Post-laboratory support using dedicated courseware

PAPER

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

Introduction

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

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

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

Characteristics of dedicated post-lab courseware

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

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

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

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

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

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

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

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

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

Operation

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

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

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

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

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

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

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

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

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

An example of a Level 2 exercise

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

Table 1: Spreadsheet for NaOH standardisation (edited)

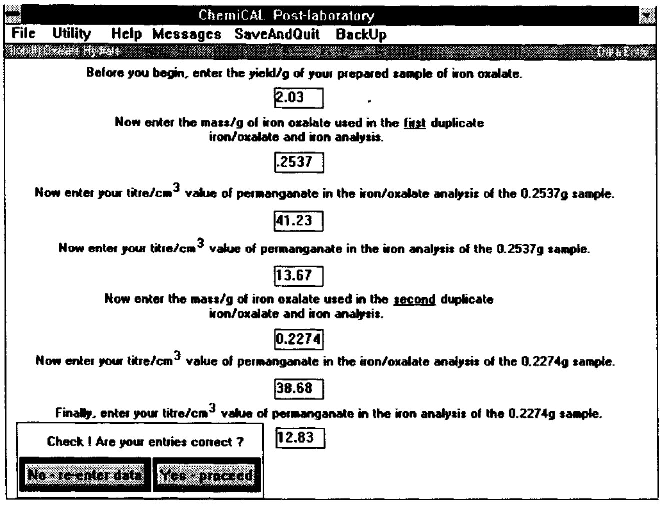
name	*date*	*mass/g KPH*	*titre/ml NaOH*	*[NaOH] mol l^{-1}*	*laboratory mark/%*	*calculations correct*	*calculations mark/%*	*total mark/%*
Average		.6445	31.83	0.09915	63	9	90	68
student1	2/11/97	.6571	32.20	0.09993	95	8	80	89
student2	4/11/97	.6536	32.21	0.09936	82	7	70	80
student3	4/11/97	.6264	31.21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

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

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

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

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



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

2.03

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

.2537

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

41.23

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

13.67

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

0.2274

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

38.68

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

12.83

Check ! Are your entries correct ?

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

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

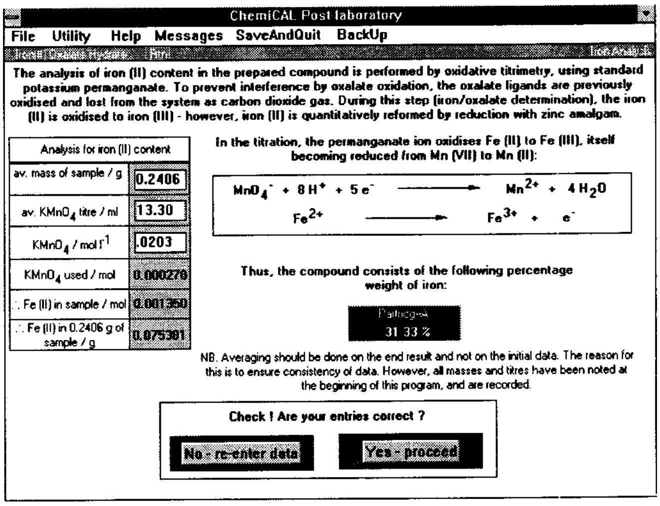
(b) Fe(II) Analysis: gives the respective half equations for the iron(II) permanganate reaction and requires the student to produce a stoichiometric equation (after 3 incorrect attempts the correct answer is supplied).As shown in Figure 2, the student then enters

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

The program responds by indicating:

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

Figure 2: Calculation of the percentage mass of iron



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

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

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

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

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

31 33 %

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

Check ! Are your entries correct ?

