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Preparing the Mind of the Learner

PAPER

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For a period of two years, examination performance in an introductory course in university chemistry was found not to be correlated with entry qualifications of the students in chemistry. For the next three years, examination performance did seem to be related to entry qualifications. The only factor that was found which might account for this was the use of pre-lectures which were employed over the first two years but were no longer in operation over the subsequent three years. On this basis, it is suggested that pre-lectures may be a useful tool in enabling students to make more sense of lectures, the effect being particularly important for students whose background in chemistry is less than adequate.

Introduction

In 1968, Ausubel made the comment: *"If I had to reduce all of educational psychology to just one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly"* [1]. This bold assertion has been supported by subsequent work. Thus, for example, Johnstone and Su[2] showed that students could have problems in lectures when lecturers assumed prior knowledge which, in fact, was absent or had been forgotten. Ebenezer[3] applied Ausubel's idea in the development of concepts in chemistry. Johnstone[4] developed the ideas further in suggesting a set of educational principles (known as 'Ten Commandments') for learning. Among these were the statements: "What you learn is controlled by what you already know" and "If learning is to be meaningful, it has to link on to existing knowledge and skills, enriching and extending both."

While appropriate knowledge and skills must be present in the mind of the learner, it is also important to recognise that they must be accessible (able to be retrieved in a meaningful form) at the time when new material is presented. It is also important that the new material must be presented in a manner consistent with the way the previous knowledge and skills have been laid down in the long term memory. It is, therefore, important that the minds of the students are prepared for lectures if the learning is to be meaningful for the students[5].

It is not easy to put these general principles into practice since students will come to lectures with a wide variety of background knowledge. In some cases, previous learning in chemistry may have led to an incomplete or incorrect grasp of concepts[6]. For other students, ideas once known and understood may not have been used for many months, making it difficult to retrieve them from long term memory. In order for effective learning to occur, background knowledge and understanding must not only be present, but stored in such a way that it is accessible and understood correctly. These principles lie behind the idea of the pre-lecture. The pre-lecture can be described as an activity carried out before a block of lectures, designed to ensure that the essential background knowledge is established and is accessible so that new learning can be built up on a sound foundation. Kristine[7] reported a system of pre-lecture assignments, involving preview reading and review, the aim being to encourage the development of study skills. A decision in this university to develop a new introductory course provided an opportunity to introduce pre-lectures. These were subsequently discontinued and this paper describes our observations on the effect on the students of both introducing and discontinuing pre-lectures.

The general chemistry experience

Before 1993-94, students studying chemistry at level-1 (of a Scottish four year degree) all followed the same course. The class included those who were planning to pursue chemistry as their main subject along with those who were required to take a first year chemistry course as a support for some other discipline and those who were taking the course merely to complete their first year curriculum. Since students typically take three subjects during their first year, the level-1 chemistry course was designed to occupy one third of the workload and included about 100 hours of lectures. The level of the course was appropriate for students who had obtained a pass in Chemistry at Higher Grade in the Scottish Certificate of Education.

Over a number of years, the characteristics of the first year entry changed. Numbers increased to around 600 – 800, and the range of entry qualifications became much broader and included some with no formal chemistry qualification at all, their entry to university being based on other qualifications. It was therefore decided to form two classes for the session 1993-94. The majority of students, those with qualifications in Scottish Higher (usually at Grade C or above) or in the Scottish Certificate of Sixth Year Studies (CSYS) would take the essentially unchanged level-1 Chemistry Course, now named Chemistry 1. The less well qualified students would take a new course designed to allow those who passed to proceed to the level-2 Chemistry Course.

The new course is called General Chemistry. The aim was to meet the needs of students for whom a career in chemistry was a less likely option and who, in general, were less qualified in chemistry. The entry qualifications of the students in

General Chemistry ranged from those who have passed Chemistry at the Scottish Higher Grade (occasionally, with a pass at the Scottish Certificate of Sixth Year Studies as well), to those who had indicated no formal chemistry qualification at all, their entry to the university being based on qualifications in other subjects. Since surveys of students showed that the majority were taking the course to fulfil faculty requirements, commitment and motivation were generally low.

The General Chemistry course was planned according to the ten educational principles, described in detail elsewhere[4]. Pre-lectures were introduced primarily to address the principle which states that learning depends on previous knowledge. In 1993-94, 8 lecture courses had an associated pre-lecture. The pre-lecture occupied one timetable lecture slot, the total lecture time thus being reduced by nearly 10%. In 1994-95, 6 pre-lectures were retained. In 1995-96, pre-lectures were discontinued, the time being given over to extra lectures. The way the course operated and the performance of the students was monitored in some detail over a period of five years and is still being monitored.

A pre-lecture can take many forms. In the General Chemistry course, the following procedure was adopted. Working in an ordinary lecture theatre, the pre-lecture involved a short test (multiple choice and very short answers) which sought to check on necessary background knowledge. The students marked this for themselves. The test and marking took less than 15 minutes. Their test performance provided the students with some evidence about the level of their background knowledge and understanding.

On this basis they were invited to see themselves as 'needing help' or 'willing to offer help' and the class was re-organised to form pairs or trios to allow the 'helping' students to interact with those needing help. In this way, support was available for those students in need of help to understand the background knowledge that would enable them to make sense of the lecture course. Those able to offer help assisted in this process of teaching, and, by the very act of teaching others, they themselves were assisted in ensuring that ideas were grasped clearly and correctly.This reflects another of the 'Ten Commandments'[4].The lecturer,supported by a demonstrator, was on hand to offer assistance as required.

The main part of the pre-lecture involved the students working with a series of short exercises which covered material that was considered an important background in allowing the students to make sense of the lecture course to follow.The exercises encouraged discussion within the pairs and trios.For example, in the first pre-lecture, topics covered included the fundamental ideas of states of matter, elements and compounds, chemical and physical changes. Another pre-lecture covered the ideas of models of matter, unit cancellation, and the nature of the mole.

Results

Student performance in the Chemistry-1 Course, which never included pre-lectures, generally correlates well with their entry qualification. The data for 1994-95 are shown in Table 1. The Certificate of Sixth Year Studies (CSYS) is a one year course taken by some students in the year after the Higher Grade course. A pass in any grade at CSYS is generally regarded as approximately equivalent to one grade higher than the same letter grade at Higher. Thus a B in CSYS is approximately equivalent to an A at Higher. Table 1 shows that the average examination mark for students with a particular grade decreases with their entry qualification.

Identical trends were seen in all years for which data are available.

Table 1: Correlation between entry qualification and average mark in Chemistry-1.

Entry Qualification	*Pass Grade*	*Average Mark (%) for 1994-95*
Certificate of Sixth	A	76
Year Studies (CSYS)	B	59
	C	44
	D	36
Higher Grade	A	51
	B	39
	C	31

In looking at General Chemistry, we tested the effect of entry qualification on exam performance by dividing the students into two roughly equal sized groups and comparing their examination performance. Group 1 included all students with a pass in chemistry at Grade C or better in Scottish Highers. Group 2 included all students with a lower entrance qualification. With the relatively small numbers of students taking General Chemistry, we could not justify dividing the class into more groups. The results for the first five years of the General Chemistry Course are shown in Table 2. As previously described, the pre-lectures were discontinued after the first two years.

Table 2 shows the difference in the average examination mark obtained by each of the two groups; since there was an examination in January and in June, the difference in average mark is shown for both individual exams and for the combined mark. The t-test was used to test whether these differences are significant. As Table 2 shows, there was no difference between the two groups when the pre-lectures were in use. When pre-lectures were discontinued in 1995, the difference between the two groups became significant.

Having shown that there was no difference between the two groups of students during the two years when pre-lectures were in use, we felt justified in combining both years and dividing this combined sample into four groups. The groups were assigned as follows:

- Scottish Higher Grade pass in Chemistry (almost all at Grade C);
- Scottish Standard Grade pass in Chemistry (approximately equivalent to GCSE);

Table 2: Difference in Average Mark in General Chemistry for groups classified by entrance qualification

Year	*Number of Pre-lectures*	*Total Number of Students*	*Difference (%) (January Exams)*	*Difference (%) (June Exams)*	*Average Difference (%)*
1993-4	8	110	3.1	1.1	2.1
1994-5	6	180	0.2	0.2	0.2
1995-6	0	169	7.2[1]	9.2[1]	8.2[1]
1996-7	0	163	8.3[1]	4.2	6.3[2]
1997-8	0	229	2.9	7.9[1]	5.4[3]

1 These differences are statistically significant (t-test, two-tailed, unrelated): $p < 0.001$
2 This difference is statistically significant (t-test, two-tailed, unrelated): $p < 0.01$
3 This difference is statistically significant (t-test, two-tailed, unrelated): $p < 0.05$

Table 3: Average Mark in General Chemistry: effect of pre-lectures

Entry Qualification	*Average Mark (%) for sessions 1993-94 and 1994-95 (pre-lectures)*	*Average Mark (%) for sessions 1995-1996, 1996-97 and 1997-98 (no pre-lectures)*
Scottish Higher Grade	49 (N = 137)	47 (N = 244)
Scottish Standard Grade [1]	50 (N = 44)	37 (N = 70)
Alternative qualification [2]	49 (N = 44)	42 (N = 63)
No formal qualification	45 (N = 31)	42 (N = 56)

1 Approximately equivalent to GCSE
2 Mainly those with entry through Access courses or modules.

- Qualifications in Chemistry based on Access courses;
- No formal qualification in Chemistry.

These four main groups include the majority of students. However a few students with unusual qualifications (e.g. from overseas) are not included in this analysis.

Table 3 shows the average examination obtained by each of these four groups. For comparison, Table 3 also shows the average marks for the same groups of students during the three years when the pre-lectures were discontinued (1995-96, 96-97, 97-98). Pre-lectures appear to have made a marked difference to those students with Scottish Standard Grade, and a smaller difference to those with alternative qualifications.

Taken together, Tables 2 and 3 provide strong evidence that the pre-lectures make a significant contribution to the creation of a course which provides all students with a reasonably equal opportunity to perform well.

Discussion

The pattern of results is surprising. Intuitively, it seems unlikely that what appears to be a small change in teaching could make this impact. However, it must be noted that the pre-lectures amounted to approaching 10% of the total time allocated for lectures, a sizeable proportion of the teaching input. Nonetheless, we examined as many other factors as possible to see whether any alternative explanation was likely.

A wide diversity of factors was examined in the first two years: preferred learning styles (following the Perry model[8] and extent of field dependence[9]), gender of students, whether they stayed at home or away from home, personality characteristics (eg extent of extroversion, extent of neuroticism), maturity, qualifications in mathematics. None of these correlated with examination performance.

An examination of other features of course organisation showed that other changes had occurred over the five year period but none had taken place specifically between 1994-95 and 1995-96. Although the size of the group had risen over the five year period, the composition of the class in terms of the proportions of students with various entry qualifications showed no discontinuity after year 2 and, indeed, no trend over the five year period. Looking at common questions in successive examinations showed a very slight deterioration in overall performance over the five year period.

It is often tempting to try to cram in more material in order to improve performance. The study by Johnstone and Su[2] of student habits in lectures shows the folly of this approach. The observations made on this course would seem to suggest that reducing the amount of material might be advantageous if the time released was used to prepare the minds of the students to make more complete sense of the new material offered. Garratt[10] claims that there is some evidence for the proposition that covering less material results in more total learning.

The use of pre-lectures might also, of course, be having more subtle effects. The confidence and motivation of more poorly qualified students will almost certainly be enhanced by learning experiences where their weaknesses were being taken into consideration. Motivation has been shown to be very important in influencing performance[11]. In addition, the use of pre-lectures could also be having a subconscious effect on the lecturers by heightening their sensitivity in checking the pre-knowledge of the students during the presentation of new material.

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Undergraduate Students' Understanding of Enthalpy Change

PAPER

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The study described in this paper is an investigation into the conceptions held about chemical thermodynamics by first year chemistry undergraduate students. Twenty students were interviewed on two occasions, each for about one hour and asked to explain temperature changes in three simple chemical reactions. The first interview sought to identify knowledge retained from A-level; the second interview followed a lecture course on chemical thermodynamics. Students' conceptions about enthalpy change are described and examples of students statements are given; it is clear that students come to the university with a very limited understanding of enthalpy change and have no knowledge of pV work. The impact of the lecture course on their conceptions is discussed; most students still held the same conceptions about enthalpy change although there was more awareness of pV work. Some quantitative information is given but the qualitative data show the range and variety of the alternative conceptions. Finally, the implications of the findings on the teaching of elementary chemical thermodynamics is discussed.

Introduction

This paper reports on part of a larger study which arose out of a concern of a chemistry department about the effectiveness of a first year course of chemical thermodynamics for undergraduate chemistry students. Although students were performing reasonably well in end of module examinations, informal discussion with tutors indicated that their understanding of basic thermodynamic concepts seemed weak. Similar views have been expressed in the literature[1,2]. The result is that, for many students, the study of thermodynamics is regarded as a chore whose equations are to be learned by rote in order to do calculations and to pass examinations.

A possible cause of the problem is a mismatch between the assumptions made by the teaching staff of the students' prior knowledge and understanding and the conceptions actually held by the students. Many previous studies of students' understandings of scientific concepts[3,4,5] have shown that students often hold conceptions which are different from the accepted science concepts and that when students construct new meanings, they are influenced by their own pre-existing (and often incorrect) conceptions. In this report, the term 'concept' is reserved for an accepted statement; the term 'conception' is used to refer to an individual's version of a concept and may be correct or not. The term 'alternative conception' is used to describe all conceptions that differ from the accepted version. Such alternative conceptions range from those that are very different from the accepted view to those that are merely incomplete.

