCT that takes students to a table-of-contents; this lists the pages which show each week of laboratory work for the semester. Pages within this path contain the pre-lab work for a particular week’s work and includes video material and quizzes.

Web-ready pre-laboratory videos were recorded with a JVC .5" IT 3-CCD S-VHS camera, a JVC S-VHS recorder/player deck, a Bogen™ 3068 Universal Cine/Video tripod with 3066 fluid head, and a Lowel™ Tota/Omni 3 light kit with 450-watt bulbs. The material was edited using Adobe™ Premiere 4.2 software on a Macintosh™ PowerPC 9600/233 with 160 MB DIMM, 4GB internal HD, 4GB external SCSI disc array (since upgraded to 64GB), a Targa™ 2000 Video Card, and an Apple™ 1710 17" color monitor. The edited material was encoded using Real Producer Pro® which enables it to be streamed at 200 kilobytes per second (kbps) for use on the campus local area network (LAN). Over 90% of the freshmen live on campus and all are required to bring their own computers equipped with internet access hardware and software. Since every dorm room on campus is wired to the LAN, students can access the pre-lab sites at any time of the day or night. By fall of 2000 it should be possible to encode the videos into multiple bandwidths for viewing from off campus as well. Once this has been done, students may access them from any place in the world with Internet access. Until then, computer clusters are available with headphones and web access for those who live off campus. The use of the Real format also adds to the security of copyrighted material for on-campus use.

The video material consists of a general introduction to the laboratory course and to safety issues, and separate video for each of the 43 exercises listed in our laboratory manual[15]. Each exercise-specific video is incorporated into a single page on the WebCT server and consists of three parts:

- an introduction describing the background to or purpose of the exercise;
- laboratory procedures including chemicals, apparatus, safety considerations, and residue disposal;
- representative calculations.

The average video lasts six to eight minutes, may be viewed an unlimited number of times, and may be paused, rewound, and fast-forwarded. Undergraduate students act as presenters in the videos and visually walk students through the laboratory exercise showing techniques, apparatus and calculations. We chose to use undergraduate students to present the material on tape because we felt that students often listen to each other and understand what their peers are saying better than they do with academic staff even when the words are exactly the same. Our primary criteria for selecting presenters were their ability to read aloud well (clearly and distinctly) and their successful completion of the Introductory Chemistry course on our campus.

On the same page as the video is a pre-laboratory quiz. The quizzes are worth 10 percent of a given lab grade and can contain anywhere from three to ten questions. The question format is variable and may include short answer, discussion, single response multiple choice, multiple response multiple choice, matching, or calculations with randomly generated numerical values. The quizzes become available to students beginning one week prior to the scheduled laboratory period and are unavailable two hours prior to lab. Quizzes may be taken only once, but students choose whether to take the quiz simultaneously with or independently of viewing the video. They are ‘open book’ and ‘open note.’

While the value of the quiz grade may seem low (10%), it appears to be enough to encourage students to take the quiz without cheating. The quiz grade is immediately available to the student and the lab TA. A student may also access any other grades the TA may have imported into the database. It is here that students may see class statistics and note their own ranking among their classmates.

A tool named ‘Class Experiments’ allows class data to be collected and distributed to each member of the section. A ‘mail-form’ is incorporated into pages within the Class Experiments path. For selected experiments students enter data as it is collected into the form in WebCT on a computer in the laboratory and this is then immediately e-mailed as a text file to the TA who checks the data, makes notes, and forwards the form on to each member of the section. The students then use data from the whole class in writing their own reports.

Results

TA Response

Viewing of the videos by the TAs is entirely voluntary. Nevertheless, all of them report that the videos provide a valuable way to prepare themselves for their teaching role. They particularly value the flexible access which allows them to study the videos at a time and place of their own choosing. They find the explanations and discussions are extremely helpful in enhancing their understanding of the terminology. As an example of the use of constructive use of videos by TAs, a group of four Chinese TA's informed the lab manager that they get together as a group, watch the video several times, discuss the language and techniques, and anticipate questions that their students might ask.

Student Response

Before we introduced the on-line pre-lab material, it used to take as much as 40 minutes of the three-hour lab session for the TA to provide information and before students could start their work at the laboratory bench. This time was spent finding out what lab they are doing, reading the procedures for the first time, asking questions of fellow students, gathering materials, etc. The introduction of the WebCT tools has greatly facilitated the flow of the laboratory exercise. TAs report that the 'time on task' is substantially higher and there are fewer questions regarding techniques and calculations.

The mark associated with the quizzes provides sufficient incentive for all the students to complete these. Since the questions are linked to the videos and the laboratory manuals, the quizzes encourage students to read their lab manuals and view the videos prior to lab. However, the quizzes are responsible for most of the negative responses regarding the use of WebCT. The problems centre around two main concerns:

- short answer questions where the student response must *exactly* match that in the program;
- calculating answers where students are not in the habit of concerning themselves with the proper use of significant figures.

They have very little trouble with matching, single- or multiple-response multiple choice, matching, or True/False questions.

Discussion

The technology needed to create this resource is neither prohibitively expensive nor is it difficult to use and can be made even more advantageous with institutional collaboration. If two or more colleges or universities are doing the same or very similar laboratory exercises, the videos could be non-institutional-specific. With the exception of an orientation video, much of the material produced on our campus may be transferable to others using the same laboratory manual. What is needed most, however, is a well-defined and carefully thought out script. Two persons worked on writing the scripts from a selected set of labs in our lab manual[15]. Each person wrote a script alone and then passed it along to the other for review. When the two were satisfied that the content was acceptable, a third person was brought in to read the script aloud. This ensured that what was envisioned in printed word sounded correct on tape.

The preparation of a script took 2-3 hours for each exercise-specific video, filming took another 2-3 hours, and editing took a further 4-5 hours (shorter now with Adobe™ 5.1RT software). This investment of time results in material which can be used each year (three terms per year if semesters and four terms per year for quarters) for as long as the particular lab manual it was scripted from remains in use – often 5 years or more. When one considers that a video which took 8 to 12 hours to produce is being used for at least 15 terms and with countless numbers of viewings, the time investment is very reasonable. In contrast to the computer-based pre-labs such as those described by Nicholls[8] and Tomlinson et al[17], this approach does not rely on the availability of a skilled computer programmer. All the equipment needed both to create and disseminate the video packages is simple enough to be operated by an academic with enthusiasm. The results may look less professional than the videos created using the substantial resources available to the Chemistry Video Consortium[10]. However, academic chemists from other departments have been impressed by the quality, and have agreed that the low-cost approach has not significantly reduced the value of the product.

A further advantage to this approach to pre-lab work is that it is extremely easy to edit and update each video. Should a procedure or apparatus in a particular experiment change, two options are available to accomplish the update:

- if the original undergraduate presenter is still available, the changed segment can be filmed again and the changes edited into the video; or
- if the original presenter is not available, the entire script can be filmed again, using the original graphics and data with a new presenter.

The approach described here does not depend critically on using WebCT, since other modes of delivery are available. These include Blackboard™[17] which has just acquired Madduck, Inc., and its product Course-in-a-Box; SocratEase™ by Eutectics Corporation[18]; convene.com; Educator® by Ucompass.com; ecollege.com; eWebUniversity.com; and e-education.com, to name a few.

We have found, however, that WebCT is easy to use, is password protected, is viewable with either Netscape™ or Internet Explorer™ browsers, is flexible in that it is easily edited and tools can be added or subtracted as needed, and is relatively inexpensive.

Conclusion

Experience indicates that anyone wishing to increase the quality of the learning experience from lab work would do well to consider the following points:

- providing a proper and safe laboratory environment;
- supplying a set of meaningful and well written experimental procedures;

- connecting the laboratory exercises to the Chemistry lectures;
- providing the students with information and assessment regarding lab in such a manner as to provide time to reflect prior to assigned laboratory time;
- provide a mechanism for questions and feedback in an unstructured environment;
- provide access to grades in a timely yet secure manner; and
- make the process of learning as timely and as meaningful as possible.

The institution provides the laboratory environment, the authors supply the experimental procedures, and the laboratory manager or laboratory instructor connects the lab to the lectures. The use of an on-line process for providing information, assessment, bulletin boards, chat rooms, and grade databases is critical in making the learning timely and meaningful. Students may spend as little or much time in preparation as they deem necessary, but they are encouraged to prepare and are provided with every mechanism to do so.

References

1. Johnstone AH 1979 A model for undergraduate practical work *J. Chem. Ed.* 61 847–849
2. Johnstone AH and Wham AJB 1982 The demands of practical work *Educ. Chem.* 19 71–73
3. Pickering 1987 1987 What goes on in students' heads in lab? *J Chem Ed* 64 521–523
4. Kolodney N H and Bayly R 1983. Enhancing laboratory experience in introductory chemistry with Apple-based pre-lab quizzes *J. Chem. Ed* 60 896–897
5. Merritt MV Schneider MJ and Darlington JA 1993 Experimental design in the general chemistry laboratory *J. Chem. Ed.* 70 660–662
6. Johnstone 1997 And some fell on good ground *U. Chem. Ed.* 1 8–13
7. Clow DJM 1996 *Computer simulations of laboratory experiments* D Phil Thesis, University of York
8. Nicholls BS 1999 Pre-laboratory support using dedicated software *U. Chem. Ed.* 3 22–27
9. Joesten MD Vanderbilt University, Personal communication.
10. Rest AJ (ed) 1995/96 *Basic Laboratory Chemistry Educational Media Film and Video Ltd,* Harrow, Middlesex
11. Rest A J University of Southampton, Personal communication
12. Brattan D Mason D and Rest AJ 1999 Changing the nature of physical chemistry practical work *U. Chem. Ed.* 3 59–63
13. http://about.webct.com/company/tech.html
14. Oxtoby DW Freeman WA and Block TF 1998 *Chemistry: Science of Change 3rd Edition*. (Saunders College Publishing, Philadelphia).
15. Hunt HR Block TF and McKelvy G 1998 *Laboratory Experiments for General Chemistry 3rd Edition.* (Saunders College Publishing, Fort Worth)
16. Tomlinson J O'Brien P and Garratt J Computer software to prepare students for laboratory work *J. Sci. Ed.* in press
17. http://www.blackboard.com
18. http://www.eutectics.com

Getting a better picture: using video to improve the presentation skills of chemistry students

PAPER

Brian Grievson and Nigel D. Lowe

Department of Chemistry, University of York, Heslington, York, YO10 5DD, UK e-mail NL6@york.ac.uk

We have introduced video recording as a routine method to help all our chemistry undergraduates to improve aspects of their presentation skills within our 3rd-year group exercises, structured learning packages. The ten-minute talks given by all teams are recorded and each team receives a copy of their own talk for review. Teams are encouraged to reflect on their recorded talk by requiring them to complete a pro forma analysing the good and bad points of their presentation. Written feedback from students provides evidence that they recognise the benefit of this exercise. We now intend to use video recording routinely in the delivery of these exercises.

Introduction

We have previously described how the format of a *structured learning package* (SLP) encourages our 3rd-year students to improve their personal key skills, in a chemistry context, by giving them the opportunity to complete back-to-back tasks, involving teamwork, oral and written communication, problem solving and information management, over the two distinct stages of the exercise[1]. This allows them to improve their skills after periods of reflection on their experience and in response to guidance from both tutors and peers.

Students participating in an SLP are each expected to devote some 40 hours of their time to the tasks and this is spread over a period of 3-4 weeks. The organisation and management of an SLP has been described previously[1]. For the purpose of this paper the key organisational feature is that approximately halfway through this period, the class meets for the four, or five, teams involved to deliver their first 10-minute team presentations to the rest of the class. Each team presentation must involve all members of the team. The learning experience in this session is enhanced through the following measures:

- the talks are formal and assessed;
- the audience comprises the balance of the class (around 20 students) and two staff, making a more sizeable audience than many will have encountered before;
- the overlap between the technical content of each talk ensures that the audience and the speakers have a comparable level of expertise providing a more critical audience for the talk, and simulating some of the pressures of delivering a ‘real world’ presentation;
- teams in the audience take turns in leading the questioning of the presenting team at the conclusion of each talk; the four or five presentations are delivered sequentially with intervening periods for these questions;
- there are questions for each team from the tutors present;
- attentiveness in the audience is prompted by revealing, at the start of the talks session, that the second stage of the SLP builds on the information presented by *all* the other teams;
- when all complete, the talks are followed by a class-wide brainstorming session on the good and bad points of presentation style with the advantage of generating a sense of ownership within the class about what defines a good talk (and avoiding the tutor producing a *prescription* of good practice);
- the latter discussions are summarised by the introduction of a detailed marking scheme to be used to assess the second talks.

Our experience suggests that this procedure works well; individual written testimonies provided by students at the end of the SLP[2] suggest that improved presentation skills are already the major perceived benefit. However, some students suggested that they would benefit from seeing video replays of their presentations. This technique is widely used in other disciplines (e.g. medicine and dentistry[3], teacher training etc.) and in company selection and training schemes. A search of the Internet and other databases quickly brings to light numerous cross-disciplinary examples of using video recording to enhance communication skills. Our view was that by responding positively to the students’ suggestion we could encourage constructive reflection on the lessons brought out during the brainstorming session which concludes the first set of presentations.

This paper describes how we have introduced and supported the use of video, and how the students perceive the benefits.

Methods

Since the introduction of the video recording, the students are informed in the opening session of the SLP that their first talk will be video recorded. We are careful to stress that each team will have access only to a copy of their own talk and that staff will make no use of the recording other than to provide guidance for students when requested. In other words, we make it clear to teams that the use of video is for their benefit, not ours, and we emphasise the potential benefit of retrospective reflection and analysis of their performance in giving talks.

We introduce the first session of talks by reminding the class about the video and demonstrating the field of view of the camera to encourage speakers to remain within the frame. The camera used is a tripod-mounted digital device which has the benefit of being small and unobtrusive. It is left running throughout the whole session to minimise any further distractions. After the completion of the talks, a class discussion is led by tutors to identify the learning points which have arisen with regard to giving presentations. The style of this is unchanged from the procedure used prior to the introduction of video to the exercise, as described above. Separate VHS tapes are prepared from the digital master so that each team can be given a copy of their own performance during the talk and post-talk questions. The teams receive email advice when their individual VHS tape is available for collection. At the same time they are provided with some feedback from the tutors on their team's performance and with a blank *pro forma* (reproduced as Table 1) to be completed by each team and submitted before the second presentation. The *pro forma* is designed to encourage students to review the tape constructively by reminding them that their first attempt is likely to have included several positive features which they will want to retain and build on in their second talk, and by asking them to concentrate objectively on identifying areas for improvement which they will address in the second talk. We offer to arrange for teams to use a room and TV/video facilities in the department for purposes of viewing the video tape though some make their own arrangements.

