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Paper

An Interactive Working Group in Chemistry used as a Diagnostic Tool for Problematic Study Styles.

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Abstract

Students entering university were tested for their subject knowledge and learning styles. Students with low scores on both tests were advised to follow a process-oriented remedial instruction by means of Interactive Working Groups (IWGs). In reality a mixture of students participated which favours student interaction and thus learning. The general aim for all IWG's is to generate autonomous study skills in particular science disciplines. In this article, the first session of an IWG developed for the general chemistry course is described. It is organised at a very early stage of the academic year (4^{th} week). Its purpose is to evaluate students' text analysis and comprehension skills of particular basic chemical concepts appearing in a text chosen for study. The text is part of their textbook and the subject is *stoichiometry*. Three activities in this IWG have been examined: their general study skills, their test results assessing basic chemical knowledge, and their ability to interpret textual information. For the latter we compared each student's scheme with that of an expert. It was found that students' performance on the assignments corresponding to these three activities could be of predictive value in identifying a surface approach to learning at an early stage.

Introduction

A major purpose of science education is to have students construct a deep conceptual understanding of any scientific topic studied. This cannot be achieved if students do not acquire higher order cognitive skills (HOCS)[1] that include the ability of asking questions,[2] solving problems, decision making and critical system thinking.[3] These skills can be developed through an appropriate process-oriented form of instruction, one that emphasizes the development of HOCS through independent learning and active participation in the instruction-learning process. The Learning and Guidance Centre at the Vrije Universiteit Brussel, a unique concept in Belgium, developed a process-oriented instructional method called Interactive Working Groups (IWG) for several science disciplines. The major goals of IWGs are the promotion of in-depth learning, knowledge construction, self-regulation, and awareness of misconceptions by the training in general and specific learning skills in a content-specific context (in science). Depending on the content and/or identified learning problems, more emphasis is laid on one of these goals. One particular IWG is the subject of this article. IWG's are based on the socio-constructivistic model.[4] According to this model the learner builds his own knowledge through the interaction with the environment; in the case of IWGs a two-way communication between students and students-instructor is represented. It is known that a two-way kind of interaction is far more supportive of meaningful science learning than a unidirectional speech.[5]

Wellington and Osborn[6] described several structural experiences and tasks to support students' interactions. They suggested the use of collaborative concept mapping activities, structured critical instances involving common misconceptions and the use of directed activities related to texts, to structure and guiding students in small-group activities and discussions. The use of visualisation techniques is a strong approach to encourage students to adopt more effective and meaningful processing strategies. It includes teaching awareness of text structure for generating explanations.[7]

Students participating in the IWG discussed in this paper were asked to demonstrate their understanding by making use of text structure visualisation techniques. The reason of using them is many-fold: students discover another study technique, the instructor has a quick tool to evaluate students' text comprehensive skills and active student participation is demanded because it is *their* scheme.

The learning process is also influenced by the way new information is passed through the filter of a learner's prior knowledge and experience.[8] Consequently, when prior knowledge is involved in the creation of meaning, what the learner already knows is of central importance.[9] "*Ascertain this and teach accordingly,*" states the oft-quoted assertion of Ausubel.[10]

Background to the problem and aim of this study

Flemish science students are not selected for entry to universities by means of national exams. As a consequence, many of them cannot (immediately) cope with the high demands of university studies. Due to the bachelor-master reorganisation, the semester is reduced from 15 to 13 weeks. It becomes at this stage even more important to identify learning deficiencies as early as possible. The question is, on the one hand how to identify students at risk in a very early stage, and on the other to prepare students for assessment that takes place three to four months after enrolment. On the level of the general chemistry course, we have identified certain factors that, we believe, influence the success rates of our students.

(a) *Prior knowledge*

To identify deficiencies in chemistry content knowledge, the Learning and Guidance Centre organises prior knowledge tests of chemistry on students' entrance day. Its main goal is to make students aware of the extent, limits and accuracy of their prior knowledge. The set-up and the evaluation of the prior knowledge test of chemistry show common elements with the chemistry exams: open questions that test for accurate recall of concepts represent a minor part and the major part tests their problem solving ability. Over a period of three years, we have found that the initial prior knowledge defines for a large part their performance on the mid-term exam of chemistry that in its turn influences the end of term exams.[11]

(b) Learning environment

Group interviews with weak and with good students reveal that the students' perception of the general chemistry course before the examination is not in accord with the complexity of the subject matter. They perceive the chemistry learning environment as well structured. The chemistry content is very well explained in the lecture sessions and extensively covered in their syllabus. Problem solving sessions and laboratory activities are fully integrated into the course set-up. The pace of the lectures and problem solving sessions is well judged. Once the exams are approaching or have been taken, many students realize that chemistry is more complicated than they had thought. Some of them understand that their struggle is due to their textbook; a textbook that extensively covers all topics in detail makes students think it is easy to study. It also seems that lectures give those students a (false) feeling of understanding which leads to procrastination. Because they think they understand and know that the content is covered by their textbook, they go home (with confidence) and devote their attention to courses that are perceived as more difficult or demanding (assignments with deadlines given after each lecture). Excellent students focus simultaneously on all courses.[12] The procrastinators do not feel the need to combine and correlate the bits of information from several lectures.

(c) Cognitive and meta-cognitive abilities

One of our tools for acquiring information on the students' cognitive and meta-cognitive abilities is the Learning Style Questionnaire of Jan Vermunt.[13] Students are invited to discuss their results and are asked whether they recognize themselves in the learning style outcome. In the case of agreement and low subscale scores for the motivational and self-regulated subscales, we strongly advise them to join the Interactive Working Groups.

In one of our quantitative studies we found that many first year students believe that finding a correct numerical solution means that one understands the theory. Their strategy consists of doing as many exercises as possible. But in the end, it turns out that a lack of study time prevents many of them to reach this goal.[12] Upon analysing students' written exam papers, we had the feeling that failures could also be attributed to weak text-interpretation abilities. This observation is also corroborated by recent studies revealing that middle school students' knowledge about reading science, meta-cognitive awareness, was only partially developed and the strategies they used to repair comprehension failures were limited and not well adapted to science texts.[14]

Both learning style inventories and prior knowledge test results are helpful indicators for potentially problematic learners, but exact correlations between an individual learning style and exam performances cannot be drawn. For instance, some of our gifted students give themselves low scores on the self-regulation subscales and some students who turned out to be weak gave themselves very high scores. What these learning styles also do not tell us is what students exactly do when studying a (chemical) text. What do these students consider as important paragraphs, do they make links between concepts seen in earlier chapters? How do they interpret the given information, for example? Do they try to understand concepts by looking for concrete examples? The IWG under discussion, the first in a series, has the purpose to evaluate students' text analysis abilities and their understanding of particular basic chemical concepts appearing in the text to be studied. This IWG should make them aware of their shortcomings. The tool that we use for this evaluation is a student scheme that has the purpose to display the students' comprehension of the logic and philosophy of the author's text. Details are to be found in the *Instructional methodology section*.

In the *Results section*, student responses are related to their end-of term-exam of chemistry performance. We expect to see differences in assignments between gifted and less gifted students. This correlation should allow us to find out if this IWG could be used as a complementary diagnostic tool in combination with the prior knowledge test in chemistry and the Learning Style Questionnaire of Vermunt. The *Discussion section* includes some advice for the use of this particular IWG as a diagnostic tool.

Instructional methodology

Interactive Working Groups; some history and general aims

Originally created as a tool to remedy problems in the transition from secondary school to university, an interactive working group (IWG) is a process oriented teaching method. It has first been developed for the general physics course. Evaluations in the past[15] have shown that IWG participation in physics may lead to better scores in examinations and induces positive effects on the learning approach. Due to these results, other disciplines such as mathematics, biology, and later on chemistry, followed and created content-specific IWG sessions. Participation in a series of sessions is a prerequisite to overcome identified learning deficiencies. However, depending on the academic staff, some disciplines do not require attendance as in the case for chemistry. The IWG sessions are open for any student but active participation is demanded of those who attend. Advice to participate is only given to those students whose performance in the chemistry prior knowledge test was below university entrance level, in combination with a problematic learning style. Students with better prior knowledge scores or less problematic learning styles who choose to participate are thus a self-selected group. Such a mixture of potentially better and weaker students allows for better student interactions.

The IWG instructor acts as a guide rather than a teacher, observes misconceptions, provides tools to enhance autonomous thinking and creates, through interaction, an atmosphere in which students feel encouraged to participate.

All IWGs are organised in parallel with regular studies. Each session takes about two hours and a maximum of fifteen students is allowed in each group. The IWG subjects refer to the lectures and seminars that were given prior to the IWG-session. The Faculty of Sciences recognizes the merits of the IWG-sessions and therefore makes slots available on the students' weekly timetable.

Chemistry Interactive Working Groups

Several IWGs for chemistry have been developed. Their subjects are stoichiometry, the historical evolution of the atomic theory, phase diagrams, chemical equilibrium applied to Brønsted acids and bases and an organic chemistry theme about aldehydes-ketones-carboxylic acids. The main purpose remains in-depth learning. Problem solving is not part of the chemistry IWGs, as we believe that text comprehension skills and concept understanding prior to problem solving skills need to be taught first. Problem solving activities are in any case embedded in the regular curriculum. All IWG sessions use the (Flemish) textbook of general chemistry.[16] Five sessions gradually build on each other; while the first two sessions deal with text analysis and content structure, the following IWG's focus more on critical thinking.

In the Learning and Guidance Centre (LGC) students find the registration list and a specific preparation task.

Enhancement of self-regulation activities

The chemistry IWG instruction is based on the general model as developed by the LGC and slightly adapted to the model of self-regulation by Zimmerman.[17] He describes self-regulation as the degree to which individuals are metacognitively, motivationally and behaviorally proactive participants in their own learning process. The self-regulation process involves three phases – forethought, performance and evaluation – that the student applies repeatedly during learning.

The aim of forethought is to guide both the mind and the performance in any specific task, and to plan future actions. Performance consists of the execution of the activity, controlling not only every aspect involved in the development of the activity, but also those factors that may affect specification and distribution of time and effort. Evaluation refers to the phase subsequent to the learning effort; that is, the analysis of whatever occurred, the results obtained and the relationships between that particular activity and other similar ones. However, the acquisition of this skill is not necessarily associated with natural development. As with any other capacity or content, it should be explicitly taught.[18] In this IWG, the first in a series, we apply Zimmermans' ideas to see what students plan to do (the forethought part) and how they implement their ideas (the performance part). Tools to help them are offered in this part. The evaluation part is merely to let students discover their own limits, i.e. their text interpretation skills.

Subject: Stoichiometry

The IWG under discussion has been chosen because it is part of the secondary school curricula. It is organised at an early stage (4th week) of the academic year. Therefore, our conclusions will reveal students' study approaches from secondary school. The subject was also covered (merely as a review of the secondary school content) in the university lectures and problem solving seminars shortly before this session. We expected our students not to experience difficulties with this concept. Students had to read seven pages in their textbook as preparation assignment at home. They had to bring their textbook to the session. To get insight into students' text analysis and comprehension skills, we gave them in the IWG session several assignments, of which the final one was to structure the 7-page text on one page of A4 by making use of visualisation techniques.

Ideally, training in mapping techniques should have been provided, but a full college timetable prevented such an initiative. Therefore, prior to the drawing activity, the text was fully analysed by group discussion. A demonstration and explication of different scheme-techniques, i.e. concept maps[19] and mind maps[20] was also given. This should provide students with ideas. We briefly explained to them the differences between the two techniques. Concept maps have a structure similar to that of mind maps in that they show main ideas and secondary ideas linked to a topic. The first strongly resembles a linear and hierarchical structure and makes no use of the whole brain, while mind mapping uses both sides of the brain, lets them work together and thus increases productivity and memory retention. Mind maps connect ideas and concepts with a topic displayed as a graphical pattern, often as an artistic image. We were guided by an article where mind mapping is used as a tool in mathematics education.[21] Students decide then individually how they want to represent the text visually on one page. They are asked to choose a theme that covers best the content of the seven pages of study. By placing this in the middle of their paper they all have the same starting point.

Feed-back on the scheme

A drawing technique such as concept mapping is used in many cases to assess students' progress in learning.[22, 23] However, this IWG tests how far an individual student has mastered the content of a given text when several different teaching activities, such as lectures and problem-based seminars, have been organised. Schemes are quickly evaluated by comparing each student's scheme with a scheme produced by the instructor, who needs to be a content expert. The instructor's scheme has been approved by the author of the text. Such a scheme could be regarded as an expert link matrix.[24] This assessment method consists of a process in which one or more experts on a given topic produce an exhaustive set of possible relationships between each pair of concepts in the allowed set. These possible relationships can then be categorized in various ways. In our expert link matrix, we distinguish three broad characteristics: formal descriptive, explanatory and procedural (summarised in Table 1). Differences in these characteristics in the students' and the expert's scheme are discussed with the students.

