Introducing first-year students to some skills of investigatory laboratory work

PAPER

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In order to introduce students to some of the skills involved in carrying out an analytical investigation, we devote the final three weeks of our first year laboratory course to the analysis of some common household products. Students, working in pairs, are allocated a specific problem and are given complete responsibility for investigating it. This involves planning the procedure, carrying it out, and interpreting the results. The procedures involved are simple titrimetric ones, but the application is non-trivial for these students. Our experience with this approach has highlighted for us some of the limitations of the recipe laboratories, and is regarded by both students and demonstrators as an effective learning experience.

Introduction

A great deal of the laboratory work carried out by chemistry undergraduates falls into the category described by Meester and Maskill[1] as 'controlled' experiments – those in which the answer is known in advance. Typically, these experiments involve following recipes and, as Bennett and O'Neal[2] argue, are more properly regarded as 'exercises' rather than 'experiments'.

There are good reasons for this as discussed by Clow[3], who argues that well-researched laboratory exercises maximise the breadth of practical experience to which students can be exposed and the quality of the results they obtain. An unfortunate consequence is that many students follow the recipes line by line without questioning or seeking to understand the exercise in a broader context[4]. Almost certainly this strategy is forced on them by the limited availability of 'working space' of the mind[5]. This can easily become overloaded by the need to manipulate theory, manual dexterity and lab management all at the same time, and overload leads to a shutting down of the mental processes with the prevention of learning[6].

A major limitation of following a prescribed protocol is that this represents only a small part of the whole process of experimental science[7]. The recipe lab omits the stages of planning and design, and it encourages 'data processing' rather than 'data interpretation'. Verdonk[8] has coined the word 'bookification' to describe the resulting move from 'fact making' to 'fact learning'; he described an investigation of ester synthesis designed to provide students with some insights into the process of scientific research. This particular exercise would not fit well in the context of our first year laboratory work. However, we saw other opportunities for introducing aspects of experimental design (fact making) using the simple procedures introduced and practised by our students during the first year of their course.

We describe here our approach to introducing our first year students to some basic features of an analytical investigation.

Planning the Investigations

The first year chemistry class consists of 20 – 25 students. Typically, these will have taken Scottish Highers (including chemistry) and some will have studied chemistry at the more advanced level needed for the Certificate of Sixth Year Studies (CSYS). The present Higher syllabus does not have a practical requirement and therefore many undergraduates enter university having only carried out test tube experiments throughout their time at school.

The practical module for the first semester needs, therefore, to place great emphasis on learning and revising practical techniques such as titrimetric analysis, purification, and identification of organic molecules. The second semester module builds on these practical techniques. At the beginning of the practical course, students are provided with a booklet entitled "Laboratory Practice/Data Handling Handbook". This contains guidelines for writing a lab diary and a formal report, together with other useful information such as units, errors, and how to draw graphs. This booklet is used as the basis for two tutorials (of 2 hour length) held in the two weeks preceeding the start of laboratory classes. During these tutorials, students discuss with the tutor all important aspects of laboratory classes including practice in drawing graphs, recording data, and writing up experiments.

During the course there is one three-hour laboratory session each week, but students are required to spend time outside the laboratory processing their data for completion of their Lab Diary. The set exercises as are not written up as a formal report, but in a lab diary or record as described in the booklet. This should contain detailed accounts of all laboratory work, including title, date, aims and objectives, results/data recorded, any necessary graphs or calculations, a discussion of errors (if relevant) and conclusions. It does not need to contain information already provided in the laboratory manual and extreme neatness is not expected since entries are made whilst the experiments are performed. However the content must be adequately detailed and the report sufficiently well-ordered and neat to allow a detailed formal report to be written at a later stage. The lab diaries are marked every week, and written and verbal feedback is provided with the result that detectable improvement is observed during the year.

The demonstrating is shared between a member of the academic staff and a post-graduate student, both of whom are present throughout the laboratory sessions.

When we decided to introduce the investigation we planned it according to the following principles:

- there must be a range of things to investigate so that not more than two pairs of students were tackling the same problem at the same time;
- each investigation must be simple enough for a pair of students to reach a successful conclusion within the two week period;
- it must motivate the students (be seen to be relevant);
- the procedures must be safe.

Using these principles, we decided that each investigation should be an analysis of some constituent(s) of a household product which could be satisfactorily carried out using a titrimetric procedure. Table 1 shows the information given to students for four of the investigations currently in use, other investigations involve analysis of the amount of iron in iron tablets, and of vitamin C in vitamin C tablets. Note that full information is not given, and so students have to make their own decisions and evaluate the likely errors in the procedures they adopt. For example, most choose to determine the water content of margarine by evaporating it to dryness and measuring the weight loss; this is a simple procedure, but one which creates opportunities to discuss the problems of removing all the water from an emulsion. Similarly, the determination of citric acid by titration leads to discussions of the assumption that other organic acids are present in negligible amounts, and it raises the importance of using appropriate controls and standards to take account of the fact that citric acid has three titratable groups.