The aim of the complete study was to explore students' understanding of thermodynamic concepts before and after they attended a lecture course and thus to throw light on the development of their conceptions with a view to drawing conclusions about possible improvements in teaching strategies. This paper deals with the enthalpy component of the thermodynamics teaching.

At the time of this study, enthalpy changes (especially Hess's Law calculations) are included in the core A-level syllabus. The syllabus demands little more than a knowledge of the term enthalpy change, that constant pressure is required (in all processes), and specific definitions of enthalpy change of formation, $\Delta H°_f$ and enthalpy change of combustion. It is often argued that reactions occur because the products have a lower enthalpy than the reactants (i.e. ΔH is negative). This leads to difficulties in understanding why endothermic reactions occur spontaneously[5,6]. Students also have difficulties in identifying exothermic and endothermic reactions. Boo[7] found that about one sixth of her sample of A-level students thought that copper reacting with air was an endothermic reaction. Similar results were reported by de Vos and Verdonk[8] in the context of a candle burning. Students confused the activation energy with the total enthalpy change of the reaction.

Studies at university level have indicated that students have difficulty in coping with the abstract nature of the concepts and their complex relations. Rozier and Viennot[9] point out that most thermodynamic problems are multi-variable usually involving changes in pressure, temperature and volume. According to Rozier and Viennot[9], students treat the system as if the changes occur as a series of sequential steps and consider first (for example) the effects of pressure change, then of temperature change rather than dealing with both at the same time. They describe this type of reasoning as linear causal reasoning, an example of concrete operational thinking. Cachapuz et al[5] also reported this kind of reasoning in 17 year-olds, with students explaining an endothermic reaction as a two stage process in which energy is envisaged as being absorbed in bond-breaking, followed by energy release in bond formation.

Difficulties in dealing with the abstract nature of the concepts involved in thermodynamics is highlighted by Dixon and Emery[10]. They developed a way of categorizing concepts in order of abstraction. Energy, work and heat occur on the third level of abstraction (two levels above temperature, for example) while enthalpy is found at a higher level again, the fifth level.

Another source of difficulty for students trying to understand thermodynamics is that instead of treating energy changes as processes, they frequently treat energy (and heat) as matter. Chi et al[11] divide all scientific entities into three different ontological categories: Matter, Processes and Mental States (each of these categories subsumes a hierarchical series of subcategories). Pinto's[12] study of undergraduate physics students' understanding of thermodynamics shows that they had difficulties in distinguishing thermodynamic process and entities. For example, students had difficulties in envisaging doing work as a process of transferring energy and instead often viewed it as a form of energy. A similar finding, reported widely in the literature (e.g.[13]), is that the way students think and argue about heat would often place heat in the ontological category of Matter whereas it should be categorized as a Process (as the process by which energy is transferred between a hot object and a colder one). The representation of heat change as the symbol 'q' in thermodynamic equations reinforces this view, that heat is Matter, as it differentiates it from enthalpy change, represented by ΔH. Chi et al[11] maintain that, if the concept to be learned occurs in a different category from that in which a student's thinking would place it, then learning is more difficult. i.e. to shift his/her thinking into a different category – in the case of heat, from the Matter category into the Process category – is difficult to achieve. Chi et al[11] see this mismatch as being more important than the abstract nature of the concepts or that concepts are represented by mathematical expressions in accounting for the difficulty of learning some concepts.

Methodology

A sample consisting of 20 first year university chemistry students was chosen at random from the total year 1 cohort of 100 students. Students took a course of 13 one hour lectures at the rate of two lectures per week in the second semester of their first year. There were also 6 examples classes held once each week. The students had been successful at A-level and had grades A, B or C for chemistry.

The course developed both classical and statistical approaches. For example, internal energy and entropy were defined in terms of energy levels. On the other hand, enthalpy was dealt with entirely from the classical standpoint. Certain assumptions were made about students' knowledge and understanding; no explanations were given of the meaning of heat and work. Enthalpy was defined mathematically through its relationship to internal energy, ΔU

i.e. $\Delta H = \Delta U + p\Delta V$.

pV work was also defined mathematically in terms of the relationship

$$w = -\int_{V_1}^{V_2} p_{surr}\,dV$$

Examples class problems were relevant to the lectures; all were numerical problems.

Each student was interviewed for just over an hour before attending the lecture course and examples classes and then, again, after the course, shortly before their examination on the course. Four of the students failed to attend the second interview and could not be followed up because of imminent examinations. The data which follow refer only to the 16 students who attended both interviews.

Three familiar chemical reactions were performed in front of each student; questions were asked about the reasons for the temperature change and why the reaction happened for each reaction in turn before moving on to the next reaction. Each reaction was chosen to illustrate different thermodynamic ideas. The reactions were:

- the neutralization between 2 mol dm^{-3} hydrochloric acid and 2 mol dm^{-3} sodium hydroxide. This is exothermic and there are no visible changes other than temperature rise as shown on the thermometer.
- the reaction between magnesium and 2 mol dm^{-3} hydrochloric acid. This again is exothermic and the visible changes include the effervescence due to the evolution of hydrogen, the 'disappearance' of the magnesium and the rise in temperature as shown on the thermometer. It was hoped that the evolution of a gas would provoke the student into making comments about work being done by the gas.
- the dissolution of ammonium chloride in water. This is endothermic and the only visible change is dissolving of the ammonium chloride and the fall in temperature as read on the thermometer. This reaction was included because, at A-level, explanations in use at that level often fail when applied to endothermic reactions. Such explanations include the notion that chemical reactions proceed from reactants to products, from a higher to a lower level in energy terms.

Each reaction was carried out and students were encouraged to comment on observable changes, take temperature readings and to write appropriate equations. They were questioned about each reaction in turn about what had happened to produce the temperature change and why the reaction happened. If the students did not mention the terms enthalpy change, internal energy, entropy and free energy during the interview, they were asked specifically about them after all the reactions had been discussed. Questions asked about the chemical reactions were deliberately open questions so that the student could decide the terms within which to frame a response. The interview focused on the quality of students' understanding of the thermodynamic concepts and so supplementary questions were asked to explore students' responses and meanings. All interviews were tape-recorded and transcribed. The researcher also attended all the lectures and examples classes and made field notes about the content of these teaching sessions and the methods used.

Analysis consisted of constructing a list of thermodynamic statements to represent a scientific view of the concepts being explored (this was a subset of all the concepts which were covered in the lecture course). The list was validated by an expert in thermodynamics and checked against the course content. All transcripts were read carefully and the students' statements compared with the list of scientific statements; correct and alternative conceptions were identified and noted.

Results

The analysis which follows shows the students' understandings related to the concept of enthalpy change before and after they did the lecture course.

Quantitative overview of the data

Ten statements giving a scientific view of what is meant by enthalpy change are listed in Table 1. These form a list of the

Table 1 *Enthalpy change* This table is a list of statments which covers (except for specific heats) the knowledge and understanding about enthalpy change which would be expected of a good student at the end of a course in elementary chemical thermodynamics.

1. Enthalpy change is the energy transfer which occurs during a chemical reaction and is measured as heat. It takes into account any pV work done (and no other types of work).
2. pV work is work done when a change in volume occurs during a chemical reaction. Work is done by the chemical system against the atmosphere when there is an increase in volume (e.g. a gas is evolved) or on the system by the atmosphere when there is a decrease in volume.
3. The enthalpy change, ΔH, is equal to q, the heat, only when the pressure on the system is constant and only pV work is possible.
4. Enthalpy is a function of state, that is, it is dependent only on the initial and final thermodynamic states of the reacting substances.
5. The thermodynamic meaning of state includes not only the physical states of the substances concerned (solid, liquid or gas) but also the temperature, pressure and volume.
6. Hess's law is a consequence of the first law of thermodynamics: if reactants can be converted to products by more than one reaction pathway, the total energy transfer will be the same no matter by which pathway. This can be summarised as:
   $\Delta H^\circ reaction = \Re\, \Delta H^\circ_f[products] - \Re\, \Delta H^\circ_f[reactants]$
7. The standard enthalpy change of formation of a substance is defined as the energy released or absorbed when one mole of the pure substance is formed from its elements in their standard states. (The enthalpy change of formation of an element in its standard state is defined as zero).
8. In order to calculate the enthalpy change for a reaction, the standard enthalpy changes of formation of all the substances involved are required.
9. Standard conditions are 1 atmosphere or 10^5 Pa, substances must be pure and in their standard state. The temperature must also be stated.
10. The standard state of a substance refers to the physical state of the pure substance at standard pressure.

Table 2 *Numbers of student conceptions*. These tables give an indication of the numbers of students who had correct ideas and alternative conceptions for each statement of Table 1 both before and after the lecture course.

(Before the lecture course) N = 16

Statement	1	2	3	4	5	6	7	8	9	10
No. correct	0	0	0	0	0	10	3	3	0	0
No. alt. Conc.	16	3	0	0	0	6	4	10	10	1
Do not know		13				3				

(after the lecture course)

Statement	1	2	3	4	5	6	7	8	9	10
No. correct	2	4	1	0	1	10	1	8	5	2
No. alt. Conc.	14	9	0	0	3	2	2	3	7	2
Do not know		4								

concepts defining enthalpy change, which a good student would understand at the end of the course in elementary thermodynamics.

When the interview transcripts were read a note was made each time a student made a statement showing that he or she has understood one of the statements in Table 1 or had an an alternative conception.

Table 2 shows the number of students who had correct conceptions and the number of students who had alternative conceptions, for each of the ten propositions in the list.

Where 'Do not know' is recorded, this means that when a student was directly asked, he or she made it clear that that concept was not known. 'Do not know' was not assumed by the researcher if a student omitted to mention the concept. Not all statements in Table 1 formed the basis for direct questioning; direct questions were only asked about enthalpy change (statement 1), pV work (statement 2) and Hess's Law (statement 6). For the other statements, the open form of the questions meant that students were free to refer to a concept if it seemed relevant to them.

Students sometimes changed their minds, even in the same context, from alternative to correct (and occasionally the other way round) providing evidence of more than one conception. Other students had more than one alternative conception. This accounts for the apparent discrepancy where there appear to be more than 16 students and why there are several boxes with no responses recorded.

It can be seen that before the lecture course the students had no knowledge of pV work (Table 1, items 1,2 and 3) and that there was a small increase in students' understanding of this aspect of the course. Some students also became familiar with the importance of specifying standard conditions (Table 1, items 9 and 10). The strongest change in the correct explanations was in item 8 (Table 1) which is about calculating enthalpy changes of reactions. There is a small decrease in the overall numbers of alternative conceptions used by students between the two interviews, but many alternative conceptions were expressed both before and after the lecture course. The tables, however, give little indication of the quality and variety of the conceptions expressed. This is given below in a more detailed qualitative description of students' responses.

Understandings before a lecture course

Before the lecture course no students gave a scientifically correct explanation of enthalpy change. Their explanations can be characterized as lacking in precision or discrimination, being devoid of any understanding of pV work and viewing enthalpy as a 'form of energy'. Most students (12/16) described enthalpy change as an energy change and failed to mention the limiting conditions (See proposition 1,Table 1).

Student 1: Enthalpy change... it's the change in energy from the start to *finish of a reaction*.

Other responses seem to assume that enthalpy is just another form of energy and simply give an example of when there is an energy transfer.

Student 8: It's when one mole of water's produced when you're adding an acid and an alkali.

A third group of responses is formed of statements where students seem to treat enthalpy, activation energy, internal energy and entropy simply as different 'forms of energy'.

Student 5: ΔH will be the energy which is supplied to the reaction.

Student 2: … whereas the enthalpy change is the change that internal energy undergoes it might get hotter in which case the enthalpy change will be an increase.

Student 1: [Interviewer: What do you understand by entropy?] I usually get confused with enthalpy like it's [i.e. entropy] just another word for enthalpy.

Underlying the notion of 'forms of energy' is the view that energy is a quasi-material substance. It was never explicitly stated but many statements make such an inference plausible. A search of the literature reveals that even experts cannot agree on a suitable definition for energy though everyone would agree that it is not material.

While most students seemed to be aware that enthalpy changes were associated with endothermic reactions (though they were often unsure about the sign convention), one student firmly believed that endothermic reactions did not have an enthalpy change.

None of the students associated work with chemical reactions. For many of them, work was a concept only learned at GCSE and not encountered since (especially if they had no A-level in physics) and the concept of pV work was entirely unknown during the first interview. Students were only asked directly whether work was done in the context of reaction B (magnesium and hydrochloric acid). Some students believed that work was done when bonds were broken or made or when atoms were ionized.

Student 17: yes I suppose there was, magnesium had to change from its atomic state to the ionic state.

Student 18: yea work was done by having to break the bonds in the HCl 'cos work done means energy given out...

Other students denied that any work was done. None related the work done to the evolution of the hydrogen.

Understandings after the lecture course

There was little change in the quality of student responses about enthalpy change between the two interviews. Only two students gave a full and correct explanation of the meaning of enthalpy change. Again, explanations lacked precision and discrimination. The commonest conception again fell into the category of incomplete definitions of enthalpy change; this type of response was give by 9/16 of the students.

Student 1: As I said it's the heat flow between system and surroundings.

There were again several explanations consisting of definitions restricted to a specific type of reaction, such as neutralization... The 'forms of energy' explanations also persisted in many explanations (4/16).