The completed *pro formas* provide useful information about the students' perceptions of the lessons they have learned. Further feedback was obtained from the individual testimonies which are an integral part of the SLP[2] and are written in response to the instruction:

'Describe how you have contributed to this team exercise and how the experience has allowed you to use, and develop, your key skills.

You should use this as an opportunity to practise writing about your achievements and also as a reflection on the exercise to identify where, and how, you have improved and where you perhaps need to concentrate on further improvement in the future.'

A final form of feedback is available from the voluntary response questionnaire handed out at the end of the SLP which includes one question specifically about the use of video and another about the development of communication skills.

Table 1: *Pro forma* for completion alongside the review of the team presentation video

Structured Learning Package: Review of presentation video

You are supplied with a video of your team presentation and question session. Please view the video and reflect on your performance by answering the questions below. You should compare your performance with the general points of good and bad practice which were discussed after the talks, and with additional points raised in the handout supplied. Can you identify any specific issues? The object of this exercise is to enable you to identify areas where you personally can improve your presentation technique. The areas for improvement that you identify should be incorporated into your next presentation.

Team number: SLP Topic:	
After viewing your video, identify aspects of your presentation that were *effective* in getting your message across to the audience. (If necessary, please use the back of this sheet)	
Identify specific aspects of your presentation that are examples of not effectively getting your message across to the audience. Do any other issues arise as a result of viewing your video that were not apparent at the time?	
Hence, decide on the four main aspects that your team will target for improvement in the second presentation.	Action point 1: Action point 2: Action point 3: Action point 4:

Results

After an initial and understandable reticence, the students display a general stoicism towards facing the video camera. We take this as an encouraging sign that the benefits are self-evident to the majority. One or two of the comments discussed below show that some students find the process of watching themselves more excruciating than others, which is only to be expected.

The written responses provided on the *pro forma* provide reassuring evidence that the students do more than simply regurgitate a few standard presentation tips and are actually responding to the opportunity to review their performance. This evidence is of two kinds. First, the actual number of recorded comments strongly suggests that something more than a cursory run through of the video had taken place: for example, in response to the second section, addressing aspects of ineffective presentation, an average of four points was raised by the 19 responding teams. The second type of evidence comes from the nature of the comments; these often referred to aspects which had not been raised in the class review of presentation skills, and, where more standard faults were highlighted, they were supported by actual evidence from the video recording. This convinces us that the students were not simply reproducing views and comments previously aired in discussion, but were viewing the videos constructively for their own benefit. Selected comments are shown in Table 2. The video seemed to be particularly effective in highlighting deficiencies in visual aids, from crowded overheads to the issue of no overhead at all, where students observed themselves talking alongside a large, blank square of light!

Despite this being a team response to viewing the video, some teams were occasionally prepared to single out their members in order to praise particular aspects of their contribution (an example is given in Table 2). Understandably, no blame was apportioned to specific individuals for detracting from the overall team performance. However, within the privacy of their own reflections on the exercise (in their individual testimonies), several individuals do recognise that their own below-average presentation skills have reduced the impact of the team's efforts. Consequently, we have evidence that whilst we currently ask for a team response to reviewing the video, the process does provoke individual ruminations about performance levels within the peer group. The value of this, of course, lies not in exposing the poorer performers but in revealing to them *how much* they can improve and, indeed, *how* they can improve. Other comments on the video review *pro forma*, and in the individual testimonies, suggest that an important aspect of the exercise is the way the poorer performers improve by virtue of learning directly from observing their more successful peers in action. We feel that this aspect is enhanced by the structured review of the video which the teams now undertake.

Table 2: Some 'good' and 'bad' points drawn from student *pro forma* responses.

Good

"Displaying 'method of attack' – showing the order we presented our sections in"

"Andrew linking together the different sections"

"Everyone knew what the other team members were doing"

"Presentation structure was logical and well-ordered, meaning that the talk was easy to follow"

"Paul pointed out certain points on the diagram making sure that everyone followed"

"Joint question answering – everyone in the team was well informed on all aspects"

Bad

"Other group members standing behind draws attention from the speaker"

"Too much information, likely to lead to people switching off"

"Sometimes there was nothing for the audience to look at"

"We had a tendency to look away from the audience and speech was often lacking enthusiasm"

"Not taking an interest when the rest of the team is talking"

"Some of us fiddled with our jumpers, hair etc., spoke into the OHP screen, and fidgeted"

The voluntary-response questionnaire was issued to 76 of the students engaged on SLPs, with 46 (61%) of these responding. The questions covered several aspects of the SLP exercise with two relevant to the use of video in improving communication skills. The wording of these questions was:

Qu.9 With respect to oral presentation skills, did you find the use of video recording helped you to identify areas for personal improvement?

No   A little   A lot

Qu.4 Did the exercise result in improvement to your knowledge and skills in the area of oral communication skills?

No   A little   A lot

The 46 student responses to these questions are shown in Figure 1. Only one student answered '*No*' to question 9. 21 (46%) chose '*A little*', and 24 (52%) '*A lot*' (Figure 1). 22 respondents volunteered an additional comment about the use of video. Two of these were critical of the way we had used video (one wanted better playback facilities, the other urged us to "make it clear that it [video] is for our benefit"), and a further three were comments from students who found the procedure particularly embarrassing! The rest provided some typical examples of how the respondents felt they had benefited from the process.

In response to question 4, 18 (39%) of the 46 responded '*A little*', and 28 (61%) '*A lot*'. Of this latter 28 respondents, 10 (36%) responded with '*A little*' to Qu.9, and 18 (64%) with '*A lot*'. This provides some evidence that the students who felt they had improved most in oral presentation skills did so by benefiting most from the video recording (Figure 1).

The third approach to assessing the impact of using video was to look at the 'individual testimonies' written by students as part of their reflective review of the completed SLP. We received 98 such testimonies. Of these, some 32 (33%) made specific mention of the role of the video in improving their presentation skills; a remarkably high proportion when the range of possible topics is considered.

Figure 1: Breakdown of student questionnaire responses to oral presentation and video questions.(Horizontal bars show the number of respondents who felt the exercise had improved their oral presentation, either 'a little' or 'a lot', and the shading indicates the extent to which the use of video was perceived to have helped)

Discussion

We are encouraged to find that 98% of respondents recognised the positive contribution of video to improving oral communication skills when questioned specifically about it. We regard it as equally striking that as many as a third of all participants single out this particular innovation for comment when asked to reflect on the impact of the *whole* exercise. The detail of some of the comments in the individual testimonies is also revealing about the ways in which some individuals benefit from reviewing their performance in this way. It is far too subjective to venture any opinion on whether or not we noticed any improvement in the actual standard of second presentations compared with the previous years when the video was not used. However, we are confident that the evidence presented above confirms that we have achieved our aim of making the learning of presentation skills a more reflective and involving process for the students. In achieving this, we would draw attention to the role of the *pro forma* in encouraging a reflective approach to learning from the video recording.

Set against the perception of improved learning is the extra workload involved in managing the video process for students and staff. For staff using our mode of operation, this comes principally in transcribing the digital master tape onto individual VHS tapes for each team, in distributing and recovering these with the *pro forma*, and in arranging the departmental facilities for some of the teams to view their video. This additional effort cannot be dismissed in a course which is already quite intensive in its demands on staff time. However, these additional tasks could all be devolved to technical staff where such support exists.

The feedback we have received has convinced us that a significant number of students are helped by the introduction of video recording of their talks. In our view this benefit more than offsets the small increase in workload and we intend to make it a permanent feature of the course. We hope the positive experiences described here will be helpful to others considering the introduction of similar technology

Acknowledgements

We are grateful to the Teaching Innovation and Development Committee of the University of York, for supporting the purchase of video equipment. From the Department of Chemistry, we thank John Olive, for help with the recording of talks and the reproduction of VHS tapes for student use, and Dr. Simon Duckett for helpful discussions.

References

1. Duckett SB Lowe ND and Taylor PC 1998 Addressing key skills in the chemistry curriculum: structured learning packages *U.Chem.Ed.* 2 45–50
2. Lowe ND 1999 Reflecting on learning *U.Chem.Ed.* 3 76
3. Feather A and Fry H 1999 in: *A Handbook for Teaching and Learning in Higher Education: Enhancing Academic Practice* (eds. H Fry S Ketteridge and S Marshall) (Kogan Page, London)

Misconceptions about Error

COMMUNICATION

John Garratt, Andrew Horn, Jane Tomlinson,

Department of Chemistry, University of York, Heslington, York, YO10 5DD Telephone: 01904 432551 e-mail: cjg2@york.ac.uk

First year students have been introduced to Least Mean Squares Linear Regression as part of a laboratory exercise in which they determined $\Delta H^{\ominus}$ from measurements of an equilibrium constant at different temperatures. We took the opportunity to obtain feedback concerning student understanding of the value of using an objective (statistical) method for fitting a line to experimental data and of the meaning of 95% confidence limits. 65 students have provided feedback by writing short comments as part of their laboratory report. Our analysis of these responses indicates that a majority of the students believe that the use of LMSLR increases the accuracy of (or reduces the error in) the calculated results, and that a large proportion hold confused views of the meaning of confidence limits. We conclude that these misconceptions are illustrative of a broader range of misconceptions about the origins and consequences of experimental error, and that these are significant barriers to learning.

Introduction

Goedhart and Verdonk[1] report that their first year students *"experienced large difficulties in performing error calculations"*. From their description of the difficulties, it appears that they expected their students to have gained from lectures a rather sophisticated understanding of statistical methods used in error analysis. However, their research into students' interpretations of statistical concepts indicated that their expectations were misplaced. They concluded that *"students interpret errors in a personal context: they think they are responsible themselves for measurement errors. This interpretation was not changed after the lectures in statistics, even if attention was explicitly drawn upon the meaning of error in statistics"*.

Our own experience with giving lectures on statistical procedures was sufficiently discouraging that we tried an empirical approach. We wrote a computer program which allows students to investigate for themselves some key concepts of common statistical procedures[2]. An underlying assumption behind our computer-based package is that students have a general appreciation that random error is a feature of experimental measurement, rather than being what Goedhart and Verdonk refer to as 'personal errors'. Our package had a mixed reception from second year students[3], and this may have been partly because we had not taken proper account of the students' misconceptions about error and error analysis. Therefore, when we devised a new strategy for introducing our first year students to the potential value of Least Mean Squares Linear Regression (LMSLR), we decided to give them the opportunity to reveal some of their misconceptions most relevant to the exercise in question.

We report here our initial conclusions, which have stimulated us to undertake a more detailed study.

Methods

The laboratory exercise which we intended to use to introduce linear regression involved measuring the equilibrium constant for the dissociation of ammonium carbamate at different temperatures, and calculating $\Delta H^{\ominus}$ for the reaction from the slope of a graph of lnK against 1/T. We assumed that all students would appreciate that, where a linear relationship between two variables is expected to exist, real data will not fall on a straight line because of the existence of experimental error. We further assumed that (most) students would have some experience of choosing a line to fit real data, though we expected that different students would have different criteria for judging the 'best' fit. We did not expect (many) students to be familiar with the concept of confidence limits, or with statistical (objective) procedures for drawing straight lines.

We took the view that, during the students' first term, it was inappropriate and unnecessary to deal with the mathematical basis of statistical theory and practice. We wished the students to appreciate the following key points:

- Fitting a line 'by eye' (i.e. subjectively) is not satisfactory because the criteria of 'best fit' cannot be described, and therefore any subjectively fitted line cannot be reproduced.
- There is a correct value for $\Delta H^{\ominus}$ for the reaction concerned, but experimental error leads to lack of confidence that the 'best' value for the slope gives this correct value; it follows that it is useful to quote a *range* of values that is likely to include the correct value. (We are aware that statistical procedures for fitting lines to data cannot take account of systematic errors).
- Least Mean Squares Linear Regression (LMSLR) is a generally accepted procedure for fitting straight lines to data; computer programs can use the criteria of LMSLR to calculate the 'best fitting' slopes and intercepts together with 95% confidence limits to these values.
- Two criteria are used to fit lines by LMSLR. One is that the line passes through the point x, y. The other is that the slope is determined by minimising the sum of squares of all the differences between observed and calculated values of y. Whether these criteria are or are not appropriate to the data is a matter of judgement.

- 95% confidence limits can be decreased by reducing experimental error or increasing the amount of data collected.

We decided that the best way to help students to understand these general principles was through the use of computer software which we developed for this purpose. This offered the following specific benefits:

- The computer allowed unique opportunities for the active involvement of the student in the learning process.
- The program could easily provide students with different sets of data to examine.
- The computer would force us to rely heavily on a visual rather than a verbal approach to explanation, and this was more likely to be more successful with this particular topic.

An important constraint was that, in order not to overload the students with extra work, it must be possible for them to complete the laboratory work and the computer-based exercise within the normal laboratory day of 5 hours, and this meant that they should spend no more than 20 minutes at the computer. We will not describe the software in detail since it is being substantially revised in the light of our subsequent evaluation of students' understanding of errors. However, our analysis of student feedback after they had used our software revealed some of their misconceptions about this subject.

We attempted to draw attention to the lessons we wished the students to learn by including the following two statements in the laboratory handbook. Both written statements were reinforced verbally in the pre-exercise briefing.

The computer program will help you to think about

- *The criteria used to calculate the line of best fit to your data as defined by the least mean squares linear regression (LMSLR) technique;*
- *The reasons for using statistical methods for estimating error and their effects upon your calculation of* $\Delta H^{\ominus}$*;*
- *The reason for quoting confidence limits.*

As part of your write-up, you should produce a paragraph summarising

- *The reasons for drawing a straight line through data using an objective rather than a subjective method.*
- *The meanings of 95% confidence limits on the values for the slope and intercept.*
- *The advisability or otherwise of using the LMSLR procedure as a routine method for determining the best fitting line to data.*

You should include a comment on the thought you have given previously to these aspects of error analysis and how useful you found the computer program in helping you to develop your thoughts.