Structure

Because this IWG is the first in a series we start the session with a general introduction of about 5 minutes. In brackets: the role of the instructor and time allowed for each stage.

Forethought (15')

Emphasis is placed on active student involvement on what students are planning to do. A two-minutes questionnaire (shown in the *Results section)* is handed out, followed by discussion. Students listen and add comments to each other's responses as an opportunity to hear how others plan.

Performance (1h 30')

Text-analysis (30'): we tell students that a good basis of critical text analysis is to ask oneself continuously three types of questions: *what* is the author trying to tell us, *what* does a concept mean. Then they should ask *why* this concept is under study with reference to former and later chapters or paragraphs, and *how* a concept is translated into practical use. Each paragraph of the text is discussed by continuously asking *what, why and how*? Students can look forwards and backwards in the textbook, because they have to bring their textbook to the session and this IWG is performed after the lecture covering stoichiometry. This text analysis part is performed by group discussion regulated by the instructor.

Test (15'): to monitor their understanding and use of chemical vocabulary and to provide feedback. This test is shown in the results section.

Demonstration (instructor, 10') of different sorts of schemes in different areas with explanation of the benefits, i.e. an example of a mind map made by a doctor showing a patient's medical history, a concept map of a redox reaction and another concept map showing relationships between formulas in classical mechanics.

Design of scheme (35'): students draw their scheme limited to one page.

Evaluation by self-explanation (15')

In this part the instructor uses the expert scheme to check whether the students' schemes are a schematic translation of the text. Attention is given to how the *what, why and how* questions are represented in their scheme. The best scheme is demonstrated and explained by the student to the whole group.

In this two-hour session, instant feedback is given during the discussion sessions. Some students are reluctant to talk and discuss in public. Therefore, individual feedback on the basis of their written assignments is provided after the IWG-session. By means of a check-list (displayed in Tables 1 and 2) feedback takes a minimum of five minutes per student.

Table 1: Checklist for fast feedback of a scheme's content:

Column 1 represents three scheme characteristics: a descriptive level ('*what*' questions), a procedural level ('*how*'questions) and an explanatory level ('*why*'questions). In column 2, the main paragraphs corresponding to each characteristic level are represented. In column 3, subparagraphs corresponding to the main blocks are given, while in column 4 text details are represented. The whole table has to be read from left to right. Codes are used to facilitate discussion.

Scheme Characteristics	Level content	Sublevel content	Sublevel content details
Descriptive: What *(is this paragraph about?)* (I)	Definition of a chemical equation (I.1)	Explanation by illustration (I.1.1)	Copy of the handbook (I.1.1.1) Student demonstrates his/her understanding by choosing another example of a chemical equation not given in the handbook. (I.1.1.2)
		Explanation in words such as: (I.1.2.)	Reactants → products are represented by their molecular formula (I.1.2.1), physical state symbols (I.1.2.2.), coefficients ≠ subscripts (I.1.2.3.)
		Balancing a chemical equation (I.1.3.)	Definition (I.1.3.1) Dalton (I.1.3.2) Two levels of interpretation and use (macro, micro) (I.1.3.3)
Procedural: How *(does one write a chemical equation?)* (II)	Balancing a chemical equation (II.1)	Demonstration of 3 techniques (II.1.1)	comment: never change the indices. (II.1.1.1)
Explanatory: Why *(does one need a chemical equation?)* (III)	Stoichiometric calculations (III.1)	Procedure: quantity A → mol A → mol B → quantity B (III.1.1) Three conditions (III.1.2)	III.1.1.1. limiting reactant III.1.1.2. stoichiometric ratio
	Application (III.2)	Examples (III.2.1)	

Table 2: Concept checklist with cross-links between descriptive and procedural scheme characteristics. Codes in the second column refer to Table 1

Concepts (IV)	Relationships between characteristic elements corresponding to a concept.
1. macroscopic use of a chemical equation (IV.1)	IV.1: Linking macro interpretations (I.1.3.3) to calculations (III.1) and applications (III.2)
2. law of conservation of matter (IV.2) 3. stoichiometric ratio (IV.3)	IV 2: Linking Dalton (I.1.3.2) to III.1.1 (Procedure)
4. limiting reactant (IV.4)	IV.3 and IV.4: Linking I.1.3.1 with calculations (III.1) and applications (III.2)

Results

Students enrolled for bio-engineering, biology and chemistry courses are the subject of this analysis. Their chemistry course books, evaluation criteria and teaching staff were the same. We received partial or complete assignments from only seventeen students, who are half of the attendees. We compared the students' own accounts of their study processes, their test and scheme results and correlated them with their chemistry exam results. We could identify three groups: those who failed on almost all mid-term exams and had to restart the first year [coded as *x*-students (8)], those who performed well [coded as *y*-students (7)] and those who failed at the end of term exams in June but resat successfully in September [coded as *z*-students (2)]. We mention that four *x*- and two *z*-students' scored below 40% on the prior knowledge test. All *y*-students performed much better.

We first report the questionnaire and the students' responses to it, followed by the test results. The last section analyses different levels in each scheme: descriptive, explanatory and procedural.

(a) Questionnaire results (from the forethought part)

Q1: Describe your study process before you draw your scheme.

Q2: What could be the benefits of a scheme? Give your personal opinion.

Q3: How will your scheme look?

The responses from *x*-and *y*-students are presented separately. Students coded *z* did not hand in their answers

Students' responses:

Q1: Study process

x3: "Scan quickly"

x4: "I look for particular expressions, the content's construction, comments and procedures."

x5: "Distinction of main and side topics, writing down main topics to link them possibly."

x7: "Reading the title, possibly subtitles. Count pages of sections. Scan quickly text by skipping figures, tables. Then reading, reading and again reading. Finally, look for relationships between topics."

x8: "Reading, underlining main topics, writing down definitions, formulas. Marking relationships, illustrating with examples."

x9: "Reading, underlining important topics, finding key terms and looking for relationships.

y4: "I should first read and underline the main issues. Then I should write these down to find relationships."

y5: "I look for the main issues. Then I read the important comments such as ...but not applicable in case of .... I look for relations between the main issues in order to get a better structure [in the scheme]. I use examples to illustrate concepts."

y6: "I read - underline main issues - look for structure and write it down."

y7: "I look for structure by reading and underlining. I look for important words."

Q2: benefits of a scheme

x3: "It [=a scheme] gives a better understanding of the theory and the relationships between the main topics."

x4: "Structure, relationships, easy to revise by key terms."

x5: "Reduction of content material. A scheme is an overview of the content and it prevents you from paying attention to less important topics."

x7: "It's easy to search certain topics."

x8: "All important topics are grouped together. Details are thrown away to better understand the content."

x9: "It serves as an abstract, it gives an overview and it easier to rehearse.

y4: "A scheme represents the structure of a text. Topics are linked and only the main topics are represented."

y5: "It's an overview of the content and easy for use in revision."
y6: "It's an overview and relationships are visually represented"
y7: "It's an overview, there is a structure and it controls" [what??]

Q3: visual representation
x3: no answer handed in
x4: "Mind map"
x5: "Subject title, abstract of the most important topics"
x7: "A content table"
x8: "Concepts, definitions and arrows"
x9: no answer handed in
y4: no answer handed in
y5: "Use lots of space"
y6: "Structure and colours for relationships"
y7: "Key terms, arrows and distinction between main and side topics by use of different layers".

Y-students describe their study process in terms of the following actions; they read, underline, look for relationships between topics and try to discover structure in the text. Their response style is quite alike: brief and it contains all necessary elements of their study process. Just one student uses a conditional tense (*y4*); indeed she never made a scheme, but it does not prevent her from having ideas. Some of these students go even further and consider comments as part of their scheme or try to illustrate the content. One constant of a scheme is that it must give them an overview. Running ahead, their scheme is a translation of their thoughts.

X-students are more varied in their responses. Many of them give long (*x7, x8*) or extremely short (*x3*) answers concerning their study process. Analyses of the content of their answers points out that many use a surface approach to learning, as defined by Entwistle;[25] i.e. scanning quickly, counting pages, writing down main topics to link them, *possibly*. The benefits of a scheme are as good as its creator's understanding of the content. Students *x5*, *x8* and *x9* serve as illustrations: for them their scheme must focus on important topics but in reality their scheme is descriptive without translation of the author's main ideas. Elements such as scanning quickly, counting pages, not attaching importance to details and only focusing on main topics are signs of problematic learning styles. These students try to reduce the content, but not by chunking or making short cuts, but by simply cutting out information. Their answers on question 3 give the impression that they have no idea about the benefits of a scheme; we find words as content table, an abstract and some arrows. There is only one student (*x4*) who gives answers that are, in our opinion, valid and his scheme is an excellent example of a mind map. It contains the whole philosophy of the author's text. Despite this, his exam performances were extremely weak in almost all disciplines. This student admitted that his study method in secondary school was inappropriate and therefore he had taken some lessons to approve his study process. Mind maps help him in understanding the content.

On the basis of simple questions, differences are noted between *x*- and *y*-students. We realise that these preliminary conclusions are based on a small number of students (10). At first sight we would say that proficient (*y*)-students express their study approach in similar terms; *overview* and *structure* are terms that frequently appear. Students who use expressions such as *counting, reading and reading again, skipping tables*, etc, could be considered as weaker students.

(b) Chemical vocabulary test results (from the performance part)
The aim of the test is to emphasise a correct use of chemical vocabulary, which in its turn will increase the comprehensibility of schemes. Students' answers are shown in the Appendix. Our experience is that good students spontaneously use the appropriate chemical vocabulary while weaker students do not. When you tell them that one cannot speak French without actively studying its vocabulary and grammar, they all agree. When chemistry is at stake, many students do not go beyond the level of passive knowledge,[26] while assessment strongly emphasizes problem solving. Reciting definitions are part of it, but of minor importance.

The content of the test is short, basic and extracted directly from the text. Prior to the test, and after the text analysis discussion part, students were asked whether they still have some questions.

The test contains 4 questions:
1. Explain the meaning of a subscript.
2. Give two examples of a formula unit
3. Explain the term: *limiting reactant*
4. Explain the term: *stoichiometric ratio of reactants.*

Comparing the groups (*x*, *y* and *z* students) we found different kinds of responses. The subscript question was well answered, though some students talked about the number of atoms in a bond (*x7, x8* and *y5*). Many students illustrate question 1; the most popular molecule seems to be Cl_2. Students (*z1* and *x5*) give partially correct answers. Their illustrations are correct, but the written explanation for question 1 does not make proper use of basic chemical terminology, i.e. talking about "*atoms from an entity that form a molecule*". Probably they mean atoms from one particular element. *Y*- and *z1*-students (we have no answers from student *z2*) gave correct examples for question 2. Errors were only made by *x*-students: some of them gave the water molecule or some acids (HF and HCl) as examples of a formula unit, or made subscript errors, i.e. BaCl. The definition for question 3 is strictly given as: that reactant that is fully consumed when the reaction is complete. Only student *y6* discussed its role in a stoichiometric calculation: namely, the reactant that governs the maximum amount of product that can be formed. Many answers (*x3, x7, x8, x9, x10, y2, y5)* are limited to the reactant that is fully consumed in a chemical equation without referring to the presence of another reactant in excess. Students *z1* and *y4* explained that the limiting reactant causes the reaction to deplete, neglecting some thermodynamic principles. It is indeed possible that this misconception could appear, as many of our students were not taught about elementary thermodynamics in secondary school. Student *x4* used his own vocabulary: "*a reaction cannot go on forever; it has to come to an end*". Concerning question 4, the stoichiometric ratio of reactants was a largely unknown term to all of our students. We found the following answers: "*it is a ratio of coefficients*" (*x3, x5, x8, x10*), some specify this by reactants' and products' coefficients (*x3*), others added that this ratio must equal the smallest whole number (*x5, x10*). But none of them connected the stoichiometric ratio of reactants to the amount of moles that are formed and disappeared. It is remarkable that none of our *y*-students answered question 4, which made us assume that they preferred not to answer when they were not sure. *X*-students were more inclined to give answers, even when these questions were half correct or nonsensical. We were surprised to see such a variety in answers after the 30 minutes text analysis part.

(c) Scheme results (from the performance part)

We were interested to find information on the following questions in their schemes: a) what do students actually retain from the text discussion (not reported here) and b) how is their use of chemical terminology that was the subject of the test? For point b) students went through the whole text, by asking *what* is this paragraph about, *how* is it explained and *why* is this (chemical equation) useful. We advised them to recall the main ideas/concepts resulting from the discussion that is an answer on *what-why-how*, to use key-terms and to avoid full-sentences.

Because we knew that some students had never produced a scheme, we asked them not to start from the top because that would initiate a top-down linear representation, which might lead to an abstract instead of a scheme. The whole group was advised to look for one idea, that should exemplify the text and that could be used as an excellent starting point, placed in the middle of what would become their scheme. In our analysis we used the checklists given in Tables 1 and 2. The hierarchic levels are based on the instructor's expert scheme produced from the same text that students had to study. It was not our purpose to grade their schemes, because students were not trained in making schemes.

