Changing the Nature of Physical Chemistry Practical Work

PAPER

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The use of computer-based resources in supporting the teaching of a 1st year physical chemistry laboratory course is described where the course has been enhanced to develop skills in experimental design, data analysis and links to theoretical parts of the subject. In particular, a number of CD ROM packages, each comprising video, background theory, worked examples and sample data, a glossary and a final test, have been created using the "Toolbook Instructor" authoring system. One package, the "Chemical Kinetics" package is described in detail. The packages contain a course management element which allows students to be assessed on their understanding of the background theory and their competence to carry out experiments. In trials at the University of Central Lancashire the new packages were well received by students and staff and scored better than 3.7 for a wide range of questions on a questionnaire (1 = very negative; 5 = very positive). It is concluded that interactive CD ROM packages can now be routinely customised to meet the individual needs of teaching and learning situations and that the onus rests on universities to provide funding for equipment, resources, and for staff development training.

Introduction

One of the central aspects of any Chemistry course is the development of practical skills in laboratory work. The recently published benchmarking document[1] describes these as follows.

- Skills in the safe handling of chemical materials;
- Skills required for the conduct of standard laboratory procedures;
- Skills in the monitoring of chemical properties, events or changes and the systematic and reliable recording and documentation thereof;
- Competence in the planning, design and execution of practical investigations;
- Skills in the operation of standard chemical instrumentation;
- Ability to interpret data derived from laboratory observations and measurements;
- Ability to conduct risk assessments.

It is not clear that our existing courses provide opportunities for students to develop all these skills. Indeed, Johnstone suggests that "*it is possible to reach the end of a laboratory period having learned nothing with the exception of some hand skills*"[2]. Masson and Lawrenson[3] have used computer testing to highlight problem areas with first year laboratory classes and concluded that problems relate to poor understanding of background theory and general scientific concepts, and to difficulty with dealing with experimental results. This conclusion is consistent with our own observations of first year students working in the physical chemistry laboratory.

Students at the beginning of a university course face a number of problems in the physical chemistry laboratory. In the first place they lack experience with the procedures concerned, and the accompanying lack of manipulative skills often means that the data they collect are of poor quality. Furthermore the amount of time available is too short for them to collect sufficient data for interesting analysis or to repeat observations in an attempt to improve their technique through practice. Tutors often respond to these problems by providing a detailed protocol for the students to follow; this is designed to minimise the faults in technique and to ensure that data are collected under optimal conditions. One consequence of this is that students carry out the manipulations mechanically and without thought[4]; this lack of engagement with the process means that students gain little inspiration from laboratory work, and lose faith in the theory which underpins it.

Different suggestions have been made to deal with these problems. For example Yates[5] has reported some success following the introduction of a number of changes into first year physical chemistry practicals, including pre-laboratory exercises involving video-learning and data analysis. Nicholls[6] has designed computer software for use as pre-lab exercises in the inorganic chemistry laboratory. Garratt and co-workers[7] have prepared computer simulations which they claim are useful both as pre-lab exercises and to provide students with the means to learn about experimental design and data interpretation.

We were encouraged by our own success with computer-based learning packages[8] to extend the approach to laboratory work. In planning our approach we were influenced by the conclusion of a recent survey which concluded that the greater the integration of CAL materials within the course, the more useful the materials are likely to be in supporting the students' learning[9]. We also determined to take advantage of the videos dealing with standard laboratory procedures which have been produced by the Chemistry Video Consortium[10].

Our aim was to produce packages, delivered by CD ROM, which would allow us to avoid the following problems which we observed were encountered by students.:

- Students enter the laboratory unfamiliar with the technique and procedure they are about to encounter; pre-lab use of the CVC videos would help them.
- Students do not see the link between their theoretical knowledge and their laboratory work, and they do not always read the theoretical section in their practical script; the computer-based package would allow greater interactivity and should encourage the students to make this link.
- The computer program could create and store a wide range of data accessible to students, thus providing opportunities for experimental design and data processing.
- A self-test section could provide the opportunity for students to evaluate their own knowledge and understanding.

CD Rom teaching and learning packages

Table 1 lists six laboratory exercises for which computer-based support packages have been created. All of these are currently in use by students on the first year of the course at the University of Central Lancashire. In the physical chemistry laboratory course the students typically work in pairs and complete each exercise within a 3 hour laboratory session. The number of exercises was reduced when the computer-based packages were introduced, in order to allow time for the students to use these before the appropriate laboratory session. This reduction in time devoted to laboratory work was justified by the expectation that effective learning would be increased by the introduction of the packages, and that the range of practical skills would be increased.

