# Pre-laboratory support using dedicated software

PAPER

Barry S. Nicholls

School of Pharmacy and Chemistry, Liverpool John Moores University, Byrom Street, Liverpool L3 3AF
email B.S.Nicholls@livjm.ac.uk

Dedicated pre-laboratory software supporting inorganic experiments has been integrated into the curriculum at Liverpool John Moores University. Its main objectives are to: (a) ensure that students prepare adequately for forthcoming experiments, (b) ensure that students are informed of hazards of those experiments and (c) offer an interactive transcript of the theory and processes involved. The fulfilment of these objectives should promote efficient, aware and safe working in the laboratory, and enable both students and demonstrators to use their time productively. Participation is mandatory; on-line data capture and processing automatically identifies unprepared students, who are excluded from the corresponding laboratory sessions on safety grounds. This paper describes the design, integration, uptake and productivity of pre-laboratory software during the 1997/98 academic year.

## Introduction

Most laboratory work carried out by students in the early years of their course involve following recipes. A common criticism is that students "seem to go through the motions of laboratory activity with their minds in neutral"[1], and they tend not to make observations unless their script tells them to do so[2]. It is now almost 20 years since Johnstone argued that laboratory scripts are presented in such a way that students in the laboratory have little choice but to follow recipes without understanding[3]. The limitation of the brain's 'working space'[4] means that it is fully occupied by the demands of unfamiliar manipulations and this precludes them from relating what they are doing to some theoretical knowledge which they have compartmentalised in a separate 'box'. If we accept that "to learn meaningfully, individuals must choose to relate new knowledge to relevant concepts and propositions they already know"[5,6], we can see that the chemistry laboratory often provides a poor learning experience.

Verdonk has advocated improving this experience by changing the structure of laboratory work so that it becomes much closer to a true investigation, and so encourages students to engage in 'fact making' rather than 'fact learning'[7]. However, this approach is not always appropriate, especially with large groups of students as is now commonly found in first-year classes. Indeed, an argument in favour of the recipe lab is that it maximises both the quantity of practical experience gained by students and the quality of the results they obtain[8]. If these potential benefits of the recipe lab are to be realised, then the student must be properly prepared by effective pre-lab work[4,9].

Some useful preparation can be achieved by the constructive viewing of videos covering specific techniques, and excellent video discs are available for this purpose[10].

Another approach is the development of customised computer software. Computer programs have a number of characteristics which can be exploited to create a meaningful pre-lab experience for students. Thus, computer programs can be written so that:

- students can work at their own rate and repeat any exercise until they understand the particular lessons involved;
- material can be presented in a variety of ways including the use of animations, graphics, simple calculations, text, and questions;
- active involvement in the learning process is ensured by requiring frequent and creative interaction with the computer;
- student usage is logged to give the tutor a usage profile for individual students;
- student competence with specified tasks is tested and automatically marked without recourse to a tutor.

This paper reports on the preparation and use of a suite of programs designed to provide an effective pre-lab experience for first-year students carrying out first-year laboratory work in inorganic chemistry.

A previous paper[11] deals with programs designed to give effective post-laboratory work for some of the same experiments.

## Methods

### Program Design

The first-year laboratory course in inorganic chemistry contains eight experiments; pre-lab software has been written to support six of them.

The pre-laboratory software has been written in the object-oriented programming language, Authorware Professional. It forms part of the ChemiCAL portfolio of software[12].

Observation of students over a number of years led to the conclusion that students are ill-prepared for laboratory work in three different ways which could be remedied by computer-based pre-lab work. These can be summarised as

- poor understanding of the best way to carry out simple procedures;
- failure to relate laboratory operations to basic chemical knowledge;
- lack of awareness of (or failure to use) safe practice.