Student 2: That's the heat changes or energy changes taking place in a reaction so whether from potential with little satchels moving to kinetic energy when they've dropped their satchels and they start running around..

The biggest change in students' conceptions related to enthalpy was their awareness of the concept of pV work. Four students provided an acceptable explanation of the meaning of pV work. Eight students showed an awareness of work but this awareness was accompanied by an increase in the variety of different alternative conceptions. Four students, even when questioned about work in the context of reaction B, still maintained that no work was done.

Only one alternative conception was given by more than one student; three students argued as follows:

Student 13: [Interviewer: Under what conditions does the production of a gas do work?] In a closed system … that's a closed system with a piston if there's a gas being produced there's be an increase in pressure in here and this piston would move out. [draws a diagram to illustrate].

When this statement is analysed, it seems likely that these students cannot envisage a gas being able to do work unless it pushes out a piston, which then does the work against the atmosphere. This is probably a relic of the calculation which converts the relationship: work = F ∞ d

to the relationship: work = pΔV.

A similar conception was of work done being associated with a weight being raised:

Student 8: It's work when you change the height of a weight or something so the gas has been released it's changed its height because it's gone from being in solution to being a gas.

This is clearly an attempt to make sense of definitions of work in text books which relate work to energy expended in raising weights.

In two conceptions it was argued that work was done because the temperature changed – up in one case, down in the other:

Student 19: … yes the formation of a gas caused work to be done because I think it's because you get a temperature rise in the gas given off.

A further conception suggested that, as gas leaves the system, it carries energy with it and identified this as work done. Other explanations proposed that work had been done because there had been a change of state:

Student 14: … well I suppose yea because it all changed.. it had changed its state.

As can be seen from the above examples, even though most students claimed to recognize the term pV work, its meaning remained far from clear.

During the second interview of this research, students were asked to explain what they understood by some of the common thermodynamic mathematical expressions such as $\Delta H = \Delta U + p\Delta V$. It was found that many of the students did no more than recognize the names of the symbols (and some not even that). In the case of this specific equation, 3 indicated that they understood what it meant, 5 students 'read' the symbols while 4 did not recognize the symbols correctly. On the whole, they appeared to have little understanding of the meanings of the equations.

Discussion

When students embark on an undergraduate course they have already developed frameworks for their ideas; these frameworks have been successful in coping with the requirements of A-level thermodynamics. Such frameworks are robust and resistant to modification or displacement by new conceptions.

One such framework which is particularly resistant to change is that of regarding energy as functioning in different inter-convertible forms. One of the difficulties which arise from this way of thinking about energy is that students incorporate new ideas such as enthalpy into this framework. While there was a small amount of improvement in the understanding of enthalpy as a result of the lecture course, it was clear that students did not see the meaning of enthalpy as problematical and did not, therefore seek to probe for any deeper meaning.

The lecturer for the first year course on chemical thermodynamics during which this research was carried out provided the researcher with a list of concepts which he would assume that students already knew. He assumed that students had a prior understanding of the concepts of heat and work. Neither concept was explained beyond introducing them as the symbols, q and w.The concepts of heat and work involve the use of words which are in everyday use and have different meanings for thermodynamics experts from these everyday meanings[14]. No assumptions were made about student knowledge of enthalpy, even though it is a concept which appears in all A-level syllabuses, but the lecturer was not aware of the prior ideas about enthalpy which the students had already developed.

Students' lack of understanding about work (and lack of any knowledge of pV work) means that it was inevitable that they would have had a limited knowledge of enthalpy at the beginning of the course.

Implications for teaching

In the constructivist view of learning, learners actively construct their own meanings which are affected by what they already know[15]. As Laurillard[16] points out, how students deal with new knowledge depends on the knowledge they bring with them to a lecture course; in this case, inadequate conceptions of enthalpy are already part of their mental 'baggage'. However, this is not the only influence on learning; learning is not a process carried out in isolation – learners construct their meanings as a result of interaction with the world around them. This interaction includes discussion with their peers, with their teachers and the more formal situations of the lecture theatre. The way lecturers present material is affected by their own private understandings, which are underpinned by an array of concepts, most of which are implicit.

It would seem essential, in the light of these arguments, that a lecturer needs to be aware at the outset of a course, of the alternative prior understandings students are likely to have. Actual student statements about concepts from research such as this can be used as problems to test future students' understanding and to encourage students to think about the problems for themselves.

There is clear evidence in this research that students do not understand the meaning of expressions like $\Delta H = \Delta U + p\Delta V$. It seems unreasonable to expect students to read into an expression like this all the meaning that is built into it and which is understood by expert thermodynamicists. It is important that thermodynamic entities are defined qualitatively and their effects talked about before they are defined quantitatively. Problems could be set that could be answered in qualitative terms and only later, when there is a reasonable understanding of the meanings attached to the thermodynamic entity should numerical calculations be introduced. This suggests a reversal from the usual procedure where calculations are set, students become proficient at manipulating the numbers to get the correct answer, with understanding following much later if at all.

It is worth pointing out that in the research exercise reported in this paper students were expected to apply their thermodynamic knowledge to real chemical reactions in a way which probed their understanding in depth. This is in contrast to the way in which assessment of thermodynamic knowledge usually takes place, that is, by expecting proficiency in performing calculations and in the rote learning of mathematical definitions. This implies that it is necessary not only to rethink the way thermodynamics is taught but also the way it is assessed.

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Exercises for chemists involving time management, judgement and initiative

PAPER

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Feedback from a range of learning opportunities frequently indicates that students feel they are given insufficient time, insufficient information, and insufficient guidance. In the light of this feedback, we have developed two exercises specifically designed to show students that real-life problems often involve coping with all three of these difficulties, and to provide opportunities to develop the skills needed to deal with the problems. These in-class exercises can be used either in isolation or as part of larger, integrated case study material. The material is also flexible in terms of level and student numbers and requires no special facilities. In order to enhance the perceived relevance of these activities, the underlying philosophy of the two exercises has been incorporated into a chemical context. Feedback on these exercises suggests that students can learn valuable lessons by completing them.

Introduction

Feedback between teachers and students takes many forms. Whatever the exact nature of this feedback, most of it is given by the teacher to the student in order to support or explain an assessment grade and to aid the learning process. It is also true that many teachers use a variety of teaching methods and/or develop new methods or styles in order to facilitate the student learning process further. But, how is the effectiveness of these methods evaluated? One way is to monitor changes in student performance in assessed work as a result of having introduced new methods or materials. This may be an appropriate measure of the effectiveness of some innovations and the best will show a positive response[1]. However, there are many reasons for supposing that this is a dangerous method to use for evaluating most changes in teaching[2]. An alternative to what Bodner describes as "the sports mentality approach to evaluation" is to obtain feedback from students and to use this to modify or update the material or mode of delivery if appropriate. This type of feedback can also be used amongst other things to verify that teaching standards are maintained from the student and tutor point of view, to provide evidence of good practice for external auditors and for supporting staff development[3,4]. Thus, the reasons for obtaining feedback are for judgement and improvement purposes. Over a number of years, we have obtained feedback from a large variety and number of students, usually at the end of lecture courses, tutorials, workshops and fieldwork. For each of these broadly defined teaching styles, feedback on assessed work has also been noted. Within this particular type of feedback, we have found there to be three extremely common and recurring themes as follows:

- insufficient time was allocated to complete the task;
- insufficient information was provided or available;
- insufficient guidance on how to tackle the task was given.

Of course, in some cases this feedback may be justified by poor teaching. However, more often, students may lack some key skills such as time management, information retrieval and the ability to think flexibly and creatively. One way to deal with this type of feedback would be to provide more instruction or help – a solution which could properly regarded as "colluding in a spoon feeding process"[5]. Since we believe that these three themes (limited time, information provided and guidance) represent real issues that students are likely to encounter outside of their courses (in the workplace), our approach has been to provide the opportunity to deal with them constructively within the chemistry curriculum. We have designed two exercises which are intended to illustrate these constraints in a positive, experiential way, and to provide an opportunity for addressing them. We have used these exercises in isolation and within more in-depth case study material that we have been developing[6]. They are suitable for use with any level of undergraduate study (though we prefer levels 2 and 3) and they can be used with class sizes of 5-35. No special facilities are required other than hard copies of the documentation and an OHP.

The first of these exercises is intended primarily to raise awareness that the three themes are often real constraints in solving problems (in the work place). The second exercise provides further opportunities to develop the skills needed to operate within these constraints.

Group Cohesion Exercise (GCE)

The first exercise is based on one of the exercises included in the module 'Personal and Professional Development for Scientists', developed by Maskill and Race[7]. In addition to being used in isolation as described here, the exercise acts as an effective 'ice-breaker' or method of introducing a larger programme of study involving group work (e.g. a case study). The utility of this type of 'chemical game' has been described elsewhere[8] and other recent and related examples are available[9]. In this instance, the group has a single objective which is to determine the precise nature of an environmental incident involving some herbicides. Each student is given one, or more information cards which between them provide sufficient clues to allow the correct conclusion to be reached.

Table 1 - Time Allocation for the Group Cohesion Exercise

TASK		Time (mins)
1.	Aims described	5
	Cards distributed	
2.	Groups share and discuss information	
	Arrive at conclusion	30-40
3.	Presentation of conclusion	5
4.	Discussion of solution	
	Reflection on the process	15-30

For this exercise we prepared 35 information cards some of which give key information, some provide supportive information, and some are irrelevant to the problem. In this way, the cards mimic the kind of information available to someone investigating a real incident of this type. We chose 35 cards because this number allows sufficient variety of information and means that the exercise can be used with a class of up to 35 students. The number of students in the class determines the number of cards each receives. The group need to decide on a mechanism for sharing all of the information, evaluate it by deciding which cards are key, supportive or irrelevant and agree on a conclusion based on this information. The conclusion is presented *via* a short (5 minute) talk which needs to include some justification. The model answer is then given by the tutor followed by a reflection session. Table 1 shows the time allocation which we have found appropriate.

The cards contain different types of information. One of the cards (shown in Figure 1) is a map of the area where the incident has occurred. Other cards describe characters involved (or not) in the incident, the timing of a series of events and extracts from letters and newspaper articles. Many of the cards relate to a chemical feature associated with the incident, so that students are made aware of the relevance of the exercise to chemists. These include information on chemical structure, spectroscopic data obtained from the chemicals and physico-chemical properties of the chemicals. Figure 2 shows six of the information cards by way of illustration. In practise, the map and cards (a) – (c) are key, (d) and (e) are supportive, while card (f) is a 'red-herring'. Since it is the group who need to arrive at these conclusions for themselves, they need to develop a strategy for disseminating and evaluating all of the information available within a limited timescale. This involves the group identifying and accepting the following features at an early stage:

- the time available is limited and not flexible;
- the information provided is all that is available and is sufficient to meet the objective;
- the initial instruction provides the only guidance for meeting the objective.

The group must not lose sight of these features though the precise method of arriving at the solution is not important.

An activity summary for the exercise is shown in Figure 3.

Commissioning A Monitoring Program (CAMP)

The second exercise described here is suitable for teams of 5 or 6, though several teams can work simultaneously and this can introduce an element of competition which adds extra impetus. We have worked successfully with class sizes of up to 35. We allow a total of 3 hours, which includes an

Figure 1 Map of the area involving the environmental incident

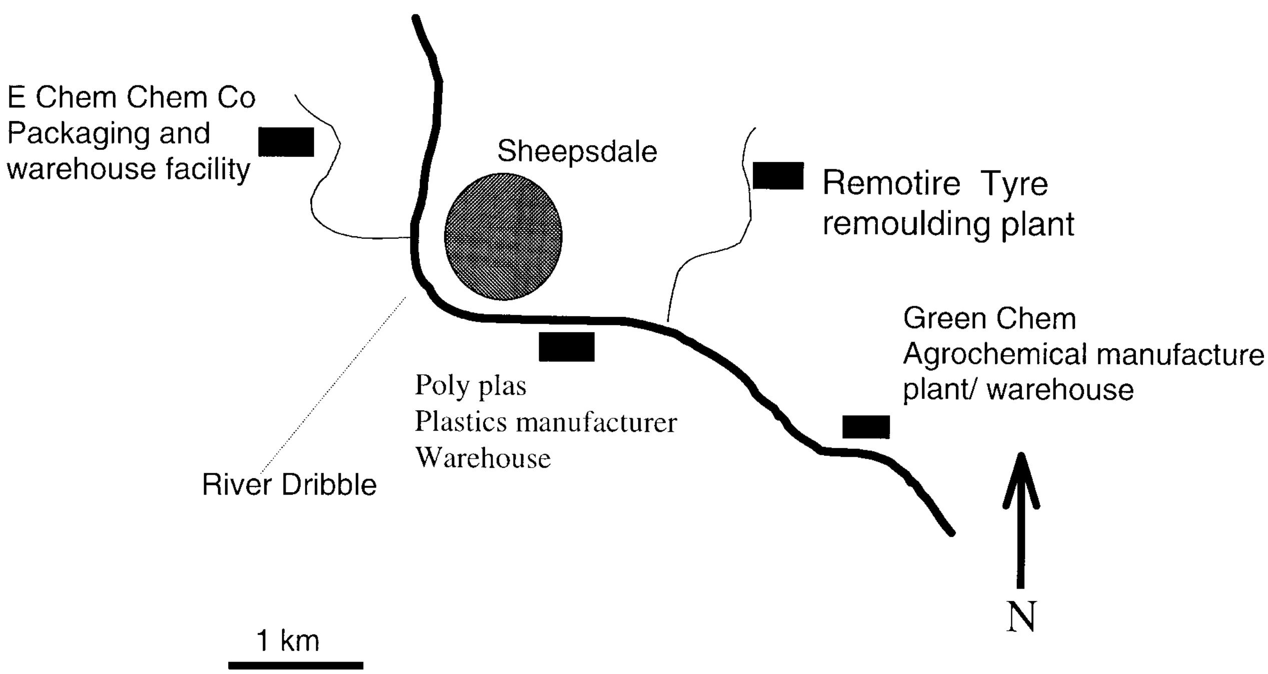
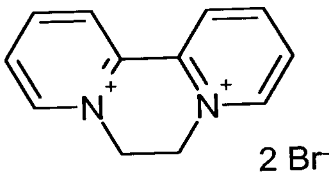


Figure 2 Examples of information cards

(a)

The chemical structure of Diquat Dibromide is:



- Water Solubility: 700,000 mg/L @ 20 °C
- Vapour Pressure: Negligible @ 20 °C
- Partition Coefficient: -4.6021
- Adsorption Coefficient: 1,000,000 (estimated)

(b)

You are Rick Niblet (date of birth 18/5/60). You wish you hadn't got quite so drunk on your birthday because, hung over and fuzzy headed, you forgot to switch off the heated shrink wrapping machine that you operate before you went home from work.