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

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

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

Table 2: Courseware table showing results computed from laboratory data

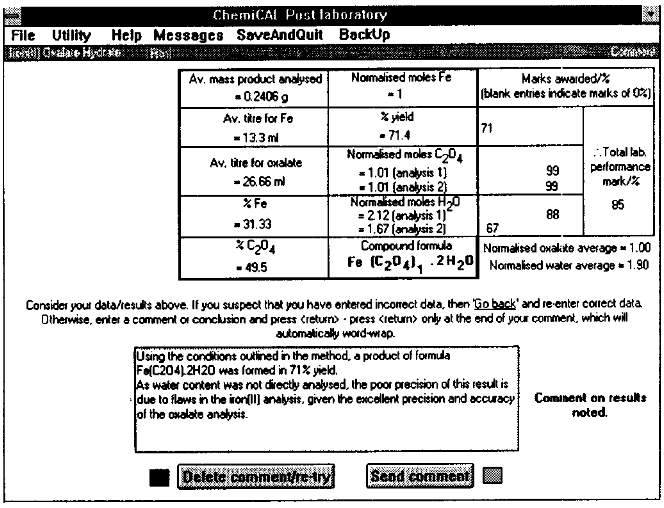
Mass of product analysed/g: 0.2406

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

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

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

Figure 3: Final results from Iron II oxalate analysis



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

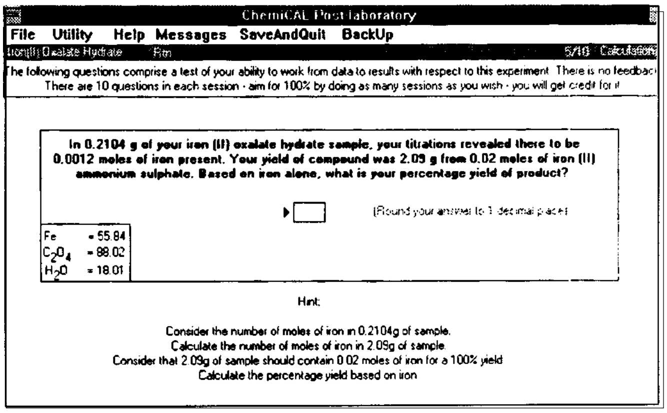
Consider your data/results above. If you suspect that you have entered incorrect data, then 'Go back' and re-enter correct data. Otherwise, enter a comment or conclusion and press <return> - press <return> only at the end of your comment, which will automatically word-wrap.

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

Comment on results noted.

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

Figure 4: A calculation based on specimen data



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

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

(Round your answer to 1 decimal place)

Fe = 55.84
C_2O_4 = 88.02
H_2O = 18.01

Hint:

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

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

Figure 5: Class results for oxalate analysis

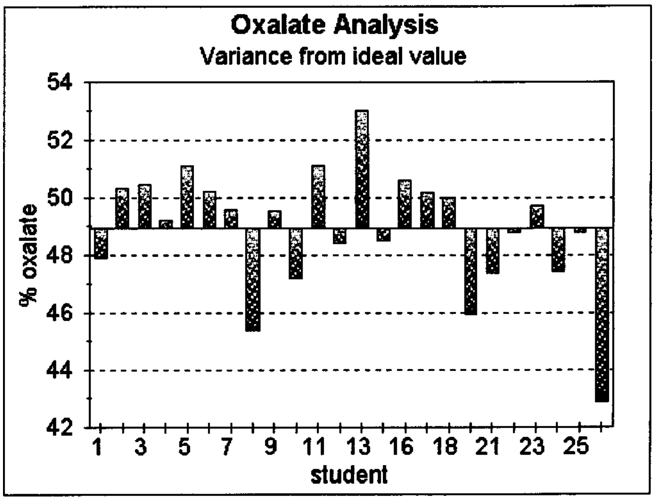
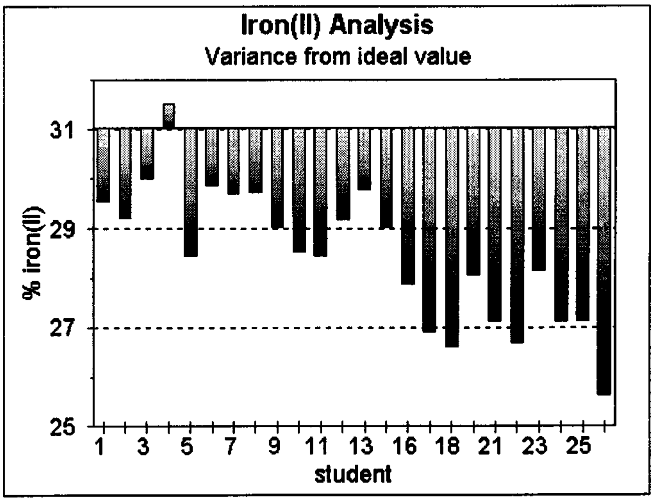


Figure 6: Class results from Iron II Analysis



Student motivation - A case study

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

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

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

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

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

Note: all experiments are preparations followed by analyses.

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

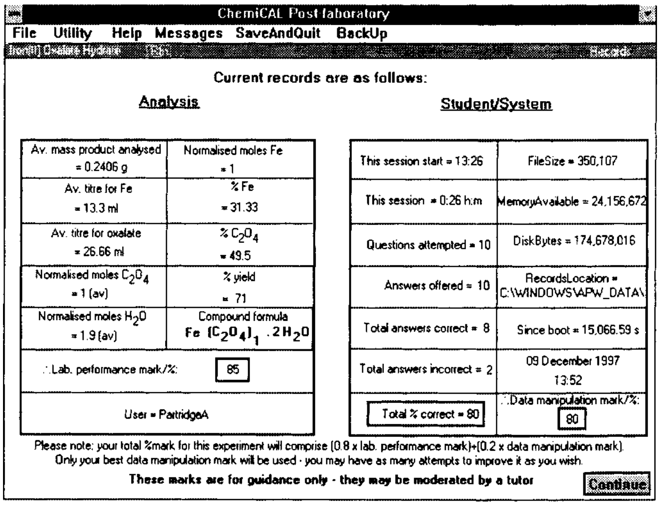
Level 2 students performed on average double the number of calculations required. Level 2 students may have found themselves to be more efficient at manipulating data possibly as a result of the effort they made at level 1. The figures also show that level 2 students, though attempting less calculations,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

Disadvantages of the system

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

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

Figure 7: Final record of results and mark



Current records are as follows:

Analysis

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

Student/System

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

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

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

Productivity Issues

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

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

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

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

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