Addressing Key Skills in the Chemistry Curriculum: Structured Learning Packages

PAPER

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An approach to addressing key (transferable) skills has been developed which builds on the chemistry background of students by means of realistic case studies sourced from the chemical industry. The development and format of the resulting *structured learning packages* are outlined. Early experiences in using these packages at two universities are described. Initial trials suggest that students can improve their understanding of chemical topics whilst developing skills in the principal areas of teamworking, communication, problem solving and information retrieval.

Introduction

Employers[1], professional bodies[2-4] and educators[5,6] continue to draw attention to the need for university degree courses to address the development of key skills alongside the subject-specific knowledge, understanding and skills of a particular discipline. This view has been emphasised further by the recent *Dearing Report* into higher education (HE) in the UK[7]. Despite the importance attached to these variously defined generic skills, there remains a perceived difficulty in finding time to introduce them adequately into an already overcrowded curriculum. One approach to resolving this problem is to teach the content itself in a way which simultaneously develops skills. This recognises that content *without* skills is limited in its value; professional chemists should be able to *extend*, *explain* and *exploit* their knowledge. There are powerful arguments in favour of this integrated approach and recent contributions have demonstrated how it might be achieved[8,9].

Recently, in the UK, the introduction of the M.Chem degree, and of modularisation, has created the space necessary for involving students in such skills based, reflective approaches to learning. We set out to develop resources to exploit this opportunity, with the specific aim to generate material which would:

- be based in chemistry;
- allow the development of key skills;
- encourage independent study;
- be sufficiently flexible to facilitate wide use.

We coined the description *structured learning packages* (SLPs) for these materials.

Characteristics of structured learning packages

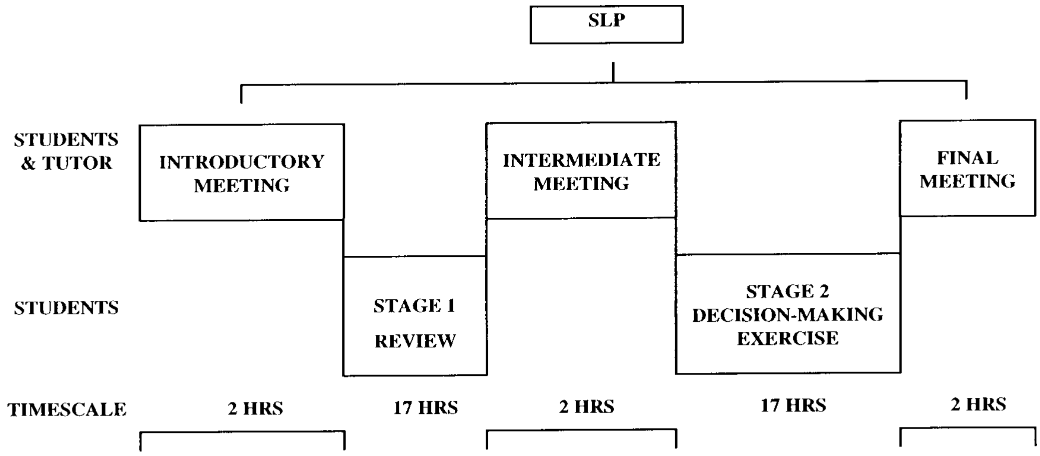
We established a consortium of academics from six universities[10] together with representatives from the chemical industry in order to discuss the style and content of the packages. In this way, we expected to maximise the suitability of the final product for use in a range of institutions whilst incorporating those skills most demanded by employers of professional chemists. From the initial discussions of this group, the following desirable characteristics for SLPs were identified.

- Each SLP should be based on a case study of industrial/pharmaceutical chemistry to provide realism;
- A library of complementary SLPs were needed which covered a range of industrial scenarios;
- Each SLP should occupy 30–40 hours of student time (equivalent to 3–4 weeks of practical work in most courses);
- The chemistry involved should be suitable for third year BSc/MChem students
- Each SLP would be designed for use by classes of up to 25 students working in teams (2–5 teams of four or five students); larger cohorts could be accommodated by dividing them into two or more classes;
- In order to engage the interest of the whole class in the work of each team, each team should be assigned a complementary (but not identical) task within the same general topic;
- The tasks set to each team should bring out the importance of two aspects of teamwork: the value of dividing up a task and the value of 'sharpening up' ideas through team discussions;
- In addition to teamwork, each SLP should involve students in retrieving information, presenting written and oral reports, making decisions in a situation where more than one could be defended, and developing some commercial awareness;
- Most of the student time should be spent working independently of support from tutors, but sufficient support should be available to provide confidence;
- Student performance should be assessed.