(c)

999 call list obtained from co-ordination centre at Sheepsdale May 19th 1987.

Incident	*Time*	*Service Required*
Suspected Heart Failure	7am	Ambulance
Lorry accident. Articulated lorry jack-knifed at Thrifty Bridge. Driver trapped in cab. Possible spinal injury. Lorry believed to be carrying hazardous materials	7.45am	Ambulance Fire Police
Drugs Overdose	8.30am	Ambulance
Fire at warehouse	8.30pm	Ambulance Fire Police
Baby Delivery	10.30pm	Ambulance
Baby Delivery	11.15pm	Ambulance

(d)

UV and IR analysis of an isolate from River Dribble from the EA sample point on May 20th 1987 showed a compound which had an aromatic moiety.

(e)

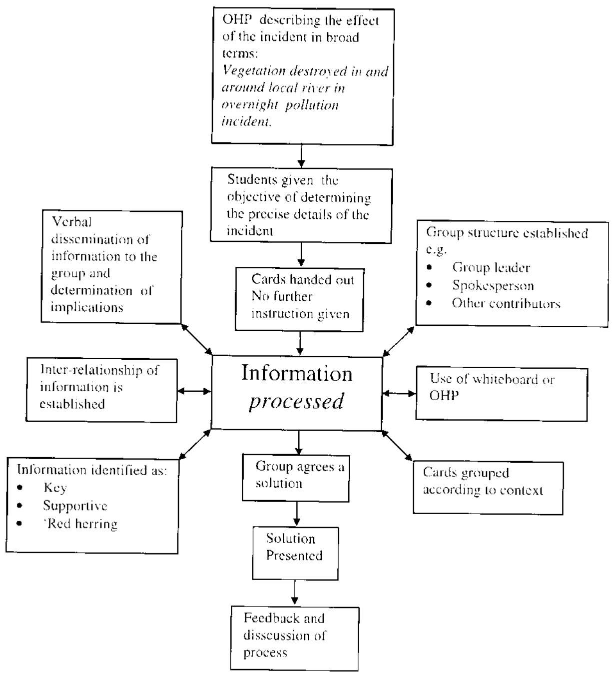
Relative Atomic Mass for selected elements

C	12
H	1
Mg	24
Ca	40
N	14
O	16
Cl	35.5
Br	80
I	127

(f)

You are Samantha Ridcully. You and your friend Audrey Grimsdale have been protesting without success about Nobby Giles' Dairy Farm. You both run a Vegan Restaurant in Sheepsdale.

Figure 3 Activity summary for GCE



introduction (5 min), arriving at a solution (120 – 150 min), and reflection (15 – 30 min). The exercise is the final stage in a series of five that constitute a case study dealing with the impact of a discharge of a herbicide (Diquat dibromide) and a surfactant (*p*-octylphenol) into a river system. Prior to working on this final task, the group will have completed the following activities:

- determined the precise nature of the incident (GCE described here);
- evaluated the likely impact of the herbicide and surfactant discharge into the river by consideration of the properties of the chemicals (literature review);
- determined the legal implications of the incident (researched Environmental Law);
- proposed a monitoring protocol for the two chemicals (literature review).

The general solution to the last of these activities (monitoring protocol) is that the two chemicals need to be monitored in two phases (sediment and water) over short and long term timescales, and using a range of analytical techniques. The quantitative aspects of the protocol (eg the exact number of sample measurements) is not important at this stage since this forms the basis for the final task, Commissioning A Monitoring Program (CAMP). This final exercise can be used as a stand alone activity, providing that the previous ones have been described in general terms in order to set the scene.

The group is given the role of working for the Environment Agency (EA) who need to complete a program of analysis of three chemicals. These are the herbicide and surfactant known to have been involved in the incident, together with a third chemical believed to be tributyl tin chloride (TBT), an anti-fouling agent. This is an industrial chemical commonly found in river systems and has a historical connection with the company.

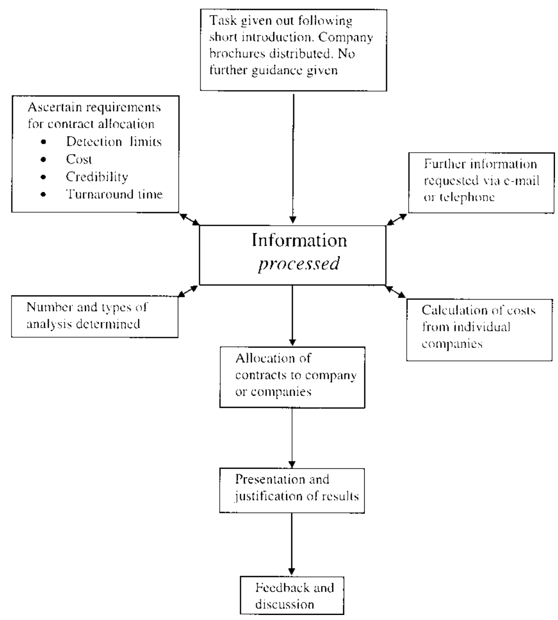
The group are given a single set of guidelines (see Appendix A) and with brochures from companies who carry out analytical work under contract[10].

The single objective for each group is to arrive at a quotation for the analysis that is at least competitive with that which can be offered by the EA. Part of the exercise involves relatively straightforward numerical analysis. However, it is also important to consider factors such as:

- the accreditation status of the companies;
- the detection limits of the analytical procedures;
- the number and type of samples to be analysed;
- the turn around time.

Some of the information needed is provided explicitly in the guidelines (Appendix A) or in the company brochures. However, the guidelines and brochures have been designed to ensure that students are operating within constraints of *limited information* and *limited guidance*. All the documents need to be read and discussed critically. Appendix B gives amplified examples of the factors which students need to consider, and some comments on how the information they have been given maps onto the problem. This illustrates how the process of arriving at a conclusion involves time management and other skills such as those described by

Figure 4 Activity summary for CAMP



Overton[11] including 'critical reading', 'constructing and understanding argument', and 'making judgements'.

An activity summary for this exercise is shown in Figure 4.

Results

The results achieved by students have varied substantially depending on the aptitude and attitude of the participants.

GCE

In almost all cases, participants have been able to reach the required conclusion in the allotted time. The most successful groups recognise at an early stage the need for a central collating mechanism. This may take the form of one person collating a summary of all the information available using a whiteboard so that the entire group can observe the connectivity of the clues and the conclusion as it emerges. Another common method of performing this task has been for the clue cards to be grouped together according to their type (character, time of event, chemical description etc) and graded as to their possible significance. Groups who fail to instigate a strategy at an early stage have usually required some tutor assistance before arriving at a reasonable conclusion. In a large class it is usually possible for the quiet or retiring student to hide behind the active or vociferous ones. However, in this exercise, the key cards are as likely to be held by the retiring student as the assertive one. Thus, all the students must participate, at least to a limited extent. A key issue for the reflection stage is to encourage all the students to consider the effectiveness of their own contributions to the process of sharing and evaluating the available information.

Commissioning A Monitoring Program (CAMP)

This exercise requires the application of a greater variety of skills to achieve a successful resolution of the problem. The range and level of skills held by the group members has therefore had a marked impact on general performance and quality of the results. Effective communication between group members is again key to a successful resolution of the task. Students who have completed the GCE will have learnt the need (and discussed some strategies) for effective time management and this is apparent from their reflection on this exercise. In the context of the CAMP exercise, the students generally recognise that delegation of tasks to individuals is essential to obtain a result within the given time constraints. This has been a common theme of feedback and reflection showing that this exercise is particularly successful in illustrating the importance of this issue. Groups members with good mathematical ability have found the numerical aspects of the exercises relatively straightforward. Those with a weaker mathematical background have sometimes struggled, and failed to reach a satisfactory conclusion. Most participants deal reasonably well with the other factors outlined earlier and in Appendix B, though it is not uncommon for one or more to be overlooked at first and some prompting from tutors may be needed. We have found it is important to emphasise that the exercise reflects real life in that students may have to use their initiative to seek additional information (which may or may not be available). To facilitate this, the tutor role-plays as a contact point with companies (if necessary using e-mail or telephone). Once students appreciate this role-playing aspect of the exercise they rapidly take advantage of it.

Undoubtedly, one of the most challenging issues of the exercise has been the oral presentation of findings. Determining a satisfactory solution to the task is one thing, but shifting gear into having to present it is another. Students find it difficult to organise themselves to give the presentation on time, since determination of the solution is perceived as being the most important feature; they also have difficulties in selecting the most appropriate information to make a convincing conclusion. Indeed, the students themselves often discuss in the reflection session that the quality of their presentation does not do justice to their well worked solution. This can be a cause of some frustration, but usefully illustrates the importance of being able to solve a problem and present the results within a limited timescale – as many will have to do in their working lives.

Chemistry in Context

For both exercises, the chemical context seems to be important in making the exercises relevant to chemists. It can also provide a distraction from the main aims. This is not necessarily a disadvantage; it can provide a 'safety net' for groups which might otherwise fragment when having difficulty in evaluating and using the available information. Amongst other things, groups have debated at length 'the substitution chemistry of heteroaromatic compounds (Diquat dibromide)' or 'the use of toxic ethyl bromide in the synthesis of herbicides' even though this information is irrelevant to the exercise. This gives them some feeling of security until the tutor is able to bring them back to the key issues. This prevents the students losing interest and motivation, and also raises as a valuable point for reflection their willingness to be sidetracked into unnecessary chemical detail.

Reflection

Reflection is a key part of the learning process[12]; it helps to identify a need for key skills, a mapping procedure by which skills and actions can be correlated, and a means of monitoring progression or development. Therefore, after each of the two exercises, there is a tutor-led discussion session that encourages the students to reflect on their performances both as individuals and as a group. The group reflection takes the form of a debate and involves the group commenting on their performance or level of achievement as measured against their own criteria, and also, an identification of how the specifics of the group work activities can be categorised in terms of group skills development (eg the need for an effective interchange of *all* information before it can be evaluated (GCE) or prioritising and division of tasks within a restricted timescale (CAMP)). A strategy of how the group may perform better on another occasion is often agreed upon. Individual reflection is then carried out by each student via a *pro forma* and this can be discussed further with the tutor if desired. During this part of the reflection process, students are encouraged to think about what they did to contribute to the group, identify a role and consider how effective their contribution was. They are also asked to look at areas for personal improvement and consider whether their style of contribution would always be appropriate or effective over a range of different types of activity. For example (GCE), some students may identify an effective contribution as one where they simply pass their card(s) to a leader without need for any further input. This however, should be seen as being a strategy of limited value particularly when a number of tasks need to be achieved in a restricted timescale (e.g. CAMP).

Considering Feedback

We have used these exercises over the last two years with postgraduate and level 2 and 3 Chemistry and Environmental Science students in Plymouth and academics at project IMPROVE workshops. During these trials, we were satisfied with the operational aspects of the exercises, but we were not so pleased with student feedback. Students welcomed the opportunity to perform group problem solving activities, but when the specifics of the group work were addressed, there were frequent complaints that there was 'insufficient time' or 'insufficient guidance'; the exact issues that we had set out to address! Interestingly, in describing the results of a recent graduate survey, Duckett *et al*[13] concluded that while chemistry students generally feel that they have received adequate provision of group work in their courses at a broad level of definition, when the utility of this experience is examined more closely (eg in motivating others, understanding the perspective of others and contributing effectively to discussions) it is often found lacking. In considering the negative feedback received from the initial trials, we were aware of becoming involved in a 'Catch 22' type scenario[14] whereby too little guidance would fail to encourage the students to think about how they would work within constraints (although the constraints themselves may be identified), while too much guidance might defeat the objective. In conclusion, we decided to re-structure the aims of these two exercises in order to achieve two different but related outcomes. The first of these involves a recognition of specific constraints and a consideration of how to work within these (GCE), while the second gives the students an opportunity to develop these methods and reflect further (CAMP). In more recent feedback, students describe 'the need to actively involve all group members', 'the need to consider the views of others' and 'the importance of critically considering information available and requirements' to be key features learnt. They are also enthused that their own feedback has been used to improve their learning experiences.Feedback from academics (to date only the GCE) has concentrated on how valuable the exercise could be for their students rather than themselves! They have also anticipated that the exercise must have taken a considerable time to put together. While the authors agree with this, it may be worth noting that the key to this process was having a template structure[7] and a final solution to work towards. Thus, the creation of related exercises may be readily achievable.