Many students chose as starting point a chemical equation, often illustrated by
$2Na\ (s) + Cl_2\ (g) \rightarrow 2\ NaCl(s)$ (I.1.1.).
At the descriptive level (I), we did not find many differences between student groups. Almost every student gave a complete definition of a chemical equation on the level of I.1.2. When a reaction equation was their central starting point, the example in their handbook was copied (I.1.1.1). They were not told to choose other examples (I.1.1.2.) than those given in the text. We were just interested to see whether *y*-students would look for other examples, which they didn't. Applications of stoichiometric calculations mentioned in the text; i.e. oxygen combustion reactions, redox and pH-calculations, which we categorised at the explanatory level (III.2.1), were not found in any of the answers, except for student *y7*. It means that the *why*-question in the explanatory level is not really one of their initial concerns. At this level, there is not much difference between *x*-, *y*- and *z*-students.

X-students do not explain what is meant by balancing a chemical equation (I.1.3.1), but do mention its interpretation at microscopic and macroscopic level (I.1.3.3.) without referring to the latter's practical use (IV.1). In the text analysis discussion, emphasis was first placed on the microscopic and then on the macroscopic interpretation. After that, the question was raised: *why* did the author mention these two levels? Despite the earlier discussion part, only *x4, x10* and *y2, y3, y6* students seemed to retain the microscopic and macroscopic interpretations of a chemical equation. *X4* was most clear in his explanation: the macroscopic interpretation of a chemical equation is for practical use.

A link between chemical equations and stoichiometric calculations was made by almost all students, though the calculation procedure (III.1.1) was in many cases not mentioned at all (*x5, x6, x8, x9, x10, y2, y5*) or only partially (*x3, x7, y3*). One (*x3)*-student recognized the aim of a stoichiometric calculation, namely the calculation of an expected yield, but the protocol and control mechanism, i.e. the law of mass (IV.2) is absent. The concept of stoichiometric ratio (IV.3) was, despite the earlier test and feedback, not found in any *x*- and *z*-scheme, except in that of student *x4*. We recall that in the chemical knowledge test (Appendix) *y*-students did not give an answer to the stoichiometric ratio question. Despite the blank answer, we notice that (perhaps due to the feedback) this term appeared in certain schemes (*y1, y3, y6, y7*). Later on, it turned out that these students were among the best of their year.

Although we realise that an expert scheme is probably more detailed than what any novice could produce, we think that certain distinctions can be drawn among students at the three characteristic levels. Almost all *x*-students kept their text representation at the descriptive and procedural level. What they call *important topics* are in most cases elements of description (see previous discussion in the *Results section: forethought*). The concepts (IV) are also largely absent.

Z-students who pass after their second resit were incomplete in their schemes. While their schemes were easy to follow, they were incomplete on the concept level. They paid much attention to procedures that would help them when problem solving calls for algorithmic procedures, but we cannot detect whether they made use of control mechanisms, such as the law of conservation of matter (IV.2) and checking for a limiting reactant (IV.4). The control aspect is one the most import self-regulation activities.

All *y*-students, who obtained a minimum score of 55% on their chemistry exam, had more complete schemes and the explanatory level is given in detail where concepts (IV.2, and IV.4) appeared on every *y*-scheme. They also differed from the other students by their choice of the topic placed in the centre of their scheme. Instead of the chemical equation (I.1.1.), they used the aim of the text: stoichiometric calculations (III.1). This term belongs to the explanatory level.

Discussion

To discover study styles that may be the source of problems for students taking the General Chemistry course, this IWG has to examine three activities. It has to look at their study plan (1) (forethoughts) which should reveal their general study skills, at their test results assessing their chemistry knowledge (2), and their ability to interpret text by means of a scheme (3). In their study plans one must look out for words or phrases that may indicate a surface approach to studying, such as: '*a quick read*', '*concentrating on just the important topics*', counting pages, and not paying much attention to details.

The way the 'how' questions are answered has to be examined as well (in the discussion part and its translation in their scheme). Is there any sign of mismatch between question and answer; does the scheme only include summary, headings and subheadings? Answers left blank, erroneous use of chemical terminology and nonsensical answers also need to be examined. When these are found, students need to be urged to practise self-assessment and reflect on their performance. Why do they not respond to the question if everything was clear after the discussion part; why do they write answers that are incorrect, what makes them feel they have everything under control? The chemical vocabulary tested and discussed should appear somewhere in their scheme.

In our analysis, we discovered that strong students immediately catch up with what they don't know or have forgotten. Weak students don't. For example, stoichiometric reaction ratio (question 4) is such a term that we did not find in any scheme made by *x*-students.

Some students did not hand in their answers to the test and study-plans questionnaire. This applies to the two *z*-coded students and some *y*-students. Some of these y-students obtained 80% scores for their chemistry exam. It would have been interesting to know their study plan and test results to see in what they differ from other students.

We have also identified some problems with this IWG approach. As the IWG outcome largely depends on the students' interaction, it is possible that there is no time available for the last part; namely the best student's scheme demonstration and its discussion. Individual feedback on shortcomings in study style has to be given then after the IWG session. With the aid of a checklist, this could be quickly provided. If the same students would enrol for a series of chemistry IWG-activities, both instructor and students could benefit more from the previous experience. For the IWG instructor, the use of schemes gives more insight into students' divergent use of thinking. Instruction methodology can thus be improved. Changes in study approaches could be studied as well when the same students follow the whole IWG series, but at this moment this is not the case. The problem of study load remains. When students also participate in other IWGs, we cannot force them to attend the chemistry IWGs. We can only hope that a certain transfer of skills happens.

If this IWG is used as a diagnostic tool, the message sent to weaker students may help them avoid premature drop out. The general goal for all IWG activities remains the training of general and domain-specific skills. In the subsequent IWG activities for chemistry, a scheme or mind map is again used as a tool for text analysis, but greater emphasis is placed on critical thinking.

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References

1. G. Tsaparlis and U. Zoller, *U. Chem.Ed*., 2003, **7**, 50.
2. C. Chin, D.E. Brown and B.C. Bruce, *Int. J. Sci. Educ*., 2002, **24**, 521.
3. T.L. Overton, *U.Chem.Ed*, 2001, **5**, 62.
4. L.S. Vygotsky, Harvard University Press, Cambridge, MA, 1978.
5. S.M. Ritchie and K. Tobin, *Int. J. Sci. Educ*, 2001, **23**, 283.
6. J. Wellington and J. Osborne, *Language and literacy in science education*, Open University Press, Philadelphia, PA, 2001.
7. M.T.H. Chi, N. De Leeuw, M.H. Chiu, and LaVancher, *Cognitive Science*, 1994, **18**, 439.
8. E. Von Glaserfeld, *J. Res. Math. Educ.*, 1990, **4**, 19.
9. R. Duit, D.F. Treagust and H. Mansfield, in Duit, Treagust and Fraser (eds) *Improving Teaching and Learning in Science and Mathematics* (New York, Teachers College Press), 1996, chapter 2, 17.
10. D. Ausubel, *Educational Psychology: A cognitive View,* Holt, Rinehart and Winston, New York, 1968.
11. A. Van Keer, Proceedings of European Conference on Research in Chemical Education (ECRICE), Aveiro, Portugal, 2001.
12. E. Carette, A. Van Keer, I. Tallon, L. Willems and H. Eisendrath, Proceedings of the 7^{th} Annual ELSIN conference, Ghent, 2002, p 65.
13. J. Vermunt in *Leerstijlen en sturen van leerprocessen in het hoger onderwijs--Naar procesgerichte instructie in zelfstandig denken [Learning styles and regulation of learning in higher education--Towards process-orientated instruction in autonomous thinking],* Lisse, Swets & Zeitlinger, Amsterdam, 1992.
14. L.D.Yore, M.T. Graig and T.O. Maguire, *J. Res. Sci. Teaching*, 1995, **35**, 27.
15. A. Schatteman, E. Carette, J. Couder and Eisendrath H., *Educational Psychology*, 1997, **17**, Nos 1 and 2.
16. P.Geerlings, Algemene Chemie, Part I, 2001, VUB-Press.
17. B.J.Zimmerman, in D.H. Schunk and B.J. Zimmerman (Eds), *Self-regulated Learning* (pp 1-19), New York: Guilford Press, 1998.
18. D.H. Schunk and B.J. Zimmerman, *Self-regulation of learning and performance: issues and educational applications.* Hillsdale: Lawrence Erlbaum Associates, 1994.
19. J.D. Novac, J. *Res. Sci. Teaching*, 1990, **27**, 937.
20. T. Buzan and B. Buzan, *The mind map book*. London, BBC Books, 1997.
21. A. Brinkmann, *Mathematics Teacher*, 2003, **96**, 96.
22. P.G. Markow and R.A. Lonning, *J. Res. Sci. Teaching*, 1998, **35** (9), 1015.
23. L. Brandt, J.Elen, J. Hellemans, L. Heerman, I. Couwenberg, L. Volckaert and H. Morisse, *Int. J. Sci. Educ*, 2001, **23** (12), 1303.
24. M.A. Ruiz-Primo, S.E. Schultz and R.J. Shavelson, *CSE Technical report 436*, National Centre for Research and Evaluation, Standards and Student testing, 1997.
25. N.J. Entwistle, in J.J.F. Forest (Ed.), *University teaching: International perspectives*, New York: Garland, 1998, pp. 73-112.
26. M.E. Hinton and M.B. Nakhleh, *Chem. Educator*, 1999, **4** (5), 158.

Appendix

Students' answers on the four test questions in the Performance part of the IWG-session.

STUDENT	MEANING OF A SUBSCRIPT	2 EXAMPLES OF A FORMULA UNIT	LIMITING REACTANT	STOICHIOMETRIC RATIO OF REACTANTS
z1	In Cl_2, the number 2 is called an index and explains how many atoms from an entity are to be found in a molecule.	KCl, NaI	The entity that causes a reaction to deplete because its quantity is smallest	The ratio of an element at the beginning and at the end of a reaction
z2	-	-	-	-
x3	In Cl_2, the number 2 is called and index and explains how many atoms are to be found in a molecule.	$BaCl_2$, KCl	It's a reactant that is fully consumed	The ratio of reactants' and products' coefficients
x4	It gives the total number of certain atoms in a molecule	HCl, HF	A reaction cannot go on forever, it has to come to an end.	There is an equal amount of atoms on both sides of the reaction equation
x5	It gives the number of certain atoms from a particular entity that appears in a molecule	BaCl, LiCl	It causes a particular reactant not to be consumed fully.	The ratio of coefficients needs to be as small as possible
x6	-	-	-	-
x7	Numbers (right under) that explain how many atoms form a compound, i.e. O_3: 3 atoms are bound.	KF	A reactant that is consumed	A ratio of numbers
x8	Number of bound atoms	KF, HF	A reactant that is consumed after the reaction is finished	A ratio of coefficients: i.e. 1:2:1.
x9	$FePO_4$: 4 is an index and represents the number of oxygen atoms	$BaCl_2$, $Ba(OH)_2$	The limiting reactant in a chemical reaction is an entity that is totally consumed.	-
x10	Indices are numbers that say how many atoms a molecule contains.	KBr, H_2O	Is an entity that is fully consumed in a reaction	It is a coefficients' ratio that must be as small as possible in a chemical reaction.
y1	-	-	-	-
y2	Number of atoms in a molecule	Diamond, graphite	Is an entity that is fully consumed in a reaction to get depleted	-
y3	-	-	-	-
y4	Cl_2, H_2O, number of specific atoms in a molecule	NaBr, KI	It is a reactant that is consumed and that finishes the reaction	-
y5	Whole numbers that explain how many times an atom appears in a chemical bound.	NaI, KI	Is an entity that is fully consumed in a reaction	-

y6	Number of specific atoms in a molecule	CsCl, KCl	A reactant that is fully consumed in a chemical reaction. It is also the reactant that governs the maximum amount of product that can be formed	-
y7	-	-	-	-

Raising the Status of Chemistry Education

Perspective

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Abstract
Despite being one of the cornerstones of science, technology and industry, and forming the foundations of the life sciences, it is apparent that chemistry is in decline internationally as an 'enabling science'. This paper, primarily using Australia as an example, explores the components of the problem, identifies the challenges involved in addressing these, and proposes some solutions, which relate to raising the status of chemistry education. Chemistry as a discipline has a bright future – providing that chemistry education can more effectively convey the truly broad scope and integral position of chemistry, not only among the sciences, but also in daily life and human activities in general. This will entail improving its public perception, altering and restructuring the curriculum from primary school through to and including university to emphasize the multidisciplinary nature of chemistry and how the individual chemistry units of study integrate together and with other disciplines, and highlighting the ultimate outcomes and career opportunities.