We had two reasons for choosing the free response format for obtaining feedback. The first was that it takes more reflection to write a free response than it does to complete a fixed-response questionnaire, and we judged that this reflection would improve the student learning experience[4]. The second was that we expected the free-response format to reveal ingrained misconceptions which might not have become apparent form a fixed-response questionnaire. We recognised that free-response questions do not easily provide quantitative data. However they go some way towards formalising both the observation and the noting of critical incidents which Goodwin recommends as an alternative to the full-scale recording and analysis of interactions in a classroom[5]. The analysis is inevitably time-consuming, but we felt that the potential advantages outweighed the disadvantages.

Results

We received photocopies of 67 scripts which included the student responses to the task of writing a paragraph about errors. Of these, we discarded two because the students had badly misinterpreted the task. Not all of the remaining 65 responded directly to all three points they were asked to cover. The responses are summarised below.

Reasons for drawing a straight line using objective method.

Forty two of the students showed that they appreciated two related disadvantages of using a subjective method: it is not possible to guarantee that the line can be reproduced, and the criteria used to draw a subjective line cannot be described precisely. Some of these explanations were not particularly well expressed (for example, two merely stated that an objective method made it easier for others to interpret the data). The underlying point that the objective method uses *defined* criteria to fit the line to the data was made explicitly by thirteen students; twelve of these were included in the forty two. Of these thirteen, three included both of the criteria used by LMSLR and two included one of them (even though they were not specifically asked to do this). In addition to these five students, a further ten gave both criteria and ten more gave one of them, but these twenty students did not comment on the advantages of being able to define the criteria. This suggests that students find it easier to remember the specifics of the criteria than to explain why it is important to have defined criteria.

Eleven students commented that the least means squares method 'assumes' three features in the data:

- that the error in x is zero (or negligible);
- that the errors in y have a normal distribution;
- that there is no systematic error.

Only three of these students appeared to be aware that these three features are not *assumptions* made in carrying out the procedure, but that they define the conditions within which the procedure is justified – an important distinction for them to learn. Only four students in total made the point that LMSLR may not always be the most appropriate way of defining the line of best fit. This again indicates that it is easier to absorb specific information such as the criteria described above than to understand its meaning.

The most common misconception about the advantages of using an objective method, in this case LMSLR, is that it somehow improves the accuracy of the best fit line, or that it removes experimental errors. A typical comment is that the best fit line "*will be far more accurate than if found by hand*

and eye", or that "*The line being drawn by this technique will therefore lead to less experimental error...*". In all, 33 students made comments of this type. This suggests that, as concluded by Goedhart and Verdonk[1], our students have a very confused understanding of the nature and origin of errors. It also suggests that first year students have not appreciated that error analysis involves more than the mechanical application of statistical procedures but requires judgements about the most appropriate methods to use.

Seven students raised the issue of anomalous results in ways which indicated that they have no clear understanding either of what these are or of the effect they have on results. Illustrative comments are

"It has the disadvantage of using every piece of data";

"The problem with LMSLR is that anomalous results could severely undermine the accuracy of the straight line";

"It also ignores misalliance results".

These, and other comments which imply that errors occur in selected data only (rather than randomly in all data), are consistent with Goedhart and Verdonk's suggestion that students regard errors as personal.

Five students made reference to the problem that the presence of error makes the theoretically linear relationship hard to see. They appear to be chasing a correct result (known in advance) and consequently feel that any data which undermines this 'rightness' is an anomaly and should be discarded. This again indicates a confused view of the nature of experimental error and how it should be treated.

The meaning of 95% confidence limits

Nineteen students made statements which showed that they understood that, in this context, confidence limits define a range of possible lines which provide an acceptable fit to the data, and that there is a 95% probability that this range includes the correct line; a number of them express this as a 1 in 20 chance that the range will not include the correct line – a perfectly acceptable equivalent to 95% probability of inclusion. A further five students described the confidence limits as providing a range of possible best fit lines but made no comment on the probability of this range including the correct value. This may indicate an understanding of a point made by the software that the range can be calculated to give any reasonable level of confidence. We would not expect at this stage that students would show deep understanding that 'correct' has no clear meaning, depending as it does on the assumption that LMSLR is the appropriate method for analysing the data.

Nine students made no significant mention of confidence limits, and thirteen made comments which were so vague or confused as to confound any attempt at interpretation.

The remaining nineteen students showed various misunderstanding of the 95% confidence limits. Seven appeared to believe that the confidence limits provide a range within which there is a 95% chance that all data points will lie; they did not appear to associate confidence limits with confidence in the slope and intercept. Six thought that the range given by the confidence limits means that the correct value lies within +/- 5% of the best fitting value and six others refer to being 95% certain that the calculated result is correct.

Typical statements which illustrate the kind of confusion which arises are:

"…the values could be + or -5% of what was recorded";

"95% confidence limits ….leads to less experimental error";

"95% certain that you have drawn the straight line in the correct place";

"…reflect the ranges in which 95% of the experimental data will fall";

"The confidence levels shows how close the line fits the position of the points";

"…tell us the possibility of a real point being outside the set area".

Previous Experience

Seventeen students made general comments about their previous experience of error analysis. The great majority of these indicated that the respondent had not previously encountered objective methods either for fitting lines to data or for calculating confidence limits. It is likely that this is true of a similar proportion of all students and is not restricted to those who commented. A few of these comments revealed other features of students background beliefs which may be more widespread. These include

"I realised that drawing a best fit line does have errors, yet I had not realised how much of an error it was";

"I have used LMSLR in maths but never applied it to real scientific data";

"Previously I have used the correlation coefficient as a way of calculating the straightness of a set of points";

"I had previously been led to believe that by drawing an estimated line of best fit, I somehow eliminated the error".

Discussion

The student responses to our computer-based introduction to LMSLR demonstrate widespread misunderstandings about the factors affecting accuracy in experimentally determined parameters and about the meaning of confidence limits. These misconceptions almost certainly reflect a wider range of misconceptions about the nature and origin of experimental error which our exercise and the feedback from it could not have brought to light. We are currently planning a more broadly based survey with a view to establishing the extent of these misconceptions. However these present results are significant in that the responses were obtained from students in their first term at university, almost all of whom had completed their A levels in the previous summer. Their misunderstandings of the treatment of error cannot have been significantly influenced by their university experience and we therefore conclude that they are typical of first year chemistry students throughout the country.

The widely held belief that LMSLR increases the accuracy of (or decreases the error in) the final result almost certainly arises from the conventional use of the phrase 'line of best fit'. For a student drilled to appreciate the importance of accuracy, it will seem natural to associate 'best' with 'most accurate'. In fact, given the limited amount of data collected, it is unlikely that the best fitting value will be the correct value (even if there is no systematic error). This is taken into account by the Confidence Limits, which are also misunderstood by many students. Both these points require a sophisticated understanding of statistical procedures which it takes experience to develop. A further conceptual sophistication is the point that a (more or less) subjective decision is taken to define the criteria of 'best fit'. For example, in our view it is unlikely that the data collected in this laboratory exercise actually comply with the criteria used to calculate the LMSLR. In this connection, many of the students themselves commented that a major source of experimental error was the difficulty of measuring the temperature of the apparatus, but none pointed out that this was contrary to the assumption that there is no error in the vale of 1/T. However we felt justified in using the opportunity provided by this exercise to introduce this important procedure, and we judge that it is of greater value to overlook the technical inappropriateness of the procedure than to introduce an additional complication.

In preparing the specification for our software we made no attempt to introduce the concept of accuracy. However, it has become clear that student misconceptions of the specialist meaning of this word are a serious barrier to an effective understanding of the virtues and limitations of LMSLR.

In contrast to the lack of coverage of the concept of accuracy, our software was designed to help students to understand the concept of confidence limits. Nevertheless, it is clear from the student responses that misconceptions about confidence limits persist in students who have used our software. Almost certainly these misconceptions arise from confusion of the use of 'confidence limits' in statistical analysis with the use of 'confidence' in everyday language. Here, 'percentage confidence' (or 'certainty') usually refers to confidence in knowing or having a correct answer (as in "I am 95% confident that I turned the cooker off"). The percentage is not normally associated with a range. Thus, everyday language is unlikely to produce a sentence such as "if I toss a penny 100 times I am 95% confident that the number of heads will be between 46 and 54". Even more alien to everyday language is the apparent paradox that the average number of heads tossed is likely to get closer to 50% as the total number of tosses increases, but it gets increasingly unlikely that the value will be exactly 50% (there is a good chance that two tosses will result in one head and one tail, but only a very small chance that 1000 tosses will result in 500 heads). We conclude that it is a particularly sophisticated scientific concept that it is normally more useful to define a range of numerical values which will (most likely) include the correct value than it is to attempt to define exactly the correct value. The concept is reflected in the caption of a cartoon which reads *"Do you want a 100% guarantee it's 99% pure or a 99% guarantee it's 100% pure?"*[6]. Students are likely to find the concept of confidence range particularly difficult since they are consistently presented with numerical values in which no errors are admitted (tables of Relative Atomic Mass, Standard Redox Potential, pK values, etc). In this context it is not surprising that spending 20 min using a simple computer program is insufficient to correct ingrained misconceptions of the scientific meaning of words which are used more loosely in everyday speech.

The constructivist view of learning holds that "*knowledge is constructed on the mind of the learner*" by integrating new knowledge with existing concepts[7,8]. It follows that effective learning is unlikely in a mind which is already full of misconceptions, unless proper account is taken of these misconceptions. We have argued here that first year chemistry students hold many misconceptions of the use and meaning of language used to describe and apply error analysis. We suggest that teachers disregard at their peril the first of Johnstone's 'Ten Educational Commandments' that "*what you learn is controlled by what we already know and understand*"[9]. We are also encouraged by the evidence that some of the objectives we set ourselves have been met by our software, and we conclude that it will be worthwhile to extend and develop this approach in order to overcome fundamental misconceptions about error.

Acknowledgements

One of us (JLT) was supported by the ESRC under grant number RO22 25 0121

References

1. Goedhart MJ and Verdonk AH 1991 The development of statistical concepts in a design-orientated laboratory course in scientific measuring *J. Chem. Ed.* 68 1005–1009.
2. Garratt J and Smith S 1994 Empirical illustration of statistical procedures *Biochem. Ed.* 22 15
3. Garratt J, Clow D, Hodgson A and Tomlinson J 1999 Computer simulations and chemical education *Chem. Ed. Rev.* 14 51–81
4. Tomlinson J 1998 Reflecting on learning *U. Chem. Ed.* 2 35
5. Goodwin A 2000 Some thoughts following "Crossing the Borders" *U. Chem. Ed.* 4 37–38
6. Garratt J, Overton T and Threlfall T 1999 *A question of chemistry* (Longmans, Harlow)
7. Bodner GM 1986 Constructivism: a theory of knowledge *J. Chem. Ed.* 63 873–878
8. Taber K 2000 A constructivist approach to university chemistry teaching *U. Chem. Ed.* 4 63–72
9. Johnstone AH 1997 Chemistry teaching – science or alchemy *J. Chem. Ed.* 74 262–268

Independent Study – providing focus and purpose

COMMUNICATION

Raymond G Wallace

Department of Chemistry and Physics, The Nottingham Trent University, Clifton Lane, Nottingham NG11 8NS, UK
e-mail: ray.wallace@ntu.ac.uk

The paper describes a final year undergraduate degree module which has been running at the Nottingham Trent University for the past four years. The module, 'Independent Study', is a student-centred programme where students study topics from two of the three main branches of chemistry, inorganic, organic and physical. The manner in which the summative end of module, revealed paper examination is structured, compels extensive coverage of the subject matter. The module allows concurrent final year project work to be carried out away from the home university. This 'end of university' unit of the course guides students to independence in their future lifelong learning. The results currently obtained with the programme show an equivalent level of academic attainment to traditionally delivered modules. The outcomes of the programme since its inception and its refinement are discussed.

Introduction

In the academic year 1995/6 the final year of our cluster of degree courses was modularised. This provided the ideal opportunity to modify our degree programme to achieve educational objectives which we believed were desirable, and which additionally, would give greater flexibility for our students in the study arrangements available to them immediately prior to graduating. The educational objectives set out in our course documents and of particular relevance to our final year students were

- Promotion of the development of the student as an independent learner;
- Encouragement of the personal and intellectual development of the student.

In the modularised programme the majority of the finals examinations were completed by the end of the first semester (February) of the final year, and the entire second semester was available for project work and a new module. The project takes up 40 of the 60 available credits for a semester, and at that time a significant number of students carried out their projects in the United States or in Continental Europe and some in industry. Thus the adoption of a new 20 credit module of Independent Study would not only meet our primary objective of encouraging the development of the skills of independent learning, but would also meet the needs of students doing project work away from the university. A further objective of the module was that it should require the students to study a broad range of topics within (at least) two of the main sub-disciplines of chemistry.

Independent Study and Learning is not a new idea in Higher Education. Much has been written about it and its value (eg [1-4]). Knowles[1], in particular, is a major proponent of the techniques and strategies related to self-directed learning which are said to constitute the distinctive practice of andragogy (as opposed to pedagogy which is said to characterise the more teacher-directed approaches of conventional education). In self-directed learning the needs and activities of the learner take precedence over those of the teacher (whose role thus becomes one of a facilitator of learning). This is the style of learning in which we would wish our students to engage by the time they graduate. Whether Independent Study can be truly 'independent' is a moot point since, as Collins[4] has pointed out, the ideas underpinning self-directed learning have been readily translated (by their proponents) into techniques which seem to set out *"in formulaic terms, how it (ie self-directed learning) has to be done; directed self-directed learning... managing a pedagogic technique, usually in the form of a learning contract with a student client."*

The writing of independent study material[5] and examples for use in university chemistry teaching[6,7] have been described and excellent sources of such materials can be found[8,9]. These will all influence the design of new strategies for developing the skills of independent learning. In addition, the design of any new module must take into account the number and background of students involved. At the time this module was planned about 100 students were expected to take it, though this number has since fallen to about 70.

This paper describes how we designed a module structure and an assessment procedure to meet the three main objectives outlined above.