Conclusion

Both exercises provide an opportunity for students to perform activities within a series of constraints (limited guidance etc). The first of these (GCE) is particularly effective at raising an *awareness* of the importance of key skills and identifying strategies for working within these constraints while the CAMP exercise provides an opportunity to *apply* these strategies and develop them further.

Groups of students tend to tackle the two exercises in a number of different ways probably due to the 'no guidance' strategy employed by the tutor.This in itself is not important. What is considered to be important is the post exercise reflection both within the group and between the groups. This way, students can learn about their thinking skills both from themselves and from each other.

Students and academics have enjoyed taking part in these exercises,and students in particular welcome the opportunity to develop their transferable skills within a chemical context. However, student progression can be a slow process. It is unlikely that students become overnight experts in disciplines such as time management and critical reading as a result of taking part in these exercises, but we have found them to be effective methods for raising awareness of these essential skills and providing an opportunity to explore methods for working within various realistic constraints. The lessons that students learn *via* these exercises and the subsequent discussions can then be applied within the wider context of their courses. The opportunity to 'do' and 'reflect' at appropriate times is considered to be key in enhancing the effectiveness of these two exercises.

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Appendix A: Student guidelines for the exercise

'Commissioning A Monitoring Program'

May 19th 1987 **2.00** p.m.

You are working for the Environment Agency and have been charged with the task of obtaining monitoring analysis for three compounds, which are thought to be present in the River Dribble following the fire at the warehouse. These are Diquat dibromide, *p*-octylphenol and tributyl tin chloride.

Monitoring should take place initially on a daily basis from the 20th of May 1987 for the first fourteen days of the program followed by weekly monitoring for the subsequent six weeks. Following the initial eight-week monitoring period, a monthly check is to be made for an indefinite period until such time as the levels have dropped below the maximum allowable concentration. This monthly analysis should only include tributyl tin chloride and *p*-octylphenol but analysis will continue on both water and sediment sample types. It has been calculated that the cost to the EA to perform this analysis 'in house' would be in the region of £300,000. It is suspected that this may be more economically achieved by contracting the work out to private companies. You are therefore supplied with brochures from four companies from which to make your choice.

You may employ any company or combination of companies for any service to obtain the lowest cost data within the constraints within which you are working.

You will be required to obtain analysis for 12 water samples and 9 sediment samples for each of three sampling sites, though sediment samples are not required for Diquat dibromide analysis. Turn-around time for the analysis should be within seven days for the Diquat dibromide samples and within twenty-eight days for the tributyl tin chloride and *p*-octylphenol samples.

The budget must include costings for collection of samples and transport. This may be performed by the EA or as part of a package, which may be provided by any of the nominated companies. Detection limits required are as follows:

	Sediment	Water
Diquat dibromide		0.1 μg dm^{-3}
p-octylphenol	1.4 ng g^{-1}	1.0 μg dm^{-3}
tributyl tin chloride	10.0 ppb	1.0 ppb

Costing of sample collection per collection date

Total sampling time per visit	(hours)	8.00
Cost per hour		£15.00

All companies must be either UKAAS/NAMAS, GMP or GLP accredited. One of the nominated companies is German based. The current exchange rate is DM/£, 2.75. Each conversion attracts a 2% commission by the exchanging bank.

You may only budget up to the end of 1987. You have until 5.00 p.m. to make your choice(s).

When you have arrived at a budget you will be required to give a 10 minute presentation justifying **all** your decisions.

Appendix B: Examples of questions addressed in the CAMP exercise.

How many samples are required of each type? Is it necessary to consider this or is it sufficient to determine a unit cost?

The calculation of a unit cost may be seen as a means of saving time that could be better used on other activities. In fact, there are discounts from some companies for larger numbers of samples and so the exact number is important. Further, since the outcome of the costings analysis and therefore the entire exercise depends directly on the number of samples, this determination needs to be checked carefully.

Are all of the costs fixed?

Apart from discounted rates applied to bulk quantities of samples, the German company quotes their costings in DM. Although the exchange rate is given, this undergoes a change half way through the allotted time. The impact of this depends on the progress of the group at this stage but it can require them to reconsider their options dramatically. Thus, working under shifting timescales is illustrated.

Does the absence of explicitly named chemicals in some of the brochures mean that these cannot be analysed?

No. In most cases, chemicals are referred to by a general classification, so each one needs to be mapped onto a compound type. Thus, Diquat dibromide can be classified as a bypyridylium herbicide, *p*-octylphenol as a surfactant and tributyl tin chloride as an organo tin compound. This requires that the students do not lose sight of the underlying chemistry involved.

Are any or all of the companies capable of meeting the detection limit and turnaround time requirements? Is all of the information available?

None of the companies offer detection limit information and only one indicates the analysis time. However, all of the brochures invite potential customers to request further information if needed. When the group does this for the first time, all of this additional information for the 4 companies is provided as a single datasheet which reveals that in a number of instances, the detection limits are not achievable. The need to interconvert units and to check these is key at this stage. One of the companies does not provide any brochure costings of individual chemicals but offers an 'instant' e-mail quotation. If the request form is submitted correctly (ie correct number and type of samples), the group is given an immediate quotation. If the submission form contains errors, there is a delay (since the revised costings would need to be calculated by the tutor) which may alert the group to there being an error.

Have all of the companies received accreditation (UKAS/NAMAS, GMP or GLP)?

This is part of the fundamental guidelines. One of the companies has received no accreditation and can therefore be discounted before any costings are considered. This would otherwise be the cheapest company, so this guideline needs to be considered carefully. Additionally, the quality of this company's literature presentation is particularly poor and suggests that they may not be sufficiently competent or experienced to deliver the services they offer. Hopefully, this fact should be identified and highlighted by participants.

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.

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

- 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.

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 1st 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

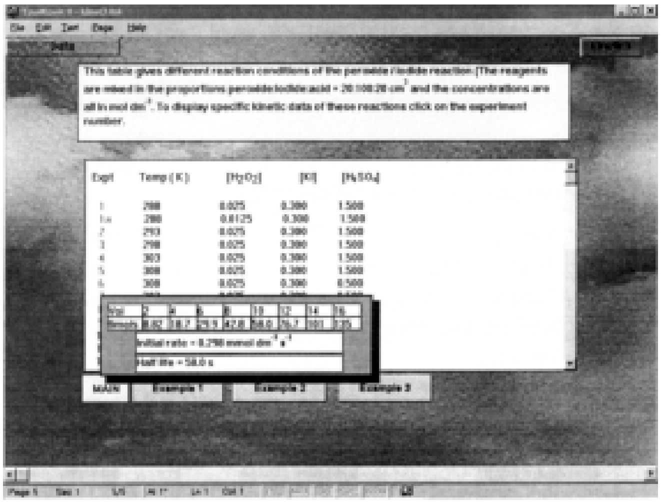

Figure 2 Worked example from sample data with pop up detail of calculation

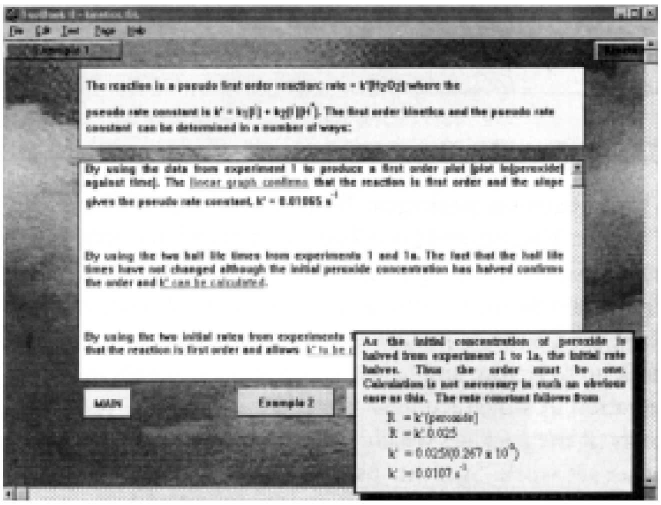

Figure 3 Sample question from test with pop up feed back

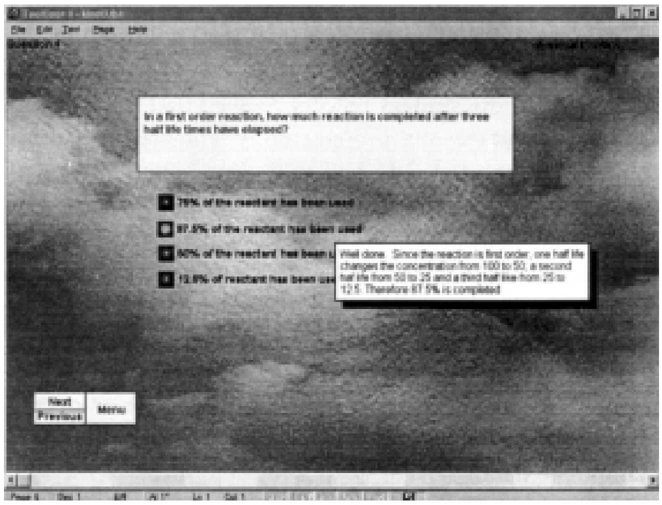

Table 2 Results from student questionnaire (1 = negative, 5 = positive).

		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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Assessment of Chemistry Degrees

PERSPECTIVE

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The problem

Do we use appropriate methods to award and classify degrees in chemistry in the UK? I fear that, to a large extent, we do not. In part, this is due to us failing to identify appropriate assessment procedures for the full range of skills required by professional chemists. But I believe that external demands for accountability are also undermining the value of standard examinations, by encouraging us to devise highly structured questions for which the marking is transparent, but for which the skills being tested are limited.

I contend that the entirely reasonable demand for accountability has taken us down a track which is to the detriment of university education because it leads to a decrease in real quality of assessment. I agree absolutely with the proposition that Universities should have clearly defined aims and objectives, and that these should be reflected in the procedures used to define the class of degree awarded to students. The problem is that the demand for *transparency* in the process of assessment has been interpreted to mean that the working process must be objective; taken to its limit, this means that the marking process could be carried out by computer. This pressure to achieve objectivity creates three inter-related problems:

- the scope for professional judgement is reduced;
- the range of possible assessment procedures becomes limited;
- opportunity for reflection is destroyed by increasing frequency of examinations.

Assessment should be addressing several issues (e.g. feedback to students, feedback to lecturers, generation of a mark), and the procedures used should be appropriate to the skills assessed. However, most HE teachers risk ignoring the first two and play safe by using traditional unseen test mechanisms which minimise the risk of cheating and which can be marked according to a scheme which involves little or no professional judgement. As a result, most assessment comes close to Ramsden's description of "a parody of bad practice"[1].

Background

University chemistry educators are committed to running high quality courses; as far as their teaching role is concerned this means quality in provision of a learning environment and quality of the procedure by which student ability is judged. The latter is a crucial factor in determining the future of the individual student. Not surprisingly, departments are under pressure to be able to *demonstrate* the effectiveness of their quality control processes. The pressure comes, for example, from accreditation bodies (the RSC), external assessors (e.g. TQA), influential reports (e.g. Dearing), university administrators (e.g. those responsible for monitoring progression and completion rates), and perhaps also employers. I will argue that the demand that quality should be objectively demonstrated puts an unacceptable limitation on our opportunities to assess quality over the range of abilities which we need to evaluate.

Here are some comments I have collected from colleagues throughout the UK, which support my argument.

- Most examination questions are highly structured questions, so students do not need to make extended arguments, or to write discursive open ended answers.
- Degrees are awarded by accumulating short term, isolated modular credits, rather than general 'professional' skills – and whilst many departments are ensuring that their courses include synoptic components, some universities are now forbidding this!
- The sheer quantity of assessment benefits students who aim to achieve good exam marks by virtue of short term memory, more than those who aim to develop as all round professional chemists.
- University administrators are imposing rigorous classification/mark correlations; thus 59.5% might be a 2:1 (rounded up to 60%), but 59.3% might be a 2:2, even though the error in the marking procedure might be as much as 1 or 2%.

All these comments are consistent with my own observations that most chemistry departments assign around 80% of the total marks available for classification purposes to formal written examinations, and the overwhelming emphasis in these examinations is on structured questions. Even with relatively unstructured questions, mark schemes significantly restrict the opportunity to give credit for anything beyond factual content. Thus, despite pressures on us to create a learning environment in which students develop a wide range of professional skills, we do little to evaluate these skills. Not surprisingly, this affects the way our students develop; students want to score high marks in examinations and they will inevitably focus their attention on those aspects of the course for which we award marks. The structured examination procedure is also convenient for external administrators and assessors; questions can be marked to such a strict protocol that it results in a reliably reproducible mark for each answer.The *reproducibility* of the mark (irrespective of marker) hides the fact that it may be completely unreliable as an indication of the full range of skills we might wish to assess. By limiting our assessment procedures to those aspects of chemistry that can be marked with high precision (e.g. by an automaton) we assess only a tiny fraction of the attributes we want our students to develop.

I emphasise that I am not arguing that our *marking* is of poor quality; on the contrary, the RSC accreditation process and the quality control exerted by external examiners lead to practice which stands up well to scrutiny. What I do argue is that we are being driven to more rigid *assessment procedures*, and this is to the detriment of our subject.

I identify three factors which should specially influence the assessment process. Firstly, we need to look at what we are expected or required to deliver in any undergraduate degree, and in chemistry degrees in particular. Secondly, we need to identify the opportunities for assessment in typical chemistry degree programmes, and consider how these correlate with course aims. And crucially, we must be aware of how our assessment processes affect the overall development of our students.