Introduction

Australia has publicly announced that one of its principal aims in the 21st century is to achieve 'knowledge nation status', and it is intuitively obvious that technical (scientific) knowledge is a major component of this somewhat abstract ambition. However, it is also obvious that science education in Australia and chemical education in particular, both in the secondary school sector and in the tertiary sector, is failing to produce sufficient numbers of professionally trained scientists, especially chemists to feed and sustain the knowledge nation concept.[1] Indeed, as noted by Roberts,[2] if insufficient graduates are produced domestically, then suitable graduates will either be obtained from overseas or research and production will be moved abroad. Hence, at the commencement of the 21st. century, Australia is in the midst of a dilemma – how to achieve 'knowledge nation' status when the mechanisms for achieving sufficient numbers of professionally trained scientists (chemists in particular) are in crisis.

Chemistry education as an academic discipline is in decline internationally – although the actual form of the decline varies with the region. Hill and Cross[3] sounded the alarm in 2001 with an article in the '*Education Age*' entitled 'Australian Chemistry in Crisis'. Recently, similar alarms have been sounded in the UK (e.g.,[2, 4-8]). Chemistry is also in decline in the Japanese University sector (e.g.,[9]) and the US and European Universities are experiencing declining (chemistry) staff/student ratios along with concomitant funding constraints.[10] However, these trends appear to be most acute in Australia. The decline in Year 1 University science students electing to study chemistry as a major was the subject of an important statement by the Royal Australian Chemical Institute in 2001[11] with the theme 'Rebuilding the Enabling Sciences - Reclaiming the key to unlock the Nation's Potential'. This was a joint statement by the professional institutes of the 'enabling sciences' in Australia - physics, chemistry, mathematics and engineering. It was directed at the Federal Government and it defined the problem thus: "*if the current rate of university (science) staff losses continues, there will be no significant enabling science education base to support technological innovation by 2020 and if the current rate (of decline) of secondary school participation in the enabling sciences continues, these sciences will disappear from the school curriculum by 2020*". Statistical data were provided to support these alarming claims.[12] This statement clearly indicates the depth of the present crisis in Australian (chemical) education. However, before solutions can be found to address the crisis, it is necessary to understand that the problem is multi-faceted, and to identify some of the contributing factors that have progressively elevated the problem to crisis proportions.

Although the prestige of chemistry as a discipline is slipping in many countries, there are differences between the countries. In Australia, for example, it is shown by the decrease in the size of chemistry departments; in the UK, rather than individual chemistry departments shrinking, it is the number of chemistry departments that are decreasing[5] and even the future of chemistry at King's College London is in doubt[13] (in fact intake there has now been halted). The number of chemistry students in the UK is declining both in absolute numbers and as a proportion of the overall number of students in higher education; the increase in the number of students studying non-science disciplines shows the university sector to be buoyant, though not in chemistry.[5]

Finally, Holman[14] has succinctly summarised the wider benefits of overcoming the problem of a global decline of the enabling sciences. Science education is justified for several reasons: utilitarian – it is useful in everyday life, economic – the world needs trained scientists and engineers, democratic – everyone needs some knowledge/understanding of science to be able to participate in public policy debates and cultural – science is part of our modern culture and is worth studying for its own sake. Chemistry is inherently always present and will always be taught in some form, but from a scientific viewpoint if knowledge is to be generated, efficiently disseminated, and time-wasting re-invention avoided, chemistry as a discipline needs to keep its underlying organization. This paper attempts to examine the problem, including international comparisons, identify the challenges and provide some solutions, with particular emphasis on attracting students back to chemistry. To gain an international perspective, feedback was sought and received from a number of high-ranking chemists in Japan (NB, also one of us, WSP, spent nine years in Japan, three as a Professor of Chemistry at Tokyo Metropolitan University), Sweden, US and the UK. This paper, although independent in origin, complements a recent paper by Wallace.[8]

The Origins of the Problem

We believe that the core of the problem is that chemistry has lost its identity and (perceived) purpose and consequently has slipped from being an elite and key science to a subservient one with non-clear cut career prospects. Since the problem of a decline in the image and emphasis of chemistry is multi-faceted, it is evident that the solution must also be multi-faceted. Perhaps the major challenge is to separate and distinguish it from other disciplines and yet to emphasize its foundation and enabling position in them. In addition, the image of chemistry needs to be modernized from the traditional stereotyped images of chemists. We believe that the present funding hardships are a consequence of the low public perception, and not the reverse. Thus the challenge is to achieve the following aims: (1) restore the public image of chemistry, (2) attract undergraduates, (3) teach chemistry in a coherent and cohesive manner, (4) retain undergraduates through to postgraduate study, and (5) to clearly define and enhance career prospects. The origins of the problem can somewhat loosely be classified under the following headings:

Lack of Identity, Public Perception and Early Education

One reason for the decline of chemistry in Australia is that, due to its very ubiquity,[15] chemistry has developed an identity problem. 'Chemistry' is perceived as an umbrella-like term instead of being an entity itself. Consequently, except for being able to state that 'chemistry looks at the world at the molecular level', it is in reality very difficult to delineate chemistry from other sciences, or more importantly, recognize that chemistry lies at the heart of other disciplines like forensic medicine or pharmacy (e.g., see[16, 17]). Further, even though the applications of chemistry might appear 'macroscopic' and to relate to the real world, the real work of the chemist is entirely focussed at the molecular level. And, as illustrated by Bard,[18] it can take a very long time for a fundamental research finding to develop into a useful application. Thus, for example, in contrast to medicine, genetic engineering and the biological sciences generally, the importance of chemistry and its positive societal impacts, although at least as great, are not so readily perceived and appreciated. Although it is difficult to imagine a more exciting discipline to work in,[19] the lack of general public recognition results in two serious consequences. First, chemistry loses its relevance in the eyes of the general public, and more particularly, students only really begin to understand the importance and enabling nature of chemistry education among the sciences after they have entered university (assuming that they have chosen to study some chemistry) – often too late to reverse their thoughts on a career path. The second consequence is that, although chemistry does lead to a myriad of career opportunities, this may not be immediately obvious from the job titles. This consequence is becoming more serious in Australia, since university fees are steadily increasing, and present day students are much more demanding of university qualifications that appear to lead more directly to clearly defined employment.

The low public perception is self-propagating, as has been realized in Japan where most university graduates are non-science graduates.[20] Consequently, they are unlikely to encourage their children to study science, and particularly chemistry, at the tertiary level. Surveys have revealed that while 70% of Japanese primary school students and 50% of junior high school students (years 7 - 9) are interested in science, only 30% of senior high school students (years 10-12) share that interest.[20] A further reason for this decline, at least in the case of Japan, can be found in the nature of the entrance examinations to high school, as they contain little chemistry and the textbooks are often uninteresting.[20]

The lack of identity of and general ignorance about chemistry has also lead to positive, chemically-based scientific advances being attributed to other disciplines; for example, newly developed anti-cancer drugs are unlikely to be presented by the media as triumphs for synthetic chemistry. In fact, chemistry has gained negative connotations, with the public blaming chemistry for the pollution evils of the world. The situation is made worse by adverse media exposure of environmental degradation portrayed as 'chemical irresponsibility' and by confusion in the public sector over the terms 'chemist' and 'pharmacist'.

Mathematics

Apart from solving particular problems, the true aim of science is to gain a sufficient understanding thereof so that it is possible to predict scientific outcomes. Thus, research can be perceived as a cyclical process, involving observation, pattern recognition, mathematical modelling, designing more cogent experiments based on the models, and further observation. With sufficient understanding it is possible to make transitions from 'macroscopic' to 'microscopic' and vice versa. Mathematics is at the heart of this process. We note Sir John Pople's Nobel Prize citation which read *"…we celebrate the fact that mathematics has invaded chemistry, that by means of theoretical calculations we can predict a large variety of chemical phenomena*".[21, 22] Hence, the present trend involving the progressive simplification or 'dumbing down' of the university Chemistry 1 course – especially, the de-emphasising of mathematical/theoretical principles[1] is of great concern. This results in the loss of some of the most important tools that chemists need to use in modelling processes. It is instructive to delve into the contents of some of yesteryear's chemically oriented mathematics texts,[23, 24] and mathematically more demanding chemistry texts.[25] These books are full of the beauty, elegance and *efficiency* of applying mathematical principles to almost all areas of chemistry. The problem is that mathematics is not perceived as a tool of chemistry. Indeed, the mathematical content of chemistry is seen as a significant turn off factor and is one of the prime reasons that chemistry is seen as a hard subject. Consequently, other seemingly more qualitative and less mathematical sciences have become more attractive. Students, who adopt this selection principle, use sophisticated software to rationalise phenomena, but do not understand how the interpretation is produced - it is 'black box' learning! Indeed, the process becomes self-propagating with employers being equally ignorant and thus perceiving little need for mathematical skills.[26] A significant challenge is to re-emphasise the importance of mathematics in chemical education at all levels, as the de-emphasising of mathematics is in reality detrimental to all of the quantitative sciences.

Loss of its Enabling Role in the Sciences and Attrition to Other Subjects

In searching for ways to increase the appeal of chemistry, in addition to lack of recognition, it is necessary to address the sustainability of chemistry as a central science discipline. A discipline can survive, at least in the short to medium term, by obviating the 'hard parts'. As chemistry is taught less comprehensively and coherently it necessarily loses its enabling role in the sciences. For example, when chemistry is only taught as a service course, some aspects of chemistry that are crucial to a career in chemistry, but which are not believed to be crucial to less quantitative disciplines, are omitted. Although it is to the detriment of the other disciplines as chemistry loses its enabling role, it is ironic that some of the other disciplines therefore become more attractive. Fragmentation of the teaching of chemistry as a discipline may also have the negative effect of some areas of chemistry having to be reinvented when the need for them is recognized.

Although similar arguments could be made for other disciplines, such as materials science, due to familiarity (one of us, WSP obtained his PhD in Physical Biochemistry) we use the discipline of biochemistry to illustrate the problems that arise if chemistry is not taught cohesively and comprehensively. Biochemistry can be viewed as a melding of biology with chemistry, originating from the need to understand and to explain biological phenomena at the molecular level. All biochemical techniques are intrinsically chemical in nature – although many biochemistry students would not realize this. Many disciplines, including biochemistry, use NMR (or MRI) routinely, but often the basic principles of this sophisticated spectroscopic technique are glossed over. The absence of a solid chemical (and physical) background greatly impedes the development and application of NMR techniques. But perhaps more importantly, this absence leaves the user less able to separate real from artifactual observations. Ultimately, the other disciplines are also losers when chemistry is not taught cohesively and the outcome of such omissions of key principles is that so-called 'trained scientists' become closer to trained technicians. It is a significant challenge to reverse this trend.

We would also note that biochemistry has developed rapidly into a stand-alone prestigious science, whilst the importance of chemistry as an enabling science is waning. Part of the reason for this is that in many chemistry departments the subdisciplines are organized along traditional lines (i.e., organic, physical, inorganic) and thus the enabling role of chemistry in the biological sciences is not emphasized. Indeed, in chemistry departments the term 'biological chemistry' is often narrowly specified as encompassing only the organic chemistry of biologically active compounds. We believe that biological chemistry is much more than this and that a more complete description that could be conveyed to students is 'the chemistry of biologically-ordered structures that ultimately lead to some form of self-replication'. Thus, biological chemistry encompasses and requires elements from all of the traditional sub-disciplines of chemistry. Hence, irrespective of whether chemistry is taught in a Chemistry department or not, what is important is that it is taught in a comprehensive manner and that the significance and integration of the individual units is explained.

Chemistry 1 Courses

Although the number of students in the University 'Chemistry 1' courses in Australia has remained reasonably constant owing to the service element of the course, fewer Year 1 University science students are electing to study chemistry as a major or view chemistry as a career opportunity or continue to undertake study for a higher degree in the discipline. Although the academic community blames the secondary school sector for not encouraging students to study science at the higher school certificate level, it is also useful to look at this from a societal perspective (as noted above). Chemistry 1 courses need to be designed to enthuse science students to 'convert to chemistry'. Cole et al[27] have highlighted some of the reasons for the flight from chemistry: students perceive little relevance of core chemistry to the real world; syllabuses are overcrowded, leading to shallow learning and little time to incorporate exciting cutting edge chemistry; students feel that a large body of knowledge has to be absorbed before they can make a worthwhile contribution; students perceive that knowledge is more important than the acquisition of transferable skills; students have difficulty making connections between the sub-disciplines of chemistry (which tend to be taught separately); the link between practical work and theory is often less than obvious; not enough emphasis is given to the social aspects of chemistry and Chemistry 1 students have inadequate levels of mathematical skills to cope with some aspects of the course. Especially, without incentive and justification of the incorporation of the component units, chemistry (esp. the mathematical content) seems to be a hard subject.[4] This also impacts on the number of students who will choose to continue on to higher degree.