Methodology

Design of the syllabus

Independent study is encouraged by minimising contact with staff. It is therefore important to build carefully on students' existing knowledge and skills, and to provide guidance and support which will enable them both to study successfully and to recognise that they have developed useful new skills. Also we took the view that some traditional topics on the syllabus do not need to be covered in lectures but are particularly suited to independent exploration by final year students with a firm grounding in chemistry. The syllabus for the module was strongly influenced by our analysis of these topics and by the availability of relevant information in standard and specialist texts. We decided to base the syllabus on the three traditional sub-disciplines of physical, inorganic and organic chemistry. This has the advantage for students of being reassuringly familiar. For the staff, it means that the full teaching load of the module does not fall on a single individual. The syllabus is defined in terms of nine examination questions. These are devised by selecting three topics from within each sub-discipline and setting an essay question on each topic. Only three of these questions appear on the examination paper, one inorganic, one organic and one physical and the students have to answer two of them. Since the students do not know which three out of the nine questions will appear, the syllabus is effectively defined by a sub-set of six of the nine questions. Students are told that they are expected to write in excess of 1000 words for each answer.

Students decide for themselves which two branches of chemistry (defined by six questions) to study. An indication of their choice is obtained when they attend the appropriate tutorials, but in the examination they can choose any two of the three questions regardless of the programme of work they have followed. They may be influenced in their choice by the opportunity provided in the previous semester to specialise in two branches of chemistry, advanced inorganic, advanced organic or advanced physical, although there is no compulsion to study the same two areas here.

Nine questions, with their lead in references, which we have typically used in recent years are shown in Figure 1.

The module is assessed by a two hour closed book examination at the end of the module. This has two perceived advantages. First, the students taking this module were also involved in project work which is engrossing and intensive; it seemed unreasonable to impose assessed course work on students committed to project work. Second, it provided reassurance for sceptical staff that this new type of module would be rigorously assessed.

Student Support

Students are issued with guidance notes about the Independent Study module at the end of the first semester and given a briefing which spells out in fuller detail what is required of them and explains that the aims of the module are to develop the skills needed to

- find, read and assimilate information
- manage their time
- structure an answer
- write a coherent essay

They are informed that that their reading and study should be directed towards answering the questions after developing a thorough understanding of the topics. Attention is drawn to the lead references provided for each question. They are given the name of a member of staff who is responsible for each subject area and who can be consulted over the concepts involved. When the module was first introduced (but see later) students were told that staff would not however read specimen answers but this since been relaxed in the interests of improving student support.

They are reminded that a 20 credit module is intended to require about 130 hours of study time spread evenly over the semester, and that in a conventional module this would involve about 70 hours of student contact and 60 hours of directed and independent study. In this module they should therefore expect to devote about 20 hours of concentrated work to each of the six questions which defines their course.

In the first year of operation students were required to complete a study timetable detailing the time that they were spending on this module. Approximately five weeks into the module, two seminar/appointment slots are timetabled with staff (email provision for those away from the university). Students are instructed to attend one to show that they had constructed essay plans. They are warned that if they do not meet these requirements that are aimed at monitoring their progress, then their names will be reported to the Finals Examination Board and the external examiners, and this may be a factor when decisions have to be made about any performance compensation etc.

Outcomes

Examination results for the past four years are shown in Figure 2.

The pattern of results shows a steady shift towards the distribution which we regard as reasonable and by 1999 the average mark was 52% and comparable with our other modules delivered in the traditional way; this compares with 48% in the first year the module was offered. By 1998/99 the proportion of fail marks had dropped to an acceptable level, and most of the candidates were able to compensate within our rules by scoring higher marks in other modules. The proportion of first class marks is lower than we would like to see, but it is a common observation that it is harder to obtain a first class mark on an essay question than on a highly structured question.

Comparison between years is bound to be speculative because of changes in student background and quality. For instance, in the early years, in addition to those taking Chemistry, a significant number of Combined Studies in Science students were taking this module. The number of the latter has markedly decreased over the four year period which this module has been running. Another factor which contributes to variation between each cohort of students is the number who have undertaken industrial training prior to their final year; these students show a markedly more mature attitude to their studies on their return from industry. In spite of the real variation in student quality over the years, we believe that at least some of the change in observed mark distribution can be attributed to changes in the support given to students, which we introduced in the light of experience.

In 1995/6 some 3% of the students admitted after the examination that they had either attempted to question spot or had started their revision only two days before the examination. Typically these students scored zero or, at best, less than 10%. It is likely that a larger proportion made the same mistake without admitting it, and that this accounts for the unacceptably high failure rate.

Accordingly, in 1996/7, we placed greater emphasis on the need to develop a responsible attitude and an effective pattern of study. This appeared to have the desired effect on reducing

Figure 1: Examination questions with lead references *(Extract from student handout)*

INORGANIC

1. Discuss the types of inorganic chemical reactions that occur in a range of nonaqueous solvents, such as anhydrous ammonia, glacial acetic acid, conc. sulfuric acid, dinitrogen tetroxide and sulfur dioxide. Demonstrate how the use of such solvents has encouraged the development of inorganic chemistry.

2. The concept of acids and bases has widespread use in inorganic chemistry. Discuss how a consideration of non-aqueous solvents, such as anhydrous ammonia, glacial acetic acid, conc. sulfuric acid, dinitrogen tetroxide and sulfur dioxide, has refined the acid-base concept and rationalised the wide range of chemical reactions known.

3. Non-aqueous solvents, such as anhydrous ammonia, glacial acetic acid, conc. sulfuric acid, dinitrogen tetroxide and sufur dioxide, provide a medium for many synthetic reactions in inorganic and organic chemistry. Discuss the properties of these solvents that make such synthetic developments possible.

References

Introduction to Modern Inorganic Chemistry, MacKay and MacKay, Intertext.
Non-Aqueous Solvents (Studies in Modern Chemistry), T.C. Waddington, Nelson (1969)

ORGANIC

1. Discuss the formation, stereochemistry and reactions of cyclic monosaccharides, and methods by which they may be further converted to *C*-glycosides. A discussion of degradative studies leading to structure determination is not expected in your answer.

2. Discuss the formation, stereochemistry and reactions of cyclic monosaccharides, and methods by which they may be further converted to *O*-glycosides. A discussion of degradative studies leading to structure determination is not expected in your answer.

3. Discuss the formation, stereochemistry and reactions of cyclic monosaccharides, and methods by which they may be further converted to *N*-glycosides. A discussion of degradative studies leading to structure determination is not expected in your answer.

   (Note: In your account you should be able to give acyclic and cyclic forms of D-glyceraldehyde, D-ribose, D-mannose, D-glucose and D-fructose, using Fischer, Haworth and other appropriate representations).

References

Organic Chemistry, 4th Edition, McMurry, pp, 1010–1033,1050
Organic Chemistry, Carey, pp. 1002–1042
Organic Chemistry, 5th Edition, Solomons, pp. 997–1022
Natural Products, Their Chemistry and Biological Significance, Mann, Davidson, Hobbs, Banthorpe & Harbourne, pp 26–41, 67–118

PHYSICAL

1. Osmometry, light scattering, viscometry and gel permeation chromatography are techniques which may be used to determine the molecular weight of polymers in solution. Describe in detail the experimental procedures used and discuss the relative advantages and disadvantages of their use in molecular weight determination.

2. Discuss the mechanism and kinetics of free radical addition polymerisation including reference to the usual physicochemical parameters.

3. Give accounts of the structures, properties and uses of:

   a) copolymers;

   b) elastomers

illustrating your answer with examples wherever appropriate.

References

General Physical Chemistry texts such as those by P W Atkins, G Barrow, Laidler & Meiser and W J Moore etc. contain chapters/sections on macromolecules/polymers which feature molecular weight determination and kinetics of polymerisation.

General texts on Material science such as:
The Structure and Properties of Materials (Moffatt et al) The Boots & Clifton libraries.
Materials Science (Anderson & Leaver). The Boots Library contains material relevant to structure and properties of polymers.

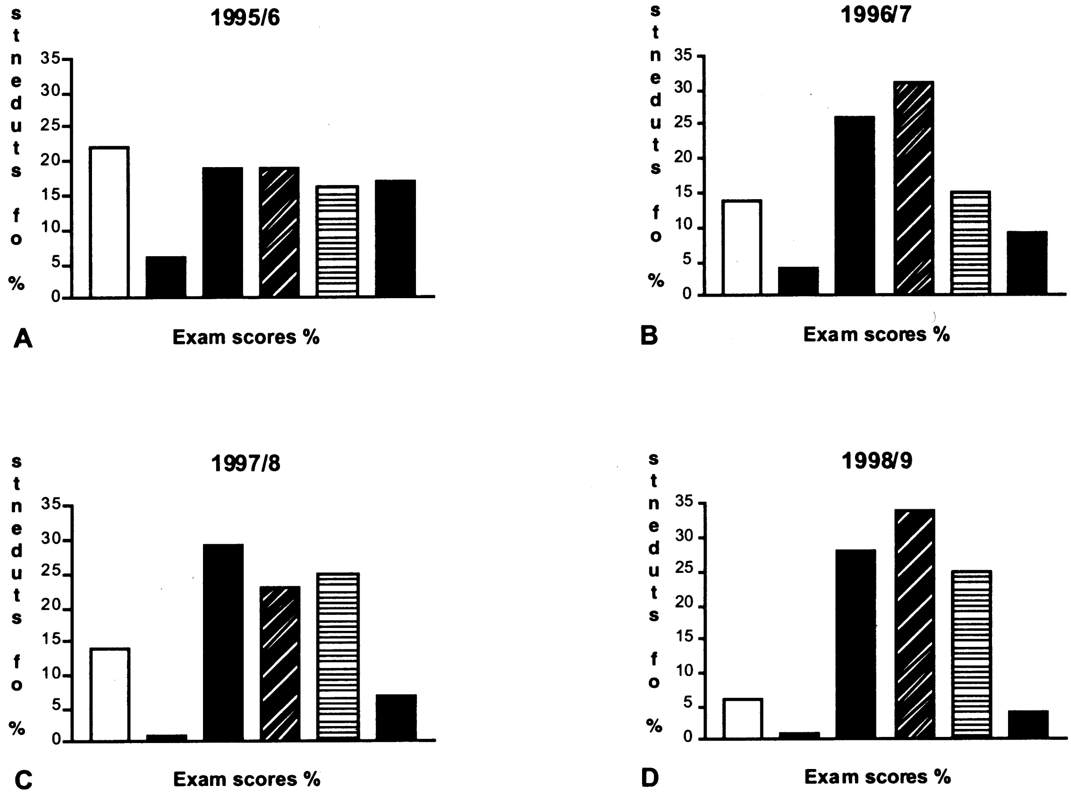
Specialist Polymer texts such as:
Textbook of Polymer Science. T W Billmeyer
Macromolecules: Structure and Properties, H G Elias
Introduction to Macromolecular Science, P Munk are available from The Boots library.

the failure rate, but the combined number of first and upper second class marks was disappointing. We noted that only about 50% of the students had completed their study timetables and attended the mid-semester seminar, suggesting that they failed to recognise that these features of the course were intended to help them to develop effective study patterns.

Further efforts to encourage the students in 1997/8 may have brought about the satisfactory increase in the proportion of upper second class marks. However the proportion of fail marks was too high, and called for a more significant revision of the available support. We decided to abandon the use of study timetables since lack of use made these ineffective, but we retained the seminars/appointments as a key point of contact with staff. Instead of refusing to read model answers, we recognised that this would also provide valuable support for the weaker students, and so we required those students whose performance had been very weak in the February Finals Examinations to submit these two weeks prior to the summer examination. This special treatment of weak students was not a precedent since these students are not allowed to carry out their projects away from the university. We noted with satisfaction that failures were reduced to 6% from 14% the previous academic year, and students moved back in numbers to the lower second class band.

The distribution of students between inorganic chemistry,

Figure 2: The examination performance for the past four years



Student numbers: A 94, B 91, C 69 and D 67.

organic chemistry and physical chemistry has tended to remain roughly constant (with physical chemistry slightly lower) over the four years of operation of the module. Over the years the average mark for the organic and physical chemistry questions are both about 50%, with inorganic chemistry being slightly higher at around 55%. We do not feel that this is significant.

Discussion

The Staff Perspective

The appointment of a single staff member for each subject area might at first sight appear a large individual burden. In practice during the first two years during which the module ran, given the spread of students and topics, it meant that the individual staff member was in theory responsible for no more than 60 students, up to 30% of whom were away from the university undertaking their projects and being in touch with the lecturer by email. In the latter two years the average number of students studying any sub-division has fallen to about 45. Despite our best encouragement, not all of our students take advantage of the tutorial sessions. Additionally students tend to pose similar questions and thus even email replies tend to be less onerous than one might imagine. Thus the overall teaching load is indeed somewhat reduced compared with the typical load of a conventional module.

We accept that marking this type of examination requires a little more time than normal. Markers had to be aware that, whereas an essay set in a conventional exam is almost invariably based on a common set of lecture notes, students in this module could well, despite lead references, consult a wide variety of sources. With this in mind, the examination scripts are all read through by the examiners and then either arranged in a pecking order of essay quality or a list drawn up of the main points made by students in their essays. They are then read through a second time and assigned a mark, either based on what the examiner reasonably expects in content for a given degree classification band dependent on subject area, or on the number of relevant points made by the student (guideline 80% of major points mentioned = 10/10). For example in the first two questions in physical chemistry (see figure 1) 50% of the marks would be awarded for description and 50% for critical analysis and derivations. In coming to a final mark, moderation of the ‘raw mark’ takes into account structure and coherence of the written account. Quality control is maintained through some sampling by a second examiner and the essays are available for scrutiny by the external examiners. With all of the students answering the same question in a particular subject area, a greater comparability between students is achieved. The differences in approach by different examiners might be criticised on the grounds that students in the different branches of chemistry are not receiving uniformity in treatment. However, there is no reason for supposing that this is any less equitable than in any other examination with multiple marking.

We are satisfied that the strategy of defining the syllabus by three examination questions from each sub discipline encourages a suitably broad study of the area, even though only one of the topics is actually examined.

The Student Perspective

At the end of all modules all students receive an end-of-module questionnaire which poses nine specific questions about the module. These relate to its organisation, students' background for it, development of new skills, help from staff, resources, clarity of assessment procedures, the Internet as a source of information, relationship to other modules, and the extent to which the aims of the module are met. Responses from the Independent Study Module have been very positive with the scores rarely falling below the upper quartile in overall satisfaction in all nine areas. In addition the questionnaires allow for individual comments. Many positive comments were received for this module, and some of these provided encouraging evidence that the students were indeed developing their ability to study independently. A number of negative comments have also been received, and these can usefully be divided into those which highlight difficulties which the module is designed to introduce and those which suggest ways in which student support can be improved. Some illustrative comments are included in Figure 3.