Factors influencing the assessment process

Chemistry degree programmes

Three recent reports are of special relevance to the design of a chemistry degree programme. These are the Dearing Report[2], the Mason Report[3], and the chemistry Benchmarking Document[4] which is based on the QAA agenda for quality[5].

Recommendation 21 of the Dearing Report sets out in general terms what we should expect to find in any programme on offer at a university.

"We recommend that institutions of higher education begin immediately to develop, for each programme they offer, a 'programme specification' which identifies potential stopping-off points, and gives the intended outcomes of the programme in terms of:

(a) the knowledge and understanding that a student will be expected to have on completion;
(b) key skills: communication, numeracy, the use of information technology, learning how to learn;
(c) cognitive skills, such as an understanding of methodologies or ability in critical analysis;
(d) subject specific skills such as laboratory skills."

The Mason Report, commissioned jointly by the Royal Society of Chemistry and the Council for Industry and Higher Education, examines ways in which the teaching of chemistry in higher education should adapt to employers' needs around the turn of the millennium. Amongst the diverse range of skills that industry would like to see better developed, it is clear that adaptability and communications skills feature highly across all sectors; mainstream chemistry employers are also concerned by limitations in the practical skills of candidates.

The Chemistry Benchmarking Document is a well-balanced document (currently still only consultative), which gives some fairly detailed advice on course content without being too prescriptive; in general, it follows the recommendations made by Dearing, requiring a balance of subject-specific and generic skills, and providing extra detail relating specifically to chemistry. In terms of what we are expected to deliver, it suggests benchmark 'performance criteria', which include aspects of knowledge and understanding, problem-solving, experimental skills, and transferable skills. However, unlike the Law and History panels, who chose to identify only baselines levels for their degrees, the Chemistry benchmarking panel decided to identify a range of standards that undergraduates might achieve in each of four areas identified in Section 6 of the QAA document as "what new graduates should know and be able to do". These four areas, clearly based on recommendation 21 of the Dearing Report, are:

(i) subject knowledge and understanding;
(ii) cognitive skills;
(iii) discipline-related practical and professional skills;
(iv) general transferable skills.

The Benchmarking Document identifies, for each of these four areas, specific attributes corresponding to an A-E classification. Although I applaud the decision, there is a high risk that the A-E classification will be misused. It was never intended to be correlated with a particular class of degree; a student who showed *all* the attributes listed in the A grade would be truly outstanding; for example, I would expect few students achieving (and worthy of) a first class degree to be able to demonstrate knowledge "significantly beyond that covered in the degree programme", although the very best undoubtedly would do so. Unfortunately, I fear that those looking at chemistry degrees from the outside (e.g. for quality assessment or accountability reasons) will use the descriptors for grades A – E precisely as guidelines for the qualities to look for in students in the degree class which apparently corresponds to each category.

In spite of this risk, which we must guard against, the grade descriptors in the benchmarking document give a useful indication of the range of knowledge, understanding and skills which students on chemistry degree courses should have the opportunity to develop. Students with these qualities would meet the criticisms of graduates raised by employers and reported by Mason[3]. However, it is not enough to provide opportunities for students to learn; we must surely also demonstrate our commitment by assessing how well they have learned, and the mark which they obtain must be seen as contributing to their degree class.

Opportunities for assessment

There are perhaps more opportunities for varied assessment methods in chemistry than in almost any other subject, and the benchmarking panel[3] identified many of them:

"Assessment procedures. It is essential that the procedures used for the assessment of students' achievement in chemistry should correspond to the knowledge, competencies and skills that are to be developed through their degree programme. Evidence on which the assessment of student achievement is based should include:

- Formal examinations, including a significant proportion of unseen examinations.
- Laboratory reports.
- Oral presentations.
- Planning, conduct and reporting of project work.

Additional evidence of use for the assessment of student achievement may be derived from:

- Essay assignments.
- Problem-solving exercises.
- Portfolios on chemical activities undertaken
- Literature surveys and evaluations.
- Collaborative project work.
- Preparation and displays of 'posters' reporting project work."

The opportunities for variety in assessment does not mean that we actually take advantage of them. I have already argued that there is pressure to move towards formal written examinations with rigid marking schemes, and that this results in most of the alternative procedures playing a rather insignificant part in the process. Key features of learning identified in the Benchmarking document do not map well onto the qualities which are appropriately assessed by formal written examinations. The first two (subject knowledge and understanding, and cognitive skills) can be suitably examined in this way, but it is hard to see how the other two key areas (discipline related practical and professional skills, and general transferable skills) can be evaluated by written tests. In most (probably all) chemistry degree courses, a mark for laboratory work and for project work contributes to the final classification. Both of these provide opportunities to assess various skills, but each typically contributes only about 10% of the total, and the marks are often rather indiscriminatory.

We need to think carefully whether the mix of assessment procedures we actually use to contribute to the classification of degrees reflects both the opportunities created by our teaching, and the skills we wish our students to develop.

Students

The assessment procedures we use send important messages to students about what we judge to be the important things for them to learn. Race and Brown[6] suggest ten methods of assessment and, more importantly, identify the advantages and disadvantages associated with each of them, and provide suggestions for making them more effective. They suggest that we should make use of as wide a range of assessment methods as possible, whilst recognising that all have merits and limitations. Unfortunately, they conclude that:

"It can be argued that presently we have far too much assessment, but neither the quality nor the diversity of this assessment is right. Students are highly intelligent people; if we confront them with a game where learning is linked to a rigid monotonous diet of assessment, they will learn according to the rules of that game. To improve their learning, we need to improve our game."

This quotation raises the problem of over-assessment. Students are assessed more extensively than ever before, both to evaluate progress through their chosen course and for the purpose of classifying their final degree. Over-assessment is almost certainly imposed with the best of intentions. A common response to poor examination results is to suggest that *more* tests along the way would help the students by providing early warning and feedback. I suggest that there are three problems with this approach.

First, most of the tests are set in a style which reinforces the student view that learning to be a chemist involves no more than learning the correct answer to a defined range of questions. In this sense, in-course tests do not offer a significant benefit to the learning habit. One of their main advantages should be the provision of detailed feedback. But I know of no evidence to show that the weaker students, who have the greatest need for such feedback, actually benefit from it.

A second problem with continual testing, discussed by Beard and Hartley[7], is that it takes little account of the different learning characteristics of students, some of whom appreciate "working gently through the year", while others "think continuous assessment is more strain". In the same survey, another student commented that the regular revising for tests prevented extra work like "background reading".

This quotation raises the third problem of over-assessment: the impact on the time available for reflection. This is an essential feature of in-depth learning. For example, Johnstone[8] has developed some highly successful new teaching material, the design of which was guided by the following model:

(a) the learning process uses working space, which is fed by external events/observations/instructions;
(b) the information that we select from the external input is controlled by a filter mechanism, which uses knowledge that is stored in our long term memory;
(c) working memory is only really effective when we have the chance to order our thoughts and seek out the inter-relation between various pieces of information;
(d) steps a – c are *all required* if we are to transfer information usefully from our working memory to our long term memory.

Without the opportunity for reflection, the long-term memory can simply become a jumble of unconnected facts, or information is largely retained in the short-term memory. This situation corresponds alarmingly well with the criticisms often levelled against many students who appear to forget topics once they have been assessed.

These three disadvantages of over-examining do not mean that there is no room for assessment at appropriate stages through the course. However, the prime purpose of this course-assessment (or continuous assessment) needs to be to encourage learning and provide feedback for both tutors and students. Learning is promoted by encouraging students to reflect on new ideas and incorporate them usefully into their long term memory. Feedback occurs when both tutors and students are able to recognise and rectify their own shortcomings (in delivery or in learning). For practical purposes, it may also be important to assign a numerical mark to these assessment procedures because it is this which convinces students that we treat them seriously.

The problem is that assessment methods which encourage learning and provide useful feedback are not usually totally objective but involve a degree of professional and subjective judgement. Students are inclined to regard this as 'unfair' because it is not immediately obvious how the mark was arrived at. Many students find it difficult to understand why good work (which is perhaps 80% correct in terms of factual content) may be worth a mark of only 60%. They are apparently unaware that it is the quality of presentation, additional knowledge, or other subtle observations, that make all the difference between good work and excellent work.This is true in the real world. It is perfectly reasonable that the same criteria should be applied to our assessments at university. Persig's observations of students' ability to identify and appreciate subjective quality[9] should encourage us to have the courage to make and defend professional judgements.

One possible way of introducing variety into assessment methods in a way which enhances learning is to make use of peer marking. Some success has been reported with various approaches to this[10,11], though other reported problems show how important it is for the students to believe that the process is well thought out and fair[12]. I suggest that, as an extension to the principle of individual students marking an individual piece of work, there is room for students to work (occasionally) in groups to mark and rank five or six pieces of work from colleagues. This might help them to appreciate the criteria we use to judge a piece of work and to recognise the difference between good work (e.g. 80% correct but worth only a mark of 60%) and excellent work worth a first class mark. This would help them to understand that there is a difference between *transparency of process* (the process by which we assign a mark) and strict allocation of each available mark to a particular piece of information. Even in a formal written examination it is possible to use a marking scheme which includes some marks for the skills demonstrated in applying and presenting knowledge. This is bound to be at least to some extent subjective and it would benefit both our students and our profession.

Conclusion

With the new QAA accreditation process now being trialled, and the provisional chemistry bench-marking document in place, we have the opportunity to address these assessment issues. We can allow the problems to get worse or make determined efforts to improve our assessment. Here are my suggestions for improvement.

- We should aim to integrate our assessment procedures more fully into the learning process, and thus emphasise the importance of feedback and self-assessment. Ramsden[1] suggests ways in which this might be done, and Rowntree[13] has written an excellent book on this.
- The assessment procedures we use need to match the knowledge and skills we wish to assess, and we simply have to allocate marks explicitly for skills if we want students to take them seriously. As Hartley and Braithwaite point out[14], is it any wonder that students gear their work specifically towards tests and exams, when this is precisely where we allocate their marks?
- We should not be afraid to use our professional judgement in assessing skills which do not lend themselves to objective measurement.We do this in other aspects of our work, and students need to appreciate that it is a feature of society.In doing this we have to recognise that *transparency of process* does not always imply *objectivity of marking.*
- We should aim to decrease the amount of assessment, whilst increasing the variety of methods used. In particular we should look as carefully at the cumulative assessment process over the whole course as we look at the assessment of each unit or module. For example, it may be that one can justify the assessment methods for each module, whereas there may be a clear over-examining of students when the course is viewed as a whole. A reduction in the amount of assessment might help students reflect on their work and gain a better understanding of it; and focussing on assessment methods that are appropriate for different skills would surely help our graduates to become more rounded professional chemists.

In summary, most chemistry courses do seem to address the 'programme specification' outlined by Dearing, and detailed in the QAA template. Most chemistry courses are RSC accredited, meet the guidelines of the benchmarking panel, and are robustly assessed. But are our graduates achieving the full range of professional skills that we, and employers, would like? And are our assessment procedures really encouraging our students to develop these skills?

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Communication: Computer programs which respond to learning styles

COMMUNICATION

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This paper describes an attempt to design and use a computer assisted learning program which responds to learners of two motivational styles. The program deals with aspects of statistics generally needed by science students. The motivational styles of the students were independently determined by a psychological test before the students were given the program. By interacting with the program the students were offered two distinct routes through it, one in which the students were led through (conscientious) and one in which students were encouraged to explore (curious). Bridges were available throughout to allow students to change from one route to the other. A record of the key strokes was kept to indicate the students' navigation. The results indicate that the choices made, by individual students, of program routes, corresponded well with the learning styles allocated in the psychological test. It is concluded that programs written to take account of learning styles can give new meaning to 'individualised learning'.

Introduction

The term individualised learning has been in use in education for some time. The ideal of a one-to-one teaching situation in which the teacher can respond to the learning of one student is largely unattainable except in the fairly rare tutorial systems of a very few universities. In most cases, larger groups have to be taught by a single teacher and the concept of true individualised learning has to be lost.

What passes for individualised learning is often just learning alone (individual learning), whether by worksheet or computer or some assignment.The idea of tailor-making the material and methodology to meet the learning style of the individual is harder to achieve. As long ago as 1967, Cronback[1] was discussing aptitudes which he defined as "a complex of personal characteristics that accounts for an individual's end state after a particular educational treatment. This may have as much to do with styles of thought and personality variables than abilities covered in conventional tests". He also states in the same article that most schools use tactics for teaching which are intended to minimise the nuisance caused by individual differences so that they can go on teaching the same unaltered goals.

At higher educational level, with increased student numbers and a broader range of entrance qualifications, the possibility of allowing for different styles presents a major problem. Logistically, universities are being driven towards larger classes and fewer tutorials thus reducing further the likelihood of individualised learning; learning taking account of individual learning characteristics.

Some writers, such as Macfarlane[2], see the solution in the increased use of technology.Learning by computer can reduce teaching loads, remove the problems of timetabling and accommodation at fixed times and provide learning opportunities on a one-to-one basis. Although there may be a trend in this direction, not all, or even most, academics are persuaded. Even if this strategy were adopted, it could still result in individual learning rather than in the individualised learning state. Although existing software enables students to go at their own pace and to track back and forth, every student is essentially doing the same programme embodying the same teaching methodology, examples, format and goals.