The design of structured learning packages

The basic format of our SLPs (three plenary sessions separated by two periods of independent study) is shown in Figure 1.

Figure 1: The format of a structured learning package (SLP)



We judged that the inclusion of an intermediate plenary session, in addition to an opening and closing one, would provide sufficient input from a tutor to support the students' activity. This intermediate plenary allowed each package to be sub-divided into two distinct stages. Stage 1 was intended to be concerned primarily with information retrieval. We supposed that students would feel relatively confident in their ability to do this, and that this would encourage them to tackle Stage 2. This involves the much less familiar task (for students) of making decisions in a context where there is incomplete information, no uniquely correct solution, and when factors other than chemistry (such as costs, safety, and the environment) have to be taken into account.

The division of the exercise into two stages had other benefits:

- The initial input of information need only be sufficient to allow completion of Stage 1;
- The success of the information retrieval could be monitored and additional information provided, if necessary, in order to ensure that all groups had an adequate background to allow them to complete Stage 2;
- It enhances reflective learning since there are two opportunities for students to prepare written and oral reports on their work, and the intermediate plenary is used to provide feedback on the effectiveness of their efforts and guidance on how to improve their performance during Stage 2;
- The scope of the information gathered during Stage 1 is increased since all groups can be required to collect complementary data which is shared at the intermediate plenary; this sets up the possibility of using a single communal problem in Stage 2 introducing a useful degree of competition between the teams.

Choosing case study topics

To date, two SLPs have been prepared. One deals with the industrial manufacture of acetic (ethanoic) acid (see Table 1 for details). The other deals with the selection of a polyaromatic polymer compound for a specific use (see Table 2 for details). Both these topics meet the following criteria:

- We had the assured collaboration of an appropriate industrial consultant with considerable expertise in the field (BP Chemicals for the acetic acid study, and ICI for the polyaromatics study);
- Each topic is currently relevant and so illustrates the kind of things chemists actually do;
- The chemistry involved is simple, so that the students can concentrate on the development of skills in a context which is clearly chemical, but not so challenging as to dominate the learning experience;
- The students need to consider aspects of chemical engineering and technological economics, thus broadening their experience and illustrating the relationship between chemistry and other important disciplines;
- Most of the necessary information (at least for Stage 1) is in the public domain and can be found without reference to highly specialised or restricted publications;
- At least four complementary tasks can be identified for Stage 1 of each exercise (see Tables 1 and 2).

Experience with structured learning packages

We have used both exercises with students at Warwick and at York. The initial trial, as a course option, at Warwick involved a group of eight third year students working in two teams of four. The teams completed both SLPs within a four week period, two weeks being allocated to each one. At York the complete cohort of 65 third year BSc students completed a single SLP as part of the core curriculum. The students were divided into three classes. One class, comprising five teams, completed the Polyaromatics exercise and two classes, each of four teams, concurrently completed the Acetic Acid exercise. In order to trial the SLPs before the end of the year Stage 1 was completed over ten days, before the finals

Table 1: Student tasks in the Acetic Acid SLP.

Stage 1

Review two processes of acetic acid manufacture (from four). Apply a scheme for estimating chemical plant capital costs to the two processes. Compare the processes in terms of their complexity, raw materials, environmental impact etc.

Review the uses of, and global market for, acetic acid and derivatives. Review the nature of the costs, other than plant capital, which contribute to the 'factory gate' cost of an industrial chemical.

Prepare a talk and a written report to summarise findings.

Stage 2

Consider a number (four) of acetic acid plants, at locations throughout the world and based on the four different processes, and use the Stage 1 reports to arrive at a capital cost estimate for each.