The positive responses stand by themselves as evidence that at least some students recognise the benefits of this module. The negative comments require more serious analysis. "Lack of books" will probably always be perceived as a problem, particularly with current restrictions on library budgets, but our view is that students ought to own at least one standard text for each of the sub disciplines which they are studying, and that this should provide a basic background. Students away from the university are less able to rely on friends and peers who may own different standard texts, and this would put them at some disadvantage. Our only solution to this problem is to encourage better use of the available tutorial support. Most of the other negative comments reveal that the students find it difficult to develop some of the key aspects of independent study. A particularly disappointing comment was "parrot fashion learning" which clearly shows that some students have failed to understand the nature and purpose of the module, and have not appreciated that good answers to the given questions are unlikely to result from the uncritical commitment of facts to memory. We are addressing this issue by using the tutorials to discuss approaches to essay writing – not simply learning by heart an essay that they have written, but fixing in their minds how they will structure it and the concepts and ideas they will wish to put forward. For example, we remind them that, in organic chemistry, the heart of the subject lies in principals and mechanisms rather than in a cursory acquaintance with a host of reactions.

General Conclusion

We are pleased that this module has met with the approval of our external examiners, who welcome the breath of fresh air that it has brought to the degree programme. We feel that this approval confirms our view that the module is rigorous and at the same time introduces an important new dimension to the learning experience of our students.

Figure 3: Illustrative student comments on the module

Those in bold were made by over 50% of respondents

Positive comments (general)

"working by yourself", "relieved exam stress", "knowing the questions for the exam", "freedom to do it as and when", "interesting research on the net", "easier to learn material for the exam", "I learnt a lot about the subject", "flexible to fit round the project", "references given", "holding tutorials made you do the work", "no lectures"

Positive comments (relating to independence)

"Making my own plan for the subject studied", "Working independently. Not being treated like I was back at school anymore", "Left to do own research and revision", "Control over own time and work". Numerous other comments contained the word 'independent'.

Negative comments

"lack of books in the library (particularly overseas)", "quantity of information", "shortening the material to a 1000 word essay", "not enough help", "difficult to work during the project", "having lecturer who wasn't available all the time", "lack of information about structuring essays", "lack of confidence in my essays", "parrot fashion learning"

Acknowledgements

The author acknowledges useful discussions with colleagues, in particular Ian Coutts, Bob Murray and Mike Rowan who were intimately involved with the module. Additionally he would like to thank John Garratt for helpful suggestions.

References

1. Knowles MS 1975 *Self Directed Learning: A Guide for Learners and Teachers* (Cambridge Books, New York)
2. Cowan J 1986 *32 Questions about Independent Learning – and some of the Answers* SCEDSIP Occasional Paper 23 (ISBN 0 946815 20 8)
3. Long DG 1990 *Learner Managed Learning* (Kogan Page, London)
4. Collins M 1996 *On contemporary practice and research. Self-directed learning and critical theory* In *Boundaries of Adult Learning* Edwards R, Hanson A and Raggatt P (eds) (Routledge, London)
5. Bennett SW 1998 *Designing Independent Learning Material for Chemistry* (Project Improve), http://science.ntu.ac.uk/chph/improve/bennett.htm
6. Bland WJ 1994 *Independent Learning Packages* In *Proceedings of Variety in Chemistry Teaching* Garratt J and Overton T (eds) RSC Tertiary Education Group
7. Adams K, Ginn B and Ruddick D 1998 *Independent Learning in an Introductory Module in Biological Chemistry: Use of Question Mark Software™ to Provide an Assessment Tool and Tutorial Support* UChemEd, 2, 40
8. The Open University Chemistry Courses, ST240, S246, S247, S342, S343, S344, http://www.ouw.co.uk
9. http://science.ntu.ac.uk/chph/improve/indlearp.htm; http://science.ntu.ac.uk/chph/improve/swapshop.htm

Chemistry lessons for universities?: a review of constructivist ideas

REVIEW

Keith S. Taber

Homerton College, University of Cambridge, Cambridge, CB2 2PH e-mail: keith.taber@physics.org; kst24@cam.ac.uk

Research in science education has identified a vast catalogue of misconceptions, or 'alternative conceptions': beliefs held by students which are at odds with orthodox science. These ideas are often held tenaciously in the face of teaching, and while many are idiosyncratic, some are found to be widely held. Alternative conceptions have been uncovered in all areas of science, and have been elicited from learners at all levels, from primary school through to graduates. University teachers need to appreciate the strength of these alternative conceptions, and the barriers they create for meaningful learning. No matter how skilfully university chemistry is explained, many students will build their new knowledge on shaky foundations. The 'constructivist' research programme seeks to explain the origins of students' alternative ideas, and to use this information to inform more effective teaching approaches. According to this perspective, knowledge is constructed in the mind of the learner, and therefore learning builds on the existing ideas in the students' minds, even if these are far from matching the (presumably 'more scientific') ideas the teacher had in mind. This review of the constructivist literature summarises the implications for teaching and learning chemistry in universities.

Introduction: student misconceptions in chemistry.

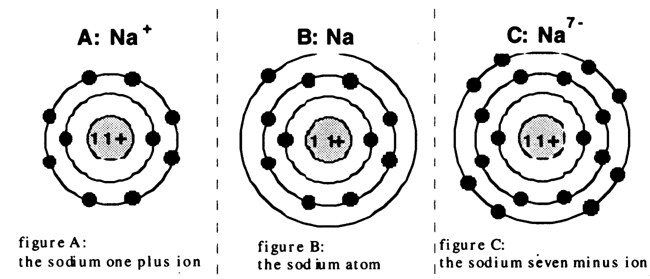
A group of science graduates, training to be teachers, was asked to compare the stability of three chemical species, represented by the simple 'Bohr-type' diagrams shown in Figure 1. A number of the respondents suggested that C, a highly charged anion of sodium, would be more stable than the neutral atom (B). Na^{7-} is not found naturally, and has such a high charge that it could only be held together under extreme conditions. One might wonder how graduates, about to embark on a career teaching science, could possibly think Na^{7-} was a stable chemical entity. One of the trainee teachers explained that "C has a full [sic] outer shell of electrons and so is less likely to give e^- up than B, which will want [sic] to give away an e^- to get a full outer shell." This is just one piece of evidence for a common misconception that *any* species with an octet, or a full outer shell of electrons, is stable, and that atoms actively seek to fill their shells[1].

Such misconceptions are very widespread, and not just among weak or lazy students. The literature reports a wide range of areas where pupils commonly misconceive the chemistry they are taught. For example, readers may recognise the following common 'errors':

- A reaction between an acid and a base *always* produces a neutral solution[2].
- In ionic bonding the ions can *only* bond with counter-ions with which they have exchanged electrons, rather than with *any* adjacent oppositely charged ions[3,4].
- To be isomers, compounds *must* belong to the same class (so, for example, CH_3CH_2OH, an alcohol, and CH_3OCH_3, an ether, cannot be isomers)[5].

Because of the widespread nature of such misconceptions, and their perceived significance for teaching and learning, there has been a great deal of research into their incidence, and some considerable theorising about why they arise, and how teaching should best respond to them. This review considers how this literature can inform chemistry teaching in universities.

Figure 1: three chemical species



The constructivist approach

A wide range of terms has been used for these 'misconceptions'. Here the term *alternative conception* will be used, but some authors refer to *intuitive theories*, *naive theories*, *preconceptions*, *alternative frameworks* or *children's science* [6]. Although there are sometimes good reasons for preferring different terms, there is no consensus, and so in effect these labels are often synonymous. The research programme is sometimes referred to as the 'alternative conceptions movement', but is also commonly labelled 'constructivism'.

Constructivism draws upon ideas from key thinkers from the psychology of learning (eg [7–10]), but since the late 1970s the theoretical base of the research programme has been developed within the context of a vast canon of empirical data collected from studies into learning in science (eg [11–17]). A number of popular books discuss constructivist ideas in science teaching[18–23]. Research into learners' ideas has produced evidence of alternative conceptions in all aspects of science that have been studied, and the findings relating to secondary level science are summarised for teachers in a much cited book[24].

Much of the work has focused on the school sectors, where there have been major projects such as LISP (Learning in Science Project) in New Zealand[20], and in the U.K., CLISP (Children's Learning in Science Project), and SPACE (Science Processes and Concept Exploration). These projects have examined a range of topics: for example SPACE (focusing on primary school science) has produced a report on pupils' ideas about materials[25] and CLISP (focusing on secondary school science) has looked at the understanding of elementary ideas in chemistry[26]. Although less research has been carried out with university students than in schools, there is considerable evidence that alternative conceptions continue to be a problem at this level[27–29]. Indeed it would be surprising if this were *not* the case, since alternative conceptions cannot be expected to disappear spontaneously, and the importance of research into this area at university level is increasingly recognised (eg [30]). Findings within chemistry at all levels have been reviewed[31, 32] and a number of topics have been identified as common sources of alternative conceptions (see Table 1). University teachers who are aware of the nature and extent of alternative conceptions and who understand how they might have arisen are best able to help students to learn effectively. Rather than being irritated or puzzled by learners' responses in assignments and examinations, lecturers may use their knowledge of why these ideas arise to develop more effective teaching strategies.

Students' alternative ideas are sometimes so ingenious that their invention would seem to involve much more effort than simply learning the conventional ideas taught in class. Other responses may be so implausible from a chemical viewpoint (such as the stability of the Na^{7-} ion discussed above) that it is difficult to conceive how students thinking along such lines could possibly believe that they had understood their lectures. The key to this apparent paradox is to appreciate something of the way learning and memory works. To a first approximation we can consider learning to be two separate processes: *adding* new information to existing frameworks of ideas, and *restructuring* these conceptual frameworks (eg [33, 34]). In order to better facilitate the student's learning, it is therefore useful to consider the nature of their prior knowledge, their assimilation of new knowledge, and the restructuring of their conceptual frameworks.

The nature of prior knowledge

By the time students enrol on a university chemistry course, they have been learning for (at least) almost two decades. During this time they have been constructing a complex set of understandings about the world. This structure of beliefs and ideas is sometimes called 'cognitive structure'[35–37]. At each point in this process, new learning has been channelled by the existing cognitive structure, so learning is something of a 'boot-strapping' operation[38]. As a person matures, their cognitive structure develops: their knowledge base increases, and – in general – becomes better integrated and more sophisticated[39]. University teachers with some understanding of how this knowledge base has developed are best able to help students to build on it effectively.

Even at birth the brain should not be considered as a blank slate upon which anything could be written. The human brain has evolved so that it is 'pre-programmed' to develop in certain ways[40]. The precise extent of this genetic input is subject to research and debate[41], but there is no doubt that the baby has predispositions to learn certain types of information, and 'chunk' information from its surroundings in specific ways[42]. The child is programmed to interact with its physical environment and to learn from that experience. Children are constantly bombarded by information from a variety of sources: parents, siblings, friends, television and so forth[43]. They make sense of what they hear and see in terms of their developing conceptual frameworks. In everyday use, language tends to be weakly defined, allowing increased scope for misinterpreting what is heard[44,45]. Even when the interpretation is accurate, much of the source information may be unclear, confused or just plain wrong[46]. The child is *then* exposed to formal schooling.

Some of the child's early learning about its surroundings provide the 'intuitive theories' that can later interfere with the learning of formal science [47,48]. For example, one of the most common and tenacious alternative conceptions uncovered by research is the erroneous belief that a force must be

Table 1: chemistry topics identified as leading to alternative conceptions.

Griffiths 1994 [31]	Garnett et al 1995 [32]
chemical equilibrium	chemical equilibrium
acids and bases	acids and bases
stoichiometry	balancing and interpreting chemical equations
electrochemistry	oxidation-reduction and electrochemistry
the nature of matter	the particulate nature of matter
bonding	covalent bonding, molecules and intermolecular forces
physical and chemical change	
dissolving and solutions	
combustion	

continuously applied to keep an object moving at a steady velocity[49]. Orthodox science holds that any net force will *accelerate* the object. The young child does not know about the frictional forces that are ubiquitous in everyday life, and falsely infers that the constant push or pull commonly needed to work against friction is *inherently* required to maintain a body's momentum. Once this alternative conception is established it tends to be retained and applied, at least until – and often well after – Newton's law of inertia is met in school physics. Many other alternative conceptions are believed to derive, at least in part, from such interpretations of early experience[50] and it should be no surprise that pupils often come away from class with a different sense than that intended[1].

Learning from teaching, then, relies on the learners perceiving *connections* between the curriculum content introduced by the lecturer and their existing cognitive structure. Effective learning depends as much on the student's existing knowledge as on the quality of the presentation. Any mismatch between the expected and actual prior knowledge can act as 'bugs' in the system, i.e. impediments to learning[51]. As Sirhan and colleagues have pointed out in this journal, we need to 'prepare the mind of the learner'[52].

Assimilating new knowledge

Although we each have enormous *long term* memory capacity, our working memories are very restricted[53]. When subjects are asked to remember nonsense information their processing capacity is extremely limited. In this kind of *rote* learning exercise, the typical person can only cope with between 5 and 9 bits of information. The number 102202216302311 (15 digits) would exceed most people's capacities. Yet, in practice, we all remember much more complicated information than this, because we impose meaning on the information, in terms of existing knowledge. It is easier to recall 102202216302311 *if* it is recognised as a representation of the ground state electronic configuration for aluminium ($10[=s]^2$, $20[=s]^2$, $21[=p]^6$, $30[=s]^2$, $31[=p]^1$). Complex information may be learnt if it can be processed into manageable chunks, and this processing involves spotting patterns in the information, by relating it to existing knowledge. For example, a complex structural formula may comprise a single chunk of information for an experienced chemist, but may overload the working space of a novice who does not share the same conceptual frameworks[54].

The human brain will automatically *construct meaning* from what is heard and seen, by relating it to whatever is already known (or, at least, already *believed*). In this way the information is altered into a form that can be assimilated into existing conceptual structures. Although this introduces distortions, it is a much more effective means of data processing than 'total recall'[55]. Ausubel used the term *meaningful* learning to distinguish this process from rote learning. By *making sense* of information we can learn it more effectively[56]. This characteristic of learning emphasises the need for teachers to offer students 'anchors' which help them to make meaningful connections with prior knowledge.