However, with the sophistication of technology, it should be possible to write software which would offer routes through a piece of learning which would fit the learning characteristics of the individual student.Visual and verbal thinkers could be accommodated in parallel programs; convergent and divergent thinkers could find a congenial approach; different personalities could be satisfied and people of different motivational traits could be stimulated. This would increase the program writing effort and would be justified only if the individual differences were real and the learning gains warranted it.

We set out to explore, in a preliminary study, the possibility of writing material which would take account of motivational styles. We wanted to know if students of different styles actually responded to the program in ways which reflected these styles, but first we had to give some more thought to motivation.

Ausubel[3] stated that "motivational characteristics are sufficiently important in school learning that they should engage our most serious consideration if we wish to maximise classroom learning". Anderson and Draper[4] suggest that motivation is the single factor which most affects learning, though they recognise that motivation is a term much used, but not well understood. Kempa and Diaz[5] looked at motivation in science education and based their analysis on the work of Adar[6].

The present study was based upon Adar's classification of motivation, and upon three particular aspects of it. She describes four motivational types which apply to the stimuli to learn, and are summarised as

Achiever	motivated by a need to achieve – to be top of the class

Curious	motivated by a need to satisfy curiosity for new knowledge
Conscientious	motivated by a need to discharge a duty
Social	motivated by a need to affiliate with others.

No student fits neatly and unequivocally into any of one of these categories, but generally one motivational characteristic predominates. In this study we had to distinguish between 'strongly curious' and 'mildly curious' and similarly for each category. The test materials which were used to categorise students were based upon the work of Al-Naeme[8].

The software

An opportunity arose for us to create a program which would form part of the teaching of statistics to biology students. The program relates to problems of sampling. The specific aim was to help the students to understand how the sampling procedure (in this case of a set of vaccine ampoules) affects the confidence with which the sample is regarded as a reliable sub-set from the point of view of detecting contamination. The principles involved are the same as those used for many problems in analytical chemistry, and so the program could be readily adapted for use by chemistry students. The general approach to programming is, in principle, applicable to almost any chemical topic.

The original intention was to produce software which would adapt, in real time, to the individuals' learning styles as they worked through the program. However, for an exploratory study, it was decided to write an interactive program in which the learner chooses a route at the beginning (which might or might not fit the motivational style) but it would be possible to switch from route to route at will. It was hoped that students would settle into the mode most congenial to their motivational style.

The two extremes on offer were a

- 'by the book' approach which offers a suggested linear route through each of 18 pages following each screen in the suggested order;
- 'free-ranging' approach which allows the student to use a non-linear, exploratory and self-driven route through the same 18 pages.

The pages consist of a mixture of text, illustrations and questions. Students interact with the program by answering questions. Different navigation buttons are provided, depending on the mode which has been selected; the free-ranging mode offers greater flexibility.

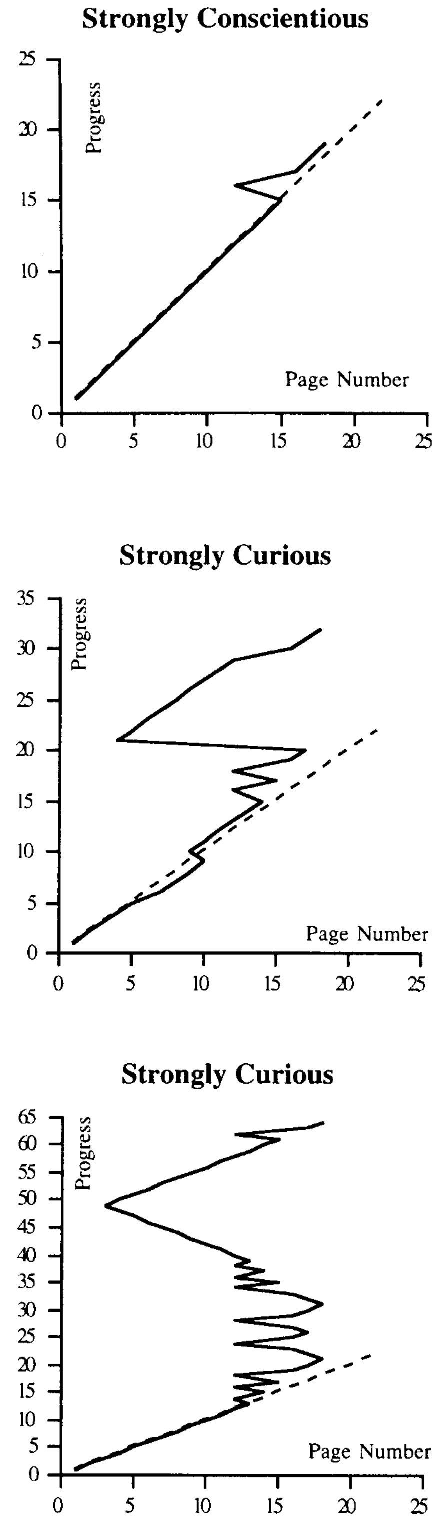
Of course, these are extremes and it was anticipated that students might switch from mode to mode more or less frequently. For example, curious students might take the direct route to see what the program was about before returning to the exploratory mode to pursue their interests.

To keep track of this navigation through the program, the computer kept a record of the screens visited, the order of the visits, the time spent at each and any revisits.

The sample

Since the program used in this study was based on an example designed to appeal to biology students, the main sample of twenty was taken from biology and statistics students. A preliminary sample of five, drawn from a wider range was used to test the 'workability' of the program. The main sample comprised one second year, fifteen third year and four postgraduate students.

Figure 1 Linetracks



The procedure

The subjects carried out three tasks:

- took a test to gain information about their motivational style (this was completed and analysed before the students used the computer);
- worked through the computer program;
- completed a questionnaire to record their experience of the program.

Results

The navigational information yields a list of codes representing the exact route taken. One way to express the results is by a 'linetrack' which gives an immediate visual indication of how directly the student followed the program. A line track is prepared by plotting each step on the vertical axis as 'Progress through the module'. Each page is given a code representing how far into the module it is (page 1 to page 18). This variable is plotted on the horizontal axis as 'Page Number'. Sample linetracks are shown in Figure 1.

A student progressing straight through the program without any deviation, would generate a plot represented by the dotted line; that is one page forward would correspond to one progress step forward.

The prediction was the Conscientious students would go through the program step by step and so generate graphs close to the dotted line. Curious students would deviate sometimes wildly, from the dotted line. The three linetracks shown in Figure 1 are chosen to illustrate the different characteristics for the Strongly Conscientious and the Strongly Curious. Only one example of the Strongly Conscientious is shown because there was almost no variation between all those in the sample who were put in this category on the basis of the test of motivational style; linetracks for all these students follow the dotted line very closely. The two examples of the Strongly Curious depart very markedly from the dotted line; following, backtracking, revisiting and map consulting. This is typical of this group of students.

There is no doubt that these two groups of students have responded very differently to the program and very much in line with the motivational style revealed in the psychological test. This cannot be explained by their being locked into a route by their initial choice, because students switched between routes and revealed their exploratory or non-exploratory styles as they progressed through the program.

As might be expected, the linetracks for the Social category cannot show up their characteristic 'need to affiliate with others'; they showed their style by wanting to work together. Linetracks for the Mildly Curious and for the Mildly Conscientious deviate from the extremes of this type, and therefore overlap. There was only one Achiever in the sample.

Table 1 shows that the Curious are much more inclined than the Conscientious to revisit pages, and that this is reflected in the longer time they spent on the program.

Table 2 shows the responses to the post-exercise questionnaire.

These results are encouraging in the first five questions. In the last item, the polarity shifts towards disagreement indicating little interest in group interaction. Two of those in the 'agree group' were 'Mildly Social' students according to their response in the psychological test.

Students were observed during their interaction with the program and only two of them entered into frequent discussion. Both of them had been rated Mildly Social.

Table 1 Percentage of revisiting of pages and of time spent on program as a function of motivational style.

Motivation Style	*Percentage of Revisiting*	*Average time spent on Program/min*
Strongly Conscientious	13.7	18.7
Mildly Conscientious	8.5	19.1
Strongly Curious	56.3	26.1
Mildly Curious	26.5	20.6
Mildly Social	27.2	21.2

Discussion

With a sample of 25 (of whom 5 were in the preliminary testing group) we cannot arrive at hard conclusions, but a sufficiently clear pattern has emerged to suggest that there is potentially a new field of science education for exploration.

Table 2 Responses to the questionnaire

Statement	*Frequencies*		
	Agree	*Neutral*	*Disagree*
I enjoyed working through the module	20	0	0
I would welcome computer based material of this type as part of my course	20	0	0
I found this software easy to use	20	0	0
The instructions on each page were clear	20	0	0
The software gave me freedom to do as I wanted	17	3	0
I would have preferred to work through the module as a group, with time for group discussion	3	9	8

It is fairly safe to arrive at the following conclusions based upon our experiments.

1. Students, who were rated Conscientious or Mildly Conscientious in this sample adopted a low-risk working style, choosing to assimilate the material according to the recommendations and shape of the program. They navigated the most direct route through the program, visiting most screens only once. They rarely revisited pages and hardly every consulted the map to see the overall pattern of the program. They tended to interact with the program in a minimal way.

2. Students, who were rated Curious or Mildly Curious displayed a more exploratory or high-risk working style. Their routes were generally non-linear giving rise to jagged linetrack diagrams. They repeated activities more often than the Conscientious, were more interactive and used the map more.

3. It has to be admitted that there were some cases which were not clear-cut either in the psychological test or in their performance in the program, but this is not unexpected since we are trying to press highly idiosyncratic people into categories to make our thinking and our research easier and not always succeeding.

4. There is enough evidence to indicate that there are possibilities here for making individual learning into individualised learning. This work has investigated only one dimension of learning style: motivation, but there is no reason why other dimensions should not yield equally promising results. Indeed, work in progress on visual versus verbal thinking in computer assisted learning in engineering, is showing interesting results and attracting student praise[9].

Perhaps Macfarlane's[2] view of the university of the future might have more chance of success if programs, which took cognisance of human learning styles, became the norm. However, education is probably at its best when lively minds interact in ways which cannot yet be emulated by technology.

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Is Peer Assisted Learning of benefit to undergraduate chemists?

COMMUNICATION

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Peer Assisted Learning has been a relatively common feature in US universities for several decades, and has been adopted more recently in Britain to help reduce student 'drop-out', and also to encourage a more student centred learning approach. Peer Assisted Study Sessions ('PASS') started in the University of Manchester Chemistry Department in 1995 and in 1997 a similar scheme was started in the Chemistry Department at UMIST. In both schemes the sessions are led by third and fourth year students (PASS Leaders) who volunteer and are given training in the support of group learning. During the first year of operation both at Manchester and UMIST the voluntary participation by first year undergraduates was very low, but now 50% of the first year cohort can be described as regular participants at the University of Manchester. Careful collection of data has indicated that those first year students who regularly participate in PASS achieve higher chemistry exam results than non-participants. There are also other hidden benefits to all the scheme stakeholders.

Introduction

Peer assisted learning is a well established feature of education at many North American universities. Often called Supplemental Instruction (S.I.), it was first introduced in 1973 at the University of Missouri-Kansas City, by Dr. Deanna Martin in the School of Health Sciences[1,2]. S.I. has since been adopted by over 350 different departments in universities across the USA, and the model has spread to include over 100 institutions in 12 other countries[3]. S.I. is one of the few post-secondary programmes to be designated as an 'Exemplary Educational Programme' by the US Department of Education who have validated the claims that S.I. improves the grades of participating students and improves student retention. The emphasis of S.I. is to help all students on 'high risk' courses, not to selectively target 'high risk' students. Two essential features of S.I. are that it is voluntary, and that it is not seen as remedial in nature so that able students participate to the benefit of all. In 1990 Kingston University, in conjunction with four other universities, adapted and developed the American S.I. model for use in Britain[4-7]. The British model emphasises the partnership with academic staff and most British S.I. schemes are introduced and co-ordinated by an enthusiastic academic in a particular university department whereas in the US, S.I. is usually administered centrally by an Educational Development Unit. In 1994, HEFCE provided funding to a consortium of academics from a number of English universities (the 'SI Network') for the production of training resources[8].

During the early 1990s the combined drop-out and failure rate in the Department of Chemistry at the University of Manchester was approximately 20% of its total first year intake. This clearly indicated that first year chemistry was a 'high risk' course. Part of the departmental response to this situation was the initiation, in 1995, of a peer tutoring scheme based upon the British model of SI. The scheme was given the title PASS (Peer Assisted Study Sessions)[9] in order to encourage the first year students to expect that participation would help their chances of progressing into the second year of study. In 1997 a similar scheme was started in the Chemistry Department at UMIST. The broad aims were to develop a framework which would:

- provide effective support for the first year programme and encourage the active participation of the majority of first year students;
- benefit PASS leaders;
- not demand excessive staff time.

This communication will describe the organisation of the PASS schemes and give preliminary, but extremely encouraging results, which indicate that PASS has a number of direct and indirect benefits to the undergraduate teaching of chemistry.

Methods

It was envisaged that third and fourth year students (PASS Leaders) would be recruited and, after appropriate training, would encourage first year students to work at problem solving in small groups. The scheme would be voluntary both for the unpaid PASS Leaders and for the first year student participants, and would run on a weekly basis during term time until Easter. Each PASS session would be based around a tutorial worksheet but more general advice on note taking, revision and exam techniques would also be provided by the PASS Leaders.

