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Chemistry Education Research and Practice

The journals, *University Chemistry Education*, published by The Royal Society of Chemistry, (http://www.rsc.org/uchemed/uchemed.htm) and *Chemistry Education Research and Practice*, published from the University of Ioannina, (http://www.uoi.gr/cerp/) have merged with effect from January 1st 2005. The new, fully electronic journal is published by The Royal Society of Chemistry under the title: ***Chemistry Education Research and Practice,*** and it will continue to be available free of charge on the Internet**.** There are four issues per year.

The new journal is edited by Georgios Tsaparlis (gtseper@cc.uoi.gr) and Stephen Breuer (s.breuer@lancaster.ac.uk) and intends to maintain the high standards set by its predecessors. Its editorial policy will be the following.

'*Chemistry Education Research and Practice*' is the journal for teachers, researchers and other practitioners in chemical education. It is the place to publish papers on:

- research, and reviews of research in chemical education;
- effective practice in the teaching of chemistry;
- in depth analyses of issues of direct relevance to chemical education

Contributions can take the form of full papers, preliminary communications, perspectives on methodological and other issues of research and/or practice, reviews, letters relating to articles published and other issues, and brief reports on new and original approaches to the teaching of a specific topic or concept.

The new journal welcomes contributions of the type described above; these should be sent to cerp@rsc.org.

Chemistry Education Research and Practice

Guidelines for Authors

Submission of contributions

Chemistry Education Research and Practice (CERP) is the journal for teachers, researchers and other practitioners in chemical education. It is published free of charge, electronically, by The Royal Society of Chemistry, four times a year. It is the place to publish papers on:

- research, and reviews of research in chemical education;
- effective practice in the teaching of chemistry;
- in depth analyses of issues of direct relevance to chemical education

Contributions can take the form of full papers, preliminary communications, perspectives on methodological and other issues of research and/or practice, reviews, letters relating to articles published and other issues, and brief reports on new and original approaches to the teaching of a specific topic or concept.

1. The original contribution should be submitted electronically, preferably in Word for Windows format. Any associated diagrams should be attached in JPG or GIF format, if possible. Submissions should be made by e-mail as a file attachment to cerp@rsc.org, or directly to the editors: Stephen Breuer at s.breuer@lancaster.ac.uk or to Georgios Tsaparlis (gtseper@cc.uoi.gr).

2. Submitted contributions are expected to fall into one of several categories (listed above). Authors are invited to suggest the category into which the work should best fit, but the editors reserve the right to assign it to a different category if that seems appropriate.

   A word count (excluding references, tables, legends etc) should be included at the end of the document.

3. Presentation should be uniform throughout the article.

   Text should be typed in 12pt Times New Roman (or similar), with 1"/ 2.5 cm margins, double-spaced, unjustified, ranged left and not hyphenated.

   Always use an appropriate mix of upper and lower case letters: do not type words in uppercase letters either in the text or in headings. **Bold** or *italic* text and not upper case letters should be used for emphasis.

   All nomenclature and units should comply with IUPAC conventions.

   Tables and figures should be numbered consecutively as they are referred to in the text (use a separate sequence of numbers for tables and for figures). Each should have an informative title and may have a legend.

Equations should be written into the text using the word processing program, either as normal text or using the program's equation facility.

Structures should, wherever possible, be treated as a figure and not incorporated into text.

References should be given by the name of the author (or the first author, if more than one), followed by the year of publication. If an author has more than one reference from the same year, then it should be given as Smith 2001a, Smith 2001b, etc.

Footnotes should be generally avoided and important additional information may be referenced and included in the reference list.

4. A title page must be provided, comprising:
   - an informative title;
   - authors' names and affiliation, full postal address and e-mail; (in the case of multi-authored papers, use an asterisk to indicate one author for correspondence, and superscript a, b, etc. to indicate the associated addresses);
   - an abstract of not more than 200 words;
   - keywords identifying the main topics covered in the paper

5. Wherever possible articles should be subsectioned with headings, subheadings and sub-sub-headings. Do **not** go lower than sub-sub-headings. Sections should not be numbered.

   The introduction should set the context for the work to be described; include references to previous related work, and outline the educational objectives.

   A concluding section (which need not be headed conclusion) will include an evaluation of the extent to which educational objectives have been met. A subjective evaluation may be acceptable.

6. The formatting of references should follow the following practice:

   Books and Special Publications:
   Author A., (year), *Title of the book italicized*, Publisher, Place of publication, page no. if applicable.

   Journal Articles:
   Author A., Author B. and Author C., (year), Title of the article in Roman type, *Full Name of the Journal Italicised*, **Volume no. in Bold**, inclusive page numbers.

   For example:
   Osborne R. and Freyberg P., (1985), *Learning in science: the implication of children's science*, Heinemann, London.

   Jackman L.E. and Moellenberg W., (1987), Evaluation of three instructional methods for teaching general chemistry, *Journal of Chemical Education*, **64**, 794-96.

7. All contributions submitted will be refereed anonymously by two independent referees. In case of a disagreement a third referee will be consulted. The decision of the Editors on

the acceptance of articles is final.

8. Authors grant *CERP* the exclusive right to publish articles. They undertake that their article is their original work, and does not infringe the copyright of any other person, or otherwise break any obligation to, or interfere with the rights of such a person, and that it contains nothing defamatory.

9. Articles will be published on the Web in PDF format.

Student recognition and construction of quality chemistry essay responses

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Abstract: Students in chemistry traditionally experience more difficulty responding to essay questions than to calculating a numerical answer for the same concept. The purpose of this study is to investigate students' understanding of what constitutes a complete and cogent essay answer in chemistry. Preliminary data from thirty-nine non-science majors support the hypothesis that students do not reliably recognize or construct adequate responses to chemistry essay questions. In addition, students' intention to construct a complete and cogent argument is compared to their actual responses. Inability to construct complete and cogent arguments may result in lower achievement scores on essay questions. Since essay questions are typically used to test both achievement and the effectiveness of innovative teaching practices, this situation may mask significant research results. These data suggest the need for a more extensive investigation of student construction of quality essay answers in chemistry as well as in other sciences. [*Chem. Educ. Res. Pract.*, 2006, **7** (3), 160-169]

Keywords: assessment, open-ended questions, cognitive load, essay questions, research methodology

Introduction

In many large university general chemistry courses, multiple choice and numerical application problems have traditionally been the assessment method of choice due to ease of administration, but such questions do not adequately measure student understanding (Moore, 1997). Student understanding can be explained in terms of Ausubel's continuum between meaningful learning and rote learning (Novak and Gowin, 1984). Rote learning lends itself more easily to being tested by multiple choice questions, while meaningful learning is better assessed through essay-type questions. Research also shows that students do not perform as well on essay or short answer test items as they do on multiple choice test items (Danili and Reid, 2005). In spite of this fact, essay questions are often used as a means of evaluating the effectiveness of innovative teaching methods which stress meaningful learning (Bodner, 1991; Oliver-Hoyo et al., 2004). Since both assessment of student understanding and evaluation of the effectiveness of teaching innovations depend on the quality of student responses to essay questions, it becomes important to ascertain why students are not performing as well on these questions. The problem may be either that students don't know the science to answer the question or don't realize the logic necessary to construct an adequate answer. The purpose of this study is to investigate this problem in terms of whether students can recognize and/or construct complete and cogent responses to essay questions in chemistry.

Inherent in the assessment of students' understanding of chemistry is the cognitive demand of both the subject of chemistry and the way chemistry questions are asked. Cognitive Load Theory (Sweller, 1994) identifies two factors of information processing that should be taken into consideration in student assessment: 1) the nature of the subject being assessed (intrinsic variable) and 2) how the assessment is designed (extraneous variable).

In chemistry, the magnitude of the intrinsic variable is high due to the fact that there is much interaction among the elements of each concept. For instance, it is difficult to study bonding if you don't understand molecular polarity. Molecular polarity, as predicted by VSEPR theory, requires in turn knowledge of Lewis Dot diagrams. Using Lewis Dot diagrams is based upon an understanding of electron configuration, which in turn is based upon an understanding of atomic structure. So, a seemingly 'direct' question on bonding requires knowledge of at least five other chemistry concepts and empirical measures. This inter-relatedness of concepts and empirical measures increases the intrinsic variable of answering chemistry questions regardless of the assessment format.

The second factor of Cognitive Load Theory is the extraneous variable, which deals with how the assessment is designed. For instance, there are several ways to ask a density problem on a test including determination of a numerical answer and/or explanation based upon the chemistry concept. In the simplest form, a student can be asked to calculate the density, given the mass and volume. Here the student essentially 'plugs and chugs' through the problem. Understanding of the concept is not as important in this situation as the application of a numerical algorithm. The extraneous load can be increased by asking the student to explain why something happens, such as why lead is more dense than iron. Here, the student must present both the underlying concept of density and explain it in a logical argument. As the extraneous variable increases, fewer students can determine the correct answer.

One advantage of using essay questions in chemistry is that the process of answering them helps students organize their information in long term memory (Wandesee et al., 1994). The ability to organize information in long term memory is critical to the transition from novice to expert understanding. Experts effectively organize their knowledge in long term memory, and this organization facilitates their ability to learn new information. Novices, on the other hand, do not organize their knowledge effectively in long term memory. As a result, their knowledge is often fragmented and thus does not help them learn additional information. Novices can be supported in their reorganization of knowledge through practice in planning responses to essay questions.

In assessment using essay questions the emphasis is not only on *what* happens but also on *why* it happens. This change should help shift the focus from students memorizing information to their placing emphasis on truly understanding the concepts and the way in which these concepts are related. Such a shift should increase the organization of information in long term memory, thus aiding in the transition from novice to expert. An added benefit of using essay questions is that they can be used by the teacher as a formative evaluation, which helps to reveal where students experience a lack of understanding or misconceptions about a chemistry concept.

Once the decision is made to include essay questions in chemistry, some thought must be given to the structure of such questions. The need to keep directions simple and avoid overloading the short term memory capacity of the student is essential (Cavallo et al., 2003). In addition, the amount of information that the student must process simultaneously should be kept to a minimum. The inclusion of key terms that serve as 'anchors' for the schemas that students used to store the original information will help ensure that students address the question asked in the way the teacher has planned.

Even if essay questions are constructed in keeping with Cavallo's theory, students still need specific instruction and practice in addressing them. Such instruction includes allowing students access to the objective and explicit rubric used to grade their answers, as well as timely feedback so that students can learn from their mistakes (Kovac and Sherwood, 1999). Experience with teaching essay writing in chemistry (Russell, 2004) has shown that students need multiple exposures to both critiquing and writing chemistry essays in order to develop the skill of producing persuasive and logical arguments.

In this study it was hypothesized, based upon Russell's (2004) research, that if students had practice evaluating sample answers to essay chemistry questions in terms of completeness and cogency, they would be better able to construct quality answers to the same questions on a separate occasion. It was further hypothesized that the opportunity to plan an answer to such questions would improve student responses by providing them with an opportunity to organize their knowledge in a more expert fashion. Additional variables of logical reasoning ability and year in school were also investigated for their effect on the construction of quality answers to chemistry essay questions.

Research questions

Complete essay responses are those that clearly and fully address the questions asked, while cogent responses use a logical argument as a means of answering the question. Quality answers to questions should be both complete and cogent, but student answers often are not. Less ideal answers can be complete but not cogent, cogent but not complete, or neither complete nor cogent.

The following research questions were investigated in this study:

1) Can students *recognize* a complete and cogent response to a chemistry essay question?
2) Can students *construct* a complete and cogent response to a chemistry essay question?
3) Does the practicing of evaluating sample essay responses for completeness and cogency increase student ability to construct quality answers to the same questions at a later time?
4) Does a relationship exist between students' planned and actual responses to chemistry essay questions?

Methodology

Sample

The sample for this study was thirty-nine undergraduate students (first through fourth year) enrolled in a chemistry course for non-science majors at a small private university in the Mid-Atlantic region of the USA. The experimental design of this study was reviewed by the University to ensure compliance with Protection of Human Subjects Protocol.

Essay questions

The questions in this study were essay questions used on exams from a previous year. They included questions on the topics of infrared absorption, interpretation of IR spectra, gasoline octane ratings and applications of entropy. Sample questions are shown in Figure 1.

Figure 1. Sample essay questions.

Exercise 4-1 (Gasoline). You and your younger brother fill up the family car with fuel on vacation. Your brother asks if there is really any difference besides price between regular and premium gasoline. Based on what you learned in this course, what would you tell him? Be sure to include as much chemistry as you can (just to impress him).

Exercise 4-3 (Entropy). Entropy is involved in many of the things you do in real life. For instance, in cooking when you melt a stick of butter, entropy is involved. Explain what happens in terms of entropy when solid butter is melted. Support your answer.

Instruments

Group Assessment of Logical Thinking (GALT) test

It was hypothesised that students' logical thinking ability would influence their ability to construct cogent essay responses. The Group Assessment of Logical Thinking (GALT) test (Roadrangka et al., 1982) was therefore used to measure logical reasoning ability. This test consists of 12 questions, each of which involves a correct answer and a reason for that answer. GALT scores range from 0 to 12. An online version of this test was used in this study.

A frequency distribution of scores was used to determine natural cut-off points for high (9-12), medium (7-8) and low (0-6) GALT levels in this sample. Due to the small number of students in the medium GALT level, this level was excluded from analysis. The number of students in the remaining GALT levels is given in Table 1.

Online survey

It was further hypothesised that students' ability to write complete and cogent essay responses would improve with their advancement in the University as measured by their class level. Demographic data, including undergraduate class level, were collected via an online survey. Table 1 summarizes the number of students in upper (third and fourth year undergraduate) and lower (first and second year undergraduate) class levels.

Table 1. Number of students by GALT and class level.

Characteristics of Subjects	Levels	Contents	Number of Students
Class Level	Lower	First and Second Year Undergraduates	21
	Upper	Third and Fourth Year Undergraduates	17
GALT Level	Low	Scores 1-6	15
	High	Scores 9-12	16

Online exercises

Students completed online exercises 24-hours prior to taking an in-class examination. As part of the exercises, students *analyzed* sample answers to essay test questions for completeness and cogency using a 5-point Likert scale (1 = extremely complete/ cogent, 5 = extremely incomplete/ non-cogent). In some cases, students were asked to *plan* their responses to essay questions. In addition, on certain essay questions, students were asked to *construct* a response within the context of the online exercise (without access to previous screens) or as part of an in-class examination. Table 2 provides an overview of the type of activity the students were asked to complete for each question in the study.