Use additional cost information (raw material prices etc.) and a scheme for estimating some process costs to derive a production cost for acid at each plant.

Make use of this cost analysis, in addition to the accumulated information on the current and forecast world market for the acid and the raw materials to arrive at a decision regarding which single plant the company would be best advised to sell off in order to diversify into other areas.

Develop a strategy for selling the plant as a going concern.

Prepare a talk and a written report to present and justify your decision and explain your strategy.

examination; three weeks later Stage 2 was introduced with an additional short plenary session, immediately following the finals examination.

In Warwick and in York, the introductory plenary session was used to emphasise the importance of key skills and the opportunities to develop these through the SLP.This was done by involving the student teams (as pre-selected by the tutor) in short periods of brain-storming followed by tutor-led class discussion. The following sequence of discussion was used:

- 'What do you understand by key skills?' (leading to agreement that these can be grouped into the four categories of skills identified for purposes of the SLP: communication, teamwork, problem solving, information retrieval).
- 'Identify good things and bad things about the way your team just worked in arriving at a conclusion, and about teamwork in general' (leading to complementary pairs of observations e.g. 'one person dominates' vs. 'everyone is encouraged to contribute' and 'there are personality clashes' vs. 'focus on the task in hand – be professional' etc.)
- Students then individually completed a skills profile form based on the expanded range of personal skills described by Gibbs *et al.*[11].
- Teams discussed individual profiles and summarised a combined profile for their team with a short presentation.
- Written details of the tasks to be completed before the next plenary session were then distributed and explained. Lists of learning outcomes were also distributed (Tables 3 and 4).
- The arrangements for a 'Help' service (available via email) and the requirement for team meeting minutes were explained. These features operated in a similar manner to that described for similar exercises[9].

The intermediate plenary session can be used for some, or all, of the following purposes:

Table 2: Student tasks in the Polyaromatics SLP.

Stage 1

Review the area of polyaromatic engineering polymers with emphasis on establishing structure-property relationships for this class of polymers.

Use the structure-property relationships to explain the choice of three polymers from the list provided which would be suitable for the prescribed application (e.g. for dialysis membranes in food technology and desalination).

Outline a route for producing each candidate polymer considering the source of monomers, processing, environmental and processing hazards.

Review the nature of the key costs involved in producing polyaromatics. Analyse the potential market for the polymer including its size and the nature of competitor materials.

Prepare a talk and a written report to summarise findings.

Stage 2

Consider all the Stage 1 applications and apply a scheme to cost out the production and processing of the candidate polymers.

Use the cost information to choose an optimum polymer for each application based on the best compromise of performance and cost.

By consideration of the costs of each of these polymers and the information on the markets available in each application (and taking account of the ability of one polymer to meet more than one of the applications), choose a single polymer to go into production.

Develop a strategy to sell the new polymer into the target application/s and suggest other areas where it may find uses.

Prepare a talk and a written report to present and justify your decision and explain your strategy.

Table 3: Learning outcomes (key skills)

On completing this course, you should be able to:

- list the key skills you regard as important in employment and describe how the case study helped to illustrate this:
- describe how your own key skills allowed you to contribute to the exercise and how you will use this experience to improve your performance:
- give examples of good and bad practice in the areas of communication, teamworking, problem solving and information retrieval.

Table 4: Learning outcomes (chemistry)

On completing this course, you should be able to:

- use examples from the case study to illustrate the role of technology, raw materials and markets in industrial strategy;
- use examples from the case study to demonstrate the differences between small scale laboratory synthesis and large-scale commercial processes:
- describe the influence of environmental and safety concerns on the operation of industrial processes.

- Each team delivers an oral presentation in which they must all participate. We have used talks of 10 minutes duration (with four or five teams presenting) though more time can be allowed in a smaller class.
- Each team can be given the responsibility for chairing the presentation and leading the questioning of another.
- At the conclusion of the presentations, a feedback and discussion session along the lines of 'what makes a good/bad presentation?' is appropriate.
- Assuming that written reports have been handed in and assessed in advance of this meeting, they can be returned together with copies of all other reports needed for the communal decision-making exercise in Stage 2. The opportunity to compare all the reports, side by side, in this way can be exploited in a 'what makes a good/bad written report?' review session.
- The tutor can ensure that the teams have sufficient accurate information to proceed with Stage 2 and introduce the requirements for this second part of the exercise.
- Comments on the operation of the 'Help' service and/or the style of team meeting minutes might also be relevant.