The first step in program design was therefore to analyse all the experiments to identify specific examples of these three general features, and to assess whether or not they could be addressed by the program (for example the program can obviously not help to develop the manual dexterity needed to carry out a titration, but it can deal with the best way to fill and read a burette).Techniques were identified as relevant if they had not been previously encountered by the students at university;this is necessary because student background is so variable that it is not safe to assume that all are able to carry out very basic procedures. Not surprisingly, not all experiments introduced new techniques. In these cases the software covered only safety and theory.These are described as type B to distinguish them from type A which include all three features.

This analysis provided a detailed set of learning objectives for each experiment. The next step in program design was therefore to plan the most effective strategy for delivering each of these learning objectives. In general, animations and graphics are most appropriate for demonstrating and teaching aspects of technique, whereas calculations, questions and text are usually sufficient to deal with aspects of theory and of safety.The primary objective of the programs is to ensure that students think about the tasks which they will face in the laboratory, so that they enter the laboratory well prepared; the only element of testing is that which is required to ensure that the students have engaged effectively with the computer. This emphasis on learning means that the program must be written in a way which forces the students to engage actively with the computer.This is achieved by requiring students to feed in frequent and meaningful responses from which instructive feedback is received.For example,if a student fails to answer questions correctly, the program allows only two further attempts before giving the correct answer,but feedback always provides the reasoning which leads to the answer.

The design of a program is best demonstrated by illustrative example.

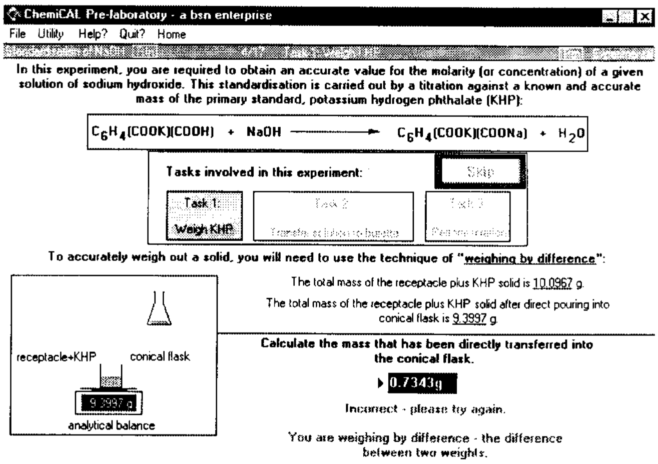
## Examples

Type A:Standardisation of hydroxide solution using potassium hydrogen phthalate (KHP).

This is one of the first experiments carried out by students on this course. It consists of five sections. Three sections deal with an aspect of technique (weighing by difference, filling the burette, and titrating). The fourth section deals with basic theory, and the final section is a test.

- *Weighing by difference* is demonstrated with three animated sequences and eight questions (see Figure 1). The first animated sequence shows transfer of KHP to a conical flask directly from a weighing boat. The student is required to interact frequently. For example, masses are given, and the student is required to calculate the mass transferred to the flask. The program then offers several methods for transferring the salt and the student is required to select the best method.Finally,the program illustrates, through similar interactive animation, the importance of using the same balance for the most accurate determination of mass transfer.

*Figure 1:* Weighing by difference - a type A pre-lab exercise




- *Transfer of hydroxide solution to burette* deals with three aspects of this process. The first alerts students to the fact that it is unnecessary and time wasting to fill the burette exactly to the zero mark. The next deals with the choice of burette size, encourages students to recognise that this matters little as long as the burette is big enough, and reinforces the notion that only *relative* volumes are of importance in a titration. Finally, the program deals with the problem of trapped air below the burette tap and the safety issue of filling the burette while below eye-level.
- *The Titration* deals with accurate burette reading and the determination of a good end-point. Students are shown a graphical display of a burette, which is used to provide an interactive exercise designed both to make students aware of the need to take readings consistently (either from top or from bottom of the meniscus, but not a mixture of both) and also reminds them to take precise readings by estimating to the nearest 0.01 $cm^3$. Students then have to answer questions designed to focus their minds on four points of technique:
  the reason for using a conical flask in preference to a beaker;
  the importance of constant swirling of the flask to ensure mixing;
  the unimportance of knowing the exact volume of water in which the solid KHP is dissolved before titration;
  the number of determinations they should perform in order to obtain a reasonably reliable result.
- *Theory section* .The students must answer ten simple questions on the theory of the experiment they are about to perform. These questions are posed randomly from a bank; no two students will get the same set of questions, although each will receive questions of a similar nature and difficulty (Figure 2 shows a typical example).Correct answers are ultimately displayed in this section.
- *The test section* displays 15 statements of theory and technique relating to the laboratory exercise which students are about to perform. Their task is to identify the correct statements by clicking each appropriate statement in turn (see Figure 3).Negative marking occurs