Table 2. Components required by exercises and examinations.

Question	Topic	Student analysis of essay answers	Student plan for essay answers	Assessment of student responses
Exercise 3-1	IR Absorption	X		
Exercise 3-2	Spectra		X	
Examination 3-1	Spectra			X
Exercise 4-1	Gasoline	X		
Exercise 4-2	Entropy		X	
Exercise 4-3	Entropy			X
Examination 4-1	Gasoline			X
Exercise 5-1	Entropy no. 2			X

Student essay responses were assessed using three subscores: completeness, cogency, and achievement. Subscores were calculated by the researchers, with discrepancies discussed and resolved. Completeness and cogency were evaluated on a scale from 1 (extremely complete/ cogent) to 5 (extremely incomplete/ non-cogent). The achievement subscore was evaluated on a scale of 0-8 points, with points awarded for inclusion of pertinent scientific concepts/ facts and logical arguments. Points were subtracted for inclusion of irrelevant scientific concepts/facts and/or weak arguments.

Results

Can students recognize *a complete and cogent response to a chemistry essay question?* Students were asked to rate four sample answers (labelled A-D) for each of two online essay questions. Sample answers were rated by students in terms of both completeness and cogency on a 5-point Likert scale as described before.

The analysis of the data included parametric methods such as ANOVA even though an ordinal Likert scale was used as the instrument in this study. Parametric methods of analysis were chosen over the nonparametric methods such as Chi Square on the basis of small sample size per cell, loss of power with nonparametric approaches, common use of parametric analysis methods in analyzing Likert scale data in educational literature, and doubts raised by statisticians on the absolute inappropriateness of parametric methods for ordinal data (Velleman and Wilkinson, 1993).

In this study, a mixed between-within subjects ANOVA was used to investigate the difference between student ratings of the four answers (A-D) for each of the two questions. For this test, the dependent variable was the Likert rating of the answers; the within-subjects variable was answer choice (A-D); and the between-subjects variables were GALT and undergraduate class level.

A significant main effect ($p<0.05$) for answer choice (A-D) was found for both questions in terms of completeness and cogency. Overall, students rate the four multiple choice answers significantly differently on both completeness and cogency. Results of the ANOVA tests are provided in Table 3.

Table 3. Difference in completeness and cogency for answers A-D.

Question	Complete			Cogent		
	Wilks' Lambda	F (3,24)	p	Wilks' Lambda	F (3,24)	p
Exercise 3-1	0.44	10.08	0.00	0.34	15.56	0.00
Exercise 4-1	0.13	51.59	0.00	0.13	52.25	0.00

Post hoc testing, with an LSD adjustment, was used to locate the significant differences in student ratings of completeness and cogency for the different answers (Table 4). For exercise 3-1, answer B was evaluated by the researchers as the most complete/cogent answer. Students rated answers B and D as equally complete and cogent, as evidenced by the non-significant difference between their means. Upon review, the researchers determined that these two answers were equally complete, but answer B was more cogent, thus it is understandable that students would have trouble differentiating between the two. A significant difference was found between the means for answers B/D and those for A and C. Overall, B and D were rated significantly more complete/cogent on the Likert scale than answers A and C.

In exercise 4-1, answer C was determined by the researchers to be the most complete/cogent answer. Students also rated answer C as significantly more complete and cogent than all other answers.

Table 4. *Post hoc* testing for differences in completeness and cogency.

Question	Best answer	Complete	Cogent	Distracters	Complete		Cogent	
		Mean[a] (SE)[b]	Mean (SE)		Mean (SE)	p[c]	Mean (SE)	p
Exercise 3-1	B	2.5 (0.19)	2.4 (0.18)	A	3.7 (0.16)	0.00	3.8 (0.18)	0.00
				C	3.7 (0.22)	0.00	3.7 (0.22)	0.00
				D	3.1 (0.20)	0.09	2.9 (0.21)	0.17
Exercise 4-1	C	1.7 (0.21)	1.6 (0.20)	A	4.4 (0.12)	0.00	4.3 (0.14)	0.00
				B	3.0 (0.16)	0.00	3.1 (0.20)	0.00
				D	2.4 (0.18)	0.02	2.3 (0.18)	0.02

[a] 1=Extremely complete/cogent, 5=Extremely incomplete/non-cogent
[b] SE= Standard Error of the Mean
[c] Significance of difference between means for Best Answer and Distracter

For these exercises, no significant main effects were found for either GALT or class level. This indicates that there is no significant difference in student ratings of each answer (A-D) based on logical reasoning ability or level of academic experience. In addition, there were no significant interaction effects between these variables.

Overall, students selected the best answers (B/D for exercise 3-1 and C for exercise 4-1) as the most complete and cogent responses. However, mean student rankings of these responses ranged from slightly complete/cogent to neutral. These results indicate that although students are able to identify the best essay response in both exercises, they are not able to accurately judge the absolute completeness/ cogency of these responses. Mean student rankings for these correct responses are given in Table 5

Table 5. Student rating of correct essay answers.

Question	Complete[a]		Cogent[a]	
	Mean	Std. Error	Mean	Std. Error
Exercise 3-1 (B)	2.5	0.19	2.4	0.18
Exercise 4-1 (C)	1.7	0.21	1.6	0.20

[a]1=Extremely complete/cogent, 5=Extremely incomplete/non-cogent

Can students construct *a complete and cogent response to a chemistry essay question?* Student responses to four chemistry essay questions were evaluated by the researchers in terms of completeness and cogency on a 5-point Likert scale (1 = extremely complete/cogent, 5 = extremely incomplete/non-cogent). Overall, student responses were evaluated as moderately complete (M=2.7, SD=1.3) and cogent (M=2.9, SD=1.4). Mean evaluations of student responses for each question are given in Table 6.

Table 6. Evaluation of student essay responses.

Question	Complete[a]		Cogent[a]	
	Mean	SD	Mean	SD
Examination 3-1	2.5	1.2	3.0	1.3
Exercise 4-3	2.5	1.4	2.9	1.6
Examination 4-1	3.1	1.4	3.3	1.5
Exercise 5-1	2.5	1.3	2.2	1.3
AVERAGE	2.7	1.3	2.9	1.4

[a] 1=Extremely complete/cogent, 5=Extremely incomplete/non-cogent

A two-way between-subjects ANOVA was used to investigate students' ability to construct quality essay responses. GALT level and class level were used as independent variables, with student subscores (completeness, cogency, and achievement) on four chemistry essay questions as dependent variables. No significant main effect was found for either GALT or class level on the subscores of three of the four exercises (Table 7). The fourth exercise differed only in the cogency subscore of student responses, with responses from high GALT students rated significantly more cogent (M=2.6, SD=1.2) than responses from low GALT students (M=3.5, SD=1.3). In addition, responses from lower classmen (first and second year undergraduates) were rated significantly more cogent (M=2.5, SD=1.2) than responses from upper classmen (third and fourth year undergraduates) (M=3.5, SD=1.2). The statistical significance of this difference should be further investigated in a larger study. Overall, in this study, data indicate that students perform equally well in terms of completeness, cogency, and achievement regardless of GALT or class level.

Table 7. ANOVA main effects for GALT and class level on student essay responses.

Question	Independent variable	Degrees of freedom	Completeness		Cogency		Achievement	
			F	p	F	p	F	p
Examination 3-1	GALT level	1,26	1.86	0.18	6.66	0.02	2.76	0.11
	Class level		3.00	0.10	8.07	0.01	1.58	0.22
Exercise 4-3	GALT level	1,26	1.09	0.31	2.01	0.17	2.43	0.13
	Class level		0.05	0.82	0.71	0.41	1.24	0.28
Examination 4-1	GALT level	1,26	0.06	0.81	0.003	0.75	0.85	0.37
	Class level		0.73	0.40	0.74	0.40	0.01	0.94
Exercise 5-1	GALT level	1,18	1.92	0.18	1.55	0.23	1.23	0.28
	Class level		0.28	0.60	1.66	0.22	0.88	0.36

Does the practicing of evaluating sample essay responses for completeness and cogency increase student ability to construct quality answers to the same questions at a later time? Students were asked to rate the completeness and cogency of essay answers to one chemistry essay question that was later given in a testing situation. A Pearson Product-Moment Correlation Coefficient was used to investigate the relationship between students' evaluation of the correct essay answer and the completeness/cogency of the students' own answers to the same question in a testing situation. There was no significant correlation for either completeness [r=-0.032, p=0.846] or cogency [r=0.105, p=0.524]. In this study, students' ability to construct complete/cogent essay responses is therefore not correlated with their ability to rate the completeness/cogency of responses to the same question. It was hypothesized that prior evaluation of a question and its possible answers would increase the quality of the students' responses to the same question. The data suggest that this is not necessarily true since the planning and the students' answers to the same question in a testing situation given within 24 hours showed no significant correlation.

What is the relationship between students' planned and actual responses to chemistry essay questions? For two questions (exercises 3-2 and 4-2), students were presented with a question and asked to plan a response by selecting options from the following list to include in their answer:

- *Definition* of science principles or concepts.
- *Use* of science principles or concepts.
- Graph.
- Drawing or diagram.
- Chemical equation.
- Calculation.
- Discussion at the molecular level.
- Example from the real world.
- Other.

Although selecting options to include in a response is not the same as a detailed plan for constructing an essay answer, the selection of options by the students suggests an overall reflection on the type of information that would be included in an essay response.

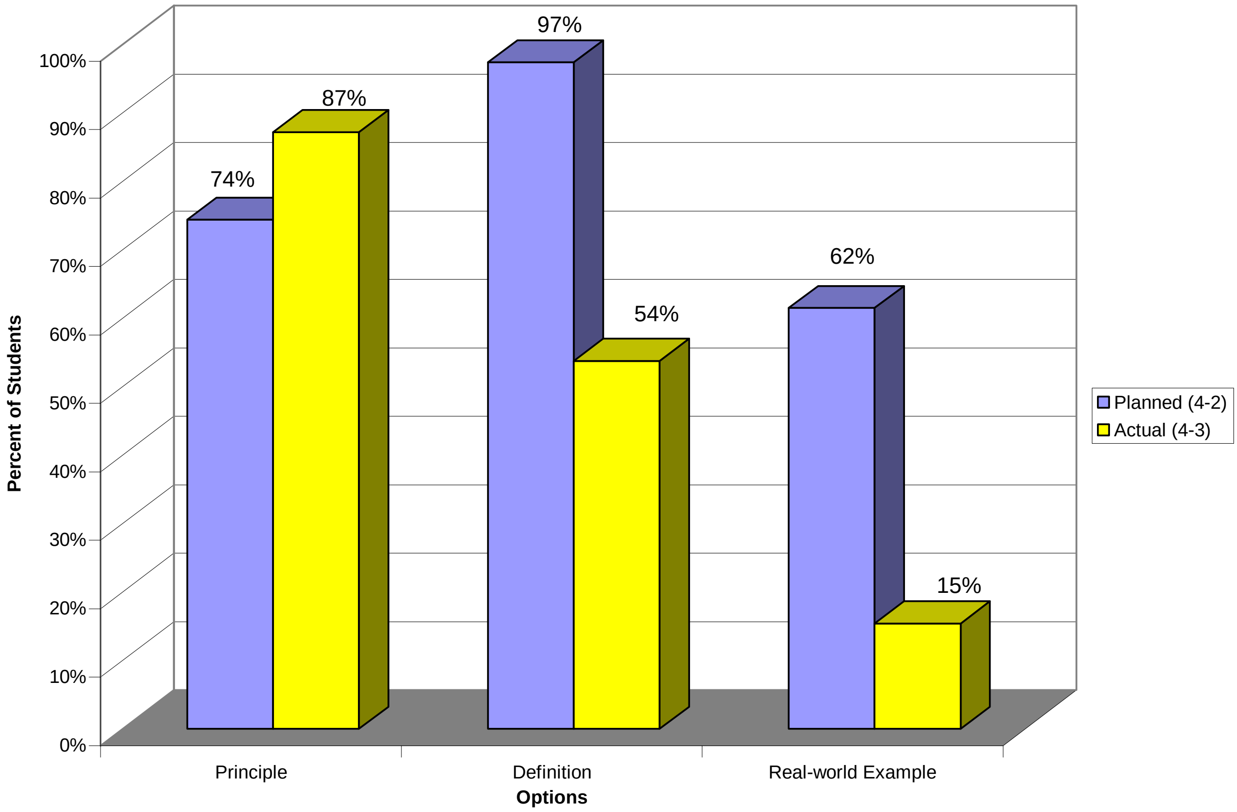
Following these exercises, students were asked to construct an answer to the same question either online or in a testing situation. Student responses were analyzed to determine which of the criteria from the above list were included. Analysis shows that students rely primarily on principles and definitions to both plan and answer essay questions. Students' use of definitions in their responses, however, was lower than planned, while students' use of principles in their responses was higher (Figure 2). The general match between the specific options selected from the list during the planning and the evaluation of options actually used in the answer suggests that students did choose options that reflected their intention in terms of answering the question.

Discussion

Data show that students are able to identify correct essay answers, but are not able to judge accurately their absolute completeness or cogency. Similarly, when asked to construct their own responses, students are unable to provide extremely complete or cogent arguments.

One would expect students with high logical reasoning ability and/or extensive experience at the university level to be better able to construct and identify quality responses to chemistry essay questions. This expectation, based upon GALT and class level, is not confirmed in this study. This may indicate two things: 1) students are approaching the study of chemistry as novices and 2) students have difficulty applying quality essay-writing approaches in this content area. As expected of novice essay writers, students in this study rely primarily on principles and definitions to plan and answer essay questions.

Figure 2. Planned vs. actual student response for exercise 4-2 vs. 4-3.