The packages were developed using the authoring system Toolbook Instructor[11]. This allows extensive course management, covering allocation of students to courses, tracking of students' attendance and progress on the package, and computer-management of the test sections. Each package consists of the following five sections.

- A video based on the HEFCE TLTP Chemistry Video Consortium series "Basic Laboratory Chemistry"[10]. This section provides effective pre-laboratory instruction for the work that students will undertake in the laboratory.
- A section detailing the theory relevant to the topic being studied. Here, sufficient theory is included to underpin the laboratory studies, both at the planning and the data analysis stages.
- A section providing worked examples and sample data. The data here can supplement the students own laboratory results. Sufficient data is stored so that students can have a choice in planning their work and in undertaking detailed data analysis. Worked examples are available for those students who need help in the analysis.
- A glossary of terms and definitions, to support the theory section of the package.
- A computer-marked test which provides feedback for the student. This can be used as self-assessment by the student or as assessment by the tutor.

The design and use of the packages is illustrated here by the Chemical Kinetics package.

Table 1: Laboratory exercises supported by computer-based packages

1. Basic Chemical Kinetics (a study of the reaction between hydrogen peroxide and iodide).
2. Basic thermochemistry (using a bomb calorimeter).
3. Basic Phase Equilibria (solid/liquid and partially miscible liquid systems).
4. Gases and Gas Equilibria (determining the molecular weight of gases and the degree of dissociation of dinitrogen tetroxide).
5. Gas Chromatography.
6. Infrared Spectroscopy

Basic chemical kinetics

This package deals with the reduction of H_2O_2 by iodide. Details of the reaction are well established[12], and the system is widely used in university laboratory courses covering chemical kinetics. The rate equation is

$$\text{Rate} = k_1[I^-][H_2O_2] + k_2[I^-][H_2O_2][H^+]$$

Conditions can be chosen so that the concentrations of iodide and acid remain effectively constant so that the reaction is pseudo-first order with respect to H_2O_2. The reaction is easy to set up, and the rate is easy to monitor. It can be used to illustrate a number of facets of introductory courses on the theory of chemical kinetics. Thus it is an ideal topic for a learning package. At the University of Central Lancashire, students are allocated sufficient laboratory time to collect data at two temperatures. This is insufficient to allow them to separate out the two rate constants (k_1 and k_2) or to calculate activation energies.

The following descriptions of the five sections of the computer-based package show how this was designed to overcome key limitations of the laboratory exercise.

The video section

The video produced by the Chemistry Video Consortium describes, in short sections, all the experimental procedures to obtain time-concentration data for this reaction. This section of the computer-based package comprises a menu page which is hyper-linked to tutorial pages each containing one of the sub-sections of the video together with its accompanying text. There are six sub-sections: introduction, experimental conditions, making up solutions, carrying out the experiment, plotting the results and determining the importance of other variables.

A study of this section of the learning package gives instruction on the experimental skills needed to collect data for the kinetic study and therefore provides effective pre-laboratory studies for the students.

The theory section

This is broken down into eight sub-sections hyper-linked through a menu page and through 'hot words' within the sub-sections which deal with

- The rate equation
- The Arrhenius equation
- The isolation method
- The differential method for reaction orders
- The trial and error method for reaction orders
- The half life time method for reaction orders
- The peroxide-iodide reaction
- Rate equations and mechanisms

These topics closely match the students' introductory theory course in chemical kinetics and provide support both for that, and for the laboratory studies. The structure, which provides the basics of the topic with hyperlinks for more detailed information, gives students rapid access to the main theory points which they can easily follow up with more in depth study. Students can be directed to particular theoretical sections or left to make their own decisions on what to study.

Worked examples and sample data

Published values for activation energies and pre-exponential factors for the two terms in the rate equation allow idealised data to be calculated for any defined conditions. A spread sheet has been used to do this for some 20 different experimental conditions. These data are available via hyper-links to a menu page (see Figure 1). Students are thus able to get data for the reaction for a range of temperatures and initial concentrations of reactants, and use this to supplement the two sets of data that they have themselves obtained in the laboratory. The students' choice of data for both experimental design and data analysis is limited to that stored in the program. However, the amount of data stored is greater than any student needs, and they are in any case dissuaded from using all of it by the time it would take them to process it. The provision of a limited choice is helpful at this stage of the student's career since their inexperience may make a completely free choice overwhelmingly daunting. As illustrated in Figure 2, this section of the learning package also allows the students to see worked examples for the calculation of:

- the pseudo 1^{st} order rate constant;
- the individual rate constants, k_1 and k_2;
- the activation energies.