Restructuring conceptual frameworks

As people are so successful at interpreting most data in a way that fits their expectations, radical conceptual change is considered to be rare[57]. Learning usually involves refinement of, or minor amendments to, existing frameworks, and it takes time to develop a new, coherent, way of organising knowledge about a complex topic. It seems that learners start to construct alternative 'versions' of their understanding in the background: versions that may come to be more coherent and so in time become the preferred way of thinking about the topic[34,57]. Clearly, then, it is not unusual for learners to hold 'multiple frameworks' for the same topic in mind[37]. An important role for the teacher is to reinforce the reasoning that justifies the scientific preference for accepted theories, and so help provide a 'scaffold' by which the student can make the transition from an entrenched alternative conception to take up the preferred framework[58,59].

Individuals are believed to compare their manifold conceptions subconsciously using the same types of criteria that scientists might use to decide between competing theories: simplicity, degree of match with empirical data, scope of explanatory power, etc.[60, 61]. The decision as to which set of ideas to apply is often dependent on the perceived context[62]. Indeed learners may access one set of ideas in a context such as a test, and a different set in more everyday contexts[63,64]. Researchers have been able to elicit different responses when presenting individuals with several versions of what is formally the same question, by embedding one version in an everyday setting, and presenting the other as a more typical abstract 'academic' question[65–67]. Thus it is important to provide contexts for the students in which the alternative conception is clearly inadequate, but which are consistent with the preferred framework.

The normally subconscious processes of coming to see the inadequacies in our ways of thinking may be accelerated by having to justify our ideas to our peers[68]. Both new connections and unexpected inconsistencies may come to light when talking through ideas[69]. Discussion between learners may therefore both utilise the social imperative to reach consensus, and also provide opportunities to elicit and explore their ideas[70].

It has been argued that learners can become much more effective by being more aware of their own study habits, and thought processes (an area referred to as metacognition)[71–74]. This may be of particular interest in chemistry, where it has been suggested that many difficulties experienced by students result from 'model confusion': not recognising how much of chemical knowledge is based around alternative models that have different ranges of application[75]. For example, it is not 'wrong' to equate oxidation with addition of oxygen, or to see acids as proton donors: but these are not the only definitions we use. Similarly, the bond between carbon and chlorine could be better labelled either covalent *or* polar, depending on the particular context[76]. Academics can cause confusion by assuming that the context alone is sufficient to make it clear which model is being used and is most appropriate; in fact students usually need help in developing the ability to select the appropriate model from the context.

A student who conceptualises scientific knowledge as a series of models of varying applicability, and who appreciates something about the way their brain analyses, stores and accesses information could be a more flexible and successful learner. Such a learner would be able to recognise their own alternative conceptions as partial models that may not always apply[37].

Applying the constructivist approach to teaching chemistry

According to the constructivist perspective each individual learner has to construct their own personal knowledge system piecemeal, whilst at each stage interpreting any new information in terms of their understanding at that point. So students come to class with a range of ideas, from various sources, which seldom come close to matching the prior knowledge suggested by the curriculum they have followed. Recognition of this perspective is of practical value to the extent that it can inform teaching practice. Suggestions have been made about what a 'constructivist' teaching programme might look like[77].

A basic tenet is that the curriculum should be a programme of activities that encourage learners to (re)construct scientific knowledge. The teacher's role is to be a "facilitator" who will provide the appropriate opportunities for the learners to undertake the construction. The focus is on the learners' thinking about scientific ideas: the elicitation of existing ideas, and their subsequent restructuring – including exposure to conflict situations and the development and evaluation of new ('more scientific') ideas. An example of the effectiveness of this approach is given by Johnston and Driver[78] who devised a constructivist scheme for teaching particle theory to pupils at age 13-14. They reported that both learners and teachers were generally positive about the approach, although there were reservations. Pupils seemed to enjoy the lessons, and being required to "think…a lot" (p.175), but showed a concern with not immediately being told the 'right' answers. Some teachers, being used to prescriptive schemes of work, found the need for a flexible response to pupils' ideas rather challenging. The emphasis on discussion and argument intended to develop *understanding* made demands on learners' concentration that were noted by both pupils and teachers. However, teachers did report that they felt pupils were more actively involved in learning during lessons, and there was evidence that significant conceptual restructuring had occurred.

'Constructivist' schemes designed for use *in schools* involve activities that engage the students in the learning process – brainstorming, designing posters, circuses of simple experiments, debates about the merits of alternative ideas. These may not readily transfer wholesale to *undergraduate* courses[79]. Millar, however, has pointed out that constructivism – as a theoretical perspective on learning – does not imply a *particular* teaching methodology[80]. Effective learning occurs whenever the teacher is able to help facilitate the students' construction of something closely resembling orthodox scientific understanding. It has been suggested that in secondary schools "animated talk and argument are likely to be the hallmark of fruitful science lessons"[24]. This might sound a more desirable prescription for a research colloquium where new and challenging ideas are being explored, than for a lecture course designed to teach established principles. Yet it is important to realise that for the undergraduate audience the ideas being presented *are* novel and challenging, and do need to be explored, and justified, and made familiar. A skilled teacher *can* achieve a great deal through talking. However, the traditional lecture, based on the assumption that knowledge is simply *transmitted* as a unidirectional stream of data flowing from lecturer to student, is unlikely to be an effective mode of teaching[81, 82].

In order to apply these principles to university teaching it is useful to consider three factors

- The students' prior knowledge;
- The selection and organisation of content;
- The choice of appropriate teaching methods.

Eliciting prior knowledge

It has long been considered as good practice when planning courses and preparing lectures to bear in mind what might traditionally be labelled as '*assumed* prior knowledge'[83]. In an ideal world the lecturer might consider the question of whether students hold the expected prior knowledge as somebody else's responsibility: the students themselves, their previous teachers, or the department admissions officer! In practice, universities enrol large numbers of students with a limited understanding of that basic chemical knowledge that might be considered as the foundation for undergraduate study[84–86]. It therefore becomes necessary for the lecturer to ensure that students are in a position to understand the material included in a lecture. One of the key features of the constructivist approach is that it takes further the common-sense view that the teacher needs to make clear (and realistic) assumptions about students' prior knowledge. In the constructivist perspective these assumptions must be made explicitly clear to the students and alternative conceptions must be taken into account.

Various techniques have been used to elicit learners' ideas in science (eg[87,88]), and some instruments have been published, for example to diagnose alternative conceptions about ionic bonding[4] and about the factors influencing ionisation energy[89]. As restructuring can be encouraged through learners trying to explore and justify their ideas, some element of interaction between students can be valuable. One way of doing this is through the technique of 'concept mapping'. This involves producing a graphical representation of ideas about a particular topic: often writing the key concepts in boxes connected with lines or arrows labelled with the relevant propositions (see figure 2). The technique can be readily learnt by students, who may appreciate its value as a study and revision technique[91, 92]. Asking small groups of students to produce joint concept maps is one way of producing in-depth discussion of their ideas.

Of course it takes time to discover the extent of students' alternative conceptions, and many teachers will argue that the syllabus is so full that they cannot afford to be distracted from teaching the curriculum. However, it is important to balance the cost of spending time on this step against the potential benefits of ensuring that students build new knowledge onto a strong foundation. In constructivist teaching schemes, the elicitation of prior knowledge is an essential part of the curriculum process. The old joke that 'I taught it, they just didn't learn it' is telling here – "the verb to cover and the noun information are responsible for much mischief"[93]. The lecturer's role in the modern university is not just to cover the subject matter, but to ensure that it is learned.

Selecting and organising content

Where the students hold alternative conceptions they are unlikely to be erased by simply pointing out that they are wrong. Students will often need to be given time to understand *why* their ideas are wrong, and why the orthodox scientific viewpoint is more sensible. As their ideas may be well integrated into their frameworks of thinking this is not an easy task[94]. However, once identified, the lecturer can plan to challenge alternative conceptions at various points in the lecture course, by providing counter-examples (for example, through data exercises), pointing out self-contradiction, and developing critical thought-experiments[95, 96].

When selecting content to prepare lecture courses it is important to make sure both that the material is closely related to the students' prior knowledge, and that the content is broken down into small manageable chunks that can be logically related and sequenced[97–99]. As discussed above, the 'size of chunk' will depend upon the prior knowledge of the learners. For the students to access the intended meaning they should only be asked to consider one new idea at a time. Each new concept or association should be explored in relation to the learners' existing knowledge before moving on.

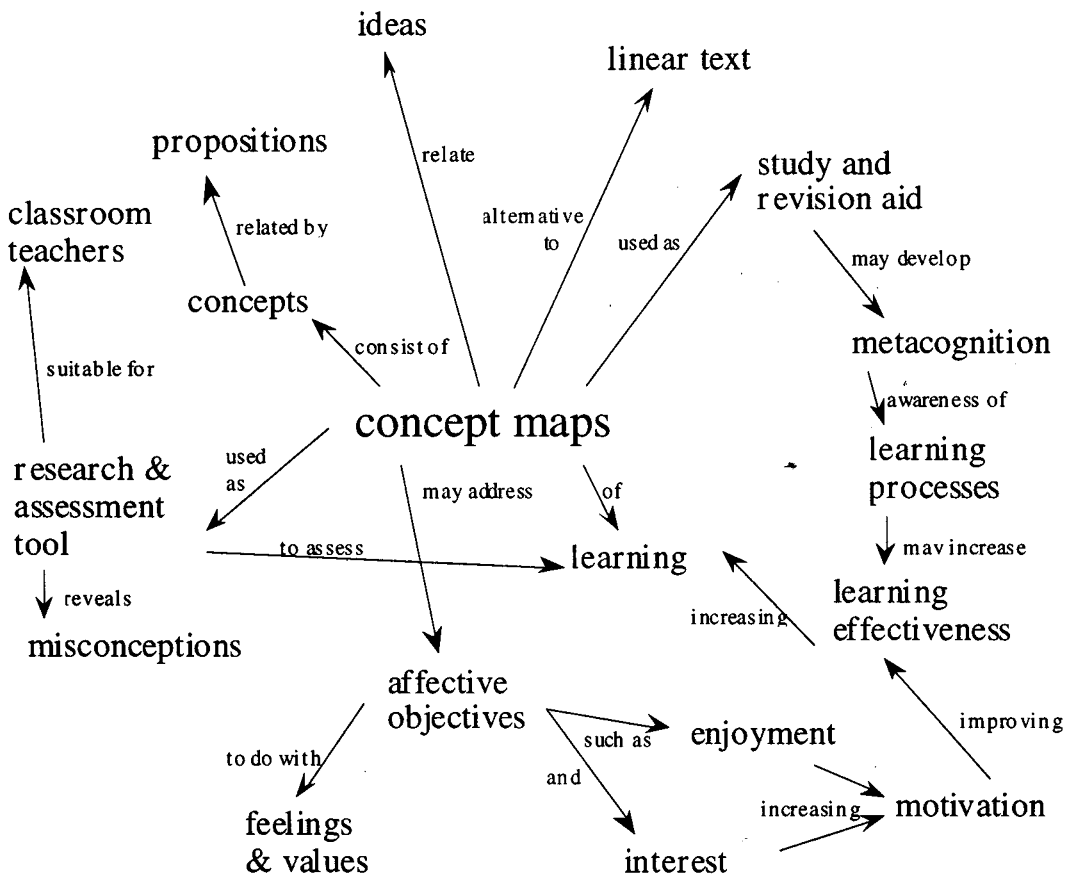
Where there is no obvious source of relevant prior knowledge – for example, some aspects of quantum theory[100] – it is important to provide the students with something familiar to which they can 'anchor' the new ideas[101]. This may be in the form of imagery[102], analogy[103–105] or metaphor[105–107].

Appropriate Teaching Methods

Lecture Style

Assuming that most university teaching will continue to be based on lecture courses, there are ways to make these more inter*active*, and therefore keep students' minds actively engaged. As learning involves relating new material to old, a brief review of the relevant background should always be part of the introduction to any new teaching episode.

Figure 2: A concept map for the concept 'concept map'.



From: Taber K S 1994 Student reaction on being introduced to concept mapping *Physics Education* 29 (5) 276-281.

It is also useful for the lecturer to provide an outline of where the lecture is heading, so that the students have an overview of the material. A rough idea of the 'shape of the territory' provides a template, which prepares the student to organise the material. (This is analogous to a jig-saw puzzle, which may be completed much more easily when the target picture is known.) Students will have different learning styles, and the logical progression of ideas is paramount to some, but an initial overview is more essential for others[58, 108]. Ideally a good presentation includes both an initial 'route map', and a careful logical exposition of the fine detail.

Even university students will not be able to focus fully on a talk for fifty minutes or more[109]. Few academics can hold their audience spell-bound for that long, and it is therefore beneficial to break lectures into short segments by varying the activity. The more *active* the students' minds, the greater the amount of learning that is likely to occur, and so it is important for the students to have to *process* the new information. However this will not be effective unless students are given time and incentive to carry out the necessary processing.

Ideally the lecturer could intersperse the presentation of material with short question and answer sessions, which check that members of the group understand key points before moving on. As Edwards and Mercer point out, teacher's questions are usually designed to teach, and can be a useful way of reinforcing ideas[110]. This may be a difficult approach with large cohorts, especially where most of the students are not known by name and cannot easily be identified in a lecture context. However, interaction between peers can be equally effective at reinforcing new ideas[111]. After each chunk of material is presented, the students could be asked to complete some simple questions – and discuss and explain their answers with the person next to them. As an alternative, students can be asked to *produce* questions for their neighbours to answer, based on what they think they understand.

Anything that might seem to 'interrupt the flow' (sic) of material in a lecture course can be criticised on the grounds that it will reduce the amount of chemistry 'taught'. However, it is well recognised that most students are unable to effectively learn all of the material in their lectures (as demonstrated in final examinations!). It makes sense to be more selective in choosing the material presented if this results in students understanding, retaining and applying that core material better. Hutchinson, for example, reports how a focus on "active intellectual engagement" can enhance retention of concepts, analytical and study skills, and indeed overall success in studying undergraduate chemistry[111].