The investigation is introduced to the students at the end of the last of the lab sessions in which they carry out set exercises. Students work in pairs, usually of their own choosing, which normally means that both members of the pair are of similar ability. Each pair of students is allocated a particular investigation and they are told that they have one week in which to plan their investigation. We recognise that not all of the investigations are of equal difficulty. We assign the more challenging ones to students who have demonstrated higher ability during the earlier part of the course. This helps to ensure that students of different ability are equally stretched by the investigation. They are reminded that, in many cases, they have carried out similar analyses earlier in the year, and their attention is drawn to useful reference books in the laboratory and the library. These provide sufficient information to allow them to plan these simple investigations. A week later the students return to discuss their proposals with one of the demonstrators. When the supervisor is satisfied that a pair of students have a sensible plan, they are allowed to proceed with the experiment. This means that they have the remainder of that session and two more full sessions in which to complete their investigation and prepare their formal report.

30 marks out of a possible 130 for the semester are allocated to the investigation. 10 of these are allocated for the quality of the planning work and discussion with the supervisor, and the other 20 for the quality of the report.

Investigations in Practice

Initial Discussions

With the relatively small numbers of students on this course, we have not found it necessary to instigate a formal timetable for the initial discussions with students. Pairs of students are dealt with on a first-come, first-served basis. Since not all the students time their arrival for the start of the lab session, most have only a short wait before a supervisor is free. Those waiting can usefully spend their time collecting (with the help of the lab technician) equipment and apparatus they plan to use, and preparing their lab manual.

Table 1: Examples of briefing statements for investigations

	Title	Aim	Background Information
1.	Purity of Baking Powder	To determine the purity of baking powder	Pure baking powder should be 100% $NaHCO_3$. It should be possible to determine the percentage by weight of $NaHCO_3$ in baking soda using a simple acid-base titration.
2.	Analysis of Margarines	To determine the salt content of margarines/butter. To investigate the relationship between salt and water content.	The salt content of margarine/butter may be determined via a precipitation titration using standard $AgNO_3$ as the reagent
3.	Citric Acid Content of Fruit Squashes and Fruit Juices.	To determine the citric acid content in fruit squashes and juices.	Determine the mass of citric acid present in fruit squash and juice using acid-base titrations. Suggest using lemon squash and grapefruit or pineapple juice.
4.	Analysis of White Vinegar	To determine the percentage of ethanoic acid (acetic acid) in white vinegar.	Vinegar should contain no less than 4% by volume of ethanoic acid. It should be possible to determine the amount of ethanoic acid in the vinegar using a simple acid-base titration.

Student preparation for the discussions is variable. Some have thought clearly about the procedures they will use and come with extensive notes. Usually discussion with such students takes only 5 – 10 minutes. Longer discussions are usually needed for students who are less well prepared. The discussions focus on the procedure. For example, for the analysis of vinegar, the supervisor needs to check that the students have selected a suitable indicator and concentration of NaOH with which to carry out the titration, and that they have a suitable strategy for determining what is an appropriate sample of vinegar. Standardisation of reagents is also discussed at this stage: students are reminded that the concentration of some solutions (for example of NaOH) is known approximately, but must be standardised. Normally, there is no discussion of apparatus and equipment; it is assumed (often wrongly!) that students have learned through experience the correct use of standard laboratory glassware.

Laboratory Work

When the students start their laboratory work they are, for the first time, following a recipe of their own design. Their response highlights the problem that their previous experience of following established recipes has not always prepared them effectively for this responsibility. For example, we have occasionally observed students making up solutions of primary standards in a beaker or a conical flask instead of in a volumetric flask. Apparently they have been following recipes so uncritically that they have not learned elementary lessons about accuracy and appropriate glassware. These kinds of mistakes lead to valuable discussions with a supervisor the key lessons of which are reinforced by the need to start again.

As well as providing students with opportunities to learn from their mistakes, these investigations also introduce other important aspects of real science. Students discover that analysis involves samples which are less amenable than laboratory solutions to which they have become accustomed. For example, grapefruit juice is sticky, and not easy to pipette; vinegar needs diluting before it can be titrated with 0.1M NaOH.

The nature of an investigation is that even the best prepared students need to make some exploratory measurements to establish that their reagents and samples are of appropriate concentration. In spite of this, and the fact that some students make basic mistakes which force them to start again, the basic procedures are sufficiently simple that all students are able to complete the laboratory work within two 3 hour laboratory sessions. Some will complete theirs within a single 3 hour period.