*Figure 2:* A simple type A pre-lab calculation

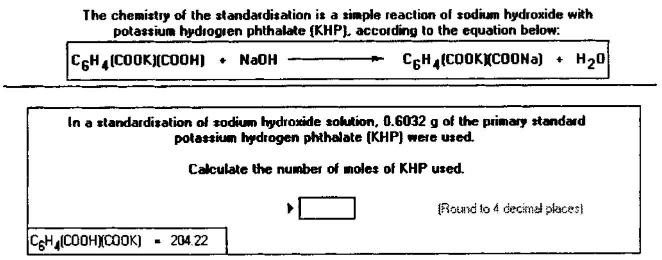
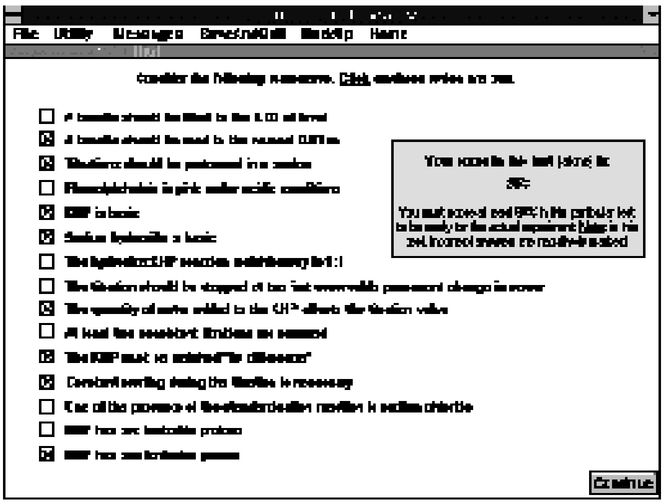



*Figure 3:* A simple type A pre-lab test




here; the selection of an incorrect statement scores –1. Typically, 8 statements are correct, and the pass mark for the test is 7 so that students can only pass by selecting all the correct statements, with a maximum of only one incorrect selection of an incorrect statement. The actual number and identity of correct statements is not revealed. Students who fail this test are obliged to re-take it until a satisfactory score is achieved. Otherwise, they remain ineligible to perform the experiment.

Type B: The preparation and analysis of Iron(II) oxalate dihydrate.

This type of exercise is designed for the more experienced students. It contains a number of questions (typically between 10 and 20) which refer to the underlying chemistry of the experiment. Students are not told whether or not they have given correct answers. However, the feedback contains further information from which the correct answer can be ascertained with a little thought. This ensures that students read the feedback – it always contains useful information and often contains safety warnings concerning the compounds in question. The example illustrated here is the preparation and analysis of iron(II) oxalate dihydrate and consists of four sections:

- *general chemistry* gives the main stoichiometric reaction between iron(II) ammonium sulfate and oxalic acid and raises simple questions about it. For example, the students are asked whether there is a change in oxidation-state of any of the reagents. They also need to assess which is the limiting reagent
- *preparation* deals with aspects of the actual preparation, so that when the students come to this in the laboratory they will already have related the quantities of reagent (given in the recipe) to the stoichiometry of the reaction. For example, in this experiment, 40 $cm^3$ of a 10% aqueous oxalic acid solution is used. The pre-lab requires students to calculate the number of moles in this quantity, and to compare it with the number of moles of iron(II) used. They should quickly ascertain that the oxalic acid is used in excess, and this relates directly to the concept of a limiting reagent (previous section). Students are also required to calculate the maximum mass of product possible, from which they gauge the appropriate size of filtration equipment. On a safety point, the students are also asked to identify the volatile and highly flammable reagent used in the preparation (*acetone*). Warnings concerning acetone and oxalic acid are displayed during these interactions.
- *analysis* involves two titrations of standard permanganate on a single sample of product. The first titration oxidises both Fe(II) and $C_2O_4^{2-}$ to Fe(III) and $CO_2$ respectively, with the latter escaping the system. The formed Fe(III) is then reduced back to Fe(II) using zinc amalgam and the solution re-titrated to give a titre for the Fe(II) content alone. The program questions these processes, with respect to the half-equations, stoichiometry derived therefrom, expected titre values, and an assessment of why it is necessary to carry out the former titration at a temperature of not less than 70°C.
- *consolidation* raises again a selection of the more important questions, giving the students a further opportunity to answer correctly in a 'quick-fire' session. However, for this section only, the feedback does not contain information from which the correct answer can be deduced; it simply states whether the student's answer is 'correct' or 'incorrect'.

## Data capture and processing

The data written by the pre-lab programs comprises: student identity; program identity; date; time; duration of study; number of questions attempted; number of questions answered correctly on first attempt; total number of questions answered correctly; total percentage correct and test score. This information is freely available to the student, both within each program and by saving to floppy disk. It is also written to the network, both in text and data form. The text file is used for back-up purposes only, in the event of data scrambling due to network faults. The data file is of a form suitable for direct importation into a spreadsheet template file. This data contains the appended efforts of the entire cohort, which can be sorted and viewed with a few clicks of the mouse button.

Students are given access to the pre-lab work for a particular experiment one week before they will meet it in the laboratory. The students may complete the tasks at any time within the week, and are restricted only by the opening hours of the university's Learning Resource Centres (currently 9.00 – 23.00 Monday to Friday and 10.00 to 17.00 Saturday and Sunday). Immediately before the corresponding laboratory session, the pre-lab results file (generated automatically by data capture) is down-loaded to a spreadsheet template, and a list of students eligible to execute the experiment is displayed on the laboratory door. Ineligible students are not allowed access to the laboratory, but are interviewed.

Eligibility to carry out an experiment is conferred by a minimum mark of 70% on any pre-lab program and in addition a minimum score of 7 on any test. No limit is set on the number of attempts to do this test. Virtually all students are successful.

During the laboratory session, sporadic checks are made to ensure that the students have used the programs appropriately. This is done via brief informal discussions with selected students concerning any potential problems that may arise within the experiment. The pre-lab marks obtained by students are not used in any assessment of the laboratory module as a whole; they serve only to 'unlock the laboratory door'.

## Results

16 pre-laboratory programs were completed for use in 1995, and have been used since with modifications. Table 1 shows usage statistics for the six programs used to support the level 1 module; the table shows the data for 1997-98 only, but illustrates well the data available for all the years and all the programs. These six programs were all performed in the order shown in the table.

The first four experiments formed part of the course for 72 chemistry students and 15 environmental science students; experiments 5 and 6 were for chemistry students only. Wastage, sickness and similar factors account for the variation in the numbers actually completing each experiment.

Experiments 1 – 4 are all type A, and therefore include questions about technique. This explains why the number of questions to answer (29-31) is greater than the number included in the two type B programs (13).

The fourth column of Table 1 shows that overall the students answered rather more than twice as many questions as the minimum. This provides a measure of the number of times students repeated all or part of each program. Observation of students carrying out these pre-lab exercises shows that they repeat questions more often than is necessary for them to score the pass mark of 70%. Many apparently find it an almost irresistible challenge to achieve a score of 100% in this kind of test.