The final meeting creates opportunities for:

- The second oral presentation, this time presenting a persuasive justification of the decision the team have reached.
- The various suggestions from the teams can make for a lively discussion session. There is a useful role for an industrial expert in leading these discussions.
- Further feedback on skills can be provided either to prepare for tackling a second exercise or summarising the role of key skills and their relevance to the future course/career activities which the students face.

Assessment

We have used the brain-storming sessions on oral and written presentation to arrive at marking schemes which are presented to the students and used subsequently to assess their presentations. This concept of negotiating a mark scheme with students has been previously applied by Wallace[12]. The content of the oral and written reports provided suitable evidence for assessing the proficiency of the teams in information retrieval and their level of acuity in problem solving. Assigning a mark to teamworking was approached through assessing the continuity and coherence of the presentations, the degree to which the teams demonstrate good teamwork when responding to questions, and the quality and content of the minutes of team meetings. This procedure arrives at overall *team* marks. Deriving *individual* marks from these is more problematical.

We have chosen peer assessment as a route to individual marks. The team was given its team mark after each stage of the exercise. Their instruction was then to multiply the mark by the number of members in the team and to agree on a division of those marks between them. On one occasion, this was done with the proviso that no individual could get more than 1.2 times the team mark. Both marking systems were accompanied by a clear grievance procedure and the additional proviso that the course tutors had the final say in any dispute. In order to help police this system we made reference to the minutes of team meetings.

We chose to weight the marks for the exercise 40:60 between Stage 1 and Stage 2. In other words, more credit given to the latter part of the exercise when teams have had the advantage of learning from their first attempts during Stage 1.

Discussion

The exercises were run at Warwick and York with the participation of five tutors, with one of us (NL) in both places. Our subsequent analysis of the effectiveness of the exercises has led to a consensus view on a number of issues which contribute to the success of exercises of this type.

In order for students to get the maximum benefit, it is crucial to remind them (and ourselves!) that the main goal of these exercises is to develop key skills. We have found it important to temper the 'over-conscientious' nature of students towards the chemistry content. In particular, we stress the importance of introducing the unfamiliar nature of problems of this kind, where there is incomplete information, no uniquely correct solution, and a range of unfamiliar and complex factors. We emphasise to students that making judgements to a strict time or financial deadline, and on the basis of incomplete information is a crucial aspect of many real situations.

The 'Help' service was not heavily used during the exercises perhaps as a result of our suggestion that injudicious use of the service might be penalised. However, an effective 'Help' service is crucial, partly to ensure that the teams can complete the exercise, and partly to act as a database of papers and other data which teams might have genuine difficulty in obtaining during the exercise.

The intermediate plenary session can prove very intensive due to the combined pressures of listening to all the talks, giving feedback on talks and written reports, reviewing teamworking, giving a technical resume of Stage 1 and preparing the ground for Stage 2. Indeed, in anything other than a very small class, it is not possible to do all these things effectively in a single two-hour session. The division of this session into two, as practised at York, has much to recommend it, especially for a large class.

At York, we benefited from having a representative from the collaborating industrial companies at the final sessions. This galvanised the teams during their presentations and catalysed a lively concluding discussion. Given the generality of factors such as costs, safety, legislation, contract law, environment and market strategies to the full range of chemical industries, we suggest that an industrial expert can make a similarly valuable contribution to the running of the exercises regardless of their actual affiliation.

The use of all the Stage 1 reports to provide information for the communal decision-making exercise of Stage 2 not only allowed the bigger task to be tackled within the timescale of Stage 2 but had the added advantage of drawing attention to flaws in the original reports. A comment such as '…this reaction, from report 3, was not given a reference…' suggests that this process drew attention to the difference between 'writing a report' and 'writing a report *which can be used*'. The decision to give all teams the same problem in Stage 2 appeared to introduce a stimulating edge of competitiveness into the