Student Report

These investigations into simple household products are used to provide the students with their first opportunity to put into practice the conversion of their lab record into a formal report. The booklet provided at the beginning of the course includes detailed help on how to do this. Some students will seek further help from the laboratory supervisors. A key feature of the report is that students are expected to evaluate the procedures they used. As described in the section on Planning the Investigations, this is not a trivial problem. The final report is expected to be produced on a word processor. Thus it offers an opportunity for students to practice their IT skills, their writing skills, and referencing skills, in all of which they have had instruction in the previous semester. Feedback (both written and verbal) is given on their performance in order to help to prepare them for formal reports which are expected in later years.

Discussion

Feedback from students has been obtained through semi-structured informal discussions. It is clear from these that the use of household substances helps the students to appreciate that chemistry has relevance and that the standard practical skills they have been learning and practising are not just academic exercises. These are key factors in the motivation of students. They find it challenging but also satisfying to take responsibility for their own procedure, and they enjoy the opportunity to work at their own pace. The overall impression from the students' comments is that they are motivated by the experience.

The supervisors are similarly enthusiastic. The quality of the interaction with the students is rewarding. Even when this results in throwing some of their freshly made solutions down the sink, the discussion itself concerns their own decisions (and the reasons why these could be improved) instead of the more usual situations in which interaction with students is largely limited to interpretation of the lab book. Like the students, the supervisors find that these lab sessions are refreshingly unpredictable and enjoyable.

The formal reports follow the guidelines provided in the Laboratory Practice/Data Handling Handbook. The standard is, as would be expected, variable, but on average the reports are sound, and the best are very good. We are satisfied that the experience provides a useful foundation on which future courses can build.

One useful feature of these investigations is that they are very appropriate for our HND students. These students are not given marks, but have to achieve the performance criteria:

(a) the proposed methodology is valid and feasible and consistent with the aims of the experiment.
(b) the experimental procedure carried out is correct in terms of safe working practice and practical skills.
(c) the report produced is clear and concise and correct in terms of the experiment outcome.

The structure of these investigations makes it very easy to assess whether HND students can be given a pass for each of these criteria, and thus whether they have passed outcome 3 of the Basic Laboratory Skills Unit.

In conclusion, we believe that the virtue of our investigations is that they involve the application of simple procedures to tackle investigations which (at least for first year students) are not trivial. This combination makes them educationally rewarding and enjoyable.

References

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Evaluation of teaching and learning: matching knowledge with confidence

COMMUNICATION

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We have used a two-part questionnaire to obtain feedback from students immediately before, immediately after, and six weeks after carrying out a computer-based simulation. The simulation is intended to help students to develop investigative skills. The first part of the questionnaire tests knowledge by means of multi-choice questions. The second part asks students to assess their confidence in their understanding or in their ability to apply knowledge. The use of this evaluation strategy has allowed us to formulate hypotheses about ways to improve the student learning experience in future years. We conclude that this evaluation strategy can be a valuable and generally applicable way of identifying whether a particular learning experience helps students to develop an appropriate balance of knowledge, understanding and ability to apply knowledge.

Introduction

"Most British people, most educators and most students now believe that it is one of higher education's purposes to prepare students well for working life"[1].This sentiment is reflected in a number of recent reports which emphasise the need for degree courses generally[2] or specifically in chemistry[3,4] to adopt a more student-centred approach to teaching so that students develop a range of personal and professional skills appropriate to a scientific education.

Many individual teaching and learning strategies have been developed to bring about more active student participation in their education[e.g. 5–8]. One largely unsolved problem is evaluation of the effectiveness of such innovations. Their aim is rarely limited to that of helping students to achieve a higher mark in a conventional examination, and therefore it is not appropriate to evaluate them by attempting to measure a change in examination performance. Bodner et al have discussed the different reasons why this is inappropriate[9]. They argue that the main purpose of evaluation of any new teaching initiative is to discover what modifications to make which will maximise the positive effects and minimise the negative ones (since we should take for granted that any significant change will have some effect). We were faced with the problem of choosing an appropriate strategy for evaluating the success of introducing one of the eLABorate computer simulations[10] to a class of first-year biochemistry students. The particular simulation is enzymeLAB[11,12,13]. This simulation allows students to investigate the effect of substrate concentration, enzyme concentration and pH on the rate of an enzyme catalysed reaction. It is designed to build on (and hence consolidate) basic knowledge of enzyme kinetics, and to develop an understanding of how this knowledge is applied in the design of an investigation.

We were attracted by the strategy recommended by Draper for evaluating interventions in the classroom[14,15]. This involves two interesting features which we have not used previously. First he recommends the use of the same questionnaire as a pre-test, a post-test, and a delayed post-test (follow-up). Second he recommends that the questionnaire should be designed to make a dual evaluation by using *"a measure of the student's confidence in fulfilling the learning objectives, and a knowledge quiz."* We therefore decided to devise a two-part questionnaire. The first part was designed to be a knowledge quiz testing aspects of knowledge of enzymes which would be useful in planning a real investigation of an enzyme. The second part would seek information about their confidence in their understanding of concepts or in their ability to apply knowledge.