The pattern of student activity is exactly what one would expect if the students gain both skill and confidence as they progress through the course. Experiments 1 – 3 are all standardisation exercises so that the type of pre-lab work is similar and it is not surprising that students repeat the program less often and also work through it more quickly (answer more questions per hour). Experiment 4 is a gravimetric exercise, sufficiently different from the first three to cause a slower work-rate. Experiments 5 and 6 are both preparations followed by analysis of products. These are supported by type B programs which involve a change in the style of question. The students respond by retracking more frequently and answering less questions per hour.

Table 1 differentiates between the number of questions answered per hour and the number of answers provided per hour. There are more answers than questions because students are allowed up to three attempts at each question.

## Discussion

The basic objective of this work was to improve the student learning experience in the laboratory by ensuring that they have an effective preparation for each experiment to be carried out.

There can be no doubt that, at least to a limited extent, this objective has been achieved. No student can now enter the laboratory without having worked through a series of relevant exercises and scored a satisfactory mark in responding to specific questions. The fact that many students needed more than one attempt to achieve the pass mark shows that they needed some practice, which would not have been available without the pre-lab.

*Table 1:* Pre-laboratory activity for selected experiments

| | | *Questions* | | *Computer Usage* | | | | |
|---|---|---|---|---|---|---|---|---|
| *Expt and Type* | *Number of Students* | *Number asked* | *Av. no. answered* | *h/ student* | *Session/ student* | *Questions per h* | *Answers per h* | *Average Score/%* |
| 1A | 84 | 28 | 78 | 1.42 | 4.2 | 56 | 73 | 67 |
| 2A | 87 | 28 | 62 | 0.87 | 3.0 | 69 | 84 | 74 |
| 3A | 82 | 28 | 50 | 0.63 | 2.7 | 82 | 97 | 77 |
| 4A | 73 | 31 | 56 | 0.79 | 3.0 | 71 | 89 | 72 |
| 5B | 68 | 13 | 31 | 0.52 | 2.7 | 59 | 60 | 73 |
| 6B | 63 | 13 | 27 | 0.46 | 3.0 | 60 | 63 | 74 |

The system of data logging and feedback ensures that the program provides a better pre-lab experience than the approach of "read your manual before you come" which is condemned by Johnstone[4]. Indeed, if the tasks have been properly designed, this pre-lab meets most of the criteria he lists as being necessary.

Furthermore, the students were able to work at their own pace and in their own time. This is a major advantage compared with an alternative approach such as a classroom activity with a tutor present to provide feedback. Apart from anything else, the students' attention span varies, and it would take an exceptional tutor to maintain the interest of the whole class for the whole period; with these programs, a student whose mind wanders cannot provide sensible input to the computer, and so the program will not progress. Of course, a computer program cannot provide the same quality of feedback as is possible in a one-to-one session of student and tutor, and the program cannot modify its responses to suit the student's preferred style of learning. But the comparison with one-to-one learning is not useful since, on this scale, it is not an option.

The more modest approach of a pre-lab classroom activity with a tutor present may seem a potential compromise between the one-to-one individual learning situation and the total impersonality of the computer. However, analysis of the data in Table 1 shows that even this could scarcely be justified as good use of tutor's time unless it could be shown that the students learned very significantly better in the tutor's presence than from the computer.

This table shows that the average length of time of a student session with the computer was about 15 mins. This is remarkably consistent with the lapses in attention which typically occur 10 – 18 min after the start of a lecture[13]. It suggests that it may not be profitable to expect students to work effectively in a pre-lab class of normal length. Furthermore, during the sessions at the computer, the students are answering questions (and obtaining feedback) at a rate greater than one per minute. No tutor could provide useful feedback to a large class at this rate. In total, the use of these six programs in a single year resulted in a total of 370 h spent in controlled and directed, but independent, study.

A further factor is the checking of student performance, whether or not a formal mark is required for assessment purposes. It is useful to ensure that the student has reached a minimum standard. ChemiCAL software ensures that the students have made real and correct judgements regarding many aspects of the forthcoming laboratory work. Table 1 shows that testing students on the six pre-labs involved 457 assignments which, without the aid of a computer, would create an unacceptably high marking load.