Continuity and progression

One lesson from the constructivist approach is the importance of making sure that the student has an overview of the subject, and appreciates the *interconnections* within and between different topics. When ideas are presented in different lecture courses, there is even more chance of the learner failing to make connections, especially where different terminology is used by different teachers. (As a personal anecdote, I was told by one A level student that different types of chemical bonds were studied in organic and in inorganic chemistry – the former used single and double bonds, and the latter ionic and covalent bonds.) As learners tend to 'compartmentalise' their knowledge, they will have difficulty accessing knowledge when they do not realise that the context requires it[112, 113].

In the school system in England, in common with many other countries, there is now a National Curriculum, which has been designed so that major topics are met at several different stages of schooling, and with links to other parts of the curriculum detailed in margin notes[114]. This helps the teacher see how a particular topic fits into a coherent curriculum. Universities can help their students by providing a similar structure, so that their course does not seem to be a disjointed set of experiences.

Tutorial work

Learners will most easily come to use scientific versions of concepts in place of their alternative conceptions when they are given the opportunity to rehearse the new ideas, and appreciate their superiority. Even if the alternative conceptions make little sense from a *conventional* viewpoint, they have presumably been fruitful for the student. For example, some learners believe that the nucleus of an atom gives rise to a certain amount of attractive force that depends upon its charge, and that this is *shared* between however many electrons are present. Although this is not good science, it enables students to make correct predictions about some aspects of the patterns observed when atoms are ionised. So, for example, students will explain that a second ionisation requires more energy than the first (true), because once one electron has been removed the others receive a greater share of the nuclear attraction (false)[113].

The student needs to be given sufficient experience of working with the scientific models, to come to appreciate their greater explanatory power. It is important, then, that the student can be *successful* in applying the new ideas. This means that the problems set have to be structured to ensure that the student is both able to achieve success, *and* to develop their skills by applying the scientific principles in increasingly difficult cases and in ever-widening contexts. Ideally, the students are provided with support and advice that is gradually reduced until they have mastered the material – an approach known as 'scaffolding'[59]. As alternative frameworks tend to be idiosyncratic, and as students have different strengths and work rates, it is difficult for the necessary experiences to be provided by including activities in lecture courses alone.

Tutorial work may play a key role, although cost implications may require this to be supplemented with other modes of delivery. In principle this could be through programmed learning *if* high-quality materials are available. Peer tutoring may also be very valuable, if other students are willing and able to help. This can take place within a large examples class, where students who have successfully completed problems help others[52]. Another approach would be schemes using, for example, students in the final year to work with first years – something that may provide experiences of benefit to both in constructing and developing chemical knowledge[115].

Practical work

The constructivist approach emphasises how experiences can only lead to meaningful learning when they can be related to existing knowledge. The need to timetable sessions to utilise available staff and laboratory resources, the time consuming nature of some practical work, and the need to employ rotas to use expensive equipment, all make it difficult to schedule undergraduate practical sessions adjacent to the most relevant lectures.

Practicals can sometimes be undertaken six months in advance of, or behind, the presentation of the relevant theory. This is a worry if we want practical work to provide the evidence for, or demonstrate, scientific principles. Work in schools has shown that even when practical work is integrated with theory within science lessons, the learner's spontaneous tendency is often to interpret observations in terms of alternative conceptions. Indeed, it is not unknown for pupils and teachers to report *seeing* different results[18]!

It is not sufficient, then, to assume that a student who has at different times been taught an aspect of theory, and undertaken the course experiment that is intended to reinforce the theory, will automatically make the connection and relate the two episodes. Clearly some students will, and some good students will put in the preparation to ensure they have a coherent experience of the overall course. The constructivist approach suggests that the two episodes can be mutually reinforcing, but that the connections need to be made explicit, and that most students will need to be provided with a framework to draw their attention to the salient features of the practical. This may mean an appropriate input from the supervisor or demonstrator during the lab sessions (which may be difficult when a wide range of practicals is occurring in the same lab), or – at least – carefully designed textual materials to accompany the laboratory session[116, 117]. At the moment students are not always provided with such resources.

Conclusion

The vast literature into learners' ideas in science suggests that whenever a science teacher sets out to teach a topic there are likely to be students in the class who hold ideas that are inconsistent with the material that is to be presented. Sometimes the learner will make little sense of the presentation, but on other occasions learners will make their own, *alternative*, sense by constructing a meaning that matches their existing ideas. This is, at least in part, an explanation for intelligent, motivated, and hard-working students commonly failing to learn the intended curriculum.

The first step in a constructivist learning approach is to make the teacher and student aware of the learner's current ideas. Teaching can then be planned that challenges alternative conceptions, and provides students with the opportunities and rationale for conceptual restructuring.

In secondary education constructivist approaches have been claimed to produce more effective science learning. Teachers are being trained to begin a topic by finding out what the pupils think they already know, and to start from that point, rather than simply assuming that the learners know what they 'should' at that stage of their education[118]. Less time is wasted repeating the over-familiar, or relying on non-existent prerequisite knowledge, and teachers are aware of where they could easily be misinterpreted through the pupils' alternative frameworks. The same approach could also pay dividends in university teaching.

Acknowledgements

I would like to thank the editor for his constructive comments on earlier drafts of this paper. I would also like to acknowledge the generosity of the Royal Society of Chemistry, who have appointed me as the Society's *Teacher Fellow* for 2000-2001. This secondment releases me from my teaching duties at Cambridge, to develop curriculum materials to help school and college chemistry teachers identify and challenge alternative conceptions. Some of the materials will be aimed at university entrance level (A level or equivalent), and I would be pleased to hear from university teachers who might wish to consider using any of the materials to diagnose freshers' misconceptions.

References

1. Taber KS 1998 An alternative conceptual framework from chemistry education *International Journal of Science Education* 20 597–608
2. Schmidt H-J 1997 Students' misconceptions – looking for a pattern *Science Education* 81 123–135
3. Taber KS 1994 Misunderstanding the Ionic Bond *Education in Chemistry* 31 100–103
4. Taber KS 1997 Student understanding of ionic bonding: molecular versus electrostatic thinking? *School Science Review* 78 85–95
5. Schmidt H-J 1992 Conceptual difficulties with isomerism *Journal of Research in Science Teaching* 29 995–1003
6. Abimbola IO 1988 The problem of terminology in the study of student conceptions in science *Science Education* 72 175–184
7. Piaget J 1973 *The Child's Conception of The World* St. Albans, U.K.: Granada (first published in Great Britain by Routledge & Kegan Paul, 1929)
8. Novak JD 1978 An alternative to Piagetian psychology for science and mathematics education *Studies in Science Education* 5 1–30
9. Vygotsky LS 1978 *Mind in Society: The development of higher psychological processes* edited by Cole M, John-Steiner V, Scribner S & Souberman E, Cambridge, Massachusetts: Harvard University Press
10. Bruner J & Haste H (Eds.) 1987 *Making sense: the child's construction of the world* London: Routledge
11. Driver R & Easley J 1978 Pupils and paradigms: a review of literature related to concept development in adolescent science students *Studies in Science Education* 5 61–84
12. Driver R & Erickson G 1983 Theories-in-action: some theoretical and empirical issues in the study of students'

conceptual frameworks in science *Studies in Science Education* 10 37–60
13. Gilbert JK & Watts DM 1983 Concepts, misconceptions and alternative conceptions: changing perspectives in science education *Studies in Science Education* 10 61–98
14. Pope M & Gilbert J 1983 Personal experience and the construction of knowledge in science *Science Education* 67 193–203
15. Bodner GM 1986 Constructivism: a theory of knowledge *Journal of Chemical Education* 63 873–78
16. Driver R 1989 Students' conceptions and the learning of science *International Journal of Science Education* 11 481–490
17. Watts M & Jofili Z 1998 Towards critical constructivist teaching *International Journal of Science Education* 20 173–185
18. Driver R 1983 *The Pupil as Scientist?* Milton Keynes: Open University Press
19. Driver R, Guesne E & Tiberghien A (Eds) 1985 *Children's Ideas in Science* Milton Keynes: Open University Press
20. Osborne R & Freyberg P 1985 *Learning in Science: The implications of children's science* Auckland: Heinemann.
21. Black PJ & Lucas AM (Eds) 1993 *Children's Informal Ideas in Science* London: Routledge
22. Fensham PJ, Gunstone RF & White RT (Eds) 1994 *The Content of Science: a constructivist approach to its teaching and learning* London: Falmer Press
23. Mintzes JJ, Wandersee, James H & Novak JD. (Eds) 1997 *Teaching Science for Understanding: A human constructivist view* San Diego, California: Academic Press
24. Driver R, Squires A, Rushworth, P & Wood-Robinson V 1994 *Making Sense of Secondary Science: research into children's ideas* London: Routledge
25. Russell T, Longden K & McGuigan L 1991 *Materials* SPACE Project Research Report, Liverpool: Liverpool University Press
26. Briggs H & Holding B 1986 *Aspects of Secondary Students' Understanding of Elementary Ideas in Chemistry: Full Report* Children's Learning in Science Project, Leeds: Centre for Studies in Science and Mathematics Education, University of Leeds
27. Cros D, Amouroux R, Chastrette M, Fayol M, Leber J & Maurin M 1986 Conceptions of first year university students of the constitution of matter and the notions of acids and bases *European Journal of Science Education* 8 305–313
28. Cros D, Chastrette M & Fayol M 1988 Conceptions of second year university students of some fundamental notions in chemistry *International Journal of Science Education* 10 331–336
29. Zoller U 1990 Students' misunderstandings and misconceptions in college freshman chemistry (general and inorganic) *Journal of Research in Science Teaching* 27 1053–1065
30. Carson EM & Watson JR 1999 Undergraduate students' understanding of enthalpy change *University Chemistry Education* 3 46–51
31. Griffiths AK 1994 A critical analysis and synthesis of research on students' chemistry misconceptions, in Schmidt H-J Proceedings of the 1994 International Symposium *Problem Solving and Misconceptions in Chemistry and Physics*, ICASE [The International Council of Associations for Science Education] Publications 70–99
32. Garnett PJ, Garnett PJ & Hackling MW 1995 Students' alternative conceptions in chemistry: A review of research and implication for teaching and learning *Studies in Science Education* 25 69–95
33. Duschl RA, Hamilton RJ & Grandy RE 1992 Psychology and epistemology: match or mismatch when applied to science education, chapter 1 of Duschl R & Hamilton R (Eds) *Philosophy of Science, Cognitive Psychology, and Educational Theory and Practice* Albany, NY: State University of New York Press 19–47
34. Vosniadou S 1994 Capturing and modeling the process of conceptual change *Learning and Instruction* 4 45–69.
35. Ausubel DP & Robinson FG 1971 *School Learning: An Introduction to Educational Psychology* London: Holt International Edition (first published by Holt, Rinehart and Winston, 1969)
36. White RT 1985 Interview protocols and dimensions of cognitive structure, chapter 4 of West LHT & Pines AL (Eds) *Cognitive Structure and Conceptual Change* London: Academic Press 51–59
37. Taber KS 2000 Multiple frameworks?: Evidence of manifold conceptions in individual cognitive structure *International Journal of Science Education* 22 399–417
38. de Bono E 1969 *The Mechanism of Mind* London: Penguin Books (first published by Jonathan Cape)
39. Novak JD & Musonda D 1991 A twelve-year longitudinal study of science concept learning *American Educational Research Journal* 28 117–153
40. Gazzaniga MS 1992 *Nature's Mind: the biological roots of thinking, emotions, sexuality, language and intelligence* London: Penguin
41. Preece PFW 1984 Intuitive science: learned or triggered? *European Journal of Science Education* 6 7–10
42. Pinker S 1995 *The Language Instinct* London: Penguin
43. Lucas A 1993 Constructing knowledge from fragments of learning?, chapter 8, in Black PJ & Lucas AM (Eds) *Children's Informal Ideas in Science* London: Routledge 134–147
44. Watts DM & Gilbert J 1983 Enigmas in school science: students' conceptions for scientifically associated words *Research in Science and Technological Education* 1 161–171
45. Bruner J 1987 The transactional self, Chapter 4 of Bruner J & Haste H (Eds) *Making sense: the child's construction of the world* London: Routledge 81–96
46. Claxton G 1993 Minitheories: a preliminary model for learning science, Chapter 3 of Black P J & Lucas AM (Eds) *Children's Informal Ideas in Science* London: Routledge 45–61
47. Piaget J 1964 Development and learning *Journal of Research in Science Teaching* 2 176–186