Career Prospects

Although a high school student has certainly been exposed to some chemistry, it is likely that, apart from their high school chemistry teacher, students do not have a strong feeling for what a chemist actually does (as noted by Wallace,[8] this source of inspiration may be further compromised if the 'chemistry teacher' is not a chemist). In fact, due to the enormous scope of chemistry, it is particularly difficult to describe succinctly what a chemist does. This situation is in complete contradistinction to other professions, for example, a physician or dentist. Further, even at the tertiary level, the majority of chemistry education is conducted by academics who, statistically, only represent the career of a small proportion of chemical graduates. Even for those who opt for academia, the allure of an academic career in chemistry is tarnished by the current economic climate and government policies resulting in the real and perceived need to spend an inordinate amount of time to raise funds to conduct research.[18] So students have only limited exposure to the types of careers available, with industrial careers receiving the least exposure. Thus the final challenge is to make chemistry a solid choice for a career and this necessarily involves some restructuring of courses to emphasize the outcomes.

Solutions

The essence of the solution is that public perception of chemistry needs to be enhanced. Obviously this would benefit from changes in primary and secondary school curricula. Similarly, increases in the salaries that science graduates can expect would also enhance its perception - but this is not the cause of the problem. The solutions presented here are mainly confined to what can be implemented inside the university setting. We also pay particular attention to retaining students on to higher degrees.

Experiences Prior to University and Public Perception

As noted above, most school children and many high school children have a strong interest in science but this popularity gradually wanes. This is of particular concern since it is the demand at the primary level that successively determines the secondary school and tertiary curricula and influences the choice of entry to university. Thus, not only is it important to introduce scientific concepts early in the educational system, but it is also imperative to maintain the level of interest. The chemical societies (e.g., RSC and RACI) would appear to be best placed to produce and distribute captivating literature and promotional material suitable for primary and secondary schools, and in Years 10, 11 and 12 organising visits to the chemical industry, companies producing everyday (chemical) products and academia. These initiatives will address the issue of 'what chemists do'. A detailed discussion of some approaches for increasing the public awareness of chemistry has recently been published.[28] Stressing the scientific method and the central role of mathematics would also greatly assist the attraction of students to chemistry and the physical sciences by alleviating the mathematical turn-off factor and this is covered in more detail below.

Chemistry departments could also try to cultivate links with the public, but especially with schools,[29] including teachers and careers advisors. Some of the strategies applied in Japan have included universities grouping together to organize a major chemical exhibition in Tokyo.[20] The purpose of the exhibition was to attract students and to increase the interest of the public (including the students' parents). Japan has also had the benefit of three recent Nobel Prizes in chemistry, which has helped in maintaining chemistry enrolments. Further, some universities have organized programmes in which chemistry staff members would go and give lectures, and perhaps more importantly, demonstrations at local high schools and junior high schools. In the case of Tokyo Metropolitan University, something like 20-30 such lecture/demonstrations were held in a year and it was deemed successful as the number of applicants to study chemistry did increase. Also, about 200 High School students come to Tokyo Metropolitan University for a day every year to be involved in chemistry. Similar ideas are being tried in the UK with the Science and Engineering Ambassadors initiative.[30] With such efforts, more high school students are likely to select chemistry at the tertiary level.

It is also necessary to 'clean-up' the traditional image of chemistry and to emphasise chemical safety more explicitly. The viewpoint that chemists are trained to handle chemicals safely must be widely promoted so that it becomes apparent that chemistry is neither a dirty nor a dangerous profession. The major advances in Green Chemistry in Australia[31] certainly contribute to an acceleration of the required chemical image change.

Attracting Students to Tertiary Chemistry and Student Retention

Research and Research-led Teaching

A significant attraction for students contemplating the study of chemistry and an impetus for continuing to study chemistry as a major is the intellectual heritage and research strength of the university and chemistry department in question. This is extremely important, as many students value the kudos associated with an institution with a strong research standing – even if they do not intend to go on to a higher degree. Indeed, the most sought after universities are without exception those where research drives the culture.[32] As noted by Callaghan, "*universities provide a unique environment because they combine teaching and research, and sometimes it is hard to tell which is which. And that confusion is precisely the ideal state of affairs*".[32] Generally, students in 1st year chemistry do not have a clear idea of what research is being conducted by their lecturers and the chemistry taught in Chemistry 1 is not 'cutting edge' – although of course it forms indispensable background knowledge. A series of short lectures given by different members of staff on their research, with some emphasis on how different elements of the chemistry curriculum integrate together to make their research possible, would increase enthusiasm for continuing on with chemistry. Studying individual chemistry units with some kind of goal in mind greatly increases their appeal. Callaghan has eloquently explained the benefits of research-led teaching under the headings of 'ownership', 'authorship and 'apprenticeship'.[33] In his thesis, only someone who has made scientific discoveries can convey a sense of intellectual *ownership* to what they teach. Similarly, a lecturer who is a published *author* can convey critical judgement to the students because he knows how fragile knowledge is. The final element is *apprenticeship* in which the students learn alongside their teacher in a mutual dialogue, with the ultimate aim for the apprentice to exceed the master. Thus the combination of teaching and research provides a powerful means of attracting, retaining and inspiring students.

Mathematics

The predictive power, beauty and economy of physical approaches needs to be emphasised in the Chemistry 1 course so that students do not see mathematics as irrelevant or unnecessary in chemistry. It is necessary to indicate in the Chemistry 1 course and earlier, the essentials of the scientific method and that mathematics in chemistry is an enrichment factor that qualifies chemistry as an elite, quantitative science and sets it apart from some of the more qualitative areas of, for example, the biological sciences. In addition to better press and public perception, the latter are sometimes viewed as more attractive by university students because of their lesser mathematical content. For example, biochemistry is often perceived by students as non-mathematical chemistry and therefore preferable. It is rather ironic, however, that mathematics is really required for many areas of biochemistry (e.g., enzyme kinetics, protein aggregation, and drug interactions) and in other biological sciences. Nevertheless, it should be emphasized that such is the scope of chemistry that if the student really dislikes or is unable to cope with much mathematics it is still possible to specialise in chemistry in areas with low mathematical requirements.[4] We believe the allure of chemistry, and indeed the other physical sciences, at university would be increased if high school mathematics curricula were amended to emphasize the inherent links and usefulness to the sciences. If students could be more enthused to study mathematics, one of the turn-off factors to studying chemistry would be eliminated.

Cohesively Teaching Chemistry and Minimizing Attrition to the Other Sciences

As chemistry is less cohesively and comprehensively taught, many aspects of chemistry are necessarily taught by and assimilated into (some might say hijacked by) other disciplines (e.g., biochemistry, materials science) and these other disciplines separate out and gain in stature. Although, ideally, it is nice to imagine that all of chemistry is taught in a chemistry department, the most crucial aspect is that chemistry should be taught in a (reasonably) comprehensive manner since the solution to most real world chemistry problems require more than one facet of chemistry. For example, designing medicinal drugs and understanding their binding to protein receptors requires knowledge of many areas of chemistry ranging from organic chemistry to computational chemistry and thermodynamics.[34, 35] Similarly, thermodynamics, organic chemistry and inorganic chemistry are needed to understand bioenergetics, including transmembrane ion transport and respiratory chains.[36, 37] Thus, a broad background in chemistry education is important so that chemistry does not lose its enabling role.

As an example of what can be done, and again taking the biological sciences as case in point, a strategy for lowering the attrition to the biological sciences would be to create a 'Biological Chemistry Sub-Discipline' with a broad scope within a chemistry school. This may not only provide a means of enhancing research funding opportunities, but it also addresses the ignorance of chemistry traditionally held by Year 1 science students about the enabling nature of chemistry and its integral role in biology and biochemistry. Such students need to recognise that these interfaces between these disciplines are flexible and porous. This presents an opportunity here to capitalise on the fact that of these three disciplines, chemistry is the most flexible and has the widest scope of topics. Chemists need to stress at every opportunity that they can tackle and solve biological problems at the molecular level – where the core interest is focused. An equally important issue to stress is that there are no realistic boundaries between the sciences. Indeed, chemistry has spawned many of the ‘new’ sciences and many of the major advances in science have emerged from science interface research. Chemistry is well placed to underpin such research because of its multi-disciplinary platform. It also needs to be emphasised that the way to tackle a complicated biological system is not to tackle the problem directly and holistically, but to do so via a series of well-chosen model systems of increasing complexity. Model systems always lead back to chemical counterparts.

A further possible strategy for retaining students in a chemistry main stream is to develop a biological chemistry project (or centre) to which all research-active members of the chemistry department can contribute, thus harnessing the full talent mix of the department. Many biological problems benefit from a concerted research input and the output in terms of results, will be greater than the sum of the individual contributions. Such a large-scale project would provide a ‘biological face’ to the chemistry department. The potential for such a research project to attract funding more successfully than any one contributing member, is an added advantage of such an initiative.

Career Prospects, Industry, Interdisciplinary Science and Rebadging

It is becoming increasingly clear that it is progressively more difficult to retain science students into Years 2 and 3 of the traditional chemistry major bachelors degree. Chemistry 1 students need to be given more information on the sorts of careers that are ultimately available to them and what combinations of units are most appropriate for these. It is necessary to identify the most able science students in the Chemistry 1 course and expose them to the wide and diverse range of career opportunities that a qualification in chemistry can lead to and the rewards that such careers offer, apart from the purely financial. It is necessary to emphasise that the traditional ‘bubble and boil’ image of chemistry, whilst appealing to many, is not a realistic representation of the whole of professional chemistry and leads to very narrow perceptions of what careers are available to chemistry graduates. Indeed, many professional chemists may not even come into contact with chemicals – the involvement of theoretical chemists with drug design is but one example. One means of making chemistry more attractive is to emphasize its relevance and career prospects by 'rebadging' and grouping some of the courses with respect to some target area of application. For example, studying thermodynamics and colloid chemistry are crucial components of an undergraduate degree in chemistry, but someone embarking on a chemistry degree does not always understand their importance. However, they may be made more palatable and attractive to students if included as strands of a course on 'chemical biotechnology'. Similarly, nanotechnology is now widely publicized and chemistry is at the heart of this.[38]

One of the strengths of chemistry is its ability to contribute to interdisciplinary research; in fact some, mainly younger, universities do not even have a distinct chemistry department. Indeed, it has been noted that the development of interdisciplinary degrees may help to solve some of the problems facing chemistry education.[2] Nevertheless, what is important is not the name of the department, but that chemistry as a discipline is still effectively taught. The setting up of interdisciplinary research centres has the advantages not only of attracting money from industry, but also the emphasizing of the industrial career paths that chemistry can lead to that would not otherwise be apparent to undergraduates. Although, as is well known, the setting up of such ventures is non-trivial and fraught with difficulties; it is recognised as means of making up financial shortfalls – even at Oxford University.[10]

The chemical industry sometimes blames the academic community for not giving chemistry courses more of an applied emphasis. Thus, just as it is necessary to promote strong links between chemistry departments and schools, it is also necessary to promote stronger links with industry and to invite industrial leaders and managers to visit chemistry departments. Interestingly, in Japan companies sponsor the Chemical Society of Japan (CSJ) as corporate members. As such, they have access to CSJ journals and, depending on the level of company sponsorship, a number of the company members can attend the annual CSJ meeting with the same conference fee as normal member although they are unable to make presentations. Although it does present some financial problem to the CSJ, this corporate mechanism constitutes the main link between academia and industry.

Recapitulation

The ubiquity of chemistry guarantees that chemical education will always have a central, commanding position amongst the sciences. The problem is that the public does not necessarily see this as being such. This perspective has explored some of the means that can be taken to increase the public perception of the value of chemical education so that chemistry will be an academic pursuit of choice and not just the prerequisite for something else, and maintain the cohesiveness of the teaching of chemistry so that it can fulfil and retain its enabling role.