There has been some debate about the potential of computers to increase academic productivity[14,15]. Whether or not the ChemiCAL programs result in increased productivity is largely a matter of definition. In this case, ignoring the time taken to create these programs, their introduction has resulted in no significant change in academic time committed to this laboratory work, and an additional extra work load of about 4.5h for the students. What is undoubtedly true is that this amount of pre-lab work could not have been provided by academic staff. Thus the computer has made it possible to introduce a new element to the learning process. Given that this is effective in the sense discussed above, the result is better learning for no extra staff input. This is one possible definition of increased productivity.

A quantitative estimate of this productivity increase would require a measure of the increase in the quality of learning. This has not been attempted. However, observation of the students in the laboratory indicates that many of them have benefited from the experience. Some have taken comprehensive notes from the pre-lab programs and incorporate them into their record keeping; this indicates that they are carrying the experience of the pre-lab into the laboratory itself. Furthermore, the advice and support now requested from demonstrators suggests that they approach their work with increased self-reliance and confidence. They also appear to be working more efficiently, and it would be interesting to be able to evaluate whether the time devoted to pre-lab work results in an equivalent saving of time in the laboratory.

There are disappointments as well as encouragements. A minority continue to make mistakes which the programs have specifically tried to address (for example, reading a burette with less precision than is possible). Given the well established rule that previous learning has an influence on new learning[16] and that it is harder to unlearn bad practice than to learn new good practice, this is not surprising and simply illustrates the need to persevere.

The conclusion of this study is that dedicated computer software can provide an effective pre-lab exercise. It is possible to create suitable software using object-orientated languages such as *Authorware* Professional (used here). These do not require specialist computer programmers, and most academic staff could quickly learn to create effective pre-lab programs using these tools. In this sense, this approach described here is widely accessible.

## Acknowledgements

The author is indebted to Professor Peter Fowler of the Learning Methods Unit at LJMU for his support of this work.

## References

1. Bennett SW and O'Neale K, 1998, Skills development and practical work in chemistry *UChemEd* **2** 58-62.
2. Kempa RF and Ward JE, 1975, The effect of different modes of task orientation on observational attainment in practical chemistry *JResSciTeach* **12** 69-76.
3. Johnstone AH, 1980 Chemical education research: facts, findings and consequences *Chem Soc Rev* **9** 365-390.
4. Johnstone AH, Chemistry teaching; science or alchemy1997 *JChemEd* **74** 262-268.
5. Novak JD and Gowin DB, 1984, Learning how to Learn, Cambridge University, Cambridge.
6. Bodner GM, 1986, Constructivism: a theory of knowledge, *JChemEd* **63** 873-878.

7. Verdonk A 1993 The role of educational research in the quest for quality in the teaching and learning of chemistry. *Proceedings, Variety in Chemistry Teaching* 49-54 (ed Aitken M), (Royal Society of Chemistry).
8. Garratt J, 1997, Virtual investigations: ways to accelerate experience *UChemEd* **1** 19-27.
9. Johnstone AH, Sleet RJ and Vianna JF, 1994, An information processing model of learning: its application to an undergraduate laboratory course in chemistry. *StudHE* **19** 77-87.
10. Rest, AJ (ed) 1995/96 Basic Laboratory Chemistry (Educational Media Film and Video Ltd., Harrow Middlesex).
11. Nicholls BS, 1998, Post-laboratory support using dedicated courseware *UChemEd* **2** 10-15.
12. Nicholls BS, 1997, Embedding ChemiCAL courseware: making technology teach *Active Learning* **6** 48-51.
13. Johnstone AH and Percival F, 1976, Attention breaks in lectures *EducChem* **13** 49-50.
14. Davies ML and Crowther D EA 1995, *Active Learning* **3** 3-6.
15. Clark DR, 1996, *Active Learning* **4** 9-11.
16. Ausubel DP, Novak JD and Hanesian H, 1978, Educational Psychology; a cognitive view (Holt, Rinehart and Winston, London).