48. Andersson B 1986 The experiential gestalt of causation: a common core to pupils' preconceptions in science *European Journal of Science Education* 8 155–171
49. Gilbert JK & Zylbersztajn A 1985 A conceptual framework for science education: The case study of force and movement *European Journal of Science Education* 7 107–120
50. Watts M & Taber KS 1996 An explanatory gestalt of essence: students' conceptions of the 'natural' in physical phenomena *International Journal of Science Education* 18 939–954
51. Taber KS 1995 Prior learning as an epistemological block?: The octet rule – an example from science education, paper presented at the *European Conference on Educational Research*, University of Bath, September 1995, available via Educati*on-line*, at http://www.leeds.ac.uk/educol/
52. Sirhan G, Gray C, Johnstone AH & Reid N 1999 Preparing the Mind of the Learner *University Chemistry Education* 3 43–46
53. Eysenck MW & Keane MT 1990 *Cognitive Psychology: a student's handbook* Hove, East Sussex: Lawrence Erlbaum Associates Publishers
54. Bennett SW & O'Neale K 1998 Skills development and practical work in chemistry *University Chemistry Education* 2 58–62
55. Luria AR 1987 *The mind of a mnemonist* Cambridge, Massachusetts: Harvard University Press
56. Ausubel DP & R obinson FG 1971 *School Learning: An Introduction to Educational Psychology* London: Holt International Edition
57. Thagard P 1992 *Conceptual Revolutions* Oxford: Princeton University Press
58. Meadows S 1993 *The Child as Thinker: the development and acquisition of cognition in childhood* London: Routledge
59. Scott P 1998 Teacher talk and meaning making in science classrooms: a review of studies from a Vygotskian perspective *Studies in Science Education* 32 45–80
60. Strike KA & Posner GJ 1985 A conceptual change view of learning and understanding, Chapter 13 of West LHT & Pines AL (Eds) *Cognitive Structure and Conceptual Change* London: Academic Press Inc., 211–231
61. Strike KA & Posner GJ 1992 A revisionist theory of conceptual change, Chapter 5 of Duschl RA & Hamilton RJ *Philosophy of Science, Cognitive Psychology, and Educational Theory and Practice* Albany, N.Y.: State University of New York Press
62. Hennessy S 1993 Situated cognition and cognitive apprenticeship: implications for classroom learning *Studies in Science Education* 22 1–41
63. Gilbert JK, Osborne RJ & Fensham PJ 1982 Children's science and its consequences for teaching *Science Education* 66 623–633
64. Solomon J 1993 The social construction of children's scientific knowledge, Chapter 5, in Black PJ & Lucas AM (Eds) *Children's Informal Ideas in Science* London: Routledge 85–101
65. Viennot L 1979 Spontaneous reasoning in elementary dynamics *European Journal of Science Education* 1 205–222
66. Viennot L 1985 Analyzing students' reasoning: tendencies in interpretation *American Journal of Physics* 53 432–436
67. Bliss J, Morrison I & Ogborn J 1988 A longitudinal study of dynamics concepts *International Journal of Science Education* 10 99–110
68. Gilbert JK & Pope ML 1986 Small group discussions about conceptions in science: a case study *Research in Science & Technological Education* 4 61–6
69. Carr M, Barker M, Bell B, Biddulph F, Jones A, Kirkwood V, Pearson J & Symington D 1994 The constructivist paradigm and some implications for science content and pedagogy, chapter 11 of Fensham PJ, Gunstone RF. & White RT (Eds) *The Content of Science: a constructivist approach to its teaching and learning* London: Falmer Press 147–160
70. Newton P, Driver R & Osborne J 1999 The place of argumentation in the pedagogy of school science *International Journal of Science Education* 21 553–576
71. Novak JD 1985 Metalearning and metaknowledge strategies to help students learn how to learn, Chapter 12 of West LHT & Pines AL (Eds) *Cognitive Structure and Conceptual Change* London: Academic Press 189–209
72. Novak JD 1989 The use of metacognitive tools to facilitate meaningful learning, chapter 11.1, in Adey P Bliss J Head J & Shayer M (Eds) *Adolescent Development and School Science* Lewes (East Sussex): The Falmer Press 227–239
73. Wittrock MC 1994 Generative science teaching, chapter 3, in Fensham PJ, Gunstone RF & White RT (Eds) *The Content of Science: a constructivist approach to its teaching and learning* London: Falmer Press 29–38
74. White RT & Mitchell IJ 1994 Metacognition and the quality of learning *Studies in Science Education* 23 21–37
75. Carr M 1984 Model confusion in chemistry *Research in Science Education* 14 97–103
76. Taber KS 1995 An analogy for discussing progression in learning chemistry *School Science Review* 76 91–95
77. Driver R & Oldham V 1986 A constructivist approach to curriculum development in science *Studies in Science Education* 13 105–122
78. Johnston K & Driver R 1991 *A Case Study of Teaching and Learning about Particle Theory: a constructivist teaching scheme in action* Children's Learning in Science Project, Leeds: Centre for Studies in Science and Mathematics Education, University of Leeds
79. Harlen W 1999 *Effective Teaching of Science: a review of research* Edinburgh: Scottish Council for research in Education
80. Millar R 1989 Constructive criticisms *International Journal of Science Education* 11 (special issue) 587–596
81. Fox D 1983 Personal theories of teaching *Studies in Higher Education* 8 151–163
82. Prosser M & Trigwell K 1999 Relational perspectives on higher education teaching and learning in the sciences *Studies in Science Education* 33 31–60

83. Curzon LB 1990 *Teaching in Further Education: An outline of principles and practice* (4th Edition), London: Cassell Educational Ltd
84. Cervellati R, Concialini V, Innorta G & Perugini D 1984 Chemical knowledge of students entering a first-year university chemistry course in Italy *European Journal of Science Education* 6 263–270
85. Assessment Subject Group of the Royal Society of Chemistry 1998 *Research in Assessment XIII: An updated report on the skills test survey of chemistry degree course entrants* The Royal Society of Chemistry Education Division, London.
86. Barker V & Bennett J 1999 The post-16 – university transition *Education in Chemistry* 36 101–104
87. White R & Gunstone R 1992 *Probing Understanding* London, The Falmer Press
88. Taber KS 1996 Chlorine is an oxide, heat causes molecules to melt, and sodium reacts badly in chlorine: a survey of the background knowledge of one A level chemistry class *School Science Review* 78 39–48
89. Taber KS 1990 The truth about ionisation energy: an instrument to diagnose common alternative conceptions *School Science Review* 81 97–104
91. Novak JD 1990 Concept mapping: a useful tool for science education *Journal of Research in Science Teaching* 27 937–949
92. Wandersee JH 1990 Concept mapping and the cartography of cognition *Journal of Research in Science Education* 27 923–936
93. Garratt J 1988 Inducing people to think *University Chemistry Education* 2 29–33
94. Chinn C & Brewer W 1993 The role of anomalous data in knowledge acquisition: a theoretical framework and implications for science instruction *Review of Educational Research* 36 1–49
95. Helm H & Gilbert J 1985 Thought experiments and physics education – part 1 *Physics Education* 20 124–131.
96. Helm H, Gilbert J & Watts DM 1985 Thought experiments and physics education – part 2 *Physics Education* 20 211–217
97. Heron JD et al 1977 Problems associated with concept analysis *Science Education* 61 185–199
98. Johnstone AH & Kellett NC 1980 Learning difficulties in school science – towards a working hypothesis *European Journal of Science Education* 2 175–181
99. Johnstone AH 2000 Teaching of Chemistry – logical or psychological? *Chemistry Education: Research and Practice in Europe* 1 9–15
100. Feynman RP 1985 *QED: The strange theory of light and matter* Princeton: Princeton University Press 9
101. Niedderer H, Bethge T & Cassens H 1990 A simplified quantum model: a teaching approach and evaluation of understanding, in Lijnse P L, Licht P, de Vos W & Waarlo A J (Eds) *Relating Macroscopic Phenomena to Microscopic Particles: a central problem in secondary science education* Utrecht: Centre for Science and Mathematics Education, University of Utrecht: CD-ß Press 67–80
102. Miller AI 1986 *Imagery in Scientific Thought* Cambridge, Massachusetts: M.I.T. Press
103. Vosniadou S & Brewer WF 1987 Theories of knowledge restructuring in development *Review of Educational Research* 57 51–67
104. Treagust DF, Harrison AG & Venville GJ 1996 Using an analogical teaching approach to engender conceptual change *International Journal of Science Education* 18 213–229
105. Duit R 1991 On the role of analogies and metaphors in learning science *Science Education* 75 649–672
106. Lakoff G & Johnson M 1980 The metaphorical structure of the human conceptual system *Cognitive Science* 4 195–208
107. Ritchie SM 1994 Metaphor as a tool for constructivist science teaching *International Journal of Science Education* 16 293–303
108. Child D 1986 *Psychology and the Teacher* (4th Edition) London: Cassell
109. Laws PM 1996 Undergraduate science education: a review of research *Studies in Science Education* 28 1–85
110. Edwards D & Mercer N 1987 *Common Knowledge: The development of understanding in the classroom* London: Routledge
111. Hutchinson JS 2000 Teaching introductory chemistry using concept development case studies: interactive and inductive learning *University Chemistry Education* 4 1–7
112. Karmiloff-Smith A 1994 Précis of Beyond Modularity: A developmental perspective on cognitive science *Behaviour and Brain Sciences* 17 693–745
113. Taber KS 1998 The sharing-out of nuclear attraction: or I can't think about Physics in Chemistry *International Journal of Science Education* 20 1001–1014
114. DFE/QCA 1999 *Science: The national curriculum for England key stages 1-4* Department for Education and Employment/Qualifications and Curriculum Authority
115. Coe EM, McDougall AO & McKeown NB. 1999 Is peer assisted learning of benefit to undergraduate chemists? *University Chemistry Education* 3 72–75
116. Johnstone AH 1997 "…And some fell on good ground" *University Chemistry Education* 1 8–13
117. Nicholls BS 1999 Pre-laboratory support using dedicated software *University Chemistry Education* 3 22–27
118. DfEE 1998 *Circular 4/98: Standards for the award of qualified teacher status: Annex A* Department for Education and Employment

Course-questionnaires as a research tool

From John Garratt, Nigel Lowe, and Jane Tomlinson
Department of Chemistry
University of York
Heslington
York YO10 5DD

In the last issue of this journal, de Jong made a plea for closer links between chemical education research and the teaching of chemistry, and he argued the case for the teacher as researcher[1]. Goodwin suggested that the teacher-researcher needs to collect data in ways which are not too time-consuming[2]. Our suggestion is that really useful action research could be carried out with little additional effort by making better use of course questionnaires which are nowadays a feature of almost all university courses. There are good reasons why academics should be willing to do this.

Many (perhaps most) course questionnaires are in a standard form (at least within a given department). Typically they make little attempt to evaluate (for example) what learning has taken place, what misconceptions students may have, or whether the students have been challenged to think (become actively involved in the learning process). It is likely that many questionnaires receive no more than a cursory analysis before being filed. Their main use (if there is one) appears to be that they provide 'evidence' that departments and individuals take their teaching seriously. However, in the light of the Dearing Report[3] 'taking teaching seriously' ought to involve a greater emphasis on student-centred learning and we are sceptical that conventional course questionnaires help to address this.

Our proposal is that individual lecturers (or course organisers) should be encouraged to replace existing standard-format questionnaires with one tailored to the learning objectives of the course in question. The preparation of the questionnaire would take a little extra effort, but have accompanying benefits. It would focus the mind of the teacher on the need for specific learning objectives (preferably broader ones than the mischief words "convey information"[4]) and on the most appropriate way of evaluating whether these have been achieved. A well-designed questionnaire would also give useful feedback on reasons why some objectives may have been poorly realised. In particular they could expose the existence of misconceptions, the importance of which is emphasised by Taber in this issue[5]. Furthermore, some styles of questionnaire can heighten the learning experience by encouraging the students to reflect on (and therefore reinforce) what they have learned[6]. Different learning objectives are best evaluated by different styles of questionnaire, and many are available – some of which stretch the definition of 'questionnaire'. For example, the 'written reflection exercise' devised by Lowe[6] and adopted by Garratt et al[7] is not really a questionnaire in the conventional sense. However, the use of this type of free-response question can lead to insights into the students' learning which can be used to better match the teaching to the students' needs. Some implications of this process for skills development in students have been discussed elsewhere[8].The confidence log proposed by Draper[9], and practised by Garratt et al[10], can give an unusual but potentially useful perspective on student attitude. The Osgood-style questionnaire, which invites respondents to place themselves between two contrasting statements can often be more revealing than the more commonly used Lickert questionnaire in which a numerical response is made to a single statement. As a final example, the 'action statement' approach adopted by Duckett et al[11] in a different context, provides another useful variant on the standard questionnaire format. The important point is to think carefully about the best method for obtaining the kind of feedback which will be of most use in a particular context.

We believe that most academics are genuinely concerned to improve their students' learning, and that the more thoughtful ones are aware that most of the course questionnaires they use do not help them to do this. Course questionnaires in this sense are a wasted opportunity, taking up the time of students and staff alike. Making good use of this opportunity could provide information which would be of use to a wider audience than the individual course-giver, and some of the data (at least) would be publishable as action-research. Teaching is (or should be) a scholarly activity in which the teachers learn from their students and strive to improve their effectiveness as facilitators of learning. Unfortunately the university community seems to have moved away from being a single community of *scholars* committed to *learning* and is becoming a divided community in which the academics see themselves as a group of *researchers* who are also required to play their part in *teaching*. This militates against the recognition of teaching as scholarship. We suggest that both the quality and the status of teaching would be improved if academics made good use of the opportunities provided by course questionnaires for action research, and went on to publish their results.

References

1. de Jong O 2000 Crossing the borders *U.Chem. Ed.* 4 29–32
2. Goodwin A 2000 Some thoughts following crossing the borders *U. Chem. Ed* 4 37
3. Dearing R 1997 *Higher education in the learning society* (HMSO)
4. Garratt J 1998 Inducing people to think *U. Chem. Ed.* 2 30–33
5. Taber K 2000 Chemistry lessons for universities *U. Chem. Ed* 4 63–72
6. Lowe N 1999 Reflecting on learning *U. Chem. Ed.* 3 76
7. Garratt J, Horn A and Tomlinson J 2000 *U. Chem. Ed.* 4 54–57
8. Lowe N *Educ. Chem.* Accepted for publication.
9. Draper S 1996 Integrative evaluation *Computers and Education* 26 17–32
10. Garratt J, Tomlinson, J, Hardy S, and Clow D 2000 *U. Chem. Ed.* 4 15–22
11. Duckett S, Garratt J and Lowe N 1999 Key skills: what do chemistry graduates think? *U.Chem. Ed.* 3 1–7

Future Arrangements for University Chemistry Education

From 1 Jan 2001 there will be significant changes in the organisation

Professor M J Pilling (Leeds) continues as Chair of the Editorial Board.
Professor P D Bailey (Heriot Watt) and Dr S W Breuer (Lancaster) become Co-Editors.
Dr C J Garratt becomes Editorial Consultant.

Volume 5 will be an electronic only journal, and will be accessible free of charge using acrobat reader software (obtainable *via* http://www.adobe.com).
The web page for U Chem Ed is accessible via the RSC Tertiary Education Group homepage at www.rsc.org/lap/rsccom/dab/educ005.htm

The URL for the UChemEd homepage is www.rsc.org/uchemed/uchemed.htm

An Email list has been set up – subscribers to this list will receive Email alerts when new issues or papers are available.
You are advised to register with this list now.
To do this
either send the following email message to listserver@list.rsc.org
join uchemed-inf youremailaddress
or use the registration form on the U Chem Ed homepage

Back numbers (except for Vol 1) will also be available from the same web address and at no charge.
Both the April and September issues of Vol 4 will also be available in the same way.
Please draw this to the attention of colleagues who do not receive hard copies of the journal.

Submission of Manuscripts.

Small changes have been introduced to the Guidelines for Authors (inside back cover)
Would authors please read these carefully and comply as closely as possible with the guidelines. Please note especially that the preferred method of submission of manuscripts is by email as an attached Word file. Manuscripts may be submitted either to:
Professor Pat Bailey, email p.d.bailey@hw.ac.uk
Department of Chemistry, Heriot Watt University, Edinburgh EH14 4AS
or to
Dr Stephen Breuer, email s.breuer@lancaster.ac.uk
School of Physics and Chemistry, Lancaster University, Lancaster LA1 4YB.