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There are no hard and fast rules for subdividing manuscripts. However, an introduction should provide a clear statement of the relationship of what is described to previous work and opinion (and is likely to include some references to some aspects of educational theory), and also the overall purpose of the article (including, where appropriate, the educational objectives, intended learning outcomes and why these are not satisfactorily achieved by other approaches). Other sections may be equivalent to 'methods', 'results', and 'discussion' as used in conventional scientific papers; these sections would describe how the work was carried out, show or illustrate the outcomes (new teaching materials etc) which have been created, and critically evaluate how far the original objectives have been met. It is accepted that evaluation will rarely involve the use of rigorous control groups; but manuscripts should include a discussion of some appropriate method of evaluation leading to critical assessment of the effectiveness of the work described.

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Full Papers: these describe a specific method of or approach to teaching, or some teaching material which has been used by the author; papers should explain the educational objectives which led to the use of the method and indicate its potential usefulness in other institutions. Where appropriate, information about the availability of supporting material should be given.

Communications: these are brief accounts of work still undergoing evaluation and development, but of sufficient interest to merit publication because it is likely either to be widely adaptable by other institutions or to provoke widespread discussion.

Perspectives: these provide an opportunity for contributors to present a concise but in-depth analysis of a topic of general interest, with clear conclusions likely to be directly useful to other academics involved in teaching. Articles intended as a perspective should deal with a topic of immediate interest and relevance.

Letters: these are a medium for the expression of well argued views or opinions on any matter falling within the remit of Journal, including comments on and experience with previous publications.

All contributions, whether or not they were solicited, are rigorously reviewed. Referees are required to evaluate the quality of the arguments presented, and not to make subjective judgements involving their personal views of what constitutes good or effective teaching. Contributions are judged on:

(i) originality and quality of content;

(ii) the appropriateness of the length to the subject matter;

(iii) accessibility of supporting material.

Key Skills: What Do Chemistry Graduates Think?

PAPER

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We report the results of a survey in which we have tried to identify which key skills are most needed by recently employed chemistry graduates, and how well they feel they are being prepared for using these skills by their chemistry courses. Across the range of job-specific skills covered in the survey, the results show a general correlation between the extent of relevant course content and the importance of the skill to typical graduate employees. However, the results also support employer opinion that there are areas in which graduates could acquire more job-specific skills, and some suggestions are offered on approaches to exploiting more effectively the opportunities for skills development within chemistry courses.

Introduction

Typical surveys of the proficiency of graduates in the workplace reflect the opinions of the *employers* of graduates[1,2]. They conclude that graduates could be better prepared for the world of work by their university education. This concern is being addressed by a number of initiatives which set out to teach chemistry in a way which delivers chemical knowledge whilst encouraging students to develop skills. Clearly, these initiatives will be most effective if they address the skills which are most needed.

Employers naturally have high expectations of the graduates they employ. Consequently, regardless of the absolute quality of recruits, they will always be able to identify areas where their employees could improve: the expectations of employers may be somewhat unrealistic. More relevant information about the skills which graduate chemists need and their opportunities to develop these skills may be obtained by surveying recent graduates directly. The DfEE "Alumni" project was set up for this reason. Reports on eleven completed projects (of which this work comprises part of one) are available[3]. One of these includes a survey of chemistry graduates[4]. Another recent survey also relates specifically to chemistry graduates[5]. However, this was limited to those working in the chemical and related industries, and the questions were not designed to allow respondents to compare their need for skills with the opportunity to develop them during their university courses. We perceived the benefits of such a survey as follows:

- Graduate employee opinion might temper unrealistic employer expectations.
- The familiarity of recent graduates with the content and structure of university courses means that they will make a better connection between what they now do and what they did at university.
- This is likely to yield more realistic suggestions as to how courses might be improved in order to facilitate progression into a wide range of jobs.
- Initiating such a survey may help establish permanent mechanisms for using feedback from recent graduates to influence the structure and content of degree courses and to develop closer links between industry and academia in teaching as well as in research.

A brief abstract of this work has been published previously[6].

Methodology

The strategy of this study and the design of the questionnaire were discussed and agreed by a consortium of academics and industrial representatives already convened to advise on a previously reported project[7]. The objectives of the study were defined as:

- to obtain information about the skills which graduate chemists find that they most need in order to make an effective contribution to their work during their first years of employment;
- to establish whether graduates believe that their first degree courses provide them with the opportunity to develop these skills.

We decided to send the questionnaire to all students graduating in a particular year from selected universities: Edinburgh, Hull, Plymouth, Sheffield Hallam, UEA, Warwick and York. Questionnaires were distributed during the summer of 1998 with the help of colleagues in the universities concerned. They were sent to all those graduating in 1995 with a BSc, MSc or PhD, where chemistry had been the major component of their *first degree*. The year 1995 was chosen because it would include a proportion of respondents still engaged in studying for a higher degree as well as those who had taken up employment on graduating either with a BSc or with a higher degree.

We decided to base the questionnaire on a set of specific action statements: a typical action statement is "contribute effectively to discussions". This approach was intended to remove any ambiguities resulting from the various interpretations which it might be possible to put on more general questions particularly where these included ill-defined terminology (e.g. "did your course develop communication skills?", "how important is problem solving in your job?"). In order to meet the two objectives of the study, two responses to each action statement were required - one referring to the importance of the action in the work environment and the other referring to the opportunity to develop the ability during the undergraduate course.

Before preparing the questionnaire, we conducted structured interviews with nine students who had returned to York to complete their courses after a year spent working in industrial placements. This gave us an overview of the most appropriate action statements to use in the survey. On this basis, we prepared a draft questionnaire which was trialled by a specially convened group of seven chemistry graduates currently working in the chemical industry.The final version took account of their comments and also of the consortium of industrial representatives and academics referred to above.

A total of 22 specific action statements were included; these are listed in full in Table 1.The wording for the two questions relating to each action statement was "In your job, how important is it for you to be able to..." and "How did your degree course prepare you to...". Respondents used a numerical scale of 0(Not at all)-3(Very (well)). Space was provided after each action statement to allow respondents to give further information on the nature of any coursework they considered relevant.Thus,they could tick boxes to distinguish between specific ("Explicit training") and general ("Chance to practise") preparation and give examples.

The questionnaire[8] was introduced by an explanation of our aims in collecting the information, with clarification of the three response fields and the difference between "Explicit training" and "Chance to practise". Respondents were specifically asked to address their **first degree** when making their responses. They were also asked to identify the university from which they had graduated and provide information about their current employment. The questionnaire concluded with a number of open-answer sections, one in particular being discussed below:

"Please indicate any other skills, relevant to a degree course, which are important in your job or which it would be beneficial for you to have."

Results

580 questionnaires were sent by post with a FREEPOST reply envelope. 125 replies were received (a response rate of 21.6%); 104 (83%) had obtained BSc in 1995, 19 (15%) PhD, and 2 (2%) MSc. All respondents completed some, or all, of the open-answer sections with 52 (42%) responding in all sections. Figure 1 provides a breakdown of the respondents by occupation. The mean values of the numerical responses to each of the two questions, for all 22 actions, are listed in Table 1.The combined response of all 125 respondents is shown in bold; also shown are values for the respondents by type of occupation. The subsequent discussion will refer only briefly to the differences in response between the different occupations, partly because of the lack of clear conclusions (due not least to the different numbers replying in each category) but principally because our interest is in chemistry degrees as preparation for careers in general rather than for any particular career. Graduate employee responses to the open-answer question quoted above are summarised in Table 2.Table 3 contains complementary information sourced from the Chemical Industries Association[2] making for some interesting comparisons of employer and employee

Figure 1: Number of survey respondents by occupation

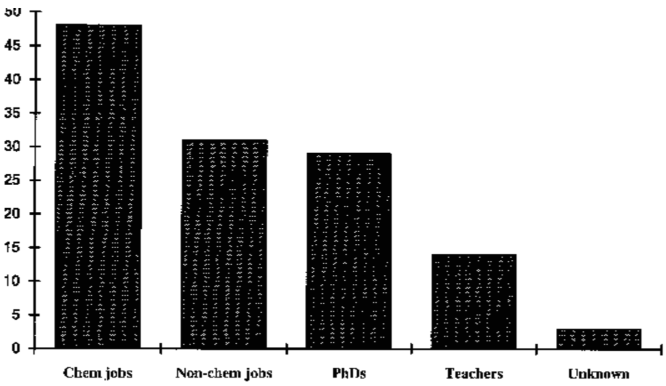
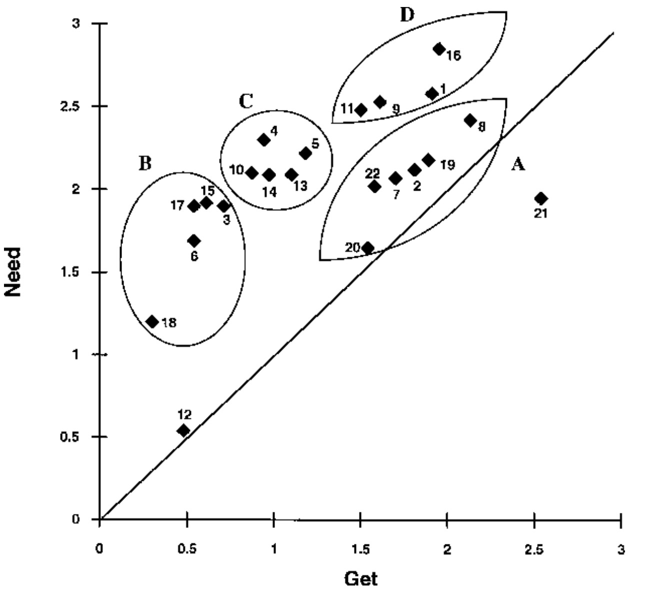


Figure 2: Representing the correlation between the importance of actions **1-22** in jobs and their coverage in chemistry degrees



perceptions of those areas in which graduates could most usefully receive better preparation.

Discussion

Overview

The first set of figures in Table 1 provides a measure (on a scale of 0-3) of the extent to which the ability to perform each action is required across the full spectrum of jobs ("Need") and the second set provides a similar measure of the extent to which preparation for performing these actions is provided during a chemistry degree ("get"). By far the most needed ability is to "manage your time between a number of overlapping tasks" (**16**), perhaps not surprisingly, followed by "update your knowledge of skills on your own initiative" (**1**). This appears to vindicate Dearing's decision to identify "learning how to learn" as a distinct key skill[9]. At the other

Table 1: Combined response to 'Need' and 'Get' for actions **1-22** for all respondents, and for respondents by occupation type.

Action Statement	*'NEED' In your job, how important is it for you to be able to...* (0-3)					*'GET' How did your degree course prepare you to...* (0-3)				
	All	Chem.	Non-chem	Ph.D.s	Teacher	*All*	Chem.	Non-chem	Ph.D.s	Teacher
1. ...update your knowledge and skills on your own initiative?	*2.58*	2.40	2.52	2.93	2.50	*1.91*	1.77	2.10	1.90	2.00
2. ...work in small teams to perform a task?	*2.12*	2.34	2.45	1.48	2.07	*1.81*	1.83	1.90	1.69	1.79
3. ...motivate others to contribute to a particular task?	*1.90*	1.88	2.06	1.31	2.71	*0.71*	0.73	0.74	0.62	0.93
4. ...understand the perspective of others?	*2.30*	2.23	2.48	1.90	2.93	*0.94*	1.13	0.90	0.71	0.93
5. ...appraise your own performance?	*2.22*	2.15	1.97	2.45	2.50	*1.18*	1.33	0.94	1.17	1.14
6. ...appraise the performance of others?	*1.69*	1.57	1.61	1.31	2.79	*0.54*	0.55	0.39	0.59	0.79
7. ...give presentations to colleagues on areas which you have evaluated?	*2.07*	1.98	1.61	2.83	1.71	*1.70*	1.73	1.90	1.48	1.57
8. ...write concise reports to summarise material for colleagues?	*2.42*	2.50	2.26	2.55	2.07	*2.13*	2.19	2.35	1.86	1.93
9. ...contribute effectively to discussions?	*2.53*	2.46	2.45	2.62	2.71	*1.61*	1.67	1.74	1.38	1.86
10. ...talk/write persuasively to non-specialists?	*2.10*	1.98	2.45	1.68	2.57	*0.87*	1.00	0.77	0.75	0.93
11. ...use computer software to present information?	*2.48*	2.38	2.32	2.86	2.29	*1.50*	1.52	1.58	1.31	1.50
12. ...use a foreign language?	*0.54*	0.69	0.48	0.45	0.43	*0.48*	0.23	0.65	0.62	0.79
13. ...make a judgement to a deadline, involving complicated and conflicting information?	*2.09*	2.19	2.48	1.69	1.71	*1.10*	1.25	1.10	0.79	1.36
14. ...elicit and evaluate the opinions of others before coming to a decision?	*2.09*	2.04	2.26	1.93	2.21	*0.97*	1.00	0.94	0.93	1.07
15. ...take responsibility for a decision which affects other people?	*1.92*	2.27	1.68	1.21	2.71	*0.61*	0.71	0.45	0.55	0.79
16. ...manage your time between a number of overlapping tasks?	*2.85*	2.83	2.87	2.76	3.00	*1.95*	1.85	2.06	1.97	2.00
17. ...consider the cost implications of your actions?	*1.90*	2.06	2.19	1.46	1.64	*0.54*	0.51	0.48	0.61	0.64
18. ...consider the market and the competition when making a decision?	*1.20*	1.33	1.52	0.86	0.86	*0.30*	0.19	0.32	0.24	0.79
19. ...consider aspects of health and safety at work?	*2.18*	2.40	1.23	2.55	2.79	*1.89*	1.58	2.16	2.00	2.21
20. ...consider the environmental consequences of your actions?	*1.65*	2.19	0.68	1.90	1.50	*1.54*	1.50	1.61	1.45	1.71
21. ...search out information using library facilities?	*1.95*	1.73	1.29	3.00	2.00	*2.54*	2.69	2.71	2.21	2.36
22. ...plan and/or conduct a search for relevant information using computer databases?	*2.02*	1.88	1.55	2.90	1.71	*1.58*	1.44	1.84	1.48	1.57
AVERAGE	*2.04*	2.06	1.93	2.03	2.16	*1.29*	1.29	1.35	1.20	1.39

end of the scale, "use a foreign language" (**12**) and "consider the market/competition when making a decision" (**18**) emerge as the least important of the actions in the working lives of these graduates.

Turning to how well the respondents feel their degrees allowed them to 'get' the ability to perform the actions **1-22**, the ability to "search out information using library facilities" (**21**) emerges as that best conveyed by chemistry courses with "writing concise reports to summarise material for colleagues" (**8**) being the only other action with a mean score greater than 2.00. At the other extreme, **12** and **18** re-appear as being actions for which courses provided least preparation. The correlation represented by actions **12** and **18** appearing jointly as the least important and least well covered actions is a general feature of the survey results made clear in a scatter plot of 'Need' *vs*. 'Get' (Figure 2). A similar approach to displaying survey results, though not for chemistry graduates, appears in another DfEE 'Alumni' report[10]. The points are distributed between the bottom left and top right corners showing, encouragingly, that the amount of preparation courses provide for using particular skills is generally in accord with the eventual usefulness of the skills to the graduates. Thus, of the top ten actions in the 'need' list (respectively, **16**, **1**, **9**, **11**, **8**, **4**, **5**, **19**, **2**, and **10**), six appear in the top ten of the 'get' list (respectively, **21**, **8**, **16**, **1**, **19**, **2**, **7**, **9**, **22**, and **20**). This suggests that when it comes to giving this group of graduates the skills they need in their jobs, their chemistry degrees do at least concentrate general skills training in the right areas.