The test section

This section of the learning package contains some 20 to 30 questions with appropriate feedback. Figure 3 shows an example. Results of the test are computer marked and can be reported back to the tutor if this is required, although, in its use at the University of Central Lancashire, the section has been used as a teaching tool with immediate feedback to the student for both correct and incorrect answers.

The glossary

A Glossary covers most of the terms and definitions relevant to the study of basic chemical kinetics.

Figure 1 Sample data menu with pop up of detailed raw results

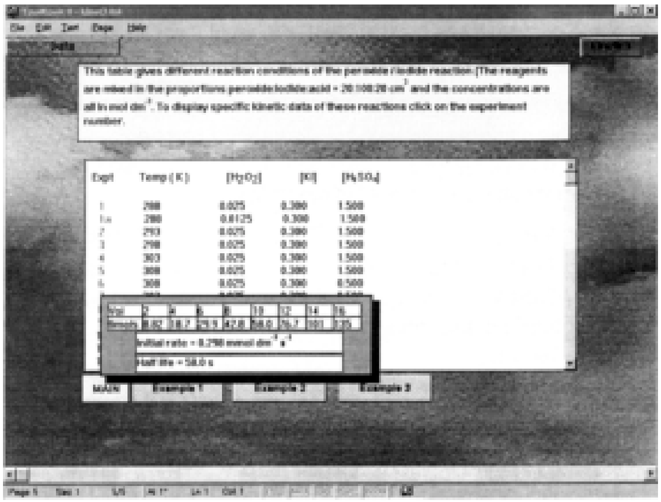

Figure 2 Worked example from sample data with pop up detail of calculation

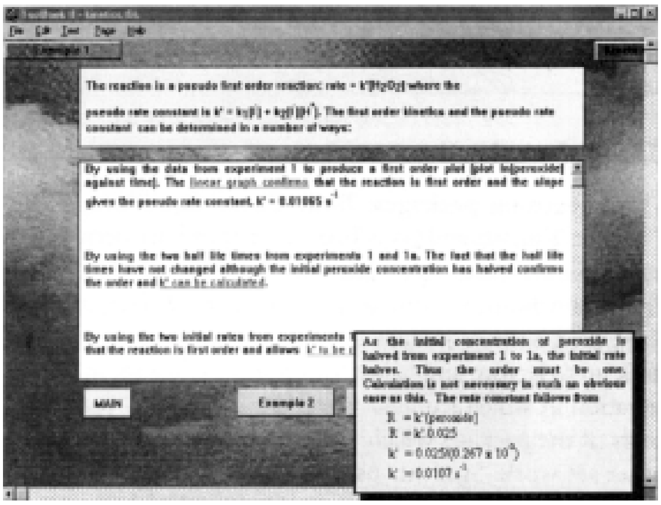

Figure 3 Sample question from test with pop up feed back

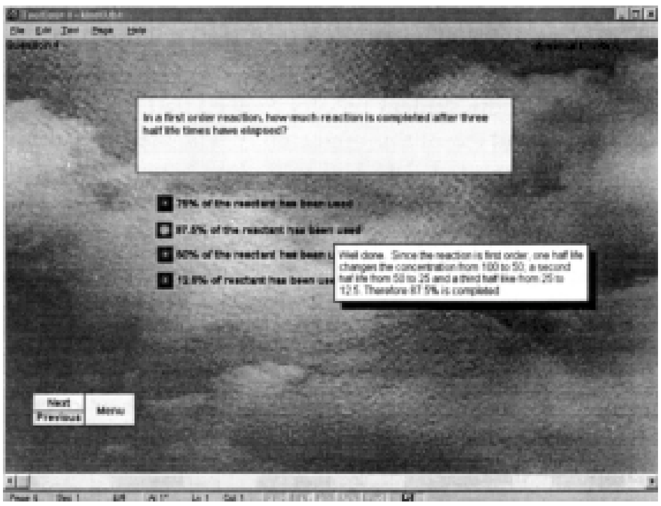

Table 2 Results from student questionnaire (1 = negative, 5 = positive).