Implications for researchers

In order to rely on essay questions as a measure of student understanding, the questions themselves must require a demonstration of understanding, analysis, or application, Simple open-ended questions that rely on recall should not be classified as essay questions that test for understanding. Although chemistry courses may never rely totally on essay questions to test for knowledge and understanding, more teachers are including essay questions as a component of their assessments. These assessments are used both to test for understanding on the part of their students and as a way to gauge the impact of teaching innovations on student learning. Research that uses student responses to chemistry essay questions as the basis for achievement is in jeopardy due to the demonstrated inability of students reliably to recognise and construct complete and cogent responses. Student exposure to sample answers with a range of completeness and cogency was insufficient training to improve student success. The literature supports this finding, and further suggests that training in essay-writing in chemistry must be deliberate and extensive (Russell, 2004). Thus, researchers who choose to rely on student responses to essay questions as an indication of student achievement or conceptual understanding should be aware of the intervening effect of inadequate student essay-writing ability.

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Contrasting the expectations for student understanding of chemistry with levels achieved: a brief case-study of student nurses

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Abstract: This case study examines the understanding of a small sample of nursing students in some aspects of general chemistry. In the United States most nursing programs require college-level nursing courses, with expectations that students will master basics of first-year general chemistry. Anxiety to achieve passing grades in such courses is high for nurses, and the courses are sometimes seen as a gatekeeper for who has access to the profession. This study examines understanding achieved for a small sample of nursing students regarding aspects of matter — basic ideas regarding understanding of matter composition, structure, amounts and properties. Our intention is to highlight the contrast between what chemistry knowledge is expected of nurses and what level they actually achieve, and what this may mean for their future professional performance. Findings include that the nursing students in the sample had limited understanding of the university-level chemistry they were being asked to master, and exhibited less comprehension and more pervasive misconceptions than comparison groups, including first term high school students, in our sample. [*Chem. Educ. Res. Pract.*, 2006, **7** (3), 170-184]

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Introduction

In a discipline such as chemistry, it is sometimes asked whether students really need to learn the material to which they are being exposed. Some argue that perhaps the exposure itself, as an 'exercise of the mind' or even as 'armchair touring' of a new intellectual domain, is sufficient when studying sciences such as chemistry, unless the student has plans to become a scientist, doctor or engineer.

One argument in favor of improved levels of scientific literacy often is that demands of so many of today's career paths require at least some and often much understanding of basic science. Here we look at a brief case study of nursing students studying chemistry, and the demands placed on their scientific knowledge by their field. Data in this paper include assessments on a group of about seventy nursing students at the completion of their required general chemistry training for satisfaction of certification requirements in a degree program leading to the RN, (registered nurse) license granted to professional nurses in the U.S., along with a bachelor's degree. The nursing students were among several different levels of chemistry students assessed in the development of assessment instruments for an NSF-funded project called ChemQuery (Scalise, 2004) and were selected only as a 'convenience sample', students readily available through their instructor and willing to participate to gain some extra credit in their course. This brief case study is not intended as a broad analysis of the chemistry training of nursing students, but is illustrative of the dilemma of the degree to which careers today can place high demands on science knowledge for the broader population.

While we expected to see previously well-documented misconceptions (see section on Conceptual Change) from the high school students in our sample, we were surprised to see an even greater level of misconceptions (a higher percentage of students broadly exhibiting misconceptions) from this sample of university-level students. In assessing chemistry students with varying instruction in the discipline, our hypothesis had been that, for the sample groups with which we worked, we would find the least understanding at pretest in high school students (with no former chemistry-specific coursework), followed by high school students at post-test after instruction, first-year university students in chemistry in non-science major tracks such as nurses, first-year university students in chemistry in science/engineering major tracks, second year chemistry students (students who stay with chemistry through second year tend to be science/engineering majors) and science students at the completion of their second year studies in chemistry. Our studies found this trend, with the notable exception of first-year university students in the biomedical, nursing pathways, for whom post-test scores were lower than the high school student post-test scores and close to high school students at pretest (novice to any formal instruction), showing major embedded misconceptions regarding basic characteristics of matter and of reactivity.

Overview of some aspects of nursing, as they relate to the need to know chemistry

Chemistry often is viewed as an essential foundation for the health professions, not just for doctors but for nurses, paramedics, technicians, respiratory therapists, waste disposal professionals and many others who handle the wide and still growing range of chemicals in modern healthcare. That this is a large group of people is undeniable. In the United States alone, there are over 2 million jobs for registered nurses, and "*nursing is the largest of all the health care occupations and the second largest of all professions…. (Teaching is the largest profession in the U.S. today.)*" (Lanzer, 2000). In addition, the health care sector is growing: it is "*one of the top 10 occupations projected to have the largest number of new jobs through 2008.*"

Nurses today can be called upon to act with a great deal of autonomy in monitoring and responding to complex technical situations. Cytotoxic drugs are common and considerations such as what the drug is, dosage and concentration are important to understand. When treated patients return to their units, general-care nurses are often responsible for chemical safety considerations and toxic waste disposal concerning byproducts of the dangerous drugs. Furthermore, as nurses train for their disciplines and specialties, coursework in physiology, microbiology and biochemistry classes often requires a basic understanding of chemistry.

Thus, accreditation groups for nursing education in the U.S. tend to require significant education in chemistry. While licensing for nurses in the U.S. is the responsibility of each state, the U.S. Department of Labor Bureau of Labor Statistics (U.S. Department of Labor, 2006) reports that as a general trend across the U.S., university level chemistry courses are required for nurse training programs. For the nursing students in this sample, the chemistry course requirement for completion of the nursing program is a one-year sequence, consisting of one 10-week term of general chemistry and then a term each of more advanced coursework in organic and biochemistry. Students in this study were assessed at the end of general chemistry, which consisted of 10 weeks of instruction at six contact hours per week, a total of 60 contact hours. Students are also expected to spend an additional eight hours per week on course assignments in general chemistry during this time, for a total of 140 hours spent over the term engaging with the concepts and ideas of general chemistry. This had been believed to be sufficient to build a base of understanding for more advanced work in organic and biochemistry, and to support subsequent learning in physiology and microbiology courses.

Additionally, while chemistry is perceived by the profession as an important required course for many individuals in the healthcare sector, it has been reported that ‘chemistry anxiety’ can run high for students enrolled in chemistry courses (House, 1995; Eddy, 2000). For the purposes of this paper, we include here a few nurse-specific ‘chemistry anxiety’ comments, citing from one thread of discussion on balancing chemical equations by student nurses in an Internet nursing discussion forum (allnurses.com, 2004). The discussion began with a question from a student nurse about balancing a reaction for a class being taken, and launched a torrent of discussion on the fears and anxieties associated with study of chemistry. Student nurses commented on homework solutions that they had been told were correct but they could not ‘see’ why the solutions were correct. Others talked about the difficulties in recognizing what their chemistry textbooks were talking about, and described how chemistry was an aggravating class because they felt they had limited ability to make sense of the coursework. One student nurse commented: “*I’m taking chem. starting in July and y’all are scarring the H.E.L.L out of me....*”

Conceptual change in chemistry: a brief review of some of the literature

Many researchers studying student conceptions and misconceptions in chemistry have focused on student understanding in two areas: the structure of matter and reactivity. Here we will share a few of the classic studies and seminal papers in chemistry misconception research. Regarding matter, many students even after instruction of from weeks to months retain a ‘concrete, continuous’ view of atoms and molecules, in which each particle retains the macroscopic properties of a small piece of its parent substance (Ben-Zvi, Eylon, & Silberstein, 1986). Subjects often believe water molecules, for instance, contain components other than oxygen and hydrogen, such as water, air, chlorine, minerals and ‘impurities’, or may have shapes in different phases, e.g. water molecules frozen into ice cubes are square (Griffiths & Preston, 1992). Individual molecules can be ‘hot’ or ‘cold’, and belief in atoms and molecules as alive is common (de Vos & Verdonk, 1985).

Regarding reactivity, gaseous products or reactants are often ignored (Hesse & Anderson, 1992), reflecting the view that substances that float in air have no mass and thus are not substances that need to be conserved (Samarapungavan & Robinson, 2001). Even after university level instruction, most students do not understand chemical reactions as reorganization of atoms, with breaking and re-formation of bonds. For instance in one study, only 6% of secondary and 14% of university chemistry students could, after instruction, describe chemical reactions as the breaking and re-forming of bonds (Ahtee & Varjola, 1998). Students often ignore laws and theories of reactivity, and transform equation writing into a mathematical game of getting symbols to add up (Yarroch, 1985).

Driver and other researchers have emphasized the interplay among the various factors of personal experience, language and socialization in the process of learning science in classrooms and argue that it is important to appreciate that scientific knowledge is both symbolic in nature and also socially negotiated (Driver and Scanlon, 1989; Driver, et al., 1994). By socially negotiated, these researchers mean that scientific entities and ideas are unlikely to be discovered by individual students through their own empirical enquiry, so learning science involves being initiated into the ideas and practices of the scientific community.

Hesse and Anderson (1992) have argued that it takes time to build sufficient understanding to be able to combine scientific models with prior knowledge and develop working understanding on which knowledge of chemistry can build. They argue that while the rules for writing and balancing chemical equations are fairly simple, the equations that result are meaningful only when they are embedded in a complex ‘conceptual ecology’ — an array of facts, theories, and beliefs about the nature of matter and the functions of explanation that chemists have developed over time, and that is part of the discourse language in chemistry.

In this study of student nurses, we see the research on the strength of misconceptions and on the length of time involved in developing a working knowledge of chemistry as being in conflict with the practice of training nurses, where they are expected to develop substantial understanding of general chemistry in just 10 weeks of study and with the students' experience of anxiety when confronted with material beyond their mastery.

Theoretical framework

We are currently engaged in developing a formative assessment system for classroom-based use in high school and university-level general chemistry, using the BEAR (Berkeley Evaluation & Assessment Research) Assessment System (Wilson and Sloane, 2000). The goal of the project is to develop one approach, of perhaps many possible useful approaches, to an assessment system for general chemistry that can map student progress in their comprehension and use of overarching ideas. The assessment system uses a framework called the *Perspectives of Chemists* (Claesgens, et al., 2002) of some of the key ideas in the discipline and criterion-referenced analysis with item response models (IRT) to map student progress.

To interpret the findings in the data section of this paper, it is important to have an understanding of the levels of the Perspectives framework, see Figure 1. On a 15-point scale, with 15 points as the highest score:

- Students score 1-3 for answers that exhibit a *Notions* view on assessment tasks. Notions answers involve the use of sound reasoning skills such as pattern matching, logic, real-world experience and mathematical skills *but no normative science models* to respond to questions and tasks.
- Students score 4-6 for answers that exhibit a *Recognition* view on assessment tasks. Recognition answers involve the use of a very simplistic single aspect of a normative science model as a conceptual and problem-solving strategy. Across questions, students at this level draw on some single aspect of an appropriate science model to reason, and show some emerging strategic competence in selecting an appropriate model. However, it is very rare for students with this strategy to extend explanations to consider more than one aspect of the model, *though in moving from one question to another they often show knowledge of multiple aspects*.

Figure 1. Perspectives of Chemists Framework.

ChemQuery Assessment System: Perspectives of Chemists on Matter

Generation 13-15	Bonding models are used as a foundation for the generation of new knowledge (e.g., about living systems, the environment, and materials).	Students are becoming experts as they gain proficiency in generating new understanding of complex systems through the development of new instruments and new experiments.	a) Composition: What is the composition of complex systems? (e.g., cells, composites, computer microchips) b) Structure: What gives rise to the structure of complex systems? (e.g., skin, bones, plastics, fabrics, paints, food,) c) Properties: What is the nature of the interactions in complex systems that accounts for their properties? (e.g., between drug molecules and receptor sites, in ecosytems, between device components) d) Quantities: How can we determine the composition of complex systems? (e.g., biomolecules, nanocomposites)
Construction 10-12	The composition, structure, and properties of matter are explained by varying strengths of interactions between particles (electrons, nuclei, atoms, ions, molecules) and by the motions of these particles.	Students are able to reason using normative models of chemistry, and use these models to explain and analyze the phase, composition, and properties of matter. They are using accurate and appropriate chemistry models in their explanations, and understand the assumptions used to construct the models.	a) Composition: How can we account for composition? b) Structure: How can we account for 3-D structure? (e.g., crystal structure, formation of drops,) c) Properties: How can we account for variations in the properties of matter? (e.g., boiling point, viscosity, solubility, hardness, pH, etc.) d) Amount: What assumptions do we make when we measure the amount of matter? (e.g., non-ideal gas law, average mass)
Formulation 7-9	The composition, structure, and properties, of matter are related to how electrons are distributed among atoms.	Students are developing a more coherent understanding that matter is made of particles and the arrangements of these particles relate to the properties of matter. Their definitions are accurate, but understanding is not fully developed so that student reasoning is limited to causal instead of explanatory mechanisms. In their interpretations of new situations students may over-generalize as they try to relate multiple ideas and construct formulas.	a) Composition: Why is the periodic table a roadmap for chemists? (Why is it a 'periodic' table?) How can we think about the arrangements of electrons in atoms? (e.g., shells, orbitals) How do the numbers of valence electrons relate to composition? (e.g., transfer/share) b) Structure: How can simple ideas about connections between atoms (bonds) and motions of atoms be used to explain the 3-D structure of matter? (e.g., diamond is rigid, water flows, air is invisible) c) Properties: How can matter be classified according to the types of bonds? (e.g., ionic solids dissolve in water, covalent solids are hard, molecules tend to exist as liquids and gases) d) Amount: How can one quantity of matter be related to another? (e.g., mass/mole/number, ideal gas law, Beer's law)
Recognition 4-6	Matter is categorized and described by various types of subatomic particles, atoms, and molecules.	Students begin to explore the language and specific symbols used by chemists to describe matter. They relate numbers of electrons, protons, and neutrons to elements and mass, and the arrangements and motions of atoms to composition and phase. The ways of thinking about and classifying matter are limited to relating one idea to another at a simplistic level of understanding.	a) Composition: How is the periodic table used to understand atoms and elements? How can elements, compounds, and mixtures be classified by the letters and symbols used by chemists? (e.g., $CuCl_2$ (s) is a blue solid, $CuCl_2$ (aq) is a clear, blue solution) b) Structure: How do the arrangements and motions of atoms differ in solids, liquids, and gases? c) Properties: How can the periodic table be used to predict properties? d) Amount: How do chemists keep track of quantities of particles? (e.g., number, mass, volume, pressure, mole)
Notions 1-3	Matter has mass and takes up space.	Students articulate their ideas about matter, and use prior experiences, observations, logical reasoning, and knowledge to provide evidence for their ideas.	a) Composition: How is matter distinct from energy, thoughts, and feelings? b) Structure: How do solids, liquids, and gases differ from one another? c) Properties: How can you use properties to classify matter? d) Amount: How can you measure the amount of matter?
Level of Success	**Big Ideas**	**Descriptions of Level**	**Item Exemplars**

- Students score 7-9 for answers that exhibit a *Formulation* view on assessment tasks. Formulation answers involve the highest strategy observed in the initial informant group of mainly high school students but also some introductory chemistry college students. Formulation involves use of and relating multiple aspects of normative science model, see Figure 1 framework description for more details of these models. Here students begin to bring together the multiple aspects of knowledge revealed but not often used together at Recognition. However, student understanding of the broader context of chemistry is still weak, so student answers often over generalize, or relate principles to situations outside the correct scope.
- Students score 10-12 for answers that exhibit a *Construction* view on assessment tasks. Construction answers were not observed among any students at the high school level but were identified sometimes at the general chemistry level and often among the students completing organic chemistry at UC Berkeley. This higher level reasoning strategy involved relating not only multiple aspects of a model, but more fully considering all aspects, for a fuller 'model view' response, see Figure 1 for details of the models involved regarding Matter.
- Note that the Perspectives framework also includes a 13-15 *Generation* category, not involved in this study.