Student leader recruitment

Recruitment of PASS leaders from upper year cohorts is started at around Easter time. This involves a short talk given by the academic in charge of the scheme (the PASS co-ordinator) which emphasises the benefits of the scheme to the PASS leaders (CV enhancement, revision of fundamental chemistry, increased confidence etc.). The PASS co-ordinator also writes to all of the students on industrial placements inviting them to be PASS leaders on their return to the department. So far, at Manchester and UMIST there have been no problems recruiting a sufficient number of PASS Leaders to run the scheme. Nor has their been so much demand that a selection process to choose PASS leaders has been necessary. Should this be the case in the future, then we believe that it is more important to select PASS leaders with enthusiasm and reliability rather than with high academic ability. Senior year students returning from a year in industry consistently prove to be enthusiastic and effective leaders and could be given priority in any selection process. PASS leaders that struggled with the first year course but ultimately passed have also proved to be successful and empathetic role models.

Student leader training

The PASS Leaders all attend a compulsory training day (usually the first Saturday of the academic year) with an external trainer. Since the introduction of the schemes at Manchester and UMIST the trainer has been Ms. Jenni Wallace, a long standing and enthusiastic member of the SI Network who was involved in adapting the American model for British higher education. The importance of effective student leader training cannot be overemphasised in order to set the right 'tone' for the whole scheme, and to provide effective training in study strategies, group handling skills and the facilitation of learning. It is emphasised that the leaders' role is not that of a teacher, but instead it is to initiate group discussion and encourage the active participation of the first year students. This initial training day is not chemistry specific and indeed the PASS Leaders mix with students from the other University Departments within which PASS schemes are operating (e.g. Mathematics, Middle Eastern Studies and Philosophy). A second subject-specific training session takes place one afternoon during the second week of the academic year, during which the PASS co-ordinator explains in detail the organisation of the Chemistry PASS scheme.

The sessions

The hour long PASS sessions are timetabled on a weekly basis to fall between two formal teaching sessions. The sessions are held in a teaching laboratory which provides a convenient space for each group to work together without being distracted by other groups. Two PASS leaders are assigned to each group, which usually consists of 5 – 8 members. At Manchester University, each session is based around a tutorial worksheet which alternates between organic, inorganic and physical chemistry. These tutorial worksheets are an important component of the first year course and are compulsory for all students, whether PASS participants or not. A few days after the PASS session all first year students are required to submit the answers to the worksheet for marking by their academic tutor prior to attending a formal tutorial which also focuses on the content of the tutorial sheet. Should incomplete or incorrect answers be produced as a result of the PASS session then these can be corrected by the tutor. In addition, the marks obtained from the worksheet answers do not contribute towards the students' final grades. At UMIST the sessions are based on problems and learning objectives given in the first year course handbooks. At both universities PASS Leaders also provide the first year students with more general advice on note taking, revision and exam techniques. It is important to emphasise that the PASS sessions are designed to supplement the existing first year course not to replace any aspect of it. More general advice and information can also be disseminated by the PASS Leaders; for example the advantages and disadvantages of taking a year out in industry or taking certain second year course options. Sometimes the sessions may take on a more informal 'social' aspect, especially early on in the semester, where they can take the form of a question and answer session about aspects of student life of relevance to the group. The first year groups are not the same as for the formal tutorials to encourage greater mixing amongst the first years.

Academic staff involvement

Staff involvement is restricted to the PASS co-ordinator who is responsible for organising recruitment, the venue, stationary, training, sorting the students into manageable groups, ensuring that the problem worksheets are distributed to the PASS leaders in time, *etc.* Negotiating a suitable timetable slot where both the leaders and first years have a formally 'free' session can sometimes be problematic. The co-ordinators also collect registers from the sessions which are confidential to the co-ordinator and allow the tracking of attendance to aid end-of-year statistical evaluations of the scheme. Initially this administrative aspect involves a significant commitment of the co-ordinator's time, however, once up and running, the PASS Leaders effectively run the scheme. Financially, the cost to the Department is minimal.

Results

Table 1 shows the number of PASS Leaders and of first-year participants at both Manchester and UMIST for each year the scheme has operated.

The averaging of the figures over both semesters obscures the observation that participation tends to decrease in the second semester. For example, at Manchester in 1997-98, an average of 68 students attended each of the nine sessions in the first semester, and this dropped to an average of 30 students for each of the five sessions in the second semester.

We have anlaysed the examination results of the students at Manchester during the 1997-98 session to assess whether any effect of participation in PASS can be detected. This year was chosen because, at the time of writing, it was the most recent (and largest) sample on which data were available. Based on attendance over the 14 sessions, students were classified as full participants (6 or more sessions), occasional participants (1 – 5 session) or non participant. Over the year as a whole, 17 students (12% of the cohort) failed to obtain the pass mark of 40% (averaged over all 3 papers) and were required to resit; none of these were regular participants in PASS. In contrast, in the year before the PASS scheme was introduced, there were 36 students (27% of the cohort) with

Table 1: Number involved in the PASS scheme

Year	*Manchester*		*UMIST*	
	Leaders	Participants*	Leaders	Participants*
1995-96	22	18	-	-
1996-97	24	41	-	-
1997-98	28	55	11	14
1998-99	24	58	12	14

* Average number of first year attending each session.
The total cohort at Manchester is about 140 and at UMIST 110.

Table 2: A comparison of examination results between PASS participants and non-participants at Manchester for the 1997-98 academic year.

	[a]No. of students	Mean No. of attendances	[b]Mean Exam results	[c]Mean A-level points
Non-participants	27	0	47.3	13.8
Occasional Participant (attended 1-5 sessions)	34	2.7	51.9	11.8
Full participant (attended 6-14 sessions)	65	9.6	60.7	13.7
all students	126	5.7	55.5	13.2

[a]Figures do not include those students who were absent for one or more exam (18); [b]based on the average of the final examination marks for the three chemistry courses covered by the PASS scheme (i.e. organic, inorganic and physical);
[c]Mean points calculated from each student's chemistry and best other science or Maths A-level results).

an average mark below 40%. This is strong evidence that the introduction of the PASS scheme is associated with improved performance.

Table 2 shows the average examination mark for full, occasional and non-participants. The average mark increases with increased participation. This supports the conclusion that participation in PASS is beneficial.

We considered the possibility that the difference between the three groups was due to a greater participation in PASS by more able students. As a measure of ability we calculated the mean A-level point-score based on the chemistry grade and the best grade achieved in any other science or maths A-level. We chose this because many of our students take, in addition to chemistry, only one other A-level in maths or science; we considered it inappropriate to include results from non-science subjects in our measure of ability in chemistry.

Table 2 shows that there is no difference in the mean A-level points score between full participants and non-participants, and so there is no reason to suppose that the strongest students are attracted to the scheme. The mean A-level point score of the occasional participants is slightly lower than that of the non-participants, yet their examination mark is a few percentage points higher. The most optimistic interpretation of this is that students can benefit from even a small commitment of time to the scheme.

We are aware of the dangers of evaluating new learning opportunities from a quantitative analysis of exam results[10]. We have therefore sought other evidence for the effectiveness of the PASS scheme. General questionnaires completed by first year students frequently refer favourably to the PASS scheme. PASS leaders provide a uniformly positive response through their specific questionnaire. Thus the scheme is clearly valued by both sets of students.

In addition we have held informal discussions with students and staff in the expectation that this is the most effective way to learn from them how the scheme could be further improved. These discussions also reveal a high degree of satisfaction with the scheme.

Discussion

Since the scheme is completely voluntary, we could not expect a high participation rate during the first years. The fact that over 50% of the first-year students at Manchester (including some of the most able ones) are now participating suggests that they believe that the scheme is worthwhile. This, in conjunction with their examination performance, provides good evidence that we have achieved the first of our key objectives. The PASS scheme has a number of other benefits for the first years. For example, students have a forum in which to discuss problems which they would feel uncomfortable talking to a personal tutor about; they realise that others are struggling with difficult aspects of the course (and that their PASS Leaders struggled and ultimately passed the course); they meet more fellow students (especially during the all important first few weeks of the academic year). PASS also helps to break down the barriers that exist between years and to reduce the feelings of bewilderment which often accompanies the first year student experience in a large department. One important aspect of the scheme at Manchester is that the PASS Leaders take an active role in registration week by running a help desk, organising Department and Library tours, and helping with social functions. At UMIST several of the PASS Leaders also help with UCAS open days for potential undergraduates.

There are also clear benefits to the PASS Leaders. On their own admission they revise and gain a better understanding of the fundamental concepts of chemistry; they discover and develop skills in communication and group work which industry requests; they feel valued by the department and gain a sense of involvement in its affairs. The prime motivation for most final year students to become a PASS Leader is to improve their CV and to be able to answer those awkward questions on application forms. However, once involved in PASS they become increasingly enthusiastic and view the scheme as their own. Academic teaching staff are impressed by the degree of enthusiasm and commitment shown by the PASS Leaders and benefit from informal feedback on courses.

We believe that the PASS scheme has improved first year learning within the Chemistry Departments of Manchester and UMIST, and that schemes like PASS could be a useful addition to most undergraduate chemistry courses. Our experience suggests that a successful scheme requires a number of elements. The most important is the availability of an enthusiastic academic co-ordinator backed by a supportive academic staff. It is also essential to ensure that there is a vacant slot in the timetable which is common to the first and the final year students at a time when there is a suitable room available. We have found that there are advantages in timetabling the PASS sessions in a 'lecture trap' between two compulsory teaching sessions; this has minimal impact on the students' flexibility to manage their time.

Initial participation is likely to be disappointing, and so perseverance is required to maintain the scheme until it is accepted and embedded in the curriculum. This means that all faculty staff need to promote the scheme and actively encourage student participation. With perseverance, the scheme eventually becomes self-perpetuating with first year students becoming keen to be PASS leaders.

The PASS scheme has many benefits, but it should not be seen as a 'cure-all' for all problems; it is just one facet of student-centred learning which is beginning to play an important role in higher education. Dearing[11] suggests that universities should be "considering how students can become active participants in the learning process" and PASS provides an excellent environment for this process. There is strong statistical and anecdotal evidence that peer support schemes are beneficial to all who participate – to the first years who gain support for the all important transitional year into university life, for the leaders who gain and develop many personal skills, and the staff and institution who gain by a reduced failure rate and by having more motivated and better prepared students.

Acknowledgements

The Chemistry Departments at Manchester and UMIST both gratefully acknowledge start-up funding for the schemes from the Enterprise Centre for Learning and Curriculum Innovation. John Garratt is also thanked for his helpful comments.

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Reflecting on learning – continued

from Dr Nigel Lowe, Department of Chemistry, University of York, Heslington, York, YO10 5DD.

Two recent letters[1,2] have continued the correspondence initiated by Tomlinson[3] on the role of reflection in teaching and learning. These letters report less successful (Gagan[1]) and more successful (Maskill and Race[2]) attempts to introduce reflection as a routine part of the learning experience for students. We would like to add our own encouraging experiences to the current debate.

The final piece of work in our group exercises – *structured learning packages* (SLPs)[4] – requires each participant to complete a written reflection exercise addressing the following (250 word) brief:

Describe how you have contributed to this team exercise and how the experience has allowed you to use, and develop, your key skills. *You should use this as an opportunity to practise writing about your achievements and also as a reflection on the exercise to identify where, and how, you have improved and where you perhaps need to concentrate on further improvement in the future.*

Of the 89 responses, an overwhelming majority provide compelling evidence for a truly reflective learning process amongst participants. This takes the form of candid self-analysis of what they thought they were good at before the exercises, what they improved at etc., with mention of specific positive steps which have been prompted by the exercise. Particularly pleasing were unsolicited comments such as those made about how participants felt that they had learned things from each other during the exercise. Only a handful of responses were pre-occupied with other matters, usually complaints from people who hadn't enjoyed the course (and even these were sufficiently reflective to acknowledge, if grudgingly, that they had benefited from the chance to practise speaking in public).

This written exercise is the culmination of a course where the whole 'culture' is to designed to encourage reflection as a means to developing personal skills. The SLP begins with a classroom session where student perceptions of the nature and importance of key skills are discussed[4]. This includes each individual completing a skills profile form, discussing their responses with each other, and delivering a short team presentation on the strengths and weaknesses of their team. Discussion at this stage also focuses on teamworking skills in preparation for the teams tackling the first stage of the case study together. Subsequent plenary sessions focus on oral and written presentation skills in the same way, and other, *ad hoc*, sessions on using the literature have been held. Consequently, by the time the students meet the concluding written exercise they are merely committing to paper the kinds of comments they have been making during discussions at the plenary sessions. This, presumably, is what Maskill and Race refer to as the 'framework of ideas'[2] which makes the process of reflection relevant, helpful and productive.

Courses where the explicit purpose is skills development present the type of learning experiences which are relatively easy to think about – generally 'learning by doing'. However, merely providing 'encouragement and opportunities to reflect'[1] might still prove counter-productive for many students if it were not for the familiarity they gain with the process during the course of our exercise.

Our conclusion then would be that, in common with other issues in the area of skills, reflection cannot be 'bolted on' to existing courses but will be effective only if it occupies a central and familiar role in the learning process.

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Correction
Small Numbers

The letter from Peter Nelson (UChemEd **3** 37) contained the statement "therefore 0.5 cm^3 contains either 0 or 1 ion". The volume should have read 0.5 µl or 0.5 mm^3. The mistake was mine, not Dr Nelson's. My apologies to him and to readers.

John Garratt

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   Journal articles:

   - Finster DC 1989 Developmental instruction I *J. Chem. Ed.* **66** 659-661
   - Johnstone AH and Letton KM 1990 Investigating undergraduate laboratory work *Educ. Chem.* **27** 9-11

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