References

1) J.O. Hill and R.T. Cross, *A Report on a Comprehensive Review of the Year 1 Chemistry Course in Australian Universities*; La Trobe University: Wodonga, 2001.
2) K. Roberts, *Educ. Chem.*, 2004, **41**, 2.
3) R. Cross and J. Hill, *Opinion, The Education Age*, 2001, 28 March.
4) L. Willcocks, *Why is Chemistry so Sexy? Varsity* 2001. http://www.varsity.cam.ac.uk/8025694e0073cfeb/pages/11102001_WhyisChemistry.html
5) S.W. Breuer, *U. Chem. Ed.*, 2002, **6**, 13.
6) M. Freemantle, *C. & E. News*, 2002, **80**, 31.
7) J. Naismith, *Chem. Brit.*, 2002, **38**, 3.
8) R.G. Wallace, *Chem. Educ. Res. Pract.*, 2004, **4**, 83.
9) H. Ogino, *Bunseki*, 1996, **257**, 329.
10) M. Jacobs, *C. & E. News*, 2002, **80**, 5.
11) National Initiatives in Education. A joint statement by Australian Institute of Physics (AIP), Royal Australian Chemical Institute (RACI), Australian Mathematical Sciences Council, Institution of Engineers Australia (IEAust), 2001. http://www.aip.org.au/initiative2001/
12) D.J. Evans, *Chem. in Australia*, 2001, **68**, 17.
13) D. Giachardi, *Chem. Brit.*, 2003, **39**, 3.
14) J. Holman, *Educ. Chem.*, 2001, **38**, 10.
15) B.K. Selinger, *Chemistry in the Market Place*; 5th ed., Allen & Unwin: Sydney, 1999.
16) P.N. Goodfellow, *Chem. Brit.*, 2002, **38**, 3.
17) W.S. Price, *Aust. J. Chem.*, 2003, **56**, 855.
18) A.J. Bard, *C. & E. News*, 2002, **80**, 44.
19) M. Trau, *Aust. J. Chem.*, 2001, **54**, 549.
20) I. Ikemoto, Tokyo Metropolitan University, Personal communication; 2003.
21) The Nobel Prize in Chemistry, 1998. http://www.nobel.se/chemistry/laureates/1998/presentation-speech.html
22) P. Wright, *Sir John Pople - Mathematician who applied his brilliance to chemistry, The Guardian*, 2004. http://www.guardian.co.uk/obituaries/story/0,3604,1172894,00.html
23) H. Margenau and G.M. Murphy, *The Mathematics of Physics and Chemistry*; D. Van Nostrand: New Jersey, 1956.

24) C.L. Perrin, *Mathematics for Chemists*; Wiley: New York, 1970.
25) A.G. Marshall, *Biophysical Chemistry Principles, Techniques, and Applications*; Wiley: New York, 1978.
26) P.C. Yates, *U. Chem. Ed.*, 2002, **6**, 17.
27) M. Cole, R. Janes, M. McLean and G. Nicholas, *Educ. Chem.*, 1998, **35**, 56.
28) R. Stevenson, *Chem. Brit.*, 2003, **39**, 20.
29) M. Berry, *Chem. Brit.*, 2002, **38**, 3.
30) Scientists in Schools, *Chem. Brit.*, 2002, **38**, 58.
31) Centre for Green Chemistry, 2003. http://web.chem.monash.edu.au/greenchem/
32) P. T. Callaghan, Unpublished public lecture given at Victoria University of Wellington; 2002.
33) Callaghan, P., Ownership, Authorship and Apprenticeship and the Research Teaching Nexus, in *Towards an Understanding of the Interdependence of Research and Teaching*, S. Paewai, G. Suddaby, Eds., Massey University: Palmerston North, 2000. http://quality.massey.ac.nz/download/MUIRT.pdf
34) J. Wyman and S.J. Gill, *Binding and Linkage - Functional Chemistry of Biological Macromolecules*; University Science Books: Mill Valley, 1990.
35) K.E. Van Holde, W.C. Johnson and P.S. Ho, *Principles of Physical Biochemistry*; Prentice Hall: New Jersey, 1998.
36) D.A. Phipps, *Metals and Metabolism*; Clarendon Press: Oxford, 1976.
37) D.G. Nicholls, *Bioenergetics*; Academic Press: London, 1982.
38) M. Wilson, K. Kannangara, G. Smith, M. Simmons and B. Raguse, *Nanotechnology: Basic Science and Emerging Technologies*; UNSW Press: Sydney, 2003.

Perspective

The Sussex 'Degree By Thesis' In Retrospect

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Introduction

"*University chemistry courses are attracting a decreasing proportion of students and must be made more attractive*." This familiar problem formed the opening sentence of an article in Chemistry in Britain in 1970 that Colin Eaborn wrote describing the Chemistry Degree by Thesis. This novel degree programme was conceived against the background of falling numbers. With the current decline in the numbers entering chemistry, there is a pressing need to retain students in chemistry. Consequently, it may be helpful to look again at the experiences gained from the Degree by Thesis (the CT degree). Students, who undertook this degree programme, had to pass tests on the lecture courses, but the class of their degree was based on their performance in research work carried out from the Easter of their first year to the summer of their third year. Their primary commitment was to their research project. The assessment of the degree was on the basis of a student's thesis and performance in oral presentations and a viva-voce examination. The underlying philosophy and student experience of the degree has been the subject of a number of earlier articles.[1, 2]

Problem-based learning builds on the motivation that is generated by the student's need for new knowledge to achieve a solution to a specific problem. It is claimed that problem-based learning affords students a deeper understanding of the subject, independence in learning and a better retention of the knowledge that they have acquired.[3] It plays an important role in the teaching of medicine. Whilst individual courses within chemistry programmes have used problem-based learning and case study approaches to develop student enthusiasm and motivation, the Chemistry Degree by Thesis scheme (CT) used this as the underlying philosophy for the whole programme.

The Sussex chemistry 'Degree by Thesis' (the Eaborn degree) ran for almost twenty years through the 1970s and 1980s. The proposal for this degree was made by Colin Eaborn in the light of evidence that he had received as Chairman of the Royal Institute of Chemistry committee of enquiry into the relationship between university chemistry departments and the needs of industry. The report of this committee was published by the Royal Institute of Chemistry in December 1970. Colin Eaborn was impressed by the enthusiasm for chemistry that a student's research project generated and wanted to build on this enthusiasm throughout the undergraduate degree to increase the appeal of the chemistry degree. The emphasis of the CT degree was to move away from assessing the ability of a student to recall information in an examination context, and towards assessing their original creative efforts in research against a background of a broad basic knowledge of chemistry. Colin Eaborn argued that the best measure of a course was not the marks that students obtained in an examination at the end of the course but the extent to which they retained and used the material later in their chemistry career.

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The degree scheme

Chemistry is a systematic subject and in the initial discussions on the degree programme there was conflict between what some feared might become a selective, random walk through the field of knowledge driven by the needs of research rather than a balanced and logical development of the subject. This was resolved by requiring the students to attend the normal chemistry lecture programme alongside their research. The CT students took the end-of-course tests. Although they only had to pass these tests, in practice many of their marks were in the excellent category. Over the years it became apparent that this course content posed too heavy a burden and in later years the number of courses that the CT students attended was reduced.

In the first two terms all students (conventional and CT) took the same lecture courses and practical work. Those entering the CT stream did not do so until the Easter of first year. The students had to achieve a particular level in the preliminary examinations. They selected their project after discussions with the various supervisors on a 'first-come, first-served' basis. Although students could move out of the programme, they did not move into the programme at a later date. Typically five or six students followed the programme each year.

The projects

Each of the projects had two supervisors drawn from different areas of chemistry, although inevitably one became the dominant partner. There was also an independent advisor. The projects were chosen to have the potential for providing experience across a broad area of chemistry and to have sufficient technical simplicity in their early stages to allow a student with a limited experimental background, to make progress. For example I and a physical chemistry colleague supervised a project on deuterium isotope effects in the ^{13}C NMR spectra of aromatic amides. This involved both synthetic aromatic chemistry and NMR spectroscopy. The projects had to be approved by the CT examination board. Although many students started with limited experimental experience, on the whole they rapidly developed competence and confidence. In their research they even saw some aspects of their chemistry coursework in practice. They gave oral presentations on their work at the end of the second year and at the end of the degree programme as well as presenting written reports and a final thesis. Their commitment to the research often extended to working during the vacations, although this was not compulsory. In a significant number of cases the results of their research were published in the major journals. Some of the experiments that led to the discovery of C_{60} were carried out by a CT student.

The projects and supervision worked best, but not exclusively, within the larger research groups and the AFRC units attached to chemistry. A number of projects were natural developments of existing research, and hence, help with the experimental techniques was available from within these groups. The students gained experience of laboratory methods that were not constrained by the limitations of the equipment in the teaching laboratories or by the need to complete an experiment within the 4- 5 hours of a laboratory session. They developed a critical awareness of the chemical literature and the important transferable skills of teamwork, presentation and communication. They became part of the postgraduate research community. However, it was also the case that some found that this commitment to their research project placed too great a demand on them and their time and, for some, it limited their wider, social, undergraduate experience. They reverted, without penalty, to the conventional undergraduate course. It was a matter of their individual personality and students reacted in different ways to the atmosphere of a research laboratory.

Evaluation

It is difficult to assess objectively how many students who succeeded, did so entirely because of the motivation that the programme generated or because they already had some of the inherent qualities that flourished in this environment. Nevertheless, the excitement of research was undoubtedly highly motivating. Although their perspective of chemistry on graduating differed from that of the conventional undergraduate, being perhaps narrower, it was certainly deeper. Their confidence in their knowledge of chemistry and their independence in working was stronger and their transferable skills of communication were more developed. A number of students not only went on to carry out doctoral research, but eventually to occupy senior positions in both academia and industry, and this might be measure of the success of the programme.

The end of an experiment

Following the prosecution of the University by the Health and Safety Executive as a result of an accident to a post-graduate student, the CT undergraduate degree came under scrutiny. The university solicitors and the registrar expressed the opinion that, were the university to be prosecuted under the HSE Act following an accident to a CT student, then there would be no effective defence unless 100% faculty supervision of the student had been provided. By the very nature of the degree and the other commitments of chemistry faculty, this was not practicable. It should be pointed out that there was no serious accident to a CT student over the 20 years of the programme. With considerable disappointment, the Chemistry Subject Group had to bow to the inevitable and on January 17th 1989 agreed with reluctance that the CT degree should be suspended. The students on the course were allowed to complete.

The academic climate today is very different from that of thirty years ago and it is perhaps worth considering some of the problems that the programme would now have to face. Firstly, the programme is expensive not just in terms of materials, but also because at Sussex spectroscopy costs are now charged to individual budgets and each student occupies the equivalent of a research student's space. The consequent space charges would therefore have to be borne by the department. As with research projects, the educational value of obtaining a spectrum would have to be weighed against its cost. The degree programme was also very expensive in faculty time and now the potentially supportive research groups are much smaller and there is very little technical support. How do you rein in a project that is becoming expensive because of a student's enthusiasm without at the same time destroying that enthusiasm? Secondly, observation of the first year laboratories suggests that many more undergraduates are coming to university with very limited experimental experience and with a greater fear of chemicals than was the case thirty years ago. Thirdly, most students now undertake paid part-time employment to reduce their level of debt. This work, which is often physically tiring, is not compatible with a research-based degree that has to be completed in a defined period. The cost to a student could be high. Finally, the University administration would have problems in awarding credits to two separate cohorts of students taking the same lecture course, one on a pass-only basis with marks making no contribution to the degree, and the other with marks awarded on a contributory basis. Courses are supposed to have the same number of credits and assessment patterns for all students taking them. If a CT student decided to revert to the conventional programme, to intermit or exercise a right to transfer to another university, how is a part of the research programme to be credit-weighted? Moreover, if course-work examinations have been taken on a pass-fail basis, how can the marks then be used in a conventional degree pattern or shown on a transcript? The administration would also raise problems of progression and on the assignment of a level to a research project extending over three academic years, let alone the calculation of the all important student-staff ratios. It does not take much imagination to realise that a central administration would have a bureaucratic field day with this programme. In these days, when it is necessary to have a university-wide structural uniformity of degrees, there is a danger that unique, subject-based innovations that do not conform to the conventional pattern will be stifled.

Future possibilities

However where there is a will, there is a way. It may be possible whilst maintaining a course-work element, to build some of the features of the CT degree into years three and four of an M.Chem. programme. It would require not only an economical and appropriately translucent use of the language of administrators to complete the university paperwork and fend off criticism, but also a careful integration of laboratories and offices so that the HSE objections over supervision can be met. Those of us who were involved with the CT degree remain convinced of its value, in enhancing a student's experience of chemistry, in developing transferable skills and above all in motivation.

Envoi

Colin Eaborn died on the 22nd February 2004, whilst this article was in preparation and I would like to dedicate it to his memory as the father of Sussex chemistry. I also wish to thank a number of colleagues who have helped me in the preparation of the article.