If we assume that the graduates used a constant scale for assessing both their 'need' for a skill and their opportunity to 'get' it during their degree course, we would expect a reasonable course to be one where the numerical values for 'need' and 'get' are similar. In other words, the points **1-22** would lie close to the line of 45^{o} slope in Figure 2. In fact, all points bar **21** ("search out information using library facilities") lie above this line suggesting that in almost all cases (though to varying extents) provision within the course could be usefully improved in order to prepare graduates better for work.

21 emerged as the only action where 'Get' (2.54, highest) exceeded 'Need' (1.95, 15th). Significantly, this was true of all occupations *except* PhD students who rated the importance of library skills at 3.00 ('Need', highest) and their preparation at 2.21 ('Get', highest), the lowest value assigned by any of the groups. These results suggest that in most situations chemistry graduates regard their library skills as more than adequate for their relatively low need for them whilst PhD students, who need these skills most, suggest there is some shortfall in the training they receive. This is an important demonstration of how groups who do not perform a particular action regularly might overestimate their ability to carry it out compared with a group who rely on it. The relatively low priority of library skills, even amongst the respondents in chemistry jobs, we take to support anecdotal evidence that much of this kind of information retrieval is performed by specialists within companies with sizeable research interests. PhD students rate action **22** (2.90, 3rd highest), using computer databases, almost as highly as **21** though with significantly less preparation. Indeed, since all groups bar teachers rate computer database searches as being of equal or greater importance than traditional library work, and score their preparation for it significantly lower, it suggests that this is an area of information retrieval which could be improved in chemistry courses.

Table 2: Recommendations for making chemistry courses better preparation for employment.

Recommended skills	*Number recommending*
Key skills	
Communication (written, oral, interpersonal etc.)	39
Computing/IT	25
Time management/organisation	9
Others (information retrieval, teamworking, problem solving)	3
Management skills	10
Business/commercial awareness	9
Chemistry skills	
Analytical	11
Practical	8
Others	
Legal (H&S, environmental, patent law)	7
Industrial experience/awareness	7
Vocational courses	5
Mathematics	3
Miscellaneous	9

Table 3: Chemical companies' perceptions of the quality of their recent graduate recruits (expressed as numbers and %)[2].

	Graduates	
	OK	**Lacking**
Scientific/technical knowledge	43 (**80**)	11 (**20**)
Practical skills	29 (**52**)	27 (**48**)
Numeracy	46 (**82**)	10 (**18**)
Interpersonal skills	28 (**56**)	22 (**44**)
Communication/presentation skills	20 (**38**)	33 (**62**)
Ability to relate to all levels	20 (**38**)	33 (**62**)
Awareness of intellectual property	18 (**34**)	35 (**66**)
General commercial awareness	11 (**29**)	27 (**71**)
Leadership qualities	23 (**46**)	27 (**54**)
Ambition and drive	44 (**81**)	10 (**19**)
Self-confidence	47 (**85**)	8 (**15**)
IT skills	47 (**85**)	8 (**15**)
Innovative thinking	22 (**42**)	31 (**58**)
General literacy	34 (**61**)	22 (**39**)
Other (please specify)..........		
Flexibility	1	1
Language skills		1
Teamworking skills		1

Prioritising key skills

We have divided the other points in Figure 2 (excluding **12**, "use a foreign language") into four areas **A-D**. The six actions included in area **A** lie close to the line which represents a satisfactory balance between 'Need' and 'Get' and would, therefore, not seem to be priority areas for improved provision. Conversely, the actions in areas **B-D** are, broadly speaking, a whole 'Get' unit deficient of the line balancing 'Need' and 'Get'. Area **B** contains the least important of the actions identified by this survey as being in need of better provision (all scoring below 2.0 on the 'Need' rating). These are:-

Area B **3** "motivate others to contribute to a particular task"
6 "appraise the performance of others"
15 "take responsibility for a decision which affects other people"
17 "consider the cost implications of your actions"
18 "consider the market/competition when making a decision"

The first three of these actions might be considered as relating to leadership and supervision whilst the last two lie in the realm of commercial awareness. The large difference in 'Need' between these latter two actions (respectively 1.90 and 1.20) suggests that issues of cost are more relevant across the full range of occupations than issues of market competition. This is true for all categories of jobs (Table 1). Cost and market issues are (obviously) less important to teachers and PhD students than to the other two (more commercial) categories but the *difference* in the 'Need' value for **17** and **18** is actually fairly uniform across all four. This observation emphasises that even in jobs where market issues are expected to be important, this importance still lags considerably behind that of costs and neither, at this stage of the 1995 graduates' careers, are paramount. Taken all together, the five actions of Area **B** would seem to be characteristic of more senior management positions which would not yet be the responsibility of graduates as recent as 1995. Whilst lack of commercial awareness and leadership skills are major concerns of industrialists (see Table 3), our survey suggests that these issues are not particularly relevant in the early years of graduate employment. Consequently, we suggest that these are not areas in which it is appropriate for chemistry courses to concentrate. They are difficult to address realistically anyway and, we suggest, are best handled through experience and training in the workplace itself.

Area **C** contains five, more important actions, all scoring above 2.00 (between 2.09 and 2.30) in the 'Need' rating. They are:-

Area C **4** "understand the perspective of others"
5 "appraise your own performance"
10 "talk/write persuasively to non-specialists"
13 "make a judgement to a deadline, involving complicated and conflicting information"
14 "elicit and evaluate the opinions of others before coming to a decision"

This list of actions includes several (e.g. **4**, **10**, **14**) which involve working with others but not with the element of leadership inherent in those featured in Area **B**. Consequently, they prove to be more routinely important to recently employed graduates and more relevant as issues in improving chemistry courses. Amongst these actions, the one involving self-appraisal, **5**, produced some interesting comments indicating a polarisation in the way students view parts of their course. For instance, only a handful of respondents recorded their recognition of the role of exam results and other assessment (e.g. in coursework, tutorials and practical write-ups) in self-appraisal. This may be an indication that the majority of students regard assessment solely as a means for the department to classify their performance. If this is indeed a widely-held belief then it would appear to be crucial that more effort be put into demonstrating the role of assessment in the process of "learning how to learn" by encouraging students to use it to guide their further study and revision.

The issue of making judgements, **13**, also prompted some interesting comments. By considering the few respondents who felt that their course *did* prepare them here, it might be possible to identify those learning opportunities which already exist within chemistry courses but which are either not being recognised, or not exploited, by most respondents. In fact, these respondents mostly quote practical project work and literature-based essay writing as means of developing skills in this area. Since all chemistry students are exposed to these tasks, it is noteworthy that so few recognise the opportunities provided. It might be interesting to know what the response would have been had the action been expressed with "deduce the correct interpretation" taking the place of "make a judgement". It is possible that those who quoted project and practical work here are the minority who recognise the role of making judgements in the sciences whereas the majority still lean towards the idea that scientific problems are resolved with a series of 'correct answers' rather than reasoned judgements. Similar examples are quoted as relevant to action **14**, mostly project work and assignments based on using the literature and/or various textbooks. Again, the identification of material in such sources as 'opinion' marks a recognition which perhaps not all students would make.

Area **D** comprises those skills most important to graduate employees (with a 'Need' rating of 2.48 or higher). Examination of the actions represented here (with the possible exception of **11**, though see below) shows how fundamental these are. Indeed, in common with many of the actions in area **C**, no department, in any discipline, would want to be seen to be producing graduates (regardless of their vocation) who were deficient in any of these key areas of 'graduateness'!

Area D **1** "update your knowledge and skills on your own initiative"
9 "contribute effectively to discussions"
11 "use computer software to present information"
16 "manage your time between a number of overlapping tasks"

Consequently, we suggest that area **D** (and to a lesser extent area **C**) reveals the types of skills we should be making sure that chemistry graduates possess. Furthermore, because of the fundamental intellectual nature of these skills, we suggest that there is no educational compromise involved in producing 'better' *graduates* who would also benefit industry by being 'better' *employees*.

The inclusion of action **11** here is a clear indication of the proliferation of computers in all spheres. Most respondents quoted practical and project write-ups as examples of the chance to practise this action but relatively few thought they had received any specific training. (Quite a number of comments referred to having acquired these skills by attending external courses, self-teaching, taking advantage of industrial placements or spending time at universities elsewhere in Europe.) We noticed some dependence on the university which respondents attended; the value for the extent of preparation ranged from 0.80 (worst) to 1.83 (best) when analysed by department. This probably reflects the different extents to which computers have penetrated the various courses; both in the sense of being available for students to use and being exploited by the content of the course itself (and this situation may have changed at the institutions involved as computer access has widened). However, this would appear to be an area which departments will want to continue to give attention to particularly as, in the open comment sections (see the responses to the second question summarised in Table 2), computing/IT skills come second only to communication skills amongst the suggestions for additional job-related skills which degree courses might include. The area of IT (as represented by actions **11** and **22**) is an example where *employer* and *employee* opinion differs markedly. Indeed, Tables 2 and 3 suggest that employees are more concerned about their IT skills than their employers are (though employers are more likely to be older and less computer literate themselves)!

Improving key skills provision

The survey itself provides pointers towards *how* skills such as those in areas **C** and **D** can be addressed more effectively. We shall look briefly at two areas - teamworking and communication.

Action **2** clearly relates to teamworking and the survey responses place it in area **A**, implying adequate coverage. This contrasts, however, with the rating of some of the other actions also involved in teamworking. Typical examples would be **3**, **4**, and **9**, which lie in areas **B**, **C**, and **D**, respectively. Consequently, the initial impression that teamwork is adequately covered in chemistry courses, from **2**, must be tempered by the additional information that whilst students may have experience of "working in small teams to perform tasks", they have not concurrently acquired adequate experience in "motivating others..", "understanding the perspective of others" or "contributing effectively to discussions". Our interpretation of these observations is that most respondents recognise things such as joint practicals and tutorials as instances of working in small teams, and register this experience accordingly. However, these experiences are more often cases of sharing equipment, or rooms, rather than genuine discussions, debate, and sharing of chemical knowledge. In other words, the teamwork which students experience is not as good a reflection as it could be of the kind of teamwork which will be useful to them later. Examining responses to clusters of related actions, in this way, reveals much more than a single question on a skill might. In this case, the suggestion of students experiencing more *realistic* teamwork (necessarily involving a range of perspectives and discussions) has emerged as one way of preparing students better for the situations of the workplace.

Oral and written communication are represented by actions such as **7** and **8**, respectively, and both lie in area **A**. However, the additional comments of employers (Table 3) and the graduates themselves (Table 2) contradict any suggestion that communication skills are adequately dealt with in chemistry courses. Again, we suggest that the reasonably high 'Get' values for actions **7** and **8** show that respondents are acknowledging that their courses involve them in considerable amounts of writing (lab reports, essays etc.) and speaking (tutorials, special projects etc.). However, the general desire for better communication skills (Tables 2 and 3) shows that these experiences are not entirely relevant to the types of communication skills needed at work. Some evidence for this comes, again, from considering other relevant actions such as **9** and **10** which most respondents recognise as being under-developed in their courses.

Conclusion

From the responses to this questionnaire and, particularly, the additional comments offered by some respondents, it is clear that chemistry degrees can provide opportunities to acquire the skills needed in performing all 22 actions included in the survey, though to a greater or lesser extent. Faced with information on the relative importance of these various skills, departments must decide whether or not they regard these key skills as being sufficiently important to do any or all of the following:

- *Draw attention* more effectively to the existing key skill learning opportunities which are currently not being recognised by many students. We have introduced key skills logbooks with the aim of helping students to recognise and exploit opportunities in the course. (Similarly, our findings back up the Dearing recommendation (Recommendation 21[9]) for producing "programme specifications" which draw attention to learning outcomes in the area of content *and* skills for all courses.)
- *Create more opportunities* for skills development, perhaps by targeting some of the deficiencies revealed in surveys of the type reported here. This might include using alumni and industrial contacts in order to ensure that skills are developed in relevant contexts[7, 11].
- *Increase the emphasis* on skill development by including more specific training rather than just providing the chance to practise.

Our approach to resolving the apparent dilemma presented by the need for both chemistry content and key skills is to teach more of the content in ways which simultaneously develop skills[7] and we feel that this approach can improve the teaching of content *per se*. At a time when all subjects are promoting their key skills content, it is important that chemists exploit fully the opportunities their discipline provides.

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The idea of a closed book IT examination: a novel approach to assessing chemistry specific information technology.

PAPER

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As part of the advanced chemistry practical module in the final-year of the BSc chemistry degree at Cardiff University, students are required to take a course in chemistry-specific information technology. The problem of assessing such a module at this level is always difficult. One possible means of overcoming this problem is by setting a closed book information technology examination in chemistry. Each student is given a three-hour examination, consisting of three questions, each assessing different aspects of the IT course taken. The nature and structure of the examination paper in question is described. This paper describes some of the problems (technical and otherwise) encountered in devising such an examination. A similar structured examination could be incorporated into any BSc chemistry course to overcome this problem of assessing the IT skills required by a chemistry graduate.

Introduction

Computing skills were identified in a report of the Royal Society of Chemistry as one of the general skills which should be an integral part of a chemistry degree course[1]. More recently, the Dearing Report[2] identified "the use of information technology" as one of the four key skills which should be developed during a university course (recommendation 21). It seems that the importance of IT skills is recognised in most chemistry courses. For example, Mason[3] reports that chemistry departments have introduced special teaching in order to "fill perceived gaps in …. IT skills ….". Furthermore, a survey carried out by the Chemical Industries Association indicates that the employers in the chemical industries are largely satisfied with the IT skills of their recently graduate employees[4]. However, a recent survey of pharmaceutical companies highlights this as a critical gap in the expertise of chemistry graduates[5].

It is possible that the pharmaceutical industry is a special case and has particularly high expectations of IT skills. Nevertheless, it is clearly important to ensure that IT skills included in chemistry courses should be relevant to future employment, and that the time spent in developing these skills should be effectively used. At the Department of Chemistry in Cardiff we set out to design a course structure which would fulfil both these requirements.

The main objective was that, by the end of the degree course, the graduates would be able to make appropriate use of IT to prepare written and oral presentations to the professional standards expected by research journals and international conferences. This involves:

- preparation of hard copy of text;
- creation of tables, graphs, histograms, etc. from spreadsheets and databases;
- producing chemical structures in an appropriate format;
- making use of PowerPoint (or equivalent) in oral presentations.

In designing the course, we recognised the importance of assessment. Race[6] aptly states that

- "assessment is often a major driving force which gets students down to serious studying".
- He also reminds us that assessment has other purposes:
- "students themselves need feedback to help them to find out how their learning is going."
- "we need feedback on how well students' learning is going so that we can adjust and develop our teaching."

These points are explored more deeply in a number of references[7–10].

Our initial survey of available assessment procedures indicated that none met all three of the functions identified by Race as well as we wanted. We were fortunate to be given access to course modules from different universities and concluded that they were assessing skills at a lower level than was required by our third-year course. We also studied the CATS programme (Computer-Aided Assessment of Transferable Skills)[11] but found that it only assesses intermediate level word-processing and text editing, and not chemistry-specific programs concerned with (for example) two-dimensional drawing, modelling chemical structures or molecular graphics.

We therefore devised our own assessment procedures. This paper is based on our experiences of the two cohorts of students graduating in 1995 and 1996. It summarises the course we have designed to teach the aspects of IT we judge to be important, describes the assessment procedure (which includes a closed-book examination) which we devised to fulfil the functions given above, and evaluates the effectiveness of the examination.

The teaching of IT at Cardiff

Students studying chemistry at Cardiff University are taught aspects of IT skills throughout the three years of their course. The topics covered during the first two years are shown in Table 1.This work is assessed by selected assignments. In the third year IT course, knowledge of this material is assumed and it is included in the examination.

The third year IT course takes up two weeks of the eight week practical module. In Cardiff, students take 12 modules in a year; the practical module is a double module and therefore corresponds to 1/6th of a year's work. Material covered in the IT course is shown in Table 2.

For the 8 week practical module, the cohort of about 80 students is split into four (approximately) equal groups. Each group spends two weeks on each of the four courses which make up the module: inorganic chemistry, organic chemistry, physical chemistry and information technology. The information technology course is based in the department's computer laboratory which (at the time) contained 23 networked Pentium 75 MHz PC's running Windows 3.1. During the two week period the students are required to attend the laboratory for two 6 hour periods per week (10.00 – 17.00hrs). During these sessions two postgraduate demonstrators and one member of the academic staff were available to offer help and advice. In addition, the students are expected to complete assignments based on the work in each session; the full assignment must be completed within two weeks after the last formal session in the computer laboratory. Since the notional time available for the IT course is about 50h (one quarter of a double module), adequate time has been allowed for this work.

This summary of the course structure shows that it introduces the individual techniques required to achieve the stated objective. By the end of the third year module, the students are expected to be able to integrate their skills and to apply them to a specific context.

Assessment

Assessment may be based on work completed during a particular course or module, or after the whole course has been delivered. An advantage of assessing coursework is that it can be to some extent formative: it is not too late for staff or students to take action before the end of the course to overcome any deficiencies. Assessing coursework has disadvantages as well as advantages. For example, it is not possible to give an assignment which requires students to integrate all their knowledge of the course until all the ground

Table 1: Information on the modular course content and nominal time allowances spent on chemistry specific IT in years one and two

Year 1:	*HRS*
• Introduction to the student network, e-mail, WWW and computer-aided learning (CAL) chemistry tutorials; Introduction to Windows and MS-DOS	1
• Introduction to Microsoft Word - letter-writing, CV's, chemical abstracts, formatting, subscripts, superscripts, symbols	1
• Molecular graphics	3
Nominal IT time in the microcomputer laboratory:	*5*

(Note this does not include the time for completion of assignments)

Year 2:	*HRS*
• Advanced word-processing - Tabs, tables, use of the equation editor in chemistry	3
• Two-dimensional chemical structure drawing - Chem-Window	6
• Introduction to Microsoft Excel - chemical spreadsheets (use of the function wizard, formulae) and graphs in chemistry (line graphs and scatter plots)	6
Nominal IT time in the microcomputer laboratory:	*15*

(Note this does not include the time for completion of assignments)

Table 2: Final-year BSc advanced chemistry practical module - IT section - time allowances, assessment and sample assignments

Year 3:	*HRS*
• Databases using Access	6
• Presentations in chemistry using PowerPoint	6
• Molecular modelling using DTMM for Windows	9
• Information technology examination	3
Nominal IT time in the microcomputer laboratory:	*24*

(Note this does not include the time for completion of assignments)

Assessment: *(Selected examples of the types of assignment shown)*	*%*
• Assignment 1 (databases)	10
• Assignment 2 (research presentation)	10
• Assignment 3 (molecular modelling)	15
• End-of-module IT examination. (Example given in appendix)	65

Assignment 1 example: Using the Opac search facility and Microsoft Access compile and print a suitable comprehensive database for all the textbooks, printed since 1985 on coordination chemistry in the library. Save the file on disk. The database should include all relevant information, such as name of author, name of textbook, publishing company, edition, year, no. of copies, location in library etc.

Assignment 2 example: Present the chemistry of boron, using PowerPoint. Save the short presentation on disk as Bor.ppt and print copies of the presentation, with summary Spider diagrams for your audience.

Assignment 3 example: You are asked to model the structure, Dopamine. Explain your design process and give the minimised energy in kJ mol^{-1} respectively. Save the minimised structure on disk as Dopa.mol. Print the structure in DTMM.

has been covered. Furthermore, in-course assessment is normally based on assignments carried out under circumstances in which students can plagiarise[12-14].

Taking these advantages and disadvantages into account we decided to divide the mark for the third year IT module into two components:

- 35% for assignments based on each IT practical session;
- 65% for a closed book examination at the end of the module and covering all the IT skills included in the course (including first and second year work).

For the assignments we considered various options for detecting plagiarism[12–14], and concluded that it was preferable to try to prevent it from occurring. The strategy we adopted was to set an assignment on each session in the computer laboratory. The forms of assignment are shown in Table 2. The requirement that part of the assignment be submitted in printed format at the end of the session was introduced in order to ensure that it was the student's own work.

The closed book examination is taken during the final 3 hours of the last session in the computer laboratory. It consists of three questions which between them assesses the IT skills which students are expected to develop over the 3 year period. The students were not allowed to bring in any IT manuals or other material into the examination, but they were encouraged to make full use of the Help facility within the software. Each student had to print their final document on completion of the examination.

Question 1 aims to assess the ability of a student to reproduce an academic paper to professional research journal publication standard. This involves using some or all of the skills covered in the 3 years of the IT course (Word, Excel, Chem-Window, etc.).

Question 2 assesses some of the more specific features of the programmes including:

- generation of scatter plots using the function wizard;
- formulae and graphical features of Excel;
- use of the equation editor using Microsoft Word (to produce mathematical equations such as those found in physical chemistry);
- more difficult features of two-dimensional structure drawing using Chem-Window, such as perspective drawings, Newman, Fischer and saw-horse projections, inorganic complexes and clusters, aspects of chemical structure modelling, etc.

Question 3 is the most challenging; a knowledge of basic chemistry is required in order to answer it. The intention is to concentrate on aspects of chemistry where understanding is particularly helped by the use of molecular graphics or molecular modelling[15]. Examples are VSEPR theory, point group symmetry, conformational analysis, and space group symmetry.

A specimen examination paper is included in the Appendix. Additional examples and marking schemes are available from the authors on request. After the examination, marked scripts with appropriate detailed comments were returned to the students in order to provide feedback. The comments identify not only weaknesses, but also sections of the scripts which were of particularly high standard.

Table 3: Student marks, 1995 and 1996

	1995	*1996*
Number of students	60	59
Examination Mark/%		
Highest	100	86
Mean	67	55
Lowest	30	15
IT course (Examination and Assignment)		
Highest	98	98
Mean	67	61
Lowest	33	28

Results

At the time of writing, the third year IT course and its associated examination had been taken by two cohorts of Cardiff students (in 1995 and 1996), a total of 119 students.

A summary of the marks obtained for these students is shown in Table 3. The mark obtained by each student was added to the marks obtained for the inorganic, organic and physical chemistry laboratory courses. The marks for all of the four courses were comparable; the mean varied between 56% to 62%, with the IT mark at 61%.

In 1995 there is some evidence that the mark for the assignments slightly helped the students who were the weakest in the examination. In 1996, the overall performance in the assignments was better than that in the examination.

No specific pass mark was set for the IT course.

Discussion

Avoiding technical problems

When about 20 students are taking a closed book examination based on computers, it is clearly important to avoid technical problems due to failure of computers, or the network, or of the printers.

We have always limited the number of students taking the examination at any one time so that there have always been 3 or 4 surplus PCs. To date, this has been sufficient to avoid any problems with the individual computers.

Networking has not, so far, caused problems. If there is a network failure, it would be necessary to reschedule the examination.

Our classroom PCs do not all have their own printer, but are connected to 2 central laser printers. Examinees can print directly to these without having to move. Naturally, the examinee must check the printout; this is particularly important because there can sometimes be loss of complex characters (e.g. when using an equation editor) when using parallel printing set up. For this reason, we located all the students as close as possible to the printer; the computers furthest away were the ones we chose to keep vacant. Printing has not been a problem; but we take the precaution of ensuring the students have a disk so that, if necessary, documents can be printed later.

Feedback from students

Feedback from students was obtained via representatives reporting to the staff student meeting. Four representatives (one for each of the four IT groups) was appointed; their role was to collate the views of all their respective group members (about 20) on the IT course, and to pass the collective views on to the nominated student representatives at the staff-student meeting. Informal discussion with the representatives indicated that they had taken their role very seriously.

The staff-student meetings are held regularly, and are attended by the Head of Department and by members of staff of the Teaching Committee. The meetings allow ample time for discussion and detailed comments are passed on to the relevant member(s) of staff for action. It is evident from the level of discussion at these meetings that the representatives do their best to reflect fairly the view of the whole class.

There was some feeling that the weight of the examination should be reduced by awarding the assignments more than 35% of the total marks. The counter arguments to this are that the examination provides a valuable test of the students' ability to work independently at the keyboard for a 3 hour period, and also that it covers all of the material included during the 3 years of the course. Furthermore, the closed book examination avoids all problems with plagiarism.

Some students felt that they should be allowed to use manuals in the examination. The arguments for and against this have been well rehearsed and can be summarised as the conflict between allowing students to spend valuable time consulting manuals and the realism of providing access to information which would be available in the real world. In this case we felt that the students had ready access to the on-line Help facility built into all Windows programs, and that this should be sufficient for the style of question we set. Denying access to additional manuals focuses the students' attention on the need to be completely familiar with basic concepts and with the Help facility – both aspects which are stressed throughout the course.

Many students were critical of question 3 in the examination on the grounds that it required knowledge of chemistry as well as of IT skills. Interestingly, at the end of the final year, it turned out that many students recognised that this question had highlighted for them areas of general chemistry in which they were weak. The discovery of this weakness at the end of the IT module gave them time to address it.

With these three reservations, which led to valuable exchange of views between staff and students, the students commented very favourably on both the content of the IT course and on the assessment procedures.

Students were particularly appreciative of the feedback they received on the examination paper. Students scoring below 45% (approximately 13% of the class) were given additional advice before starting to write their project report. These two methods for providing feedback allowed all students to identify weaknesses and improve their skills before they needed to apply them in the preparation of project reports at the end of the year.

The class representatives also reported that those scoring marks over 75% (approximately 16% of the class) were particularly motivated and identified IT skills as one of their significant strengths.

Feedback to the course tutor

Four members of staff were involved in the planning, teaching and examining of this course. They were able to form an impression of the students' progress by observation during the session in the computer classroom. These impressions were reinforced and enhanced by careful analysis of the strengths and weaknesses of the examination scripts. The identification of specific weaknesses (failure to use the spellchecker, problems with modelling, etc.) allowed the course tutors to improve the delivery of the course.

The teaching of IT throughout the 3 year course is reviewed at regular meetings of the four members of staff. On the basis of the evidence presented here, we are convinced that the closed book examination we have designed is a fair procedure for assessing the students' competence at the skills we wish them to learn. Furthermore, it meets the three criteria specified earlier.

The students respond positively to the examination; they see the virtue of being able to apply all appropriate aspects of IT to a particular problem and, through question 3, they are encouraged to see IT as an integral part of chemistry.

By holding the examination at the end of the third year of the course, the students receive useful feedback in time to improve their skills before they use them in preparing their final year project reports.

The tutors are able to make use of the examination scripts to identify aspects of the course which need improvement.

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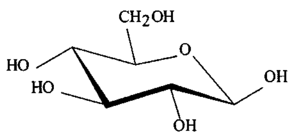
Appendix:
Sample chemistry IT examination paper

<u>Instructions to Candidates</u>: Candidates are required to answer <u>all</u> three questions. No IT manuals are allowed in the examination. Each document must be printed by the end of the examination. Each file must be saved to disk, which is collected at the end of the examination. Time: 2.00-5.00 PM

1. (i) Attached is a recent academic paper (1995 *Tetrahedron Letters* **36** 21 3745-3748) by C J Richards, D E Hibbs and M B Hursthouse. Using 12 point Times New Roman font type, 1" margins all round, 1.5 line spacing, portrait page and full justification, reproduce: (a) The reaction scheme number 2, on P. 3746 forming complex 10, from reactant 7; (b) Reference 6 on P. 3748; (c) Table 1 on P. 3746. For Table 1, use a List 2 type format. Centre the table horizontally and vertically on a landscape page with the same criteria as listed above. Include the title and footnote for the table. Include a bottom centre-aligned page numbering scheme in your document, starting at i etc. Save the document as Pap.doc file in Word, and print your document on single-sided A4 paper. (25 marks)

(ii) Draw the following structure in Chem-Window, and paste it into the Pap.doc Word document using the Paste Special facility. Print the structure in Word. Print a ball and stick representation of the structure in DTMM also. (15 marks)



(iii) **Either**: Type the following passage in Word, using Times New Roman 12 point font type, 1.5 line spacing, full justification, portrait page and 1" margins all-round. Give the page number as 65 (bottom, centre-aligned). Save the file as Cryst.doc. Print the document.

Crystal data for $C_{28}H_{28}FeNOP$, M_r = 481.33, orthorhombic, $P2_12_12_1$, a = 9.098(4), b = 10.924(3), c = 23.448(8) Å, V = 2330.4(14) Å^3, Z = 4, D_c = 1.372 g cm^{-3}, μ(MoK_α) = 0.737 mm^{-1}, F(000) = 1008, T = 120 K. Intensity data were collected on a FAST area TV detector diffractometer with MoK_α radiation (λ = 0.71069) as previously described. 10654 reflections were measured giving 3731 unique data. The structure was solved by direct methods (SHELX-S) and refined by full-matrix least squares on F_o^2 (SHELXL-93) using all unique data. Final wR_2 (on F_o^2) and R (on F) were 0.0719 and 0.0445 for all data

or type the Schrödinger wave equation in Word:

[Object too big for pasting as inline graphic. | In-line Graphic *]*

Save the document as Wave.doc file in Word, and print your document. (15 marks)

2. Using the formulae, function wizard and graphing facilities of Excel, find $E_{act.}$, the activation energy and A, the pre-exponential factor, of the reaction $A_{2(g)} + B_{2(g)}$ ∅ 2AB, given that R = 8.314 J K^{-1} mol^{-1} and the following data:

T/K	540	642	733	792	877
k/(Ms^{-1})	7.36 x 10^{-7}	6.32 x 10^{-5}	2.37 x 10^{-3}	7.65 x 10^{-2}	3.19 x 10^{-1}

Plot the graph in Excel (save the file as Act.xls) using the following criteria:

(a) Full size portrait page; (b) No header or footer; (c) Times New Roman, 10 point for the title of the graph and 8 point for the *x* and *y* axes numbers; (d) Times New Roman, 9 point for the *x* and *y* axes titles (include units); (e) Insert a trendline for the plot (use a fine weighted thin line); (f) Use a white background for the plot area; (g) Include the correlation coefficient on the same line as the title of the graph; (h) Use bold and italics for the title of the graph, and bold for the titles of the axes; (i) Do not include a legend on the plot; (j) Ensure that all units are given, with appropriate superscripts etc. (if applicable). (30 marks)

3. Either: Use VSEPR theory to deduce the structure of the nitrate oxyanion. Print the structure in Word (save the file as Symm.doc), including the determination of the shape and approximate bond angle and hybridisation. List also the elements of symmetry and the point group symmetry of the oxyanion

or model the cage compound, cubane. Minimise the energy, and comment on the stereochemical aspects of the structure in terms of the contributing terms of the force field. Save the structure on disk as Cube.mol. Print the minimised structure in DTMM, and draw a two-dimensional representation of the structure in Chem-Window. Import and print this structure in Word, and express the minimised value in kJ mol^{-1}. (15 marks)

The Chemistry Quiz, a Tool for Reinforcement Learning

PAPER

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The Chemistry Quiz (The Quiz) comprises a series of programs used to improve students' competence with the everyday numeric manipulations required in chemistry and is designed to complement the existing range of software available. The Quiz allows the generation of random input data so that every student receives a different value even when attempting the same question. The Quiz is designed only for this type of question and makes no attempt to incorporate textual input, multiple choice, or other features found in other products. All computations use integer arithmetic to avoid rounding errors, with sensible use of significant figures. Quizzes have been produced covering volumetric calculations, spectroscopy, thermochemistry, particles and waves, and algebraic manipulation.

The Quiz has been used by staff and students for three complete academic years and, in this same period of time, it has been used to test students' ability to carry out volumetric calculations. The results suggest that an increase in reinforcement learning does improve the ability to perform these simple calculations as evidenced by higher pass rates and improved scores. In addition, there is a considerable saving in staff time compared with more traditional testing scenarios.

Introduction

Chemistry Departments have been struggling with the reluctance of students to carry out even simple mathematical exercises for some time now. Physical chemists have traditionally borne the brunt of this problem but the decline in mathematical ability has become so marked that it is now affecting all aspects of the subject. In seeking to find pragmatic remedies it was pointed out that 'learning reinforcement'[1] might be used to good effect.

Feedback and reinforcement are two of the most pivotal concepts in learning. Feedback involves providing learners with information about their responses whereas reinforcement affects the tendency to make a specific response again. Feedback can be positive, negative or neutral; reinforcement is either positive (increases the response) or negative (decreases the response). Feedback is almost always considered external while reinforcement can be external (extrinsic) or intrinsic (ie. generated by the individual). Information processing theories tend to emphasise the importance of feedback to learning since knowledge of results is necessary to correct mistakes and develop new plans. On the other hand, behavioural theories focus on the role of reinforcement in motivating the individual to behave in certain ways. One of the critical variables in both cases is the length of time between the response and the feedback or reinforcement. In general, the more immediate the feedback or reinforcement, the more learning is facilitated. The nature of the feedback or reinforcement provided was the basis for many early instructional principles, especially in the context of programmed instruction[1]. For example, the use of 'prompting' (ie. providing hints) was recommended in order to 'shape' (ie. selectively reinforce) the correct responses. Other principles concerned the choice of an appropriate 'step size' (ie. how much information to present at once) and how often feedback or reinforcement should be provided. These principles are often used in CAL drill and practice software.

Schools have employed this technique successfully in the past in extrinsic mode, but its use has declined in recent years and universities usually expect students to assume this responsibility for themselves (intrinsic). However, it seems that many students are insufficiently motivated to persevere for long enough for effective learning to result. The computer provides a medium with which to create an environment suitable for this type of learning **and** the motivation to practice effectively.

With careful design, a computer program which can deliver numerical problems for the student to practice their mathematical skills would also be able to set and mark a test designed to assess those skills. This was particularly relevant in Liverpool where staff in the first year laboratory, being concerned at students' inability to cope with the routine calculations associated with volumetric analysis, had initiated a test that all students were required to pass, even if it meant taking the test several times. This imposed a substantial workload on the staff involved, with the need for setting and marking multiple tests for classes of about 100. A number of packages have been produced with the aim of helping students with their mathematical skills[2]. Despite the excellence of some of them, none of those available at the time (1995) provided sufficient numbers of exercises to ensure that each student would be given a unique collection of problems to solve. Because we regarded this as an essential characteristic we decided to create software for ourselves. (During the course of this project, other programs became available which do not suffer from this limitation.[3])

Thus the objective was to create a series of programs, now described as the Chemistry Quiz (The Quiz) which could be used by students for learning reinforcement (to practice their mathematical skills) but which could also be used by tutors to administer an acceptable test (which, in the case of volumetric calculations, would replace an existing test).

Methodology

The requirements of the program were defined as follows,

- it must have a practice mode and an examination mode;
- it must be able to generate sufficient questions so that students can both practice and be tested without there being a significant risk that the test and the practice examples would be identical;
- it must be easy to use (by staff and students);
- it must be secure;
- it must provide automatic feedback or marking.

Five topics were selected to cover most of the material that students would be expected to encounter in their first year course. Within each topic, a number of different types of question were defined. The topics and the number of question types defined for each are listed in Table 1. A good description of the kind of question would be 'chemarithmetic'. The Quiz is designed only for this type of numeric question and makes no attempt to incorporate textual input, multiple choice or other features found in other products. All computations use integer arithmetic to avoid rounding errors, with sensible use of significant figures.

The twelve types of question defined for the topic 'volumetric analysis' are listed in the appendix. They illustrate both the style of question and also the method of generating a huge number of different specific questions from each original type. This depends essentially on two strategies:

- choosing for each question type an appropriate range of numerical values, and generating a random number within this range for each specific question;
- where appropriate, selecting at random one reagent from a set of plausible ones.

Modes

In order to satisfy the needs for learning reinforcement and for testing, The Quiz may be set up for student use in one of three different modes. The tutor controls which modes are available to the student through the part of the program "Quizmaker" (see section on Program Design).

1. Practice mode

This is the default mode. In this mode the student is presented with a total of 20 questions chosen at random from all the available question types for a particular quiz. The total of 20 questions has been chosen to minimise time and resources and to provide a reasonable length of study. In this mode a student may opt to exit at any time or, indeed, to repeat the quiz an unlimited number of times. Students may save and review their work in order to gauge their progress and for this purpose the quiz considers the students' answers to be 'correct' if they are within 5% of the true answer. The student also has the ability to choose a particular question type at any time, which is useful to staff when setting tutorials and homework.

Table 1: The five quizzes and the number of questions within a topic.

Topic	*Question Types*
Algebraic Manipulation	12
Thermochemistry	13
Particles and Waves	11
Elementary Molecular Spectroscopy	9
Volumetric Analysis	12

2. Directed practice mode

In this mode the tutor controls both the available question types and their relative frequency. This is useful if some of the question types are not covered in a particular syllabus, if the class requires extensive practice in a particular method, or if the quiz needs to be modified during a course as material is progressively put in front of students. Students are unaware of the differences between modes 1) and 2) - they are both perceived as practice mode. However, in the directed practice mode students cannot opt to choose a particular question type.

3. Examination mode

In this mode, the number of questions, their relative frequency and order are completely specified by the tutor. In complete contrast to modes 1) and 2), students cannot exit until they have seen all the questions stipulated (although not necessarily answered!) and when they finish, their answers are recorded in 'csv' format for compatibility with spreadsheets. Students have the facility to review their answers to all questions and to change the values should they so wish. In this mode students do not have the capability of saving the answers in their own file records.

Program design

The Quiz comprises four parts.

- *Quizmaker* is installed on the tutor's own computer and is never accessible to students. It is used to control which modes are available to students and to create tests using a file setup.dat.
- *Quizzes* creates individual questions from the basic question types.
- *Rich Text Writer* is used by the tutor to create Help files customised to the course.
- *Analyser* works the answers.

Quizmaker

The Quizmaker program consists of a number of pages. Quizmaker is not used if The Quiz is to be used only in the default practice mode.

1. Mode and student registry.

This page is used only to set up a test or exam. If directed practice is chosen then the program will immediately jump to the next page. If examination is chosen, this page allows the tutor to define the type of information required of a student taking the test - first name, family name and password. All of these are optional and the password field entered by the student is encrypted for security. This page also allows the tutor to set a time limit for the test.

2. Quiz choice

The second page asks for the name of the quiz to be used. A list box is presented with the names of all the quizzes currently installed and a button is activated which allows access to the details of the particular quiz selected so that the lecturer can decide which type of questions should be included in the quiz.

The next box on this page asks if all of the questions should be included and the last box asks if the question order should be randomised. In directed practice mode the responses to these two questions are ignored since the program assumes, by definition, that only a sub-set of questions will be used and random order is obligatory.

3. Answers

The third page only appears in examination mode. It asks for the location of the students' answer file and its name. The second question asks for the number of questions to be included, up to a maximum of 20. If a time limit is not specified then there are no further questions. Alternatively, a final question box will appear inviting the time limit to be specified in minutes.

4. Questions

This page presents a grid for specifying the Question Types and their frequency. Initially the question types are assigned in ascending order to fill the total number of questions desired, with a wrap over if there are more questions than types. At this point the exact order and type of question may be specified. If random order has been specified then this grid is used to determine the frequency of occurrence of each type - the program will randomise the order for each student. In directed practice mode, randomisation is obligatory.

5. Final page

The last page summarises the choices and allows the user either to re-start or to save the data. The file called 'setup.dat' is then automatically created, saved and copied into the same directory as the particular quiz chosen.

Quizzes

When a quiz file is opened, the program looks for the file 'setup.dat' in its own directory. If it fails to find it then it will proceed in practice mode. If the set-up file is found and practice mode has been specified, the student will perceive the program as operating in practice mode. If the examination mode has been specified then the student has the choice of continuing to practice or opting to sit the examination.

Having opted to sit the examination the student must answer the quiz in the style defined by the lecturer. Any question can be skipped by clicking on 'Next Question'. Once all the required questions have been presented, the student has the option of reviewing the answers and changing them if desired. This can be repeated as often as required until the student is satisfied. At this point the student should click on "Exit Exercise" and the answers will be appended to the data file.

If a time limit has been specified then the quiz begins with a reminder to the student that this is in operation. The timing does not start until this message has been dismissed by the student. The time remaining is displayed below the question number in minutes (to 1/10 minute). When 5 minutes are left this display changes colour to red and with 1 minute to go a message is placed on the screen. If the time runs out before the student saves the answers then the time remaining message changes to a flashing Time Expired notice and after 5 seconds the data are recorded and the program shuts down.

Rich text writer

Help with the calculations is written using the program Rich Text Writer by the tutor in the institution running the program. This is called 'Calculation Help' and gives advice on the calculation method for a particular question in terms appropriate to the lecture course. *Rich Text Writer* is designed to assist with this and generates the type of text needed by chemists. If a tutor decides that help is not required, then the program will simply report 'Sorry, no help available'.

Other help on how to run the software is built into the program.

Analyses

A separate marking program has been developed which completely automates the marking process and will, if required, generate a final '.csv' file for use in spreadsheets. This program is optional since the answer format is compatible with all spreadsheets and a custom template can be constructed using any preferred program. *Analyzer* allows the accuracy levels required and the mark awarded, to be set for each question. The major difference between computer marking and paper marking is that in the former it is an 'all or nothing' process with full marks for a correct answer and zero for one outside the prescribed accuracy limits. A human marker will probably give partial marks – for example, for writing a correctly balanced equation. Computer marking is thus likely to give apparently lower marks unless one realises that two different types of question are being asked and either adjust the marking scheme accordingly or accept that two different tests exist.

Examination implementation

Advice on the setting of computer-based tests is readily available[4] The volumetric quiz was set up for examination with the following specifications,

1 Number of questions: 6
2 Question types (see Appendix): 1,3,5,7,10,11
3 Order of questions: strictly as set down in 2.
4 Time limit: 45 minutes.
5 No passwords required.

The appearance of the quiz is shown in Figure 1.

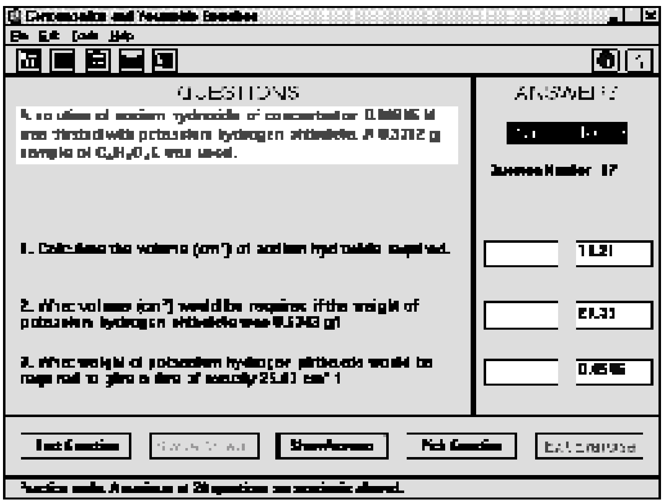
The students were given a 'window' of two weeks in which to take the test and acquire sufficient competency via reinforcement learning. They were able to take the test at any time within this period but the majority opted to do this on the final two days. There was no attempt to check for collaboration, impersonation or cheating and no form of traditional exam supervision was maintained. The examination window was scheduled for a period when all students had had time to learn the computer's operation and become confident in the mechanics.

Table 2: Examination results in volumetric analysis for 1995-98.

Method	*Year and Test*	*Candidates*	*Performance*	*Mean Mark*
Paper	1995 First test	81	27 Fail (1 withdrew)	52%
	1995 First resit	26	16 Fail	50%
	1995 Second resit	16	2 Fail (withdrew)	55%
Computer	1996 First test	101	11 Fail (1 withdrew)	72%
	1996 First resit	10	0 Fail	65%
	1997 First test	91	7 Fail (6 withdrew)	73%
	1997 First resit	1	0 Fail	
	1998 First test	89	7 Fail	73%
	1998 First resit	7	2 Fail (withdrew)	65%

Figure 1: The screen as seen by the student in practice mode with the computed answers displayed.

The students have access at all times to a calculator (with the ability to copy and paste into the answer box) and a table of appropriate relative molecular masses (so as not to introduce errors from this calculation)



Results

The Quiz program on volumetric analysis was introduced in all three modes in 1996. Prior to this all students sat a written examination of exactly the same form as that specified for the computer test. The written test was designed to be taken in a lecture slot of 45 minutes, whereas the computer test could be taken at any time within a 2 week period. Students failing the written or computer test are required to take resit tests until they either pass or withdraw from the course. The pass mark was set at 40%.

The results of the test and the resits for 1995 – 1998 are shown in Table 2. 1995 was the last year in which a written test was taken. The results are typical of previous years.

The key features of these results are that from 1996

- the mean mark shows a substantial increase;
- the number of failures shows a decrease;
- only one resit was necessary.

Discussion

The very clear implication of the results is that the major reason for the improvement is practice. In the allowed fortnight, students spent the first week practising and only attempted the test when they felt confident. The end result, whatever the means, is that the class can now carry out their volumetric calculations with confidence. This may simply reflect training in a specific type of calculation. Critical evaluation of the same students' performance in tutorials associated with the remedial mathematics course provides no evidence of improvement in their basic mathematical skills. It appears that improvement in one aspect of chemarithmetic is not necessarily transferable to other aspects. However, even if this exercise has only improved one aspect of student numeracy, this must be of significant value. At best, it suggests that a similar strategy could lead to a more general improvement in mathematical skills.

The other four quizzes on spectroscopy, thermochemistry, particles and waves, and algebraic manipulation, have been used only in the practice modes (sometimes in conjunction with tutorials). They are popular with students, many of whom have purchased their own copies for use on their own computers. There is no information on how much they are actually used. Furthermore, in the absence of specific performance tests before and after the introduction of the quizzes, it is not possible to assess whether students show an improvement in ability to deal with these areas of chemarithmetic. It would be interesting to know how much the impending test increases the students' motivation to take the opportunity for the 'learning reinforcement' offered by the programs.

As far as staff are concerned, the computer-based volumetric analysis test has been a significant advantage. The time taken to prepare, invigilate, and mark an examination is now 10 minutes compared to approximately 20 hours for the series of paper-based tests. Of course, it ignores the time required to write the programs and staff time devoted to running the computer network. However, the development time for the programs can (in theory) be spread over their total use; if more institutions adopt the programs, the development time becomes more effective.

Students are generally supportive, although it is difficult to extract anything sensible when asking their opinion of examinations. They like to practice, they like the two-week window and they like to be trusted. The only genuine negative note concerns their inability to indicate their thought processes and to add textual comment to their answers (a bonus as far as staff are concerned!). It may surprise some that they made no attempt to work together (there was, they said, insufficient time for chat), nor to personate, nor did they make any attempt to cheat in this completely unsupervised examination. Since 1997 the computer classroom has been fitted with a remote surveillance camera for security reasons and spot checks confirmed that serious individual work was carried out.

There is no evidence for the 'under-marking' traditionally expected when using a computer based test since the marking scheme for the paper test concentrated on numeric accuracy alone.

Acknowledgement

I would like to thank Dr H. Aspinall of this department for devising the questions used in the volumetric test and agreeing to submit her class to the experiment.

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Appendix 1: The Volumetric Quiz

The volumetric quiz contains the following 12 question types,

• Type 1. Concentration-1

A random weight (from 0.2 to 2 g) of a typical volumetric reagent, chosen at random from a list of 10, is dissolved in water (from 50 cm^3 to 1000 cm^3) with no details of how the solution is prepared (e.g. acid required etc.).

One question is asked: find the molarity of the reagent.

• Type 2. Concentration-2

Similar to Type 1. Two questions are asked,

Question 1. Find the molarity of the reagent.

Question 2. Calculate the concentration of one of the elements in the reagent.

• Type 3. Concentration-3

Similar to Type 1. Three questions are asked,

Question 1. Find the molarity of the species.

Question 2. Calculate the volume of solution required producing a molarity of exactly 0.10000, 0.01000, 0.00100 etc. as appropriate.

Question 3. As question 2, but with a randomly chosen molarity.

• Type 4. Acid/Base-1

Randomly chooses either the standardisation of sodium hydroxide by potassium hydrogen phthalate or of hydrochloric acid by potassium hydrogen carbonate. Unknown molarities are in the range 0.08 to 0.13 with the unknown solution being titrated against random weights of the standard substance.

One question is asked. Find the molarity of the unknown reagent.

• Type 5. Acid/Base-2

Similar to Type 4. Three questions are asked,

Question 1. Calculate the molarity of the unknown solution.

Question 2. Repeats the calculation for a different weight of standard.

Question 3. Asks for the weight of standard required to produce a titre of exactly 25 cm^3.

• Type 6. Permanganate-1

The standardisation of unknown permanganate solutions by sodium oxalate. Molarities are in the range 0.018 to 0.024. One question is asked. Find the molarity of the permanganate.

• Type 7. Permanganate-2

As Type 6. Three questions are asked,

Question 1. Find the molarity of the permanganate.

Question 2. Repeats the calculation for a different weight of oxalate.

Question 3. Asks for the weight of oxalate required to produce a titre of exactly 25 cm^3.

• Type 8. Dichromate

The standardization of potassium dichromate with either iron(II) sulfate or iron(II) ammonium sulfate. Molarities are in the range 0.014 to 0.019.

One question is asked. Find the molarity of the dichromate.

• Type 9. Thiosulfate

The standardisation of sodium thiosulfate with potassium iodate using starch indicator. Molarities are in the range 0.08 to 0.13.

One question is asked. Find the molarity of the thiosulfate.

• Type 10. Chromium Ore

A back titration example. The chromium is oxidised to dichromate and reacted with an excess of iron(II) sulfate (25 cm^3 of ca. 0.4 M). The remaining iron is titrated with potassium permanganate.

One question is asked. Find the weight percentage of chromium (in the range 8 to 13%).

• Type 11. Calcium Ore

The calcium (25 to 40%) is precipitated as oxalate, dissolved in acid and titrated with permanganate.

One question is asked. Find the weight percentage of calcium.

• Type 12. Argentimetric

Titration of a halide (randomly chloride, bromide, or iodide) against silver nitrate using dichlorofluoroscein. Molarities are in the range 0.08 to 0.13.

One question is asked. Calculate the percentage of halogen in the unknown.

Electronic Presentation of Lectures - Effect upon Student Performance

PAPER

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The effects of transferring lecture material from overhead acetates to the computer presentation package Microsoft "PowerPoint" are described. The advantages of this method and some simple additional techniques are described. There is a marked increase in the students' performance in the end of module examination which has been sustained over two years. The possible reasons for this increase are discussed, together with the results of informal feedback from the students.

Introduction

The lecture has been described as "a grossly inefficient way of engaging with academic knowledge[1]". No doubt it is reasoning like this which has prompted a few examples of lectureless course modules[2,3]. Nevertheless, the lecture is likely to play a key part in the learning experience of university students in the foreseeable future[1,4,5]. Paradoxically, one of the arguments in favour of the lecture is that it is 'efficient'[6]. The paradox arises because the lecture provides an opportunity for a very large number of students to be exposed simultaneously to a large amount of information. The lecturer needs to be aware that not everything that has been covered has been learned: in the words of an anonymous quotation "the verb 'to cover' and the noun 'information' are responsible for much mischief"[7]. Indeed, Johnstone and Su[8] have concluded that students may record in their notes as little as 52% of the 'units of sense' delivered in a lecture. One reason why information is not transferred efficiently from the lecturer to the student is that students suffer from 'attention breaks'[9]. Any device which can prevent these breaks in attention can therefore lead to improved learning.

Sanctury[10] has reported that student interest in lectures can be greatly increased by incorporating sophisticated audio-visual techniques.To follow this example would require more preparation time than most people would be prepared to spend.However,it seemed possible that student interest could be raised (and therefore student learning improved) by a much more modest introduction of technology into the lecture.

I therefore decided to test the effect of using a PowerPoint presentation to replace all the OHP transparencies in a single lecture course.

Methodology

The Lecture course

The series of lectures selected for this trial is given to first-year students on the BSc course in Environmental Science at the University of Plymouth. The course is taken by 130 – 180 students who have a wide range of backgrounds in terms both of academic subjects studied and of the type of course taken prior to university (A-levels, foundation years, etc). The syllabus comprises topics in physical chemistry in two main areas: water (hydrogen bonding, solubility, pH, redox) and energy (first and second laws of thermodynamics, Carnot efficiency, enthalpy, entropy, Gibbs free energy).

The course is scheduled for the first semester, and is allocated 12 contact hours (normally lectures); a further 12 hours of private study is expected. This series of lectures comprises one twelfth of the workload of the students in the first semester. Students are expected to study for approximately 40 hours per week.

Previous method of presentation

Until 1995 the course was presented in ten 1 hour lectures and two 1 hour problem solving sessions. The lectures made extensive use of OHP transparencies created by a word processor or graphics package. The sheets were then printed out in monochrome and 'spot colour' added using fibre-tipped pens. Complicated diagrams were built up by overlaying several layers of acetate and, if multiple points were on a single transparency, these were revealed one-by-one using a sheet of paper to cover part of the OHP.All lectures were preceded by a transparency outlining the essential points that would be covered and the final acetate contained a summary.

The problem solving sessions were organised as follows:-

- students were given a sheet of numerical problems the week before the session;
- during the week, students would attempt to solve the given problems;
- during the session itself, the tutor would go through model answers.

These sessions did not allow any one-to-one interaction between tutor and student and many students were unable to attempt the problems because they could not see how they should be approached.

Current method of presentation

In 1995-96 all the material previously presented on OHP transparencies was instead presented in Microsoft PowerPoint (V4) running in the Windows 3.1 environment. Like all presentation software, Microsoft PowerPoint[11] offers

- consistent use of colour;
- easily created signposting/summaries;
- gradual building of text;
- simple animation of diagrams;
- facilities for simple editing and updating.

Without the use of specialist software such as PowerPoint these features can only be achieved with considerable time and effort.

Every effort was made to restrict the changes in the presentation to the exchange of OHP transparencies for screens presented by PowerPoint.The use of PowerPoint is possible because the large lecture theatres at Plymouth are equipped with standard PCs connected to a video projector (VGA resolution or better), and the PC screen is projected at the front of the lecture theatre to form an image of a size suitable for the room. All the screens were created in PowerPoint and used a range of colours from a standard palate. Diagrams were re-drawn using the tools available in the program and clip-art was only used where a similar illustration had been used previously (e.g. photocopied cartoon). No images were scanned in. Simple animation was used for some diagrams, see Figure 1.

The use of PowerPoint made it possible to revise the problem solving sessions to allow better tutor-student interaction. The new process is as follows:

- students are given a problem sheet the week before;
- during the week, students attempt to solve the given problems;
- during the session, the correct answers are read out (at which point students who have solved the problems correctly may leave);
- the PowerPoint presentation is started;
- the first screen shows a flow diagram outlining *how* the problem should be approached;
- subsequent screens slowly reveal a model answer: the internal clock of the PC is used to change the screens; each step in the answer is displayed for about two minutes before the next step is added.

Students who were previously unable to see how to tackle the problem or who had problems with the initial steps are thus led through them at a reasonable pace, and are motivated by the opportunity to 'beat the computer' to the final answer. Meanwhile, the tutor has been freed from the task of giving the explanation to the class and is available for one-to-one discussions with any student in difficulties.

Figure 2 shows screens from one of the more simple problems.

Assessment

A 45 minute multiple choice test containing 30 questions is taken by the students at the beginning of the second term. The questions are marked by a PC linked to an optical mark reader and the package also generates reports containing frequency histograms. No changes were made to the method of assessment during the period covered by the study. Student feedback was obtained by requesting students from the 1996/97 cohort to complete a short questionnaire at the end of the course.

Figure 1: Simple animation sequence to illustrate the Carnot cycle

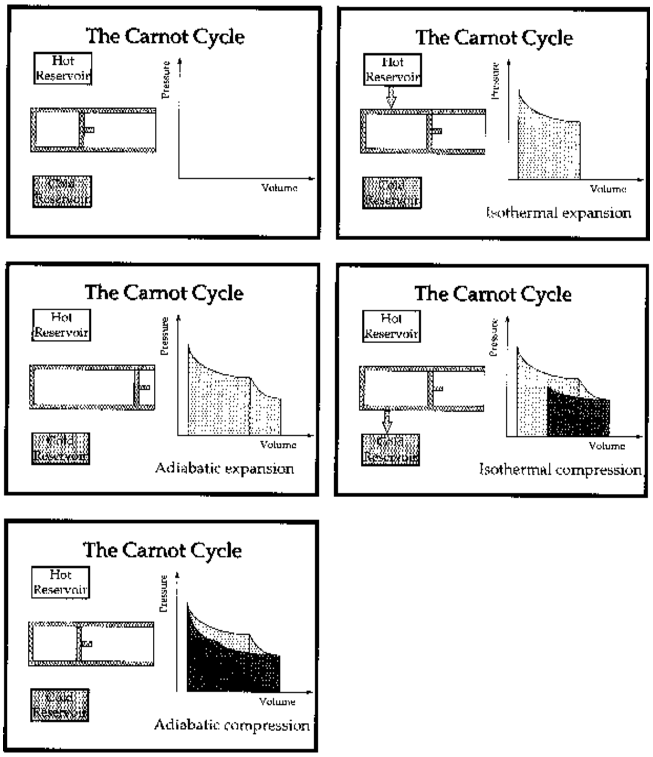

Figure 2: Progressive reveal of model answer

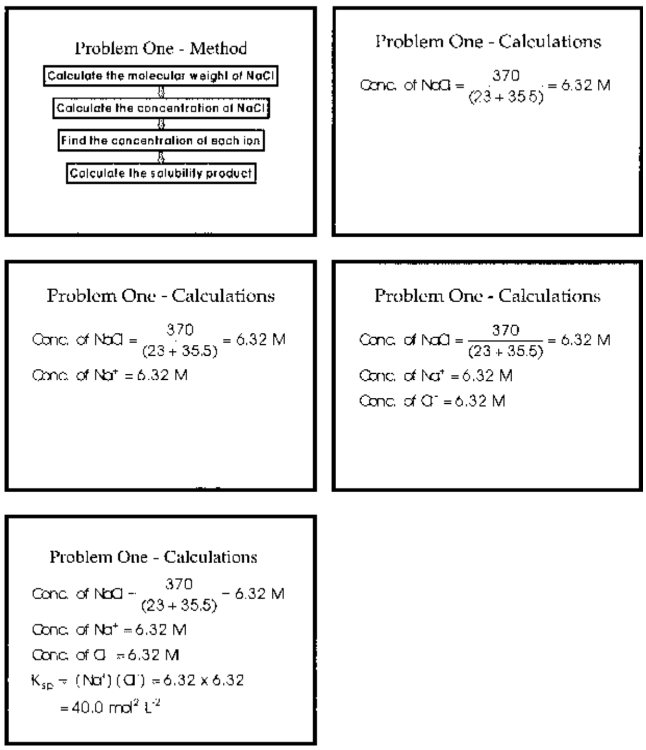

Figure 3: Effect upon examination performance

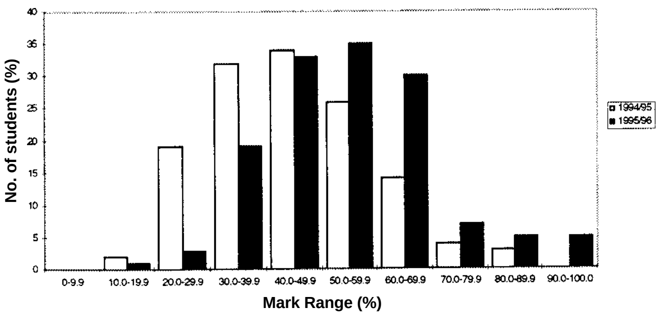

Table 1: Summary Statistics

	1994/95	*1995/96*	*1996/97*
No. of students	134	145	160
Mean mark	43.5	51.8	51.9
Standard Deviation	14.4	16.2	15.6
t_{obs} (cf 1994/95)		4.5	4.7
t_{crit} one-tail		1.7	1.7

Table 2: Written Responses from Students

Feature	*Number of responses*	*% age of returns*
Use of PC	37	43 %
Visual aids	19	22 %
Presentation	14	16%
Lecture plan / structure	14	16%
Clarity	10	12 %
Pleased with lecturer	8	9 %
Well explained	8	9 %
Humour	8	9 %

Results

Examination performance

Figure 3 shows the distribution of marks for the academic years 1994/95 (before the introduction of PowerPoint) and 1995/6 the year that PowerPoint was introduced.

There is a clear impression that the marks increased after the introduction of the PowerPoint presentation.This visual impression is confirmed by statistical analysis shown in Table 1 in which a one-tailed test is used to compare each of two cohorts of students who experienced the PowerPoint presentation (1995/6 and 1996/7) with the 1994/5 cohort who had not.

The t_{crit} (critical values for t) given in the table are for the 95% confidence level. It is clear that the differences in the means between each of the two cohorts and the 1994/95 students (which is the basis for the t-test) are statistically significant. Indeed, the probability that the differences in the examination means are due to random factors is less than 0.01%. The effect has been sustained over two academic years. Thus, the enhancement is unlikely to be due to the increased enthusiasm of the lecturer caused by a new experience.

Student perception

The questionnaire given to students from the 1996/7 cohort asked what could be improved and included a section for comments. 86 forms were returned from the 160 students. 76 rated the course "very good", and 10 "good", the top two of the ratings offered.

The majority of the comments were very positive, with some students remarking on the clarity of both the material and the structure.Table 2 lists the comments written by the students when asked to complete the sentence "A good feature of this series of lectures was".

Discussion

For two successive years after the introduction of PowerPoint presentations, the mean examination performance of the cohort of over 130 students was significantly increased. Furthermore, the student perception of the new learning experience is positive, with a majority of students picking out some aspect of the presentation method as a good feature of the course.

Naturally the use of a previous cohort of students as a control has limitations. The validity of the comparison depends on four main assumptions:

- That the lecturer's own style and enthusiasm are unaffected by the change;
- That the only change in the presentation is in the exchange of PowerPoint screens for OHP transparencies;
- That the student cohorts are of equal academic ability;
- That the assessment procedure each year was equally demanding.

The fact that the improvement was sustained for two successive years is an indication that the PowerPoint presentation led to a substantial improvement in learning. There are at least four possible explanations for this.

- The ability to change the screen display with the click of a mouse button means that the structure of the lecture is not obscured by the need to replace transparencies, and/or cover up selected material.
- The opportunity to introduce animations and to build up diagrams sequentially can be particularly instructive. Furthermore, PowerPoint imposes a discipline on the lecturer which makes it particularly easy to present clear signposts and summaries. Brown and Atkins[5] conclude that this is one reason for associating audio-visual aids with the process of learning.
- The new style of the workshop sessions may provide a significantly better learning environment for some students.
- The quality of the presentation may go some way towards preventing the attention breaks which limit the effectiveness of lectures as a learning experience[9]

Of course, this last point may suggest that it is the novelty effect of PowerPoint, rather than its quality, which attracts the attention of the students. If this is so, then the success of the approach depends on it *not* being adopted universally! In spite of this, and of other reservations about the interpretation of the improvement reported here, the data are sufficiently encouraging for it to seem worth recommending a much wider use of PowerPoint to present lecture material.

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Pre-laboratory support using dedicated software

PAPER

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

Introduction

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

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

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

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

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

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

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

Methods

Program Design

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

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

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

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

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

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

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

Examples

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

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

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

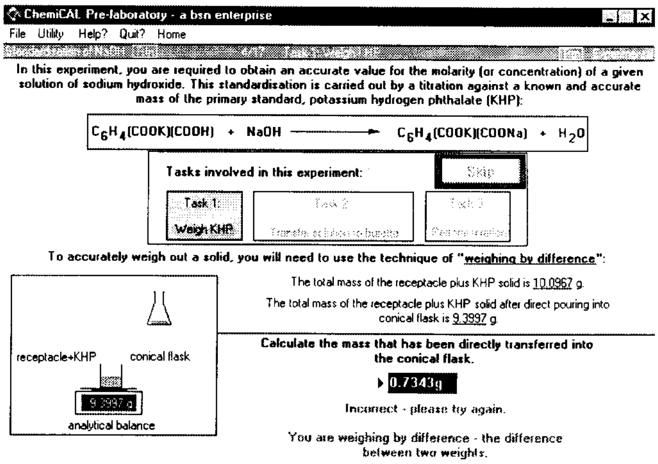


Figure 1: Weighing by difference - a type A pre-lab exercise

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

Figure 2: A simple type A pre-lab calculation

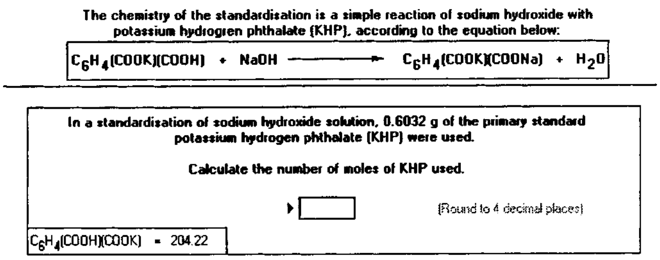
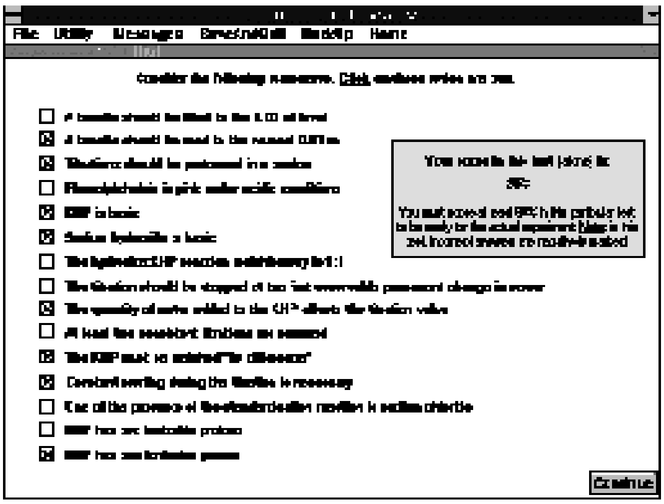


Figure 3: A simple type A pre-lab test



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

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

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

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

Data capture and processing

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

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

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

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

Results

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

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

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

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

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

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

Discussion

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

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

Table 1: Pre-laboratory activity for selected experiments

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

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

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

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

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

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

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

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

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

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

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Empirical Research into Chemical Education

PERSPECTIVE

The *motivation, research domains, methods* and *infrastructure* of a maturing scientific discipline

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Getting in touch

The number of universities and colleges at which chemists and researchers in chemical education work side by side has been growing and so has the wish, and the need, to cultivate partnerships. The exchange of information is important in fostering mutual understanding and appreciation. In conversation with a new colleague from a department of chemical education, a chemist could reveal that she or he is developing tools for chemistry teaching, or is involved in the elaboration of curricula. The chemist would also discover that the colleague conducts *empirical research in chemical education*. This paper intends to give an introduction to that particular field of interest.

Chemistry and chemical education are closely related. We hope that this paper can contribute to the enhancement of the partnership between chemists and chemical educators. Close contact between the two disciplines is highly desirable for both sides. A well-found knowledge-base provided by empirical studies in chemical education is essential for making sound decisions about the practice of chemistry teaching.

Why research in chemical education?

Science and technology are omnipresent in today's society. More and more jobs require training in the natural sciences. In the media, and in many situations in everyday life, people are confronted with scientific terms, surveys and research results. Scientific language is often used to advertise products. Education in science is needed to help people form an opinion about science-related topics. Many political decisions have to be made which involve science and technology. Hence, scientific literacy is essential for the democratic process. By promoting scientific literacy, a scientific education is beneficial to society at large.

However, chemical education faces a number of important difficulties. Learning chemistry is highly demanding, perhaps more so than other school subjects. A large number of school children perceive it as difficult and therefore chemistry courses are rather unpopular[1]. Those who work in chemical education have recognised the need for better chemistry curricula, in place of those which are sometimes overloaded, vaguely structured and short of modern topics[2]. Also, in the education of chemistry teachers, as in their pre-service teacher training courses, it is considered necessary to try and bridge the gap between the theories taught in these courses and the classroom reality experienced by prospective teachers[3].

What researchers investigate is, in the broadest sense, the ways in which teachers and learners deal with chemistry in a given educational context. Research is conducted in order to understand the underlying processes, with the aim of improving education in chemistry. Thus educational research provides a foundation on which chemistry educators can discuss and implement ways to make education in chemistry effective and worthwhile for all.

What are the main research domains?

The general processes of teaching and learning are investigated by scientific disciplines such as educational psychology. Research into chemical education focuses on the more specific field of teaching and learning chemistry, which in itself is a very rich and complex area. Knowledge of chemistry is essential to conduct research in this field. Three major research areas can be distinguished:

1. Learning: This area is concerned with how chemistry is learned. Students' conceptions, their ways of solving problems, and their difficulties with the abstract mode of thinking in chemistry, are investigated. It is also intended to connect the description of the process of learning chemistry to general theories of learning.

Example: Students bring their own misconceptions into the classroom, which can interfere with their understanding of the concepts being taught. Research has revealed some of these misconceptions[4], and teachers who are aware of these can anticipate their students' problems, and thus their teaching can become more effective. Students often have difficulties in understanding the particulate nature of matter[5]. Research has shown that it is not sufficient to teach the concepts of substances and particles in a way that is structured from a chemical point of view only[6].

2. Teaching: This area is concerned with how teachers create the optimum conditions for learning. It involves the evaluation of different teaching tools (such as textbooks and experiments) and different curricula.

Example: Experienced teachers and novices have different ways in which they organise their teaching. Research has shown what are the characteristics that experienced chemistry teachers display[7]. This information can help prospective chemistry teachers to develop and improve their own teaching strategies.

3. Educational context: Research also focuses on other factors which influence chemistry teaching and learning. These

are subsumed under the term *educational context*. Among these are the gender, and the cultural and social backgrounds of chemistry teachers and their students, as well as the interaction between the individuals in the chemistry class.

Example: In a chemistry lesson teachers and students do not always fully understand each other. Teachers are experts in school chemistry and perhaps unconsciously use a scientific language with certain fixed definitions. Students are often not familiar with this scientific language[8]. This can cause communication problems which may not be recognised by either side. Research has identified such difficulties in understanding[9], and this information can be used to improve the teaching of chemistry.

How can chemical education be investigated?

As chemical education is a multifaceted research domain, the choice, or more frequently the development, of a suitable research method is a very important step in any investigation. The development of new research methods, as well as the adaptation of existing methods to new situations, is one of the key issues in our research field.

It is important to match the methods used to the problem being studied and to the constraints imposed by the situation. For example, because it is people who teach and learn, it is not always possible to carry out controlled experiments with the rigour to which physical scientists are accustomed. This does not preclude useful observations being made, or invalidate the conclusions reached by their analysis.

In chemical education research there are a number of well-developed, different methods for collecting and analysing data. The most familiar method is to obtain feedback from students or teachers through questionnaires. Other examples include the analysis of essays, structured or semi-structured interviews[10] and the so-called 'think-aloud protocols' - in which students are invited to say what they think when performing a certain task (introspection), or after they have finished it (retrospection)[11]. In a classroom/laboratory environment so-called 'classroom protocols' are very useful[12]. These protocols are documented by audio-taping discussions of students and teachers in educational situations and transcribing their statements. There is a substantial literature on the advantages and disadvantages of these methods, and on the most effective ways of using them.[13]

The research community

Almost all European research groups dealing with chemical education are relatively small, but pan-European co-operation between individual groups is increasing. This development is contributing to the building up of a pan-European *forum of chemistry education researchers*.

In several ways communication is growing between researchers. For example, new research developments are presented at the conferences of the FECS Division of Chemical Education[14] which have taken place in one of the member countries since 1992. European conferences of the International Council of Associations for Science Education (ICASE) have been held in Germany since 1988, and in The Netherlands since 1998[15].

Researchers can publish research outcomes in several European scientific journals, such as the *European* (nowadays: *International*) *Journal of Science Education*,[16] founded in 1979, and the *European Journal of Teacher Education* since 1977. Additionally, there is a growing rate of organisation among researchers. A promising example is the recent European Science Education Research Association, established in England in 1995[17]. Finally, the training of new researchers is being stimulated. A recent initiative is the organisation of pan-European summer schools for researchers in science education, held especially for PhD. students. The first of these took place in Holland in 1993, and the most recent, the fourth, in France in 1998.

In conclusion, we believe that researchers in chemical education in many European institutions have contributed to the improvement of science teaching, and hopefully will continue to do so in the future. We look forward to seeing more countries developing and organising, within the range of their possibilities, a research base for their education in chemistry. This will involve training new researchers, and ensuring the wider dissemination of research results.

We are also convinced that a key step in the development of effective chemical education research is an increased interchange of ideas and a more active collaboration between researchers, developers and practitioners (the teachers and lecturers) all of whom share the common aim of providing the best possible education in chemistry for the next generation of student.

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Action research: Overcoming the Sports Mentality Approach to Assessment/Evaluation

REVIEW

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Introduction

Each time we make significant changes in what we teach or how we teach we are faced with the same question: how can we find out whether the innovation we have brought into our classroom is worthwhile? Chemists, familiar as they are with the criteria for decision-making adopted by physical scientists, find this question so difficult to answer that they often avoid doing the experiment that might provide evidence on which to base an answer. Let us therefore build a metaphor on a recent example from medical research.

In 1997, Bailar and Gornik reported an analysis of age-adjusted mortality rates due to cancer from 1950 to 1994[1]. This paper was picked up by the popular press, who reported that the war on cancer had been a failure[2]. Bailar and Gornik chose to analyze age-adjusted mortality rates because they regarded it as "the most basic measure of progress against cancer" and because it "focuses attention on the outcome that is most reliably reported"[1]. The question before us is simple: would they have reached the same conclusions if they had examined changes in the length of the patient's survival, or changes in the quality of life after cancer had been diagnosed?

Bailar and Gornik's paper provides a metaphor on which discussions of the evaluation of instructional innovation can be based because it illustrates the role that the choice of methodology for evaluation has on the conclusions that are reached. Chemists concerned with improving the way they teach chemistry need to recognize this and act accordingly.

The sports mentality approach to evaluation

Suppose a group of chemistry teachers wanted to evaluate the effectiveness of a set of new curriculum materials or a new method of teaching. What kind of experiment would they be most likely to design? And, what hidden assumptions would underlie their choice of methodology?

History has shown that chemists often base the design of such experiments on the hidden assumption that assessment and evaluation are synonyms. Within the context of the classroom this may be just as incorrect as the assumption that accuracy and precision are synonyms within the context of the chemical laboratory. *Assessment* might best be defined as the process by which the performance of individual students or groups of students is measured[3]. (This use of the term is consistent with the first definition of assessment in the *New Shorter Oxford English Dictionary*: The determination of the amount of a tax, fine, etc.; a scheme of taxation etc.)

Evaluation is the process by which information is collected to make decisions on how instruction can or should be improved[4]. Assessment is therefore a necessary but not sufficient component of evaluation.

Once the fundamental assumption that assessment and evaluation are synonyms is made, chemists often presume that the optimum design for the evaluation experiment is to compare student performance on a common exam for an experimental group using the new curriculum materials (or the new approach to teaching the course) with a control group using the old curriculum[5]. All too often, the result of this experiment is data that are precise, and sometimes statistically significant, but not necessarily useful in answering the original question.

We have described this strategy for the design of evaluation experiments as the sports mentality approach[6]. It provides results that are equivalent to hearing a sports commentator announce the results of a cricket match in terms of one team declaring their innings closed at a score of 318 for 6. For the casual sports fan, this is all the information one needs because it is used to tell us who 'won.' But it is difficult to imagine a coach selecting a team for the next match based only on this information.

There are several potential sources of error in basing evaluations of changes in either course content or the approach to teaching this content on student performance in a summative exam, either during or at the end of the course.

Herron has written about the Principle of Least Cognitive Effort, which presumes that students make the choice that appears to require the least effort[7]. This aspect of human behavior can be a confounding variable in the traditional experiment, which assumes that students will always take advantage of opportunities to do better in a course. What about the students who don't want to do better, who will do whatever is necessary to get a B or even a C? We have found that it is possible to make a change that significantly improves the classroom environment without seeing any effect on exam performance[8]. The traditional experiment is also plagued by the many factors that influence test performance besides the instructional innovation being studied.

A more serious problem with the traditional experiment might best be understood in terms of the metaphor of a drunk searching for a coin beneath the lamp post – not because this is where the coin was dropped, but because it is where the light is. By focusing on how much is learned, the traditional experiment fails to measure differences in *what is learned*, or what knowledge is *retained*, or whether a new instructional technique leads to improvement in students' understanding of knowledge we *value*, rather than knowledge that can be easily tested. In other words, it is not sensible to use the mark scored in a summative exam as a measure of the effect of an educational innovation unless the sole purpose of the innovation was to improve the mark in that exam.

A subtle, but potentially serious, problem with the traditional experiment is its assumption that the change being made is either 'good' or 'bad', i.e. that students, in general, will either benefit from the change or not. What if the change is bipolar? What if some students benefit, while others do not? The traditional experiment does not answer the question: *cui bono*? Who benefits from the intervention? Is it the intended audience? (The traditional experiment presumes that innovations will benefit all students equally, which is seldom if ever true).

Qualitative techniques as an alternative approach to evaluation

Qualitative techniques have been offered by their proponents as a naturalistic alternative to the experimental, quantitative, behaviourist tradition described above[9]. These techniques are built on the social science tradition of ethnography[10,11] and therefore involve extensive interviews[12] that are analyzed in terms of either case studies[13] or cross-case analyses[14].

Qualitative techniques are most often associated with educational research[15]. While qualitative research can inform teachers, it is usually done to inform researchers and has little (if any) effect on classroom practice. As working professionals, teachers are quite aware of what is happening in their classes - they do not believe that they need to be the subjects of anthropological research.As we will see, however, qualitative techniques can be applied to the more pragmatic issue of evaluating the impact of changes in instruction.

Unorthodox methodologies: formative research

In what amounts to a rejection of the 'methodolitry' endemic to both the qualitative and quantitative paradigms, practicing teachers have developed an approach to evaluation known as formative research. Walker has argued that this approach is "usually eclectic in its choice of techniques for eliciting data, including self-reports (in the form of diaries, interviews or questionnaires), observations, tests, and records"[16]. Walker cites the work of Treisman[17,18] as an example of this approach.

"Treisman... carried out a chain of studies that were by traditional standards methodologically primitive but nevertheless exceptionally productive.... *By any reasonable standards...this [Treisman's study] was an outstanding study....* [Treisman] focused his attention on the crucial practical problem, observed practises closely, kept himself open to a wide variety of evidence at every stage of the inquiry, compared circumstances in which a practice seemed to succeed with circumstances in which it failed, searched for factors in the situation that could be changed, redesigned practises to reflect what he thought he had learned from his observations, and tested the new practises by using the standards of achievement actually employed in the real course. His results have been widely reported and have already begun to influence research and practise in mathematics education... And all this work was accomplished in three years on a modest budget."

Action research as a method for doing formative research

Action research is an approach to formative research that can be traced back to the end of World War II, when the social psychologist Kurt Lewin[19] developed most of its current methodological characteristics. Action research soon fell out of favour among those who pursued "the promise of quantitative methods (uniform regularities, predictability, control, etc.)"[20]. In the '80's and '90's, however, as the positivist foundations of quantitative methods came under increasing attack, action research became increasingly popular, particularly through the work of Kemmis and McTaggert[21-27]. Indeed, a search of the ERIC database brought up 2094 hits under the category 'action research' from 1978 to present.

Kemmis and McTaggert describe action research as a recursive, reflexive, dialectical technique whose goal is to help people investigate reality in order to change it, or to change reality in order to investigate it, by changing their practices in a collaborative, self-reflective spiral of cycles[24]. It is *recursive* because it is a cyclic process in which the product of one step is used as the input for the next. It is *reflexive* because it is characterized by constant reflection on the results of each step in the cycle. It is *dialectical* in the sense of a critical investigation of the truth of people's opinions. Hopkins described action research as an informal, qualitative, formative, subjective, interpretive, reflective, and experiential mode of inquiry in which all individuals are knowing and contributing participants[28].

Our use of action research has been based on a series of assumptions that are so fundamental to this work they might be considered beliefs. We believe that chemists introduce changes in the curriculum or in the way they teach because they have perceived weaknesses in the current situation. Essentially they have formulated an hypothesis (which may or may not be precisely defined) that a particular change will lead to a particular improvement. As concerned scientists they will wish to test or evaluate their hypothesis. This means that a systematic evaluation should be done whenever significant changes are made in an established curriculum or in the way the curriculum is delivered. These evaluations should look behind the facade of answers to the question: "Do the students like it?", toward deeper questions such as "What do students learn that they were not learning before?" and, "If we could provide students with a voice to express their opinions and concerns, what changes would they recommend?"[29].

We believe that any significant intervention into a practicing classroom will have an effect. (If no effect is found, this is more likely to result from poor experimental design than from a flaw in the intervention.) Instead of asking: does the intervention have an effect on the classroom environment, we prefer asking: what is the effect of the intervention, what happens to the teacher; what happens to the students?

We believe that evaluations should assume that any change in instruction will have both positive and negative effects; some students will benefit, others may be harmed. Evaluations should help us to understand what aspects of the intervention are responsible for the positive effects and what facets give rise to the negative effects. One of the goals of evaluation should be modifications of the intervention to increase the positive effects on the target population and minimize any negative effects. We recognise that innovators in education are under severe pressures which prevent them from spending much time evaluating their innovations. Nevertheless, through a knowledge of what is possible, it is possible to select an approach which will generate useful information without spending the amount of time which a committed educational researcher would consider necessary.

How is action research done?

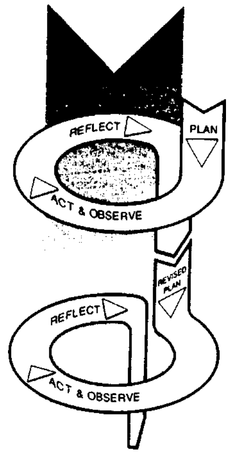
Elliott has described action research in terms of an iterative cycle of four steps or stages[30].

- The Reconnaissance and General Plan: an exploratory stance is adopted, where an understanding of a problem is developed and plans are made for some form of intervention.
- The Action in Action Research: the intervention is then carried out.
- Monitoring the Implementation: during and around the time of the intervention, pertinent observations are collected in various forms.
- The Revised Plan: the data are examined for trends and characteristics, and a new strategy is developed for implementation.

The new intervention strategies are then carried out, and the cyclic process repeats, continuing until a sufficient understanding of (or implementable solution for) the problem is achieved.

Kemmis and McTaggert[24] characterize action research in terms of a spiral of three steps or stages - plan, act and observe, and reflect - as shown in Figure 1.This view of action research has several advantages. By coupling 'act' and 'observe', it emphasizes the formative nature of this methodology. It also emphasizes the cyclic nature of action research as it moves through one iteration after another. In some ways, action research is similar in nature to the numerical technique known as successive approximation - the goal is to achieve a desirable outcome by a process of repeated iterations.

Figure 1: The action research spiral



The role of communication in action research

One of the distinguishing characteristics of action research is the degree of empowerment given to all participants. Whereas educational research has historically been *done on* students or their instructors, action research is *done with* students and their instructors. All participants - students, instructors, and other parties - are knowing, active members of the research project. All participants - including the researchers, the teachers, and the students - contribute to the process by which meaning is extracted from the data and in decisions about modifications that are made in the next cycle or iteration.

Proponents of action research often talk about involving all the major stakeholders in the evaluation process. In the simplest case, this means both the instructors and their students. But it can also involve curriculum developers, researchers, administrators, parents, and so on.

Elliott[30] considers the need for communication between all participants to be of paramount importance: "Since action research looks at a problem from the point of view of those involved it can only be validated in unconstrained dialogue with them." Kemmis[24] argues that action research is a *social* process in which students and teachers work together to improve the processes of teaching and learning. It is *participatory* in the sense that people can only do action research on themselves, either individually or collectively, as a group. It is both *practical* and *collaborative* because it provides those involved with a framework which helps them to avoid making irrational, unproductive and unjust judgements about the topic under consideration.

Every teacher a researcher?

Anyone who has pondered the forces that lead to schism in an established religion should accept the existence of differing opinions on one or more aspects of a methodology, such as action research. Regardless of whether it is applied to curriculum development, professional development, or planning and policy development, there is a consensus that action research is intrinsically *collaborative*. Kemmis and McTaggart[24] argue that it occurs within groups of participants who can be teachers, students, principals, parents, or other community members. What is important is a shared concern among the members of the group. There are proponents of action research whose slogan is 'each teacher a researcher'[31]. Others argue that an outsider should be included in the community being studied, who is neither the instructor nor a student, but who is actively involved with both students and their instructor(s) in the action research cycle and who does not have a vested interest in the success of the change being studied. The latter approach is characteristic of our work using action research.

How do we recognize when an experiment is successful?

In theory, the model of educational research popularized by Campbell and Stanley[5], in which the performance of experimental and control sections is compared, has the advantage that we always know who 'won.' We simply leave the question to the cold, hard, objective test of statistics. In practice, however, as noted in the section on the sports mentality approach to evaluation, we achieve this power at a significant cost. By focusing on measurements that can be subjected to statistical tests we often lose the ability to measure the phenomenon in which we are interested. Or we find the power of our statistical tests diluted by the many confounding variables that influence measurements such as test scores. Or, returning to the metaphor of the cricket match, we find ourselves trading useful descriptive results about individual performance for definitive, but less useful, information about the final score.

This raises an important question: what characteristic of action research plays the role in this methodology that p values, F values, or tables of two-tailed tests of significance play in more traditional educational research? In particular, how do we ensure that mistakes are not made in deciding which effects of an intervention are 'positive?'

The answer is simple: no research methodology operates in a philosophical vacuum. Quantitative research is based on a philosophical tradition that its proponents describe as scientific and its opponents label behaviourist and positivist[20]. Action research is inexorably coupled to critical theory and often linked most explicitly with the work of the German sociologist-philosopher Jurgen Habermas[32-34]. Rather than delve into a lengthy consideration of critical theory and the implications of Habermas' differentiation among technical, practical, and emancipatory knowledge, we will propose a safeguard against potential abuse of the action research methodology based on the argument of Kemmis and McTaggert that action research is "...a process in which people deliberately set out to contest and reconstitute irrational, unproductive (or inefficient), unjust and/or unsatisfying (alienating) ways of interpreting and describing their world..., ways of working..., and ways of relating to others."[24]. As long as action research is a process done by a group, in which each member of the group is a knowing participant, and decisions or conclusions are agreed to by the group - not just the individual in charge of the course - they are likely to be the correct decisions or conclusions.

How action research can change the questions we ask

Action research has become an increasingly valuable methodology in our research group. It has been used to probe the effect of the implementation of computer simulations in a senior-level chemical engineering laboratory on design[29]; to guide the development and implementation of microcomputer-based laboratories in our introductory physics curriculum[35]; to examine the effect of a novel laboratory course on advanced experiments in chemical engineering[36]; to study the effect on both students and their instructor when an alternative approach is taken to teaching organic chemistry[37,38]; to guide the development of Web-based instruction materials for distance learning in general chemistry[39]; and to bring about significant improvements in student attitude toward a sophomore-level analytical chemistry course for non-majors[40]. To illustrate how the choice of methodology used for evaluation can influence the questions being asked and the conclusions that are reached, let us look at examples of this work.

One of these projects was a response to a request from a colleague in Pharmacy who wanted to change the way he taught his organic chemistry course. The traditional lectures in his section of the course were replaced with a problem-oriented approach in which the instructor presented students with a problem, solicited answers from individual students or groups of students, and then helped the students examine the logical consequences of these answers.To encourage students to work together in groups both in and outside of the classroom, the groups were given time to discuss each hour exam before they split up to write their individual responses to the exam questions.

As one might expect, we analyzed student performance on the exams, which suggested that the individual members of a group often wrote very different answers to the exam questions, but that the class as a whole seemed to understand the questions better than ever before.We also noted that these students did significantly better than students from a traditional lecture section when the two sections of the course were merged for the second-semester of organic chemistry.

Our evaluation of this experiment went far beyond the analysis of exam data, however.We taped and then transcribed each of the 43 classes during the semester and recorded field notes that reported on a day-by-day basis observations about the interactions among the students and between the students and the instructor.We collected attitude data using both Likert scale[41] and open-ended questions.We taped and transcribed extensive interviews with the instructor of the course, his colleagues who taught other sections of the course, and the students taking the course.

It should come as no surprise that the quality of the insight obtained from this information was directly proportional to the effort required in its collection. The results of the Likert scale questionnaires, which took little effort on anyone's part, were pleasing - they suggested that the experiment was worth repeating. The more time-consuming analysis of responses to open-ended questionnaires provided better insight into the aspects of the intervention that needed to be kept and the problems faced by individual students. But it was the transcripts of the lectures and the interviews that provided the information needed to enter the second cycle of the action research iteration.

The action research methodology helped us answer questions that might not otherwise have been asked, such as:

- how do we overcome student resistance to this approach,
- what do we have to do to ensure that groups operate effectively,
- what is the nature of the dissatisfaction that might lead an instructor to change to a problem-oriented approach,
- what factors make it difficult to change the classroom environment,
- what factors interfere with the ease with which this technique can be used by other instructors, or transported to other institutions,
- what effect does this mode of instruction have on the instructor's attitude toward teaching,
- what effect does it have on students' perception of the difficulty of organic chemistry,
- does this approach to instruction produce students who are more likely to think the way an organic chemist thinks?

Another project began with a request for help on the evaluation of computer simulations being used as a substitute for traditional experiments in a capstone chemical engineering laboratory course on design. Our results suggest that it would be a mistake to ask which laboratory format is 'better' for students. They indicate that computer simulations and traditional experiments have different roles in the curriculum because they emphasize different aspects of engineering and require both different levels and types of expertise.

By providing the students with a voice, the action research methodology helped us understand that the environment in which the simulations were implemented had a major effect on students' perceptions of their value and therefore provided useful information on the optimum way in which these simulations could be used. It also clearly showed that computer simulations, by themselves, are not magic bullets that provide instruction and pedagogical benefits for the students in the absence of a human interaction between the students and their instructor. Action research therefore allowed us to provide the authors of the simulations with more information, and more useful information, than they expected.

Our work in analytical chemistry began with classroom observations of students and interviews with students to identify the source of their dissatisfaction with the course, and has extended through three year-long cycles. The work on Web-based learning began with the software developers' efforts to write what they hoped were useful elements of a program. Students were then observed while they used components of this program and revisions were made based on their suggestions. In this case, the action research cycle was significantly shorter, on the order of weeks or at most months.

The key features of our use of the action research methodology could be summarized as follows. Changes are made in what we teach or the way we teach it. Evaluation occurs while the changes are being made. As many sources of information are collected as possible. We never presume that all students will benefit from the change, and are constantly searching for ways to maximize positive effects and minimize negative effects of these changes. And the students are knowing, active participants in the decision-making process about changes that should be made in the next iteration in the innovation cycle.

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Small numbers

From Dr Jack Hoppé, Retired, Maidstone

In his letter in the September issue of UChemEd, Greaves[1] has presented an interesting apparent paradox associated with the solubility product of $Fe(OH)_3$. Assuming the equilibrium

$Fe(OH)_3(s) \rightleftharpoons Fe^{3+}(aq) + 3OH^{-}(aq)$

then, based on the figures used, the sums are correct, the conclusion is logical and the explanation given is reasonable. Whether the explanation is right or not, it is not possible to say, particularly since other equilibria involving $Fe(OH)^{2+}$ and $Fe(OH)_2^{+}$ may well be present[2]. What we can say, however, is that the explanation can be accepted without any necessity to question whether the normal laws of chemistry apply to very small numbers (amounts). As such, this is a good example, albeit on a very small scale, of thermodynamics (solubility product) predicting that a reaction is energetically possible, but which does not occur because of unfavourable kinetics (the absence of a suitable nucleation site). Indeed, this could be a useful additional example to include when discussing the importance of both thermodynamics and kinetics in considering whether a reaction will occur.

1. Greaves R 1998 Problems with Small Numbers *U.Chem. Ed*, **2** 63.
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From Professor Robin Perutz
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Chemistry beats other branches of science for generating large numbers and small alike (letter from R. Greaves in Issue 2). Some of you may remember Mary Archer's beautiful demonstration of an electrochemical cell on television ("Don't Take Anybody's Word For It"). She made a cell out of a pie dish as one electrode, her gold ring as another electrode and some lemon juice as electrolyte. The question is why her ring doesn't dissolve. The redox potentials for Al^{3+}/Al and Au^{3+}/Au are -1.68 and +1.50 volts respectively. With these three electron changes, the equilibrium constant for the reaction below is 10^{161}, so Mary Archer knows full well that her ring is safe.

$Au^{3+}(aq) + Al(s) \rightleftharpoons Au(s) + Al^{3+}(aq)$

Try giving this problem to your undergraduates and see how many come back thinking they have got the answer wrong because their calculator won't cope.

From Dr P G Nelson, Department of Chemistry, University of Hull, HULL, HU6 7RX

Dr Greaves[1] asks the question of what to say to a perceptive student who works out from the solubility of product of $Fe(OH)_3$ that $1cm^3$ of a saturated solution contains 1.2 ions of Fe^{3+}, and therefore $0.5cm^3$ contains either 0 or 1 ion.

The answer is that, according to statistical thermodynamics, equilibrium concentration is a mean quantity over a long period of time (long enough to smooth out fluctuations). Thus $0.5cm^3$ of a solution that is in equilibrium with solid $Fe(OH)_3$ will sometimes contain no Fe^{3+} ions, sometimes one, occasionally two, and so on, averaging over time 0.6. If the solution is removed from the solid, it ceases to be in equilibrium with it, and will then be either unsaturated or supersaturated, depending on the number of Fe^{3+} ions it happens to contain. What happens next will depend on the numbers of other iron-containing species present (e.g. $FeOH^{2+}$), and on the nature of any surfaces in contact with the solution.

1. Greaves R, *U.Chem.Ed.* 1998 **2** 63.

Reflecting on learning

From Dr Michael Gagan, The Open University in the North West, 70 Manchester Road, MANCHESTER, M21 9UN
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In a recent letter to U.Chem.Ed, Tomlinson[1] refers to the value of students reflecting on their learning experience. Tutors need to do the same, and encouraging them to do this has been part of the strategy of the Open University's staff development programme for its Associate Lecturers for several years. Indeed the term 'reflective practitioner', alongside 'facilitator of learning' has become the hallmark of the effective tutor. This approach is thoroughly expounded in the Supporting Open Learners Reader[2], and some practical suggestions are given in the Open Teaching Toolkit: *How do I know I am doing a good job?*[3]. Reflection is even described as the "core process for effective professional learning.[4]

Both these texts[2,3] recognise that tutors need not only to be effective practitioners themselves, but also to encourage their students to develop the habit of reflection on learning. The justification is that "students become more aware of how they learn, and thus enable themselves to be more proactive in managing their own study strategies," [5]. There is some evidence that students gain from this: an Open University tutor on an organic chemistry course, writing to an Examination Board, says that she sends out letters "asking students to reflect on their work and to share their insights with me."[6]. She continues: "Among my students this has been productive", although she adds "even if many of their responses are just at the intuitive level, and do not develop deeper objective thinking." Unfortunately, this is a rare example of even limited success with encouraging reflection.

In a bold experiment in 1998, the new science foundation course, *S103: Discovering science*, included short, assessed (but low scoring) questions asking students to reflect on their study and learning strategies. These questions led students to explore in a structured way how they interacted with the course materials - both successfully and unsuccessfully, and how they set about answering the questions in their assignments. They were asked, for example, to analyse and describe skills used in a particular task, like interpreting graphs; how they had formulated an answer plan, and whether they had adhered to it; if they had developed a problem solving strategy, and whether it had proved effective for a particular problem they had encountered; and which parts of a question they thought they had answered well (or not so well), and why. These questions were not set in isolation, but within the context of a detailed *Study File*, which also gave them structured opportunities to practice reflection.

These questions met with a variety of responses from students, most of which were negative. Students felt puzzled, scared, worried, bored, and affronted by them. Many students considered them a waste of time, and a large number either simply did not attempt them, or returned fairly banal answers. This suggests that they were also disregarding the similar exercises set in the *Study File*. So it would appear that providing students with encouragement and opportunities to reflect on their learning[6] is not enough. Tutors also need to convince them that spending time and effort on reflection is worthwhile.

1. Tomlinson J 1998 Reflecting on learning, *U. Chem. Ed.* **2** 35
2. *Supporting Open Learners Reader*, Open University 1996, Chapter 7.
3. *Open Teaching Toolkit: How do I know I am doing a good job?* Open University 1997
4. Reference 1, p.102
5. Reference 1, p.101
6. Wood H, *S246: Organic chemistry*, Tutor Monitor's report to the Examination Board, November 1998

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It was interesting to read the letter by Jane Tomlinson in the recent issue of U.Chem Ed[1] about reflecting on learning. In the course of teaching to which she refers, an FDTL project being developed here at UEA on 'Personal and Professional Skills for Scientists', we have made reflection about learning a central feature of the teaching. The course will eventually contain ten units of teaching, comprising about forty individual learning activities. Almost all of these activities are concerned with teaching students how to conduct themselves productively when working on problems in small group situations.

We quickly found that most students are not aware of how and why they act as they do in the social contexts of group activities. For example, laddish behaviours appropriate to the pub or to the coffee bar were evident, and do not work in serious groups. Some students became seriously confused and could not understand where they were going wrong. When we started researching our teaching, it quickly became clear that the skills of working closely with other people - talking, listening, negotiating points of view, leading and being lead, supporting, accepting group responsibility *etc.* - are not practised very much, if at all, in conventional teaching and learning situations in most HE courses. It was also clear that students would not learn the skills required without practising them and being given guidance and feedback on what they were doing and how well they were doing it.

Common sense and Educational Psychology both suggest that social skills, like other skills, are learned through repeated practice with feedback. They also suggest that this learning cycle will be speeded up if the learners have explicit knowledge which they can use to consider and change what they do, according to how successful it has been. This is where reflection plays such a key role. If we were able to instruct the students in types of behaviour which were productive - good talking and listening skills for example which are crucial to good group work - then the students can very quickly recognise these behaviours in themselves and in others and, on reflection, make adjustments and improve themselves. This is the guiding principle behind our use of reflection in our teaching activities. However, reflection by itself is not enough. Clearly, the learner must have a serious need to learn and without this the reflection becomes gratuitous, and students will quickly tell you so. It is not enough just to get the students to consider what they did and how they did it. An improvement in the skill must be rewarding in some way or other. In our course, the students assess each other very seriously - the skill of assessing colleagues, and accepting assessment from colleagues, is one of the things to be learned in the course - and unless an individual student gets the grades from his/her colleagues, they will do badly on the course and could fail. This focuses minds wonderfully and actually works very well. But this can only be done when the students have a framework for reflecting on how well they, and others, have worked. It also requires a great deal of confidence in colleagues, something which is also very important in group work, which some students find it very difficult to learn.

So, we have found that reflection on how things have gone, together with a clear framework of ideas with which to consider behaviours and events, and positive reason and purpose for changing and improving a skill has worked very well in the course we have put together. Perhaps other science skills (practical work, project work *etc.*) could be improved in the same way.

1. TomlinsonJ, 1998, Reflecting on learning. *U.Chem.Ed.* **2** 35.

Assessment of CIT courses

From Dr R B Moyes, Department of Chemistry, University of Hull

I was grateful for the sight of the paper by Murphy, Hursthouse and Stickland[1] and an opportunity to contribute to the debate on assessment of computer skills. The lack of such assessment was criticised in the *HEFCE* assessment of teaching in the 1993/4 series, and was commented on in the Overview Report[2] with the comment. Institutions emphasize the importance of acquiring general or transferable skills in addition to subject specialist skills, although it is rare to find transferable skills being assessed. It is clear that the aims of inculcating specialist and transferable skills are being achieved, but with varying success.

These skills include Computing and Information Technology (CIT). Most universities have courses to familiarise students with the local network and computer facilities, but there are substantial difficulties in bending this teaching to acceptable assessment. The problems include:

- the heterogeneity of CIT experience in the intake;
- the rate of change in software and hardware;
- the range of software available and its match to the university's provision;
- the wide range of mathematical and communication skills;
- student and staff unwillingness to recognise the value of chemistry-related CIT skills;
- staff unwillingness to 'dilute' chemistry teaching by spending time on skills development;
- lack of agreed objectives for the module;
- assignments which encourage plagiarism;
- reliability difficulties of examining using computers.

All of these make fair assessment difficult. In the 1994 Variety in Chemistry Teaching conference I suggested aims for a CIT course and produced a 'wish list' for its content, most of which is still relevant, in spite of the speed of change in this area[3].

At Hull, Chemistry students take a 10 credit (100 study-hour) module in CIT during the first or second year. Its aims are:

- To make students competent in the use of computers at a level appropriate to the graduate.
- To make students capable of using computers to enhance their learning.
- We interpret these aims in the following competence objectives (which are similar to those of Murphy et al):
- use of the university network, Windows 3.1, e-mail and the Internet;
- use of MS Word and the associated Equation Editor;

- use of Isis Draw;
- use of the Excel spreadsheet for handling data, graphical representations, templating and mathematical modelling;
- more specifically, use of the Excel statistics functions to deal with chemistry-related problems;
- use of databases, CD roms, and external reference sources.

The current work schedule is available (4), but it is updated annually to deal with local and general changes. At the beginning of the module, students are told that they have to complete a 'project'[4] which counts as 70% of the module mark. The topic must be different for each student, so that straightforward copying is not possible.

The 'practical' sessions allow students to consult demonstrators and each other. Independent working to suit student experience and ability is achieved by setting a series of exercises which are held on the Network server, and which can be tackled at their own pace. The exercises require students to enter data accurately, but demonstrate that data sets can be loaded more accurately than entering by hand.

There is a problem with setting a fair assessment in CIT early in the course because of the variable backgrounds of students. Schools and colleges now have extensive CIT facilities and the Dearing II (16 to 19) report underlined the need for CIT as part of the A level syllabus[5]. The new Chemistry syllabus includes statements to that effect. Thus most 18 year olds now have a grasp of CIT, although is does not usually extend to working with a network. Mature students often have difficulties in the beginning but more easily recognise the importance of key skills. Because of these variable student backgrounds, in the early stages of the course we correct word-processing and spreadsheet assignments (often sent by e-mail) as formative assessment, but record no marks.

Assessment of the Excel part of the module takes the form of a one-hour test of statistics and data handling. The time constraint requires students to be familiar with the computers as hand calculation is much slower and data sets can be downloaded from the server into Excel rather than entered by hand. This measures the level of competence to a large degree. The formal examination conditions require individual effort.

Assessment of 50 or more different projects is a large task, and the university's requirement that no module assessment was to be in the hands of a single member of staff raises further difficulties. Until recently this involved averaging with the mark of a colleague, but an alternative approach based on Murray's work[6] has proved highly successful. Briefly the class is divided into small groups who each mark the (anonymised) projects to a given marking scheme. The group then compare their marks and reach a second, joint conclusion. The mark is then moderated with a staff mark to ensure consistency. This has the advantage of demonstrating the ideas of standards, marking schemes, and the wide range of competence which has to be assessed. Student response has been encouraging; they have suggested a separate exercise on earlier projects should be undertaken earlier in the course.

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1. Murphy B, Hursthouse M, Stickland, R 1999 The idea of a closed book IT examination: a novel approach to assessing chemistry specific information technology, *U.Chem.Ed.* **3** 8
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4. http://science.ntu.ac.uk/chph/improve/improve.html
5. Dearing R, Review of Qualifications for 16-19 year olds, COM/96/459, SCAA Publications, Hayes Middx. 1996
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   Journal articles:

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   - Johnstone AH and Letton KM 1990 Investigating undergraduate laboratory work *Educ. Chem.* **27** 9-11

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