Methods

Data source and assessment instruments

A total of 638 students participated in the Perspective of Chemists study, of which sixty-seven were nursing students who are the subject of the case study in this paper. The additional students are described in the results section of this paper as comparison groups, so the full student sample will be described here:

- There were 399 students at the university level in UC Berkeley's Chemistry 3B course. These students, usually in medical or biological science pathways, were on the verge of completing their second semester course in organic chemistry when they participated in Smart Homework. Most had a prior year of general chemistry at the university level and a prior year of high school chemistry, although some combined the high school and university first year by completing advanced placement chemistry, or in other words a university level chemistry course while still in high school, or by taking only one semester of university general chemistry in addition to high school chemistry.
- A further 117 students had just satisfied the requirement for completion of first-year general chemistry at UC Berkeley and had enrolled in the first organic chemistry course in the bioscience pathway. Most of these students, usually in a medical or biological science pathway major, had a year of general chemistry at the university level and a prior year of high school chemistry, although some again combined the high school and university first year.
- Sixty-seven students were completing their general chemistry studies at another four-year public university in California, in the medical pathway, most training to become nurses. This university focuses on expert instruction in small classes and offers more than 100 fields of study. It was recently selected as a 2005 Best College in the U.S. Western Region by *The Princeton Review*, which rates college programs for undergraduates. The campus has a

history of excellence in teaching and relatively high faculty-student ratios for California (1:22).

- Fifty-five students were secondary students in high school chemistry at a Catholic high school in the San Francisco Bay Area.

The nursing students in this case study were enrolled in an undergraduate program leading to the Bachelor of Science degree with a major in Nursing, 'designed to prepare a nurse generalist' who could work as a professional nurse or pursue graduate training in nursing. The chemistry course requirement for the program is a one-year sequence 'for students prepared for careers in health-related sciences including nursing.' The year consists of 10 weeks of study in general chemistry which is intended as foundation for a subsequent 10 weeks of study in organic chemistry and 10 weeks in biochemistry.

Students in the nursing sample were measured just prior to the final examination for the first quarter course in general chemistry, which explored atomic and molecular structure and related to topics mostly in the area of Matter as described by the Perspectives framework, see Figure 1. The assessment tasks were selected by a chemist working with the nursing course instructor to address specifically the material these students had been taught during the quarter, and not to include other material available in the assessment bank that had not yet been taught to these students.

BEAR Assessment System tasks are typically 'embedded' assessments, or in other words assessments placed within learning materials used in classrooms or for classroom-based instruction. For this case study, the assessments were part of the BEAR CAT Smart Homework implementation. BEAR CAT — Berkeley Evaluation and Assessment Research Computer-Adaptive Tools (Scalise and Scalise, 2004) — is a computer adaptive version of the BEAR criterion-referenced assessment approach described previously. BEAR CAT Smart Homework consists of homework sets designed to adapt to the individual needs of different students in near real-time, by electronically adjusting questions and feedback to the measured levels of the Perspectives performance framework.

A team of chemistry content experts at UC Berkeley designed the adaptive Smart Homework content. The multimedia package was built and delivered through the Distributed Learning Workshop's Learning Conductor software (http://www.dlworkshop.net/), modified to make the BEAR CAT adaptivity possible. We describe the environment afforded by the modified tools as an 'Autonomous Learning Environment', potentially capable of supporting not only adaptive homework described here, but also many other kinds of guided, independent (autonomous) learning activities that employ adaptivity (Scalise and Wilson, 2005).

Question and task formats in the Smart Homework sets varied. Some were multiple choice, others open-ended and requiring composed or calculated answers. Both right/wrong (dichotomous) and partial credit (polytomous) scoring schemes were used. The partial credit score levels were assigned based on the Perspectives of Chemists framework previously described.

We list here some technical information that is helpful to understand the evidence when computer adaptive instruments are used for assessment. Note that computer adaptivity, and thus the more complicated measurement approaches described below, were used because we wanted to assess students at a wide range of proficiency with the homework sets, from novice to any chemistry instruction through three years of instruction. Standard tests that gave the same questions to everyone would not readily assess this range in a single instrument. Computer adaptive instruments overlap enough items between students to put all the students on a common scale but are also able to extend up for students showing high proficiency and down for students showing low proficiency.

The primary item design in BEAR CAT is the 'testlet', or item bundle, which in this case consisted of an initial prompt, or question, followed by 'probes' or subsequent tasks of varying difficulty depending on how the student performed on the previous questions.

The BEAR CAT Smart Homework sets for the 521-person study consisted of a bank of about 15 testlets, consisting of a total of about 100 items. The ACER ConQuest Generalized Item Response Modelling Software (Wu et al., 1998) was used to calibrate the items and generate parameters under two item response models: partial credit and iota models. The details of the partial credit and iota model are discussed in more detail in other papers (Scalise and Scalise, 2004; Scalise and Wilson, 2005). The partial credit model allows students to be given partial credit on an assessment task, according to the scoring in the Perspectives framework, and then the difficulty of achieving each level of partial credit is estimated and student ability estimates and standard errors around the estimates can be assigned by score level. The iota model, which is a multi-facet bundle model, takes this approach to partial credit scoring one step farther for computer adaptive contexts, where considerations of the various student paths through multiple possible item sets and issues of statistical dependency may arise (Scalise and Wilson, 2005). In computer adaptive testing with questions and follow-up probes students may take different paths through the questions and probes, but ultimately arrive at providing the same answer, and thus receive the same score via different paths of probes and answers. The iota model estimates the difficulty of achieving each path, so that paths to the same score can be compared for whether, based on empirical data, they are equivalently difficult, as predicted. This tests whether path independence is a reasonable assumption for a particular computer adaptive assessment instrument based on testlets.

EAP/PV reliability for the 15-testlet BEAR CAT instrument was 0.82, which shows good reliability and indicates a slightly higher than 0.9 correlation with the expected true score, if the assessment were taken many times. Standard errors for the BEAR CAT instruments were small so that virtually no students would be expected to move from Notions to Recognition or Recognition to Formulation if they were retested or were given other items from the bank, unless the student had happened to measure at a point very near to the boundary between the two levels. Note that a study was conducted comparing measurement via the BEAR CAT Smart Homework instruments with a constructed-response instrument and a multiple-choice control comparison instrument from Kaplan AP Chem preparatory materials (Dumas et al., 2003). Student placement, fit and distribution on the three instruments was found to be quite comparable, and the instruments measured similarly in the validity study (Scalise and Wilson, 2005).

Results

Comparison results

The comparison groups investigated in this study were high school students in first-year introductory chemistry, nursing students at a public university completing the first quarter of university-level general chemistry for their pathway, UC Berkeley students soon after completion of their first-year general chemistry requirement as they began second-year organic chemistry for bioscience pathways, and UC Berkeley students at completion of second-year organic chemistry for bioscience pathways. Generally, the performance trend was expected to be lowest with high school students, and rising for students with increasingly more exposure to university-level chemistry.

While mean scores generally reflected this trend, the exception was the nursing student cohort, which had a somewhat lower mean score after completion of university-level general chemistry than the high school students in our sample. The mean high school scores for the 2003 high school ‘Living by Chemistry’ student cohort who used the BEAR CAT instrument showed about 90% of students measuring in Recognition and 10% in Notions. It should be noted that these students were at a generally high performing school, drawing from a relatively high socio-economic population, so unsurprisingly, performed academically better than average high school students. More typically, from the larger studies of high school students in our trials not reported here, high school students have been found to score about half in Notions and half in Recognition at the point in the curriculum at which these high school students were measured.

By comparison, the nursing students scored lower than these high school students, and somewhat lower than average high school students, based on past trials, with 75% of the nursing students measuring in Notions at the end of general chemistry and only 25% measuring in Recognition. Additional support for the placement of these students mostly in Notions comes from qualitative analysis of their responses to open-ended items, where the majority of the responses also fell into the Notions level (see Table 1 for an example of answers on one question and Table 2 for summary statistics over a set of items).

Table 1. Facets of reasoning used in student responses regarding why N_2H_6 does not exist, a valence electron question.

If NH_3 exists, why doesn’t N_2H_6?	**N**	**%**	**Level**
I don’t know, ‘no idea’, or non-response	13	21.7	0
N_2H_6 can be made, question is wrong	1	1.7	1
N_2H_6 name is wrong (no explanation for why not)	1	1.7	1
NH_3 and N_2H_6 have different names	1	1.7	1
gases can’t be put in a container	2	3.3	2
nitrogen and hydrogen can’t be mixed	2	3.3	2
the container will be too full with more gas	2	3.3	2
NH_3 cannot be broken apart	6	10.0	2
NH_3 can’t be ‘doubled’ to make N_2H_6 (no explanation)	1	1.7	2
not enough nitrogen available to make N_2H_6	5	8.3	2
N and H both have the same charge (+ or –)	2	3.3	3
Conditions aren’t right (acidity or non-aq.)	2	3.3	3
Nitrogen only forms triple bonds	1	1.7	3
Conservation of Mass—not all particles conserved[1]	10	16.7	3
N ion has a charge of 3, H ion has a charge of 1	2	3.3	3
Charges won’t balance	1	1.7	4
Valence elec., octet rule or Lewis dot described but inaccuracies	5	8.3	4
Valence elec., octet rule or Lewis dot fairly correctly	3	5.0	5

[1] These answers appear to be based on confusing this question with a prior question in which carbon was included as one of the reactants.

UC Berkeley students in the bioscience pathway at the completion of first-year general chemistry measured about 15% in Notions, about 45% in Recognition, 35% in Formulation and slightly less than 5% in Construction, showing the broadest spread of levels of any of the groups.

By the end of second-year organic chemistry, the sampled students in this pathway measured about 20% in Recognitions, 75% in Formulation and slightly less than 5% in Construction. Generally, the spread of students over Perspectives levels was much greater at the beginning of organic chemistry than at the end, where by the time they completed organic chemistry most students had progressed to Formulation and none remained in Notions. This may be a combined effect of learning over instructional time and the attrition of lower performing students.

Facets results

As discussed in the analysis section, the performance of the nursing students was heavily clustered in the Notions level, where responses revealed for the most part sound reasoning with real-world knowledge, pattern matching and logic, but no use or attempted use of actual domain knowledge in chemistry by most of the students, following the 10 weeks of instruction in this course. About 75% of the students measured in Notions. The remaining 25% had achieved the transition to Recognition, where they were beginning to use chemical knowledge in simple definitional ways with some but limited accuracy, which is probably well in accord with the intentions of the course. To frame this in terms of what nurses would actually need to know on the job, a reasonable understanding of concentration of solutions, for instance, would seem to be a key aspect of knowledge for proper monitoring of administration and dosage of medications. This, however, would fall into the next level, or Formulation level of the framework, two levels above Notions where most of the nursing students measured at the completion of their study of general chemistry. A beginning conceptual understanding of concentration might be expected to start to develop in the higher levels of Recognition, while only about 25% of the nursing students had achieved even the lower levels of Recognition by the end of their general chemistry course.

To give an example of actual student answers and how they may relate to notions and misconceptions about matter, the qualitative data in Table 1 considers the facets of student understanding on one assessment task, taken by most of the nursing students through the computer-adaptive instrument, in which students were asked to explain why NH_3 exists but not N_2H_6. This question taps fairly typical general chemistry content regarding bonding rules, and what atoms can be expected to combine to form what molecules. A possible correct answer at a Recognition level, a low level but definitionally correct answer could, for instance, involve NH_3 having the correct number of valence electrons to satisfy the octet rule, while N_2H_6 does not. Other ways of expressing this could include discussing noble gas configurations or showing Lewis Dot diagrams. Higher level answers on this question could, of course, involve more expert answers and explanations.

Table 1 identifies the facets of reasoning used in student responses, and shows percentages across facets and scores assigned according to the Perspectives framework. To summarize the data, after one quarter of general chemistry only three of the sixty students who engaged in the assessment task were able to answer this question correctly at the Recognition level, with five others on the right track in thinking about valence electrons and bonding but somewhat misinterpreting concepts.

Table 2. % of respondents scoring at each level, for a set of items taken by most of the nursing students.

Level	**1**	**2**	**3**	**4**	**5**	**6**	**7**
0	21.7	20.6	16.7	19.7	15	0	0
1	5.1	3.2	1.7	0	1.7	21.1	21.4
2	29.9	7.9	1.7	25.8	20	7	10.7
3	28.3	19	18.3	31.8	36.7	22.8	0
4	10	36.5	46.7	16.7	25	49.1	67.9
5	5	12.7	15	6.1	1.7	0	0
Mean level	2.15	2.86	3.22	2.44	2.6	3	3.14

Table 2 shows a summary of similar score data across general chemistry items that most students took in the BEAR CAT testlets. As shown in the bottom row of Table 2, the mean Perspective level scores across items ranged from 2.15 to 3.22. (We leave the decimal showing in the mean rather than rounding down to the actual 2-level score awarded or up to the 3-level score to give the reader a better indication of where the mean fell). With scores 0-3 falling in Notions and scores 4-6 in Recognition, this again shows that across numerous general chemistry items, the student nurse sample strongly tended to respond with Notions prechemistry ideas, or that is with ideas that did not reflect any correct use of normative chemistry models, even at a very basic definitional level.

Nursing facets as they relate to conceptual change and misconceptions

The reasoning facets data described above in the qualitative example are typical of student performance across items and relate to the previously discussed conceptual change findings in chemistry. Again we will use the NH_3 question as a typical example to get a sense of student reasoning patterns. Regarding the two major areas of evidence collection in chemistry misconceptions research – structure of matter and concepts of chemical reactivity — the 18% of students who responded with facets describing NH_3 as a molecule that cannot be broken apart or from which there would not be enough nitrogen to make N_2H_6 show misconceptions in the particulate view of matter, at the molecular level in the first example and at the systems level in the second example. The 10% of students who focused on macroscopic reasons, such as the container being too full for the reaction to occur showed, depending on aspects of their answers, misunderstanding of gas characteristics, principles of reactivity and/or conservation of mass. The 22% of students who said they had 'no idea' why N_2H_6 did not exist showed an inability to enter the problem space of considering either macroscopic or particulate explanations for the behavior, though the atomic view of matter had been the focus of their course in general chemistry.

In reference to the character of scientific knowledge as symbolic in nature, effective understanding of the symbol systems of chemistry includes making them meaningful in the context of thinking about basic models of particulate matter and chemical reactivity. Students here showed some ability to parse N as nitrogen and use other basic symbols of the periodic table, but many retained a concrete, continuous view of matter. The symbol systems themselves and how they are meaningful in applied contexts may be an important component of what nurses need to know in practice, for instance in conditions such as acidosis when nurses are need to correctly interpret the meaning of hydrogen ion concentrations and pH.

Discussion

For this small sample of nursing students, who were not intended to be a generalizable sample but only a case study, there was a large difference between what was mastered following completion of their general chemistry requirements and even the emergent beginnings of moving from a 'notions' view of chemistry and toward a basic definitional understanding of simple principles of particulate chemistry, from which knowledge of concentration, solubility, behaviors of gases and liquids, and other important considerations could be interpreted. Nursing students were studied at the end of general chemistry for several reasons, including that their subsequent studies in organic chemistry and biochemistry were intended to build on a foundation of knowledge from general chemistry. We wanted to see whether understanding at the end of general chemistry revealed a base upon which the nurses might successfully build. For most of the students, the answers revealed what might be called 'prechemistry' reasoning, or in other words reasoning that drew on logical patterning or attempted to apply real-world experience but did not use models or concepts of general chemistry.

This is not different from what has been found in other areas of introductory chemistry teaching and learning, where despite instruction in chemistry that ranged from a few months to a year or more, many students retained a concrete, continuous views of atoms and molecules. Reasoning facets of nurses regarding gases, for instance, that seem to agree with this continuous view include that gases cannot be put in containers, that during reactions in containers no more gases could be generated if gases currently were present in the container because the containers would already be full, and that the atoms of a molecule of gaseous substance cannot be recombined and rearranged in a chemical reaction.

However, while we expected to see such misconceptions from the high school students in our sample, it was a surprise to us to see an even greater level of misconceptions from this sample of university-level students, as measured by a higher percentage of students broadly exhibiting thinking at the prechemistry or Notions level across numerous items.

Of course the preparedness and abilities of the entering student population to any particular program of study are likely to affect how quickly students may master new knowledge. While we have no data to report on, for instance, student verbal and quantitative ability for the various sample groups given, UC Berkeley, as a top public research university, has a student population that tends to score considerably higher on these measures than most other four-year universities in California, so they could be expected to outpace students at other universities. However, the nursing students scored similarly at the end of general chemistry to disadvantaged high school populations we have studied in low socio-economic areas after a module of just six weeks of general chemistry instruction. This is true even where all the high school students are required to enroll in chemistry so that there is no selectivity effect in the high school population and when many of these students would not qualify for admittance to the California four-year public university from which the nurse sample was drawn. In this regard, the nursing students can be seen as better prepared than some of the comparison groups we have studied.

In any case, if courses in chemistry are mandatory because of skills supposedly needed in professional work, then it would seem that more attention must be paid to how such skills are to be mastered. This seems especially true, knowing that incoming preparedness for professional programs such as presented here may likely be an additional challenge as compared, for instance, to educating science students at top research universities. Conceptual change research does not suggest that such expectations can be met in such brief courses of study as are currently the norm. Alternatively, if such skills are not deemed necessary, then perhaps standards and the contents of courses of instruction might need to be adjusted when considering the educational needs for practice in this large field, as the course can function as a gatekeeper, generating anxiety and perceptions of limiting access to the field. This practice/research dilemma includes the fact that many students are both frustrated and/or anxious about their degree of mastery, which has been shown to be low for at least this sample, yet most who do attempt and complete the courses also go on for successful careers in these professions.

This raises several questions, including whether the degree of mastery is greater than that suggested by this study or whether students passed qualifying examinations such as the final examination without a real understanding of the subject. The validity and reliability evidence for the student measures in this study is rather strong, and qualitative inspection of student answers such as can be seen in the example question indicates lack of student understanding. Assessment research in chemistry has also shown that students can often problem-solve sufficiently in some examinations without much real understanding of the underlying concepts (Ahtee and Varjola, 1998).

That nurses who show limited mastery of chemistry concepts go on to apparently successful careers in nursing also raises the question whether nurses and other biomedical professionals need what chemistry was being taught to them in the first place. This emerging conversation is well summarized by the words of one clinical professor in a distinguished U.S. nursing education program (Day, 2005, p. 1):

> *"This is very interesting and a debate in which I am not at all certain of my position…. One of the questions we have been grappling with is what kinds of background knowledge do nursing students need (natural and social sciences, humanities). Many, but certainly not all, nursing schools require basic general chemistry when the form in which we deal with chemistry in nursing is biochemistry…. One question I am confronted with every summer is can I teach the basics of biochemistry without going through all the abstraction (at least what I perceive as abstraction) you have to go through in basic general chemistry classes. For example, I'm not convinced nurses need to know the details of the periodic table, or things like what a mole is, Avogadro's number, and stoichiometry…. But, what this translates into in some schools is putting together a chemistry class for nurses that is a way dumbed-down version in which no one learns anything. And I'm certainly not in favor of this."*

The dilemma of what should be taught and how it should be taught for the biomedical pathways is not a small one for science education and chemistry education in particular, especially given the anxiety of students who fear that the requirements of the sciences may close doors and opportunities. The nursing and medical profession should have a close and realistic look at what chemical skills and concepts their professionals really need and then should come to chemistry instructors, or work with chemistry instructors, and say, "*Please teach our students this*." It may be that the present situation is that chemistry instructors are told to teach a year of chemistry, including organic and biochemistry and are left much to themselves in working out the details of what, how much, how and when. A practice-appropriate curriculum would not have to be a 'dumbed down' version of chemistry, but such a proposal could echo the ideas from Day (above) and perhaps better support student needs. For instance, the valence electron example question described earlier reflects concepts that are quite typical for general chemistry, but deal with concepts that arguably no nurse will ever need to know for a professional career.

Possible solutions to more successful courses, from our perspective, may include changing *how* chemistry is taught to nursing students and others who are non-scientists, such as bringing chemistry instruction more closely into the field locations of nurse clinical practice, with a context-based or guided inquiry approach. Chemistry could be taught in the context of real practice examples relevant to nursing. Then when a topic such as concentration is part of the chemistry curriculum, student nurses could be considering real situations they might find themselves in, such as the difference between two saline solutions at different concentrations that they might be using for an intravenous drip. This would be more appropriate to the working knowledge of nursing practice, and would offer nurses more concrete ways of connecting the chemistry they are learning to their prior knowledge.

The focus could also be placed on changing accreditation requirements and standards for scientific understanding in such biomedical professions as nursing. This could be thought of as changing *what* instruction consists of for students in this population, since the fundamental standards and instructional frameworks might then change. What would need to stay from general chemistry and what could go would have to be carefully considered, so that nurses would have enough knowledge for their work and would be able to continue in their other courses such as physiology and microbiology. But it would be interesting to see what ideas of chemistry nursing instructors really feel are necessary for their students, and whether chemists can come up with ways to successfully help such programs help their students understand what they need to know in this field.

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Open learning support for foundation chemistry as taught to health science students

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Abstract: On-line learning support for foundation chemistry was supplied to health science students via Blackboard and interactive web pages. The examples supplied were deliberately numerous, and very gently staged in order of difficulty. Our experience confirmed the advantages of using JavaScript rather than commercial software in the provision of this material. Students appeared to be enthusiastic and extremely grateful for provision of this additional learning material, but it was found that use of the material was mainly by students that were already both conscientious and good attendees. Preliminary indications were that most students, who regularly accessed the material, achieved better examinations results than those who did not although, as yet, we cannot claim these results are statistically significant. [*Chem. Educ. Res. Pract.*, 2006, **7** (3), 185-194]

Keywords: Computer-aided learning, formative assessment, self assessment, on-line tutorial support, foundation studies, health science chemistry courses.

Introduction

Many UK further and higher education establishments run foundation year (sometimes called 'access') programmes. These are designed so that mature participants, without the usual formal entrance requirements, can gain the necessary skills and knowledge to proceed to the first year of a degree. Most students who successfully complete Glamorgan's health sciences foundation year go on to BSc (honours) programmes in Nursing or Human Biology. The foundation programme comprises modules devoted to: mathematics, computer literacy, learning strategies, biology and chemistry. These students were previously taught chemistry within a module developed to service the needs of all Applied Science students, a large proportion of whom require at least the equivalent of UK 'A' level Chemistry in order to pursue successfully the chemically related science degree of their choice (e.g. Forensic Science). The Health Science students differ from Applied Science students in all, or some, of the following respects:

- A high proportion are mature females (21+) and have been out of full-time education for a number of years.
- They are less confident with mathematics – indeed, they are less confident with all things that require a 'scientific' perspective (see Stephenson and Percy, 1989 and Hunter et al., 2001).
- They are less likely to recognise that chemistry is relevant to their chosen course and, in order to maintain their interest, references to chemicals that commonly occur in relation to health or medical matters need to be frequent.

With the above observations in mind, a new module entitled 'Chemistry for Health Sciences' was designed specifically to address the needs of these students. The cohort is large (typically 120+) and lecturer contact time is, as is usual for modules within the school, 3 h per week on average. This comprises: 1 h lecture, 1 h tutorial (for the teaching year) and 2 h practical (for half a teaching year). End of module assessment is via a two hour examination, practical work and coursework.

The principal objectives in constructing a 'tailor-made' module for this group were:

- To demonstrate the relevance of chemistry to their daily lives and in the medical professions, thus enhancing their motivation to learn
- To increase their confidence in dealing with scientific and numerical concepts
- To improve the end-of-year results
- And, hopefully, to introduce some enjoyment into the learning process!

Method

'Chemistry for Health Sciences' – structure and content

As with the other foundation chemistry course, all students received a copy of the lecture notes and a practical booklet at the beginning of the teaching year. The university has had a web-based virtual learning environment package (Blackboard[*]) available to both students and lecturers for some time and a 'back-up' copy of these booklets was made available on the Blackboard site. Both booklets covered the essentials of a basic chemistry course: formulae and equations, amount and concentration calculations, atomic structure, bonding, organic chemistry, basic spectroscopy and the periodic table. However, the notes, lectures and practicals were liberally sprinkled with chemical examples that were thought to appeal to these students as relevant.

For example, practical exercises included:

- determining the degrees of unsaturation in different cooking fats and oils;
- finding the citric acid content in Alka-Seltzer tablets;
- finding the content of Vitamin C in a cold remedy preparation by titration;
- testing the pH of common household substances, investigating the pH behaviour of several natural indicators and using a pH meter to monitor the pH change during an acid/base titration;
- determining the percentage of ethanoic acid in commercial vinegar.

Confidence building

In previous years, students from this cohort have requested that they be given more tutorial work so, in addition, end of topic self-study examples, with answers, were also posted on the Blackboard site (see later for a more detailed description of this aspect of the project). These examples were deliberately numerous and very gently staged with the intention that the student, having mastered a particular technique, should receive many positive 'can-do' reinforcements before proceeding to examples demanding the next small incremental level of understanding. This technique (overlearning) is well-known within educational circles (Driskell et al., 1992) as a good mechanism for aiding retention and, we reasoned, it should increase confidence in that the students would be able to confirm the correctness of response to a problem many times. There was no compulsion to do these exercises, but the students had previously demonstrated that they were anxious to 'do well' and we expected a high take-up rate.

[*] see www.blackboard.com

On line tutorial material

We looked for means of delivering extensive practice material that would not, in the long term, involve an increasing burden on the teaching staff. The delivery of paper based material (multiple problems all different) has been discussed elsewhere (Hall, 1998) and provides the basis for individualized course work. While this does also provide a mechanism for additional tutorial work, feedback requires a substantial input from teacher. We therefore investigated the possibility of on-line delivery of such material, which can offer interaction, feedback and support without significantly increasing student-instructor contact time (Cole and Todd, 2003). It was decided to undertake this work ourselves rather than involve professional computing support. This would allow us to maintain control of content and delivery timescale. It would also put us in a better position to explain the use of the material to students and to make adjustments in the light of their comments. In addition, given the modest computing background of the cohort, we wished to make the material as technically straightforward as possible – for example, it was considered that the requirement to download ‘browser plug-ins’ could be a significant turn-off for the students. Early student feedback certainly underlined the importance of off-campus access.

All Glamorgan students have access to Blackboard, the university’s chosen virtual learning environment. This has proved useful for gathering student-use data and for delivering text (back-up copies of lecture notes, for example) but we have found the system somewhat restrictive for delivery of more interactive material. Blackboard was thus used as a portal through which students accessed a website. Interaction on the web pages was by means of JavaScript, a simple programming language able to operate within the HTML environment of a web page. JavaScript is widely used by professional web developers, but is simple enough to be used by non-specialists such as ourselves. We have now been offering on-line, formative self-assessment work to our B.Sc. students for many years and have not yet found a commercial assessment package able to offer the same flexibility as a JavaScript activated web page, nor even as an Excel spreadsheet incorporating macros.

Previous authors have discussed the use of commercial packages for delivery of on line ‘quizzes’ (Bunce et al., 2006) and examples are available on line – (see, for example, Lowry, 2005) and the European Chemistry Thematic Network. These, however, are dominated by a relatively simple structure; generally multiple choice questions and the provision of limited feedback – the answers are provided immediately and help is not ‘staged’. Also, the exercises are tied into commercial templates. JavaScript allows us far greater flexibility in terms of question type, style and response structure. At first sight it might appear that this makes question and response provision more difficult than with Questionmark, WebCt, etc. However, once the initial learning time had been invested this has not proved to be the case, particularly since so many textbooks are available for programmers from novice to expert (Negrino and Smith, 2003).

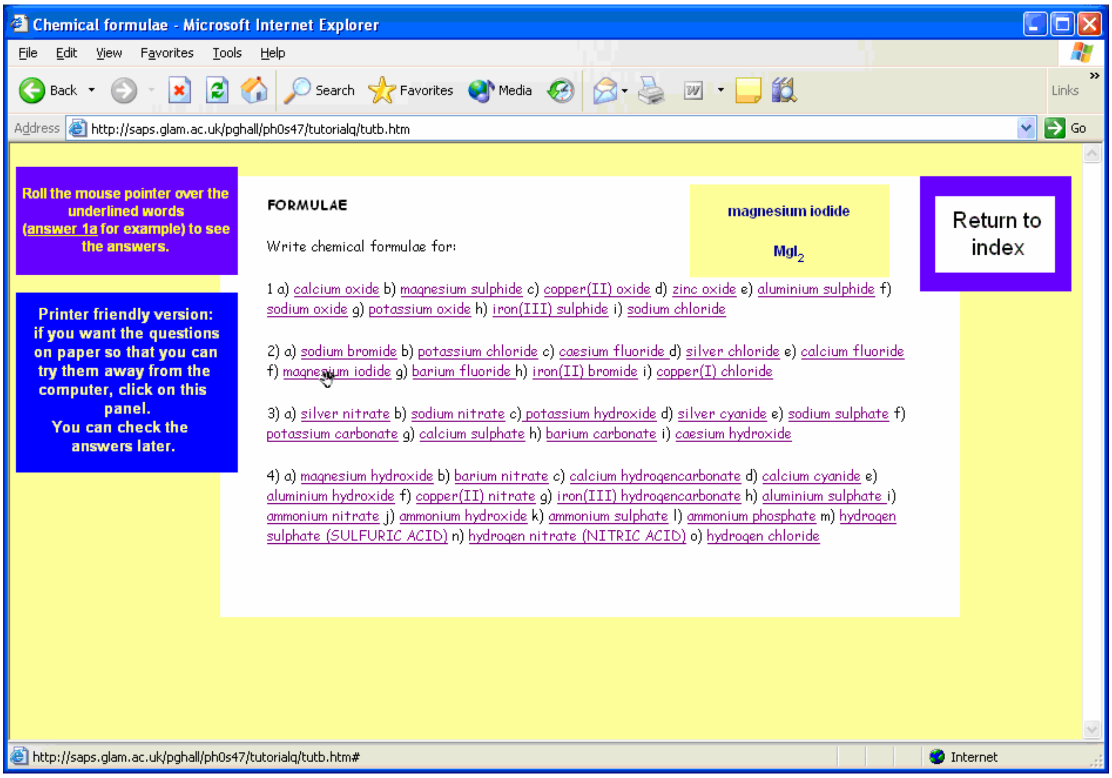
We duplicated one section of work using the commercial package, Authorware, and this only strengthened our commitment to JavaScript web-page development. Not only was the latter more flexible, it was also easier to work with and easier for the students to use. At the other extreme, we investigated the use of Java applets on the web pages. This, however, proved to be very time consuming and introduced a number of technical problems that have been identified elsewhere (Reid, 2004).

It should be stressed that our emphasis has been on providing material to aid students’ learning rather than providing assessment material – particularly not summative assessment. We would be happy if others made use of our material and have designed some of it with this in mind. An individual item of our work can be incorporated as a known size pop-up window into the web page of other teachers/lecturers (Hall, 2005). The material can be used directly by others or be copied and modified – an important difference between our work and that of others.

In other subject areas (language teaching, for example) there are authors (Morrison) and organizations (Virginia Commonwealth University) who encourage the use of script languages to introduce interaction in on-line teaching material so, in the hope of persuading others to provide chemistry support in this way, we describe briefly how we set about this provision.

The material was developed along two lines. The first, the simplest from a programming point of view, involved limited interaction. The students were provided with problems based on paper materials given to them in tutorials. Interaction was limited to 'pop-up' answers and some pop-up support. This allowed us to provide a wide range of material available from day one. An example is shown in Figure 1. The pop-up nature of the answers prevents the students from printing these. Our past experience suggests that some students equate printing off the answers to having done the problems.

Figure 1. The most basic interaction, a pop-up response: rolling the mouse pointer over the question provides the answer (yellow box).



The second line of development involved a more interactive range of material. This provided more help and support for the students (see Figures 2 and 3). Feedback on student answers was immediate and a number of common errors were identified and commented on. As our experience developed, a certain amount of 'entertainment' was introduced into the material to encourage the students to return.

Figure 2. Interaction becomes more sophisticated: here students fill in the blanks to complete the periodic table. The software checks the answer and, if requested, shuffles the spaces to provide a new problem.

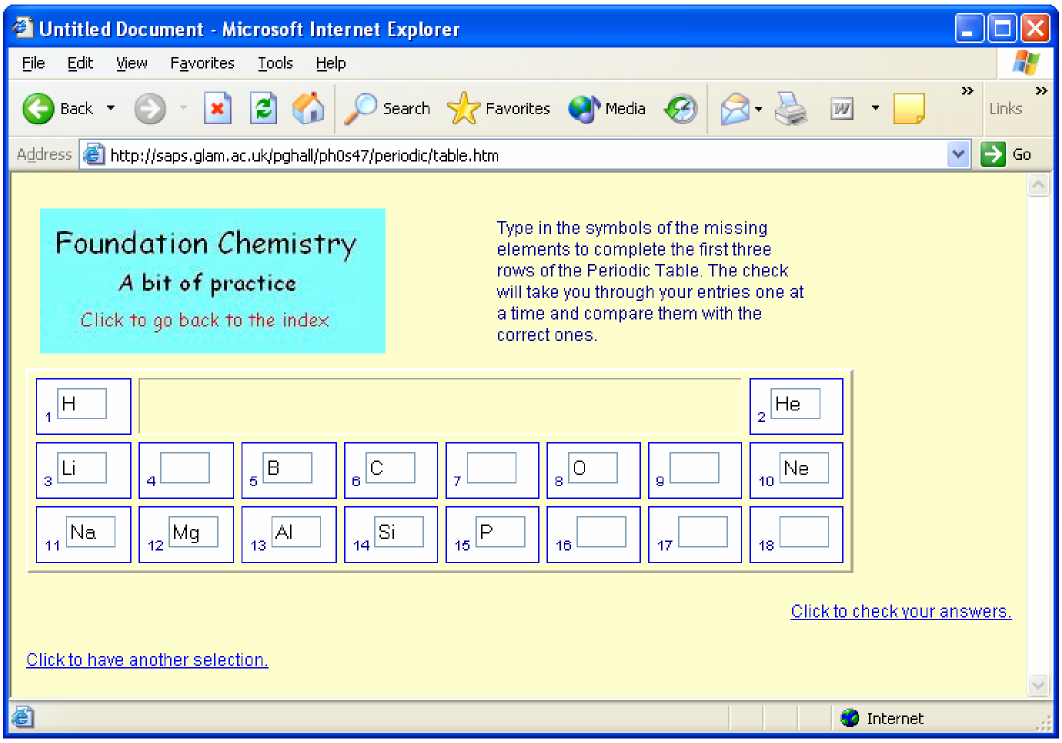
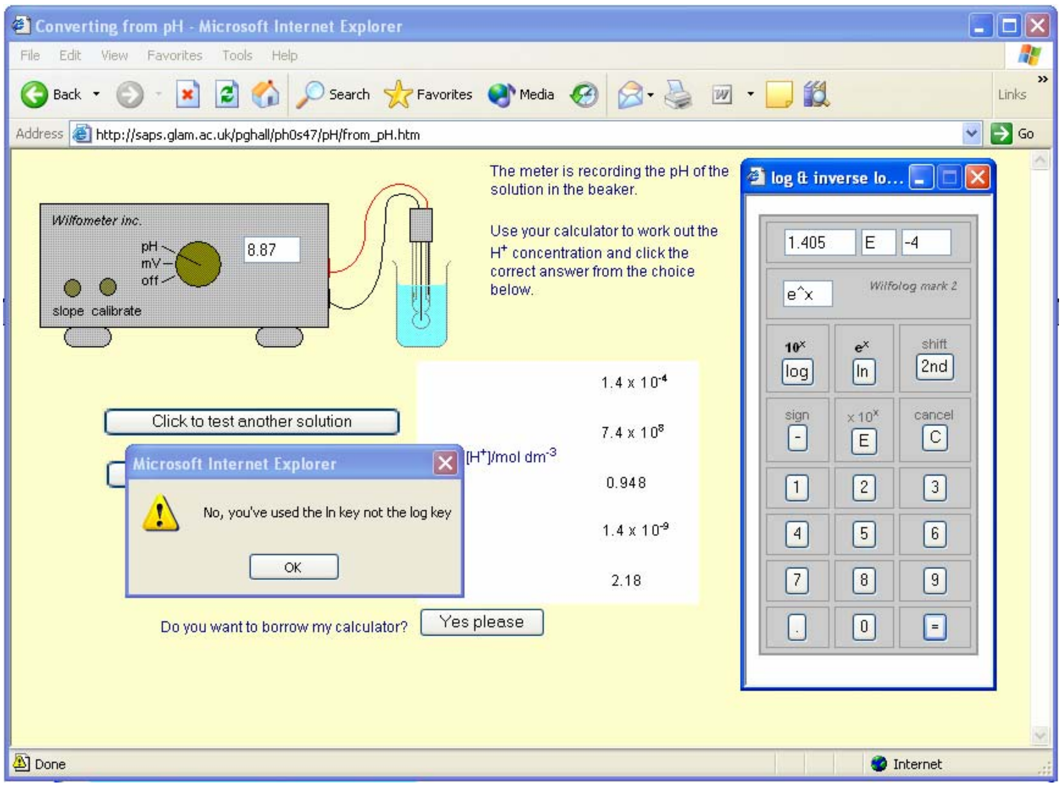


Figure 3. Help and support become more sophisticated: the student can access a calculator and the software can identify many common errors. The next problem is taken at random from a large array so that the student is presented with a new problem every time.



Results

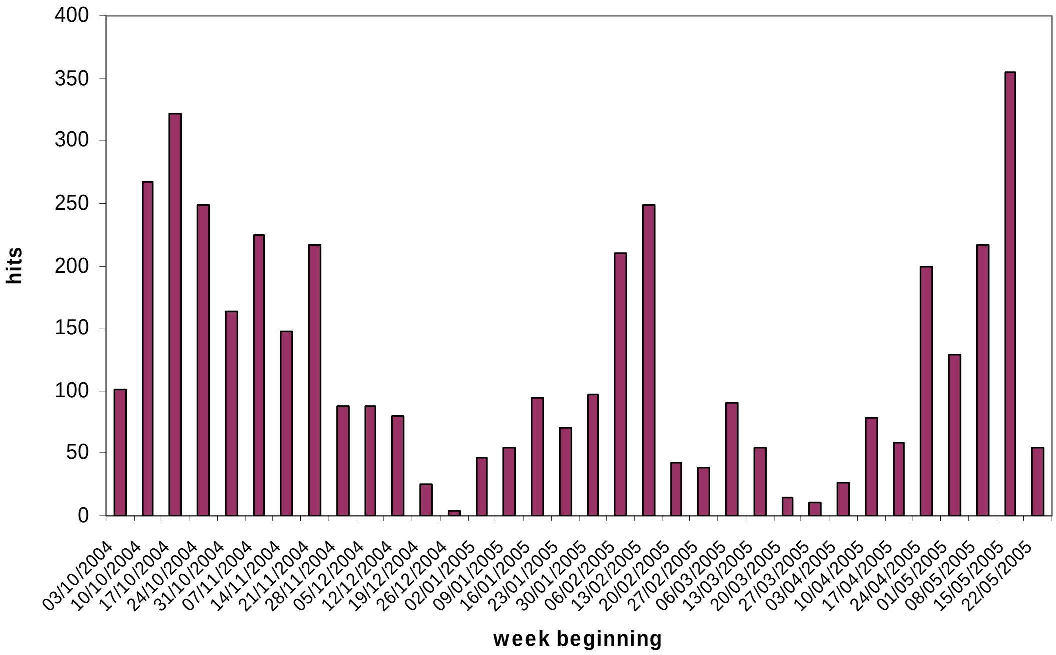
Monitoring of use

Our primary aim was to respond to student demand and provide the material rather than to undertake 'educational research'. To investigate the effect of this material on the students, however, two processes were used to provide quantitative information. One was the maintenance of an attendance register by the lecturer, and the other was the logging of use by Blackboard. It should be pointed out that the latter data were limited since once the students accessed the web material; they were no longer logged by Blackboard. In addition, a small but increasing number of students accessed the web site directly because it was simpler than access via Blackboard. This was primarily a teaching project, not a research project, so we were not prepared to halt free access to the web site.

The first encouraging point to arise from the limited data was that student use of the material did not seem to be dropping off as the year progressed (Figure 4). As would be expected, the initial Blackboard count was relatively high as students enrolled themselves onto the module on Blackboard and found out what all the buttons did. Although there was no requirement whatsoever on students to enrol on Blackboard, about 70% did so. This is similar to the take up reported by Lowry (2005) for on-line material delivered to what appears to be a comparable student group in terms of age and background. It is, however, much lower than the take up we obtained when first experimenting with on-line tutorial material with first year BSc students.

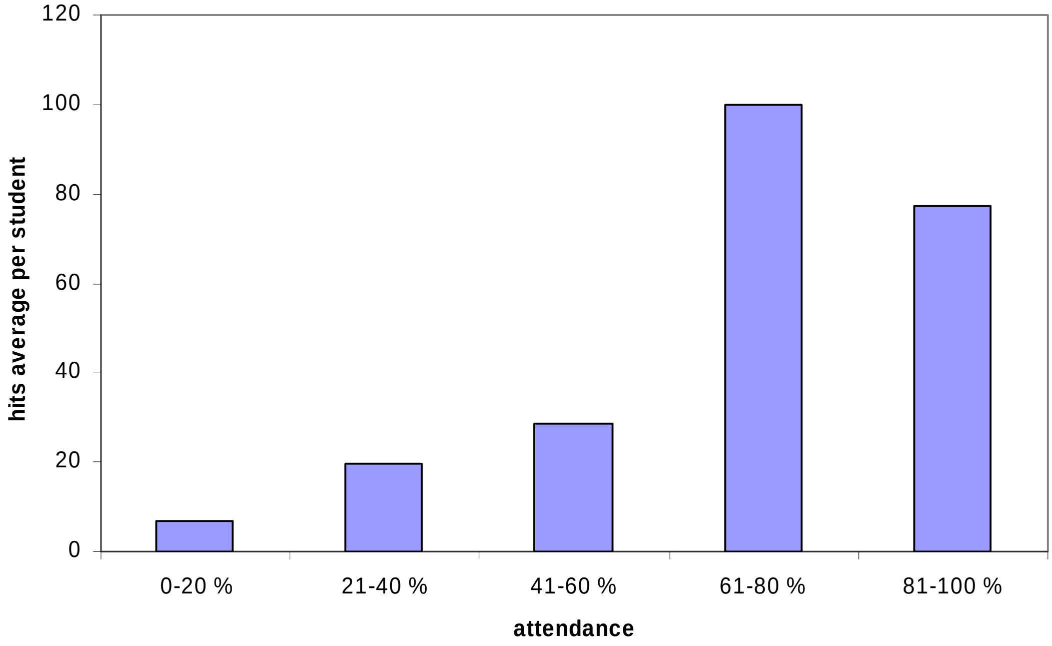
Initially, the web site was not available off-campus, but following considerable student pressure we were able to persuade the university to make the site available to the outside world. The results show that students made use of the material seven days a week and at all hours of the day and night – though the most favoured access time was not 11 p.m. to 1 a.m. as reported by Freasier et al., (2003).

Figure 4. Hits counted by Blackboard on a weekly basis. Note that the lulls correspond to the student vacation periods: December 18th-January 9th and March 19th-April 10th.



The second feature to appear quite clearly was the correlation between attendance at lectures and use of the on-line material (Figure 5).

Figure 5. The relationship between student attendance at lectures and hits counted by Blackboard: 0-20 % 14 students, 21-40 % 21, 41-60 % 25, 61-80 % 27, 81-100 % 15.

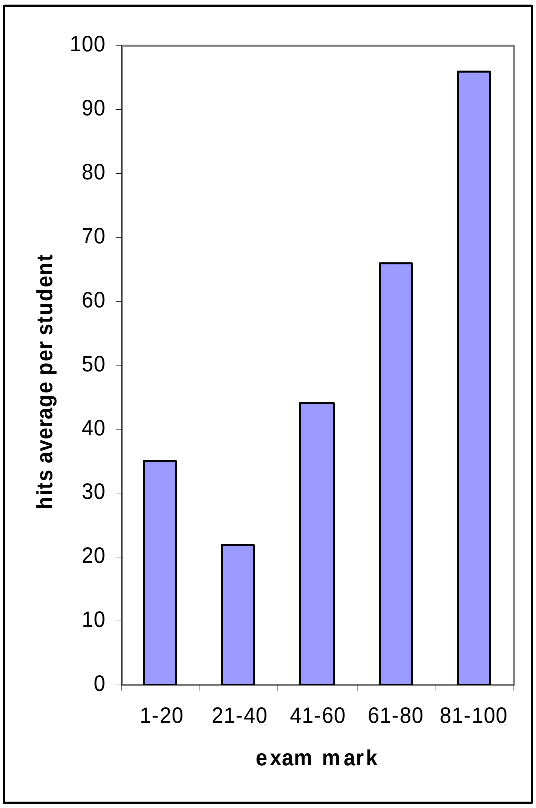


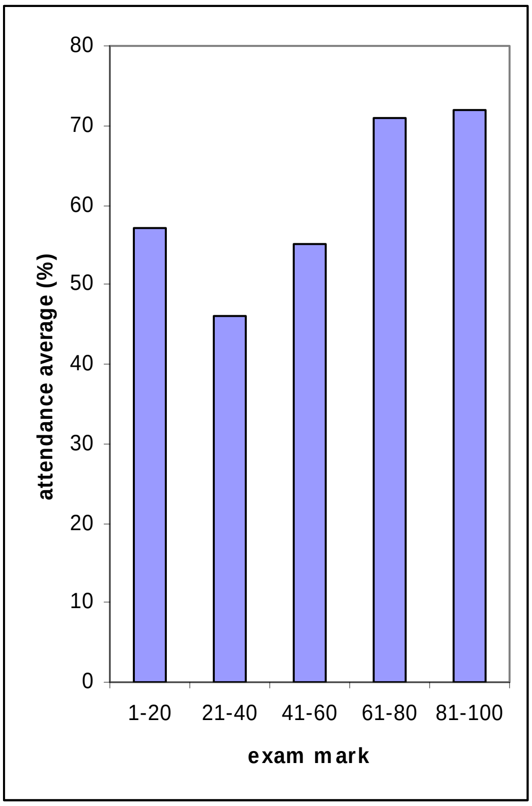
Another feature of the data, not shown by averaging as in Figure 5, was that whilst there were many students who had a high lecture attendance who did not access Blackboard, the reverse was not seen. There was not one poor attendee with a high hits count on Blackboard.

End of year examination

The data in Figure 4 show a one week spike (week beginning 15/02/2005) immediately prior to the exam. In the main, this is attributable to those who had been, in previous weeks, moderate users. There are few new users at this late stage of the year and those who had been heavy users no longer dominate the 'hits' count.

Figure 6. Attendance and 'hits' records as a function of exam mark.





Once the examination had been completed, we were able to investigate the attendance and 'hits' records as a function of exam mark. A summary of the results is shown in Figure 6 where, once again, the relationship between attendance and 'hits' is apparent. Also apparent, though not shown on the charts, is the effect that one individual can have on the figures. One student (out of 14) in the 1-20 mark range was both a good attendee and the second biggest user of the Blackboard/web material. Neglecting this one result reduces the 1-20 column of the 'hits' chart to 20 %.

Our view is that the link between 'hits' and exam mark is a result of both being a measure of conscientiousness and study skills. It is not therefore possible for us to say that use of the on-line tutorials improved exam performance since Blackboard use was so closely correlated with lecture attendance. We can state, however, that the exam average went up by 6 marks (out of 100) following the introduction of the on-line material. The exams for the two years were very similar but since no two student cohorts are the same, we cannot claim that this is significant.

Student feedback

We requested comments and criticisms through Blackboard and a number of students posted replies [their spelling and grammar have been corrected. Editor]. In the main, comments were extremely supportive, for example:

"Just to let you know that all the links are now working from home. The stuff on Blackboard is brilliant… ",

"THE STUFF IN THE LINK WAS A GREAT HELP TO A FEW OF US, SO CHEERS", and

"Thanks for this information I have learnt a lot; wish I took it in as well as you have shown it".

It is clear too that the students appreciate the amount of time involved:

"Just a quick e-mail to let you know that I find the Blackboard system very helpful. Thank you for spending the time in putting all the relevant information there".

"I log on black board everyday to revise my lecture notes. The online notes provide you an opportunity to study anywhere you are irrespective of time. It is a worth effort to put notes on-line. Thank you for the effort"

To date only one critical comment has arisen from a student who would like to see a clearer indication as to which lecture each component of the support material relates to:

"I do feel that the layout of chemistry on blackboard should be improved. When you log on it doesn't remind you what week that lecture was done…".

Account will be taken of this when revising the material for the next academic year.

Conclusions

Students appeared to find the presence of the on-line teaching exercises reassuring, in the sense that they knew there was extra revision material available if they required it. It also became clear, from the statistics available on the Blackboard site, that students were regularly accessing the site on weekends and so working from home.

Part of the argument for undertaking this work was to increase the amount of teaching material outside of class hours – thus benefiting students with non-traditional backgrounds and with family responsibilities that sometimes caused erratic attendance. It became apparent, however, whilst the material was extensively used, it was providing additional support for conscientious students, and it was not being significantly used by the non-attendees.

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Chemistry in sport: context-based e-learning in chemistry

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Abstract: This paper details the design and use of a learning resource for independent learning in chemistry. The course presents chemistry in the context of sport and draws upon a number of models of teaching and learning, including the Perry scheme of intellectual development, multiple intelligences (MI) theory, problem/context-based learning (P/CBL), mind mapping, case studies and web-based independent learning. The resource was produced as a website containing the context, content, and the tasks to be completed as part of the assessment. Hyperlinks to additional content and external web-pages were also included. The students' response to the learning resource was positive; they enjoyed the course, found the context interesting and the presentation helpful. The assessment marks compared well with those from other modules taken by the same students in the same academic year. [*Chem. Educ. Res. Pract.*, 2006, **7** (3), 195-202]

Keywords: Sport, chemistry in sport, chemistry in context, case-study, independent learning, web-based learning.

Introduction

A survey published recently by the English Manpower Services Commission showed that four fifths of the top 10% of British companies invested significant amounts of time and money into training (Buzan, 2003). Employers from around the world have identified the main areas requiring improvement as reading speed and comprehension, general study skills, handling the information explosion and assimilation, memory, concentration, oral and written communication skills, creative and analytical thinking, planning, note-taking, problem solving and analysis, motivation, prioritising, and time management.

Employers are now looking for graduates with a range of transferable skills (Dearing, 1995; Finer, 1996; Mason, 1998). In addition to the skills mentioned above, those of numeracy, the ability to acquire further knowledge and good interpersonal skills are desirable qualities in a graduate. However, many of these skills may be absent (Dearing, 1995, Mason, 1998). In order to facilitate a more immediately effective transition into the world of work upon graduation, students need to have acquired the skills of critical thinking and be able to tackle unfamiliar and/or open-ended problems (Belt et al., 2002). The focus of this study was to apply a number of alternative teaching and learning approaches to create a learning resource with the aim of meeting some of the aforementioned requirements.

In '*Forms of intellectual and ethical development during the college years: a scheme*' Perry described nine 'positions' on the 'journey' to intellectual (and moral) development (Perry, 1970). Each level characterises the students' attitude towards knowledge, their courses of study, their teachers and their own roles in the learning process. To effect a transition through the Perry levels Knefelkamp identified the need for designing courses that will appeal to and not alienate students at various positions (Cornfield and Knefelkamp, 1979). Felder, (1997) stated that challenging students by assigning open-ended problems in context with marks less dependent upon the outcomes than on the process of solving the problem, especially early on in the course, will allow students to develop higher order cognitive skills, such as critical thinking.

Gardner's theory of multiple intelligences (MI) identified seven components of intelligence through anthropological, neurophysiological and cultural studies (Gardner, 1983). Gardner has encouraged alternative approaches to teaching in order to tap into and make the best use of these seven intelligences (Gardner, 1993). Kornhaber, (2001) found that MI theory reflects educators' everyday experience: students think and learn in many different ways. She says this has led many educators to develop new approaches that might better meet the needs of the range of students.

Problem- and Context-Based Learning aims to stimulate students to learn by presenting them with a real life problem that they wish to solve (Margetson, 1998). Using previously acquired knowledge, acquiring new knowledge and learning new skills, they are expected to solve the problem. Margetson stresses the value of knowledge and skills acquired in context. He also identifies the value of the learning process of inquiry, which he sees as lacking in subject-based learning where only the products of inquiry are given. Coles (1990) sees a context based approach as being effective in producing what he calls elaborated learning. Students who see the interconnections and links between different knowledge areas gained the highest scores in examinations, because they were better able to recall and use the information they had learnt.

Broadbent (1976) argues that recall is increased when the learner has multiple routes of access to the stored information. Rogers (1960) says context provides a motivating force by which the student develops a wish to know more; that is, wants rather than needs to learn something.

Context-based learning resources can be presented as problem solving case studies. According to Belt and Phipps (1998), case studies can be used to address a range of skills, develop a mode of thinking, working and communicating, and are best done by tackling open-ended problems. Overton (2001) states that students undertaking problem- and context-based courses show that there are many benefits to be gained from this approach. Students' motivation, attitude to study, long-term retention of knowledge, use of resources, key skills and success as postgraduates are all significantly superior when compared to students taught by conventional methods.

Hutchinson (2000) used case studies on the development of fundamental chemical concepts such as: the atomic molecular theory; the kinetic molecular theory; periodicity and valence; chemical bonding and electron pair sharing and more. Assignments and examinations throughout the course were designed to challenge the students to explain the logical connections between experimental observations and theoretical models.

Although many learning resources are made available via the web, a limited amount of research has been carried out on its effectiveness as a learning tool. Arasasingham et al. (2005) assessed large numbers of students on their understanding of stoichiometry using a web-based assessment program. With a group of students using textbooks and paper to complete the assessments as the control group, they were able to compare the web- and non-web-based approaches. The assessment results found that the web-based students outperformed the non-web-based students and showed greater conceptual understanding. The students using the web-based course also reported that having to work independently with the program forced them to work harder on the subject, with the pay offs being instant feedback and greater understanding. Valuable feedback is often gained from the use of alternative approaches, because students have been able to appraise their course of study (usually in a positive light) and gain insight into their individual preferences, strengths and weaknesses, etc. They have reported enhanced understanding and retention, greater success in study, and the acquisition of new skills and knowledge.

In the past, approaches that have made use of the Perry scheme, MI theory, context/problem-based learning, mind mapping and case studies have been, on the whole, limited to paper-based courses in a classroom environment.

Chemistry in Sport: the learning resource

Overview

The learning resource developed was essentially a case study on the applications of chemistry in sport. It was designed to aid the students' acquisition of new knowledge and skills. The new knowledge included the content provided within the learning resource, the additional knowledge and skills gained by carrying out assessment tasks, information gathering using literature and the Internet; the important skills developed included critical reasoning and learning independently using alternative media e.g. the Internet.

The target students were part-time chemistry undergraduates without timetabled support for the module and with limited access to the library, so the teaching method had to be tailored to an independent learning approach. The resource provided the students with content and they were given tasks throughout. The tasks were designed to enhance understanding and extend the content already presented. Many of the tasks were open ended without a definite right or wrong answer, and the students had to support and defend their answers.

Content and Context

As sport pervades modern popular culture, it was decided to use the applications of chemistry in sport as the context. Interest in the context would be a 'way in' to the subject matter, prompting a motivation to learn on the part of the students (Rogers, 1960; Broadbent, 1976; Coles, 1990).

The learning resource comprised three sections. The first to be tackled by the students looked at the use of performance-enhancing drugs from the point of view of detection and was, therefore, primarily concerned with analytical chemistry. The students were asked to look at the cases of three British athletes who had recently been involved in drug scandals. Using these examples as case studies immediately put a familiar context and a human face on the learning resource.

In recent years, the methods employed to detect performance-enhancing drugs, and the validity of those methods, have courted as much controversy as the cases themselves. Each case, in some way, had called into question the techniques of detection, and highlighted the problems involved in the detection of performance enhancing drugs. These case studies provided a useful introduction to the concept and application of analytical chemistry (Hutchinson, 2000; Overton, 2001).

The second section looked at the three energy systems present within muscle cells and was, therefore, primarily concerned with biochemistry, focusing on the biochemical precursors to muscle movement and the ways in which athletes can legally supplement these.

The final section looked at sporting equipment, thus focusing on materials chemistry. Carbon fibre and Kevlar were identified as materials frequently used in sporting equipment, and the production, structure and application of these materials was investigated.

As a whole, the learning resource provided an insight into three aspects of applied chemistry not normally encountered at this stage of a chemistry degree course. Such a learning resource provided a built-in flexibility as each section could be used individually to supplement other areas of the chemistry curriculum.

Presentation

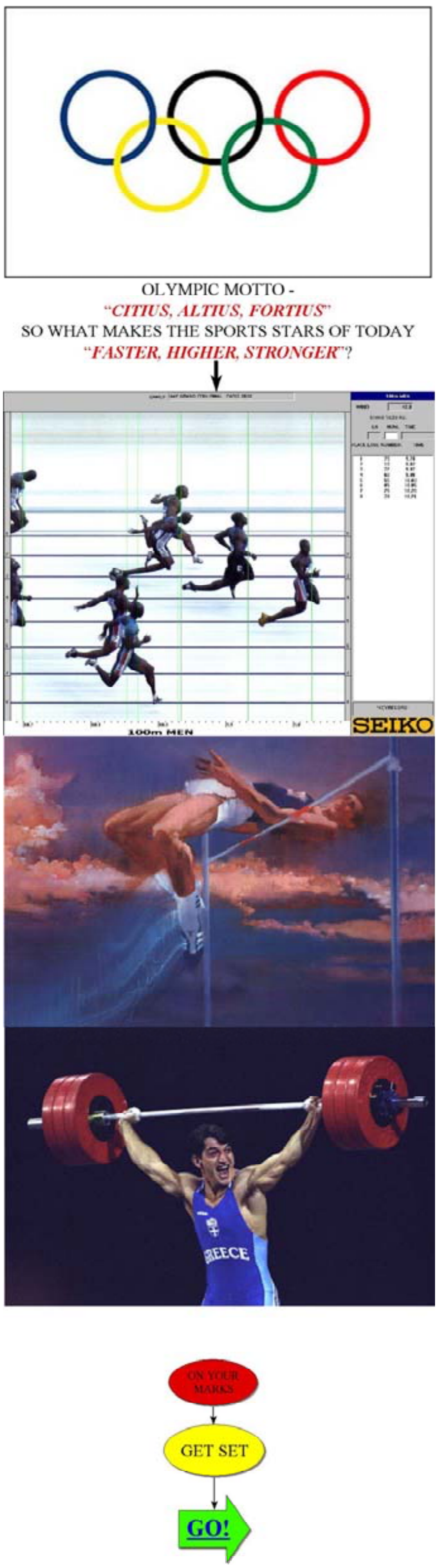
The overall structure of the course was visualised using a mind mapping software called Inspiration (ver 7.5 Intl.). Mind mapping is a method of note taking and/or representing information in a non-linear, visually stimulating way (Buzan, 1991, 2003). In producing and viewing a mind map both sides of the brain are being stimulated. Such a mind map, in combination with assimilation and perception through vision, the organisation, storage and recall abilities of the brain, draws on a wide range of mental skills.

As well as text, the software could display pictures, diagrams and links between ideas and concepts. All these factors could be useful in conveying the subject matter to the students (Gardner, 1983, 1993, Kornhaber, 2001).

The Inspiration software was capable of producing an HTML document from the collection of hyperlinked mind maps. This enabled us to present the resource as a website, and content could then be linked to external websites containing relevant information for background and further reading, putting the content further into context and informing the students' learning. Using the Internet would also enable the students to develop the skill of information gathering. By using the principles of MI theory and mind mapping in a web resource, a more visual medium with which to present the course was realised (Gardner, 1993, Buzan, 1991, 2003).

The Olympic motto is "*citius, altius, fortius*" (faster, higher, stronger). The introductory page of the learning resource posed the question: what makes our sports stars faster, higher, stronger? (See Figure 1.) With the Olympic Games in Athens (2004) having taken place only 5 months previously, this was an event still fresh in people's minds.

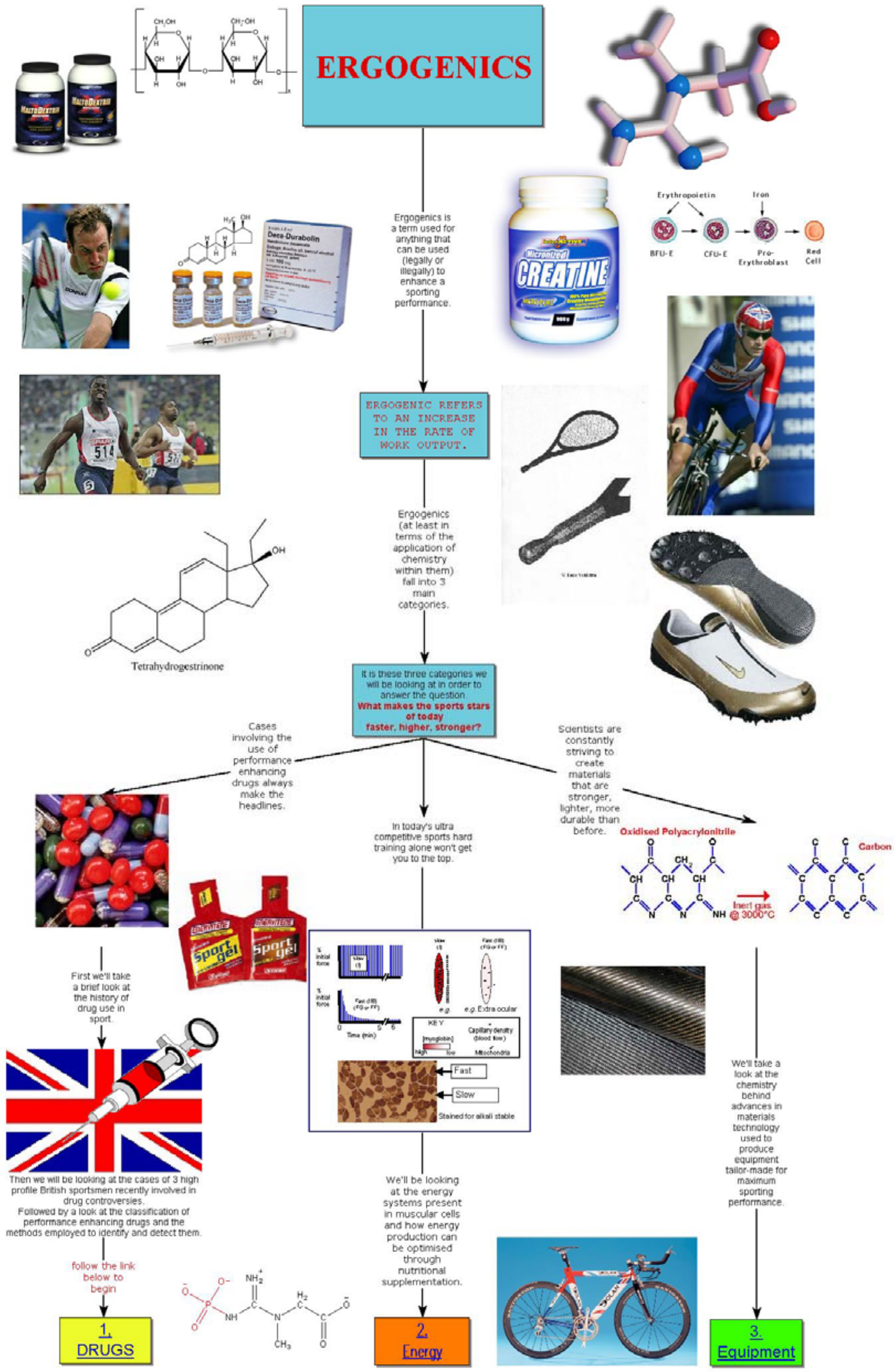
Figure 1



Results

Before the students began the course they were asked to complete a pre-course questionnaire in order to assess the types of learning previously experienced. The pre-course questionnaire results show that, although relatively inexperienced at carrying out independent study, the students were reasonably confident about their ability to study this way. In their most recent attempt using this method more than half of them felt they had performed averagely. They did, however, enjoy the experience. Despite only half of them having used PCs in such assignments, they were confident in working with computers and about information retrieval using the internet, but somewhat less confident using the library. The group showed a range of experiences with respect to online learning.

Figure 2. A screenshot of the introductory page.



The students were then asked to view the learning resource via the departmental website, and complete the tasks in each section to preset deadlines. A screenshot of the introductory page is shown in Figure 2. A summary of the learning resource content and tasks can be found in Table 1.

Table 1. Resource content and task details.

Content	**Tasks**
Drug use in sport, *case studies and history*.	Choose athlete/learn case details/background reading
Drug use in sport, *nomenclature and use*.	Find drug classes and effects
Drug use in sport, *analytical techniques used for THG, nandrolone & EPO*	Identify problems in analysis of chosen case
	Reasons for methods of analysis
Drug use in sport, *analytical instruments used for THG, nandrolone & EPO analysis and associated side effects of abuse*	Identification of health risks
	Closer look at analytical techniques for chosen case
	Closer look at problems in analysis
Energy systems in muscle cells of humans	Background reading
ATP; *energy producing biochemical*	Find chemical structure
ATP; *Energy characteristics*	Find reaction and compare energy characteristics
Oxygen energy system; *aerobic glycolysis*	Predict products of reaction
Lactic acid energy system; *anaerobic glycolysis*	Predict products of reaction
Lactic acid energy system; *lactic acid build-up*	Summarise training techniques
ATP-CP energy system; *Creatine phosphate*	Find purpose of chemical in energy system
	Find and show functions of reaction
Muscle fuel; *types and sources of carbohydrates and electrolytes*	Give examples of saccharides
	Calculation of energy required from food
	Calculation of molarity of a sports drink
Energy systems; *summarisation of concepts learnt in this section*	Assigning energy systems to sporting events and justifying answers
Sporting equipment	Information retrieval
Materials chemistry; *synthesis and use of Kevlar and carbon fibre*	Account of uses of Kevlar and carbon fibre in production of materials used in sport

Discussion

About three weeks after handing in their assignments the students were given a post-course questionnaire from which useful feedback was gained.

A few technical problems were encountered because of differences in operating system, software, monitor dimensions and the use of a rudimentary website design software (Inspiration). Overall the responses to the questionnaire were positive, and showed that the majority of students had been reasonably confident about carrying out the assignments, even though they felt they had performed averagely in their previous attempt at independent learning. They enjoyed the experience, found the subject matter interesting, found the presentation helpful, and retained most of the content 3-4 weeks after completing the course. They found the amount and difficulty of work neither too much nor too taxing; they thought that the learning method was effective, especially in comparison to the more traditional paper-based approach to independent learning. Some students commented on the fact that a paper-based version of the learning resource would have been more convenient, since being web-based necessitated regular and reliable internet access and not every household had these facilities, and being part-time students, they had restricted access to the on-campus PCs. The students also indicated that they would be happy to undertake a similar course of study in the future.

The students' assessment results were encouraging. The marks for the continuously assessed, year long module of which 'Chemistry in Sport' formed half, averaged 67% in the first semester and 65% in the second semester. By comparison, the marks for the examined modules for that year for the same group of students averaged marks of 54% and 51%. This sort of increase in marks for a continuously assessed module is commonplace and expected, regardless of the teaching method. Since the data comes from a sample of only eight students, it cannot be seen as statistically significant but provides some indication that this was an effective approach.

Using the techniques of mind mapping, multiple intelligences (MI) theory, problem-based learning (PBL), context-based learning (CBL) and case studies seems to have enhanced the learning experience, according to the feedback from the students. Their assessed responses from this course showed that effective independent learning had occurred. Unlike the more traditional approaches used to teaching chemistry, they were given the freedom to express themselves and took the opportunity well. Being in the first year of a foundation degree course, the marks from this module will not have a large bearing on the final degree mark. Using an amalgamation of alternative teaching and learning techniques, this learning resource allowed the students the chance to make mistakes and freedom to explore how they learn without having to worry too much about the results in terms of marks. What was more important was the acquisition of new knowledge and skills that would stand them in good stead for the rest of the course and the future in general.

For the future, courses using any number of contexts could be designed in a similar format. These could include the chemistry behind everyday household items, the chemistry in food science, case studies on the development of fundamental chemical concepts, other case studies detailing the processes of discovery as well as the products and interdisciplinary approaches involving liaison with other departments. There is evidence in the literature of the effectiveness of the above techniques of MI theory, PBL, CBL and mind mapping, and such courses could make use of these.

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CHEMISTRY EDUCATION RESEARCH AND PRACTICE
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