		Mean Score	*Range*
1.	How would you rate your general IT skills?	3.8	2 - 5
2.	How would you rate your previous experience of computer based learning?	3.1	1 - 5
3.	Did you find navigation in the package easy	4.2	2 - 5
4.	Comment on ease of use of the package:		
	Overall	4.2	2 - 5
	Video section	4.0	2 - 5
	Theory section	4.1	2 - 5
	Sample data/worked examples	3.7	2 - 5
	Glossary	4.0	1 - 5
	Self assessment test	3.7	2 - 5
5.	Comment on the usefulness of the package to your understanding of the topic:		
	Overall	4.1	2 - 5
	Video section	3.7	1 - 5
	Theory section	4.0	2 - 5
	Sample data/worked examples	3.7	2 - 5
	Glossary	4.0	2 - 5
	Self assessment test	3.7	2 - 5
6.	Would you like to see other topics developed as computer based learning packages?	4.1	2 - 5
7.	Would you prefer to use packages in a class or self-learning mode?	63% prefer self-learning	

Use and evaluation

Three learning packages, Basic Phase Equilibria, Basic Chemical Kinetics and Gas Chromatography have been tested with diploma and degree students at the University of Central Lancashire during the first semester of 1998/99. The packages were used both as student self-learning material to provide back up to lecture and laboratory courses and also, in a class situation in which students were first directed to particular parts of the package which were relevant to laboratory and other set work. Students used the Basic Chemical Kinetics package before collecting their own data in the laboratory. In particular, they were asked to study the theory section dealing with the determination of reaction orders, and the section dealing with worked examples of these methods. They were required to select data from the stored pre-calculated results which would complement their own data collected in the laboratory.

Analysis of the student reports showed that the students had made good use of this opportunity. The use of idealised computer-generated data had two clear benefits. First, it avoided the need for students to rely on data generated by other students in order to collect sufficient for meaningful analysis; this is always problematic because some students are less reliable than others. Second, the ideal (errorless) nature of the computer-generated data was an effective way of demonstrating the effect that experimental error has on results, and the inclusion of perfect data in their overall processing gave the students confidence in their ability to manipulate data.

Supervising staff reported that the student attitude to laboratory work appeared to have been improved through the use of the package. Students had worked conscientiously at the computer, spending a significant amount of time, benefiting from discussion with their peers, and following this up with questions to the supervising staff. In the laboratory, students appeared confident in their ability to plan and carry out the procedures with minimum input from supervisors, suggesting that the structured way of introducing them to the video clips dealing with technique is an effective way of using this valuable resource. Furthermore, their selection of appropriate data to supplement their own, and the quality of their data processing, showed that they understood the background theory.

A simple questionnaire was completed by 27 students and the results are shown in Table 2. This shows that the students also revealed a very positive attitude to their work.

Outside the questionnaire, the most common comment was "can we borrow these CD ROM materials for use at home?" This comment reveals that, in the case of the University of Central Lancashire, a high proportion of the students (over 70%) have access to good computing facilities away from the University. A consequence which arises from this is that the Faculty of Science will need to set up a loan service for IT packages.

A second major comment was the request "can the materials be placed on the University computer network?" This request could not be accommodated, not because of copyright problems, but because of bandwidth problems encountered with playing the video section on networked machines. Such problems are likely to persist for some time to come. A way round them is to use a local network server for a 'pod' of CD ROM PCs within a Department.

The results from the use of the learning packages at the University of Central Lancashire are in accord with other similar studies. Effectiveness is linked with the direct integration of the computer based materials within existing courses[9], there is a need to consider ways of dealing with student weaknesses in basic theory and data analysis in first year laboratory classes[3], and pre-laboratory exercises and data analysis enhance physical chemistry practicals[5].

The positive responses by students and staff to the material tested at the University of Central Lancashire and to the Pilot CD ROM circulated to UK University chemistry departments suggests that the difficulties of producing high quality video on a PC and meaningful interactivity (self-learning and self-assessment) have been overcome. The challenge now shifts to Universities in order to facilitate a student culture in which all students have a CD ROM PC on day one of their degree course, a teaching and learning culture in which students can proceed at their own pace, laboratory experiences where students develop both practical and presentational skills, and staff development facilities whereby staff can be enabled to produce the new IT materials for the 21st century.

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