References

1. C.Eaborn, *Chem. Brit.*, 1970, **6**, 330
2. B.Courtis, *Educ. Chem.*, 1974, **11**, 47.
3. For leading references on problem-based learning see: D. Boud and G. Felleti, *The Challenge of Problem Based Learning,* 2nd Ed., (Kogan Page). 1998; S.T. Belt, E.H. Evans, T. McCreedy, T.L. Overton and S. Summerfield, *U. Chem. Ed*., 2002, **6**, 65; T.L. Overton, *Problem based learning: An introduction*, LTSN Physical Sciences Primer 4, version 1, 2001, http://dbweb.liv.ac.uk/ltsnpsc/primers/intrpbl4.htm

Letters

Conceptual understanding of electricity: Galvanic cells

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In a recent letter to University Chemistry Education,[1] Alan Goodwin comments on one of the conceptual questions (Question 15) involved in our article.[2] First of all, we would like to thank Alan Goodwin for his valuable comments. He states that he is a little worried by Question 15 and our offered 'correct' answer. In his opinion, Question 15 and our offered 'correct' answer to it suggest that we believe that current between the electrode compartments will not flow along a conducting wire. We are aware of the fact that if a metal wire replaces the salt bridge in a galvanic cell the ammeter connected through the circuit may show a reading, but we also know that this current reading is very low (as also stated by Goodwin) compared to the current measured using a salt bridge. It is necessary to use a very sensitive ammeter to be able to measure such a low current. We could not measure it when we used an ordinary ammeter in the circuit. Therefore, during the construction of the question, we thought that this very low current could be ignored. Question 15 is very similar to the one involved in the article reported by Ogude and Bradley (Question 11).[3] The only difference between the two is that the one reported by Ogude and Bradley replaced the salt bridge with graphite while our question replaces it with a piece of platinum wire. Ogude and Bradley's ideas about this issue were probably similar to ours when constructing Question 11, since they offered the same alternative as the 'correct' answer, so we do not believe that it is necessary to correct either Question 15 or our offered 'correct' answer.

In his letter Alan Goodwin cites Ogude and Bradley's article[4] published in 1996 and states that he found a convincing explanation about how positively charged copper ions are deposited on the copper electrode labelled positive when current is drawn from the cell, but it seems that he was unaware of the article published by Ogude and Bradley[3] in 1994 when writing his letter. Had he been aware of this article he would have directed his criticisms towards them since it was published long before our article appeared in this journal.

In his letter,[1] Goodwin suggests a model to explain how the electrical potential differences change across the external circuit and within the cell when electric current flows around the circuit (p.60, his Figures 2 and 3). He states that the outline of his discussion was presented at the 'Variety in Chemistry' Conference in Dublin, September 2003, and proved to be controversial. Perhaps, he will publish this proposed model in a journal to share his ideas with the instructors and electrochemists. We would like to share our common ideas about his model with him in the hope that our comments will help him to improve his model. In his letter it is stated that [his] Figures 2B and 2C indicate *QUALITATIVELY* how the electrical potential differences change across the external circuit and within the cell (p.60), but various potential values are assigned *QUANTITATIVELY* to the internal and external parts of the electrodes. In his Figure 2, cell emf is divided between internal and external parts of the circuit. *Really, this is a very radical approach*. We could not find such an approach in electrochemistry texts. It is not reasonable in terms of basic aspects of cell emf and electrode potentials. The half-cell potential or electrode potential talked about in electrochemistry is the potential difference between the solution and the electrode, and this potential difference cannot be measured, but *the difference between two differences,* or the potential difference between two half-cells, can. In his Figure 2A, the values of +0.34V and –0.76V are assigned to the external parts of the cathode and anode respectively in the absence of current flow; when the cell potential changes from 1.1V to 0.8V as a result of the moderate current flow, these values are given as +0.24V and -0.56 V respectively.

At this point, we need to make an evaluation in terms of the Nernst Equation. When current flow is allowed to pass through the cell, i.e. a low impedance pathway is provided until the cell voltage as read on the voltmeter decreases to a particular value, the concentrations of the electro-active species in the anode and cathode compartments also change since chemical changes occur at each half-cell (at each interface). There is a strong relation between the electrode and cell potentials, and the concentration of the electro-active species. For example, according to the Nernst Equation, a change from -0.76V to -0.56V in the potential of the anode requires a change from 1M to 4.641589 x 10^6 M in the concentration of Zn^{2+}. Clearly, this is not possible. This evaluation suggests that it is not sensible to assign random values to the electrode potentials after current is allowed to pass through the cell during a time period. As outlined in Figure 1 in this letter, it may be better to adopt a qualitative approach that explains how the potential of each electrode (the potential difference at each metal/solution interface), and the concentrations of electro-active species at each compartment change during the passage of current through the cell until the electrode potentials become equal to each other, i.e. cell potential is zero.

As shown in Figure 1A (in this letter), when each electrode is immersed in a solution containing its ions, the metal electrode and the ions in solution come to an electrochemical equilibrium as a result of the interactions between the metal atoms in the electrode and the ions in solution, and a potential difference develops at each metal/solution interface during the approach to equilibrium. The establishment of this equilibrium takes a very short time, less than a microsecond. During this very short time, either a very small amount of the metal will dissolve or traces of the metal ion in solution will be reduced. Accordingly, a small transfer of charge will occur at metal/solution interface (*electrical double layer*) during the approach to equilibrium. These processes are the origin of all electrode potentials. The net numbers of electrons on the electrode before and after equilibrium

$M(s) \rightleftharpoons M^{n+}(aq) + ne^-$

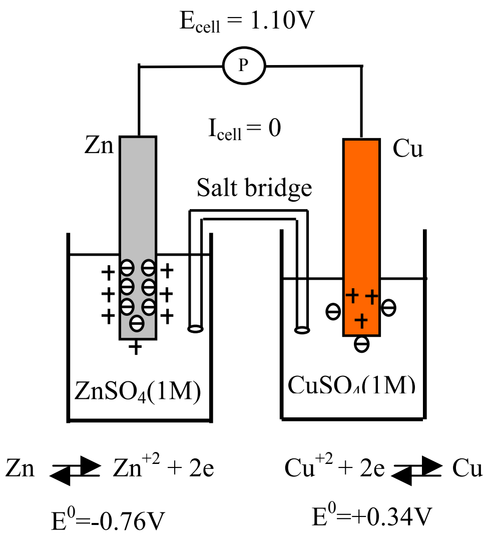
is established will be slightly different. Thus the electrode acquires a slight electrical charge; the solution acquires the opposite charge. The equilibrium is established for all metals (except for those metals that react with water). However, for some metals the tendency for metal atoms on the surface of the electrode to be oxidized is higher than the tendency for metal ions in solution to be reduced, while for others the tendency for metal ions in solution to be reduced is higher than the tendency for metal atoms on the surface of the electrode to be oxidized. In other words, for some metals the equilibrium has a higher tendency to go to the 'right' (these give extra positive charge into the solution and leave electrons on the electrode) while for others it has a higher tendency to go to the left (positive ions leave the solution, thus give the surrounding solution an overall negative charge).

Once equilibrium between each electrode and the corresponding metal ions in solution has been established, each electrode is then attached to one of the inputs of a potentiometer to measure the difference between the voltages of the two metal/solution interfaces. The connection of a potentiometer (a special voltmeter with very high resistance) through the electrodes ensures that the potential difference between the two half-cells is measured under the conditions of no current flow; therefore no net electrochemical reactions can occur. The reading on the potentiometer in the external circuit is the *cell potential,* E_{cell} and represents the potential difference between the two half-cells. Since this potential difference is the '*driving force*' for electrons, it is sometimes referred to as *the electromotive force (emf) of the cell*. This term should, however, only be used to denote the potential difference between the electrodes when the cell is not giving current. This potential difference tends to fall when current does flow and only a portion of the total is available for driving current in the external circuit. In other words, when a current flows through the cell, the potential difference between the terminals is less than the emf of the cell. This is why the emf of a cell gives an indication of the *maximum capacity of the cell* to do electrical work. If a very high resistance voltmeter (potentiometer) is used the emf of a cell can be measured. On the other hand, an ordinary voltmeter connected across the poles of a galvanic cell will only approximately measure its emf because an ordinary voltmeter cannot work without a small current flow.

When the electrodes are connected by an ammeter as represented in Figure 1B in this letter (or by a metal wire directly) i.e., when a low impedance pathway is provided, current would flow through the cell. As current passes through the cell, net electrochemical reactions occur at each electrode. The flow of electric current between the metal electrodes occurs as electrons flow from the more negative electrode (anode) to the more positive one (cathode) through the external circuit. On the other hand, the flow of electric current between the solutions must be in the form of *migration* of ions. This cannot occur through a wire but through another solution that bridges the two half-cells; this connection is called a *salt bridge*. During the passage of current through the cell, the potential of the cathode decreases while that of the anode increases; the concentration of electro-active species in each compartment also changes since

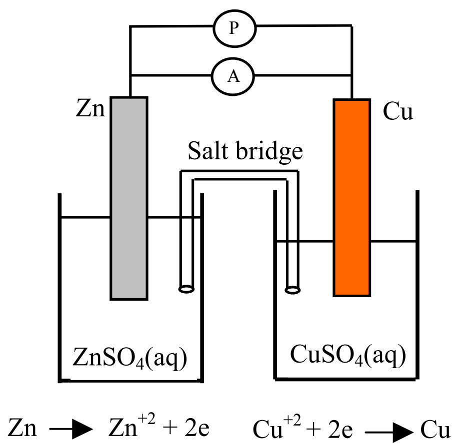
Figure 1

(A)



- No net current flows through the cell.
- There is an electrochemical equilibrium state both at each half-cell and the cell.
- Cell potential is also called the electromotive force of the cell.
- No net reaction occurs both at each interface and the cell

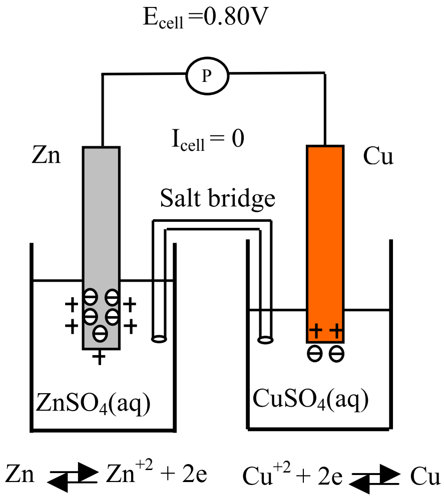
(B)



- A low impedance pathway is provided by the connection of an ammeter in the circuit, and thus current is allowed to pass through the cell until the cell voltage as read on the potentiometer decreases to a particular value.
- During the passage of current, electrons move from the more negative electrode (anode) to the more positive one (cathode) through the external circuit; cations move towards to the cathode and anions move towards to the anode in electrolyte solutions in the anode and cathode compartments, and in the salt bridge
- Net reactions occur at each electrode (reduction at the cathode and oxidation at the anode).
- The potential of the cathode decreases while the potential of the anode increases during the passage of current; cell voltage also decreases according to the Nernst Equation.
- Concentration of electro-active species in each compartment changes because chemical changes occur at each interface ([Cu^{2+}] decreases while [Zn^{2+}] increases).
- There is no electrochemical equilibrium state at each half-cell, and thus also in the cell ($I_{cell} \neq 0$).

Figure 1. continuing

(C)

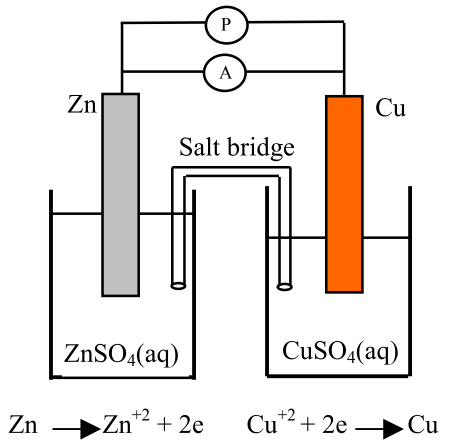


- The low impedance pathway is cut off by taking the ammeter out of the circuit after current has been allowed to pass during a time period and cell voltage has decreased to 0.80V. Thus an electrochemical equilibrium state is established again.

  $E_{cathode}$< +0.34V and E_{anode}> -0.76V

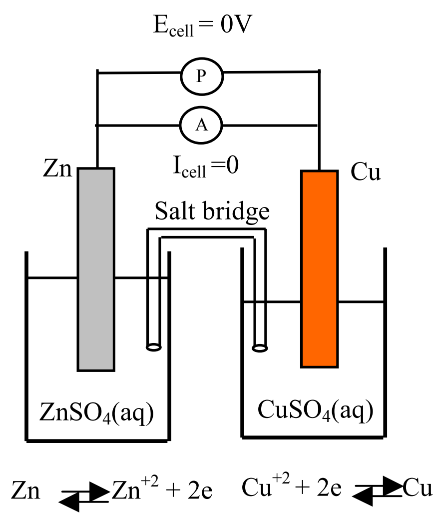
- $[Cu^{2+}]$ < 1M and $[Zn^{2+}]$ > 1M

(D)



- Current is allowed to pass through the cell again by the connection of an ammeter in the circuit until the cell voltage as read on the potentiometer decreases to zero.

(E)



- There are two usages of the term *"equilibrium"* in electrochemistry; *electrochemical equilibrium and chemical equilibrium*. Electrochemical equilibrium refers to the situation in which no current flows either a single half-cell or a pair of half-cells. Since no current is permitted to flow, no net electrochemical reactions can occur at the state of electrochemical equilibrium. Chemical equilibrium refers to the state of the system after two half-cells have been allowed to react with each other, i.e., current has been allowed to pass through the cell, until the cell voltage is zero. At this point concentrations of ions and the partial pressures of gases reach their equilibrium values. Since no current flows at zero cell potential, chemical equilibrium is a special instance of electrochemical equilibrium. $E_{cathode} = E_{anode}$, E_{cell} = 0 V, and thus I_{cell} = 0.

- $E_{cell} = E^0_{cell} - (RT/nF) \ln Q$
  $E_{cell} = 0$, so $I_{cell} = 0$, and $Q = K = [Zn^{2+}]/ [Cu^{2+}]$
  $0 = E^0_{cell} - (RT/nF) \ln K$
  $\ln K = (E^0_{cell}\ nF) / RT$

- As a result, the equilibrium constant of the reaction involved in a galvanic cell can be calculated from the standard cell potential or from the standard half cell potentials since $E^0_{cell} = E^0_{cathode} - E^0_{anode}$
- $[Cu^{2+}] = [Zn^{2+}]/K$ and $[Zn^{2+}] = [Cu^{2+}]\ K$

chemical changes occur at each interface (for the Daniell cell, $[Cu^{2+}]$ decreases while $[Zn^{2+}]$ increases). Thus, the potential difference between the electrodes is diminished. If the low impedance pathway is cut off by taking the ammeter out of the circuit after current is allowed to pass during a time period, an electrochemical equilibrium state is established again as shown Figure 1C above.

There are two usages of the term *'equilibrium'* in electrochemistry; *electrochemical equilibrium* and *chemical equilibrium*. Electrochemical equilibrium refers to the situation in which no current flows either in a single half-cell or in a pair of half-cells. Since no current is permitted to flow, no net electrochemical reactions can occur at the state of electrochemical equilibrium. Chemical equilibrium refers to the state of the system after two half-cells have been allowed to react with each other, i.e., current has been allowed to pass through the cell, until the cell voltage is zero (Figures 1D and E). At this point concentrations of ions and the partial pressures of gases reach their equilibrium values. This state is called *chemical equilibrium*. Since no current flows at zero cell potential, chemical equilibrium is a special instance of electrochemical equilibrium. When the cell reaches chemical equilibrium, current no longer flows and E_{cell} = 0 V. At the state of electrochemical equilibrium,

$$I_{cell} = 0$$
$$E_{cell} = E^0_{cell} - (RT/nF) \ln Q$$

while at the state of chemical equilibrium,

$$E_{cell} = 0, \quad \text{so} \quad I_{cell} = 0, \quad \text{and} \quad Q = K$$
$$0 = E^0_{cell} - (RT/nF) \ln K$$
$$\ln K = (E^0_{cell}\, nF) / RT$$

As a result, the equilibrium constant of the reaction involved in a galvanic cell can be calculated from the standard cell potential or from the standard half cell potentials since

$$E^0_{cell} = E^0_{cathode} - E^0_{anode}$$

Goodwin states in his letter (p.60) that *from the perspective of the solution*, ***when current flows*** the sign on the copper electrode is ***negative*** whereas *from the perspective of the external circuit* the copper electrode is still positive. In our opinion, these signs should be assigned to the metal electrode and to the solution containing its ions, not to the different parts of the metal electrode from different perspectives. Moreover, these sign assignments are used not only when current flows but also when it does not flow (at the state of electrochemical equilibrium). Instead of assigning different signs to the different parts of the metal electrodes as in Figure 3 in his letter, it may be better to explain the *separation of charge at each interface* (*electrode polarity*) by choosing a terminology that for the Daniell cell, in terms of the charges at solution and metal sides of each interface, the potential of the copper metal is higher than that of the copper sulphate solution while the potential of the zinc metal is lower than that of the zinc sulphate solution. This can be modelled assigning charges to both sides of each interface as shown in Figures 1A and 1C in this letter. When the zinc electrode is dipped into the solution involving its ions, due to the electro-positive character of this element, there is a tendency for zinc atoms to escape into the solution as Zn^{2+} ions, each of them leaving two electrons behind on the strip. On the other hand, there is a tendency for Zn^{2+} ions in the solution to cling on to the metal, each of them attracting two electrons on its surface, but the former tendency is the stronger so that some zinc atoms do escape from the metal surface, which becomes negatively charged by the electrons that are left behind. This results in the electrode having a lower potential than the solution. Similar phenomena occur when the copper electrode is dipped into the solution containing its ions. But copper is less electro-positive than zinc and so its tendency to form ions is not so strong. Hence some copper ions drive on to the metal, each of them transferring two electrons from copper atoms, and give the surrounding solution an overall negative charge. The loss of electrons from the copper electrode causes it to be positively charged and hence raised to a higher potential than the solution. It follows from these phenomena at the half-cells that the zinc electrode will be lower in potential than the copper V). Thus, the metal electrodes (the metal side of the electrical double layer in each half-cell) in a galvanic cell do have net positive or negative charges); however, these charges are extremely small (only about one electron for every 10^{14} metal atoms) and exceedingly difficult to measure. The magnitude and direction of the charge imbalance between the metal electrode and the electrolyte solution differs from metal to metal and is responsible for the different standard reduction potentials for metals. A galvanic cell is a source of current. Every source of current has two poles. The one with *higher potential* is called the *positive pole,* and the other with *lower potential* is the *negative pole*. Thus, the copper electrode is labelled (+) while the zinc electrode is labelled (-). To obtain a current the poles must be connected by a system of metallic conductors forming the external circuit (by a metal wire directly or via an ammeter).

In Figure 3 in his letter, Goodwin represents the charges on different parts of the electrodes from the two different perspectives according to his ideas. This is not reasonable in our opinion, as explained previously. In addition, in this figure, an arrow that is directed from cathode to anode is used to represent electron flow within the cell (in the electrolyte solutions). The statement appended with the arrow, ***'equivalent electron flow within cell'*** in this figure may lead students into believing that electrons enter the solution at the cathode, move through the electrolyte and emerge at the anode to complete the circuit during the passage of current through the cell; this is one of the most widely recognized misconceptions among the students. Students' misconceptions and conceptual difficulties were well documented by several researchers as cited in our previous paper.[2] The researchers also discussed probable sources of student misconceptions. They had the shared idea that a major source of student misconceptions comes from imprecise, insufficient, and inappropriate textbook or instructor comments. Instructors and authors should use carefully chosen terminology to explain electrochemical processes.

References

1. A. Goodwin, *U.Chem.Ed.*, 2003, **7**, 59.
2. A.R.Özkaya, M.Üce and M.Şahin, *U.Chem.Ed.*, 2003, **7**, 1.
3. N.A.Ogude and J.D. Bradley, *J.Chem. Ed.,* 1994, **71**, 29.
4. N.A.Ogude and J.D. Bradley, *J.Chem. Ed.,* 1996, **73**, 1145.

The Bologna Process and Chemistry Degrees in the UK

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A remarkable change is taking place in higher education across Europe, which has potentially serious implications for university studies in the physical sciences and engineering in the UK. Since the Bologna Declaration in 1999 the pace of change has accelerated, so that many of the 40 signatory countries are now expecting to implement a Bologna-style two-cycle Bachelors and Masters degree structure by 2005. Although not strictly specified, a pattern of 3 years (BA) + 2 years (MA) is becoming widely recognised, with the further assumption that a second cycle qualification will become an essential prerequisite for starting PhD studies. As student mobility has increased in Europe, and a European Credit Transfer Scheme (ECTS) has developed, such a change is long overdue. Comparability between different national HE qualifications was difficult to establish when the time taken to complete a first degree varied between three and seven years; but now there is a real possibility of extending ECTS into a credit accumulation as well as transfer scheme.

Although the Government is a signatory of the original Bologna Declaration, it seems to be largely ignoring its obligations. UK Education Ministers stress that Bologna lays no *compulsion* on any country to reorganise its higher education structure, and even suggest that the pressure is on other European countries to move towards the UK pattern of higher education. This may be true for those academic subjects where a three-year Bachelors degree is the norm, but it raises a particular difficulty for the physical sciences and engineering where the MSci has become the preferred option.

While many European countries struggle to reduce their Bachelor degree to three years, the problems facing English universities are most severe in the second cycle. Current academic opinion is that the four-year integrated MSci (here used as a generic term to include MChem, MPhys, and similar engineering and mathematics qualifications), which science and engineering faculties have worked so hard to establish, is a popular, flexible and entirely satisfactory qualification, equipping graduates to enter doctoral studies or employment as a professional chemist. Funding for the MSci is secure, and universities are unlikely to change unless pressure is applied by the Government through the Funding Councils. This they are unwilling even to consider, believing that with no direct requirement for change stipulated, the MSci can stay as it is, and there is therefore no direct funding implication.

Unfortunately, the Bologna Process will probably not accept the current 4-year MSci as a second cycle qualification, especially as contact hours in UK universities are generally lower than in continental institutions. Neither is there a recognisable exit point and qualification for students, equivalent to the BSc at the end of the first Bologna cycle, nor a clear delineation between first cycle and second cycle study material. If additional credit points have to be added to meet the second cycle requirement (the minimum to open negotiations is thought to be 90 credit points), they could not be incorporated under the present funding regime. All the material in this extended final year would also have to be of recognisably second cycle standard.

The Government refuses to see this as a problem. Again, they see no requirement that a second cycle qualification is necessary for a student to begin PhD studies. They seem not to recognise that when the rest of Europe has adopted a system 'based essentially on two main cycles', such attitudes will no longer be valid.

It is interesting to note that Scotland may be better placed for developing a Bologna pattern from its present degree structures; and that the Republic of Ireland is looking to implement the Bologna proposals. One possible route to acceptance for those English universities who run an MSci including a year's industrial placement could be for them to add a further university-based year to their course. This would also meet the criterion that Bologna-style degrees should seek to improve the employability of European graduates.

Running alongside the Bologna developments is the Chemistry Eurobachelor, an initiative of the European Chemistry Thematic Network, which also has the support of the Federation of European Chemical Societies. The RSC is well represented on both these bodies, and a staff member of the Education Department has recently joined the Chemistry

Eurobachelor Working Group. Ironically, this proposed programme of study, aiming to provide a basis for the first cycle, is substantially based on the UK Chemistry Benchmarking document. The Eurobachelor discussion document, originally submitted to the Tuning Educational Structures in Europe project, but since much revised, addresses aspects of content, learning outcomes, methods of teaching and learning, assessment procedures, and quality assurance. Despite its origins, there is little enthusiasm for this proposal in UK Chemistry Departments, possibly deterred by the inclusion of a second European language and a 'Bachelor thesis' in the specification.

So what might be the implications for UK chemistry if no effort is made to follow the Bologna pattern? At worst, UK graduates without a recognised two-cycle qualification might be considered less well prepared, and so passed over for employment opportunities elsewhere in Europe. MSci graduates might not be accepted for PhD studies in other European countries, and we would not be producing first cycle students qualified to enjoy the social, cultural and educational benefit of pursuing their Masters in a continental university. Correspondingly, we should lose the advantage of students coming to the UK, because there would be no second cycle two-year MSc courses for them to study in our Chemistry Departments. The effect might not be immediate, but as more European countries adopt the Bologna Process, the UK will become increasingly isolated from mainstream European higher education.

Perhaps the most effective way to change current thinking will be for the professional bodies for science and engineering (including the Royal Society), and the employers' organisations, to act in concert to try and influence the government. It is good to see that such activities are under way, and a number of joint meetings have been held, though at the moment the RSC seems to be showing more concern than the Institute of Physics over the lack of governmental interest.

However, the Government has also indicated that HE institutions should separately consider how they might need to change to remain competitive in the international higher education marketplace. So there is an opportunity for individuals within Departments, who think that the future of UK chemistry graduates will be more assured if higher education becomes more closely aligned with the European developments stemming from Bologna, to influence the opinion of their own universities. If Chemistry Departments are willing to offer support to the RSC in its attempts to influence Government thinking on the importance of the Bologna Process for the UK, there is a chance that we might all share the benefits of chemistry higher education with a European dimension.

For information on these matters, the following websites and documents can be consulted:

***The Bologna Declaration and the Bologna Process*:**
'University Reforms in Europe, the Bologna Process', *RSC Educational Issues*, No. 24, July 2003; 'The Bologna Process and UK Physics Degrees', Institute of Physics, October 2003; The Berlin-Bologna-Webpage (all documents) http://www.bologna-berlin2003.de/en/main_documents/index.htm

The Chemistry Eurobachelor:
'The Eurobachelor is coming', Kathryn Roberts, *Education in Chemistry*, November 2002, p.142; www.cpe.fr/ect/arch/doc/2004/N01/Eurobachelor_2004.pdf

Tuning Educational Structures in Europe
http://www.cpe.fr/ectn/tuning_project.htm

MChem: 'MChem the first decade', RSC 2003

European Chemistry Thematic Network:
http://www.cpe.fr/ectn/

Federation of European Chemical Societies:
http://www.chemsoc.org/networks/enc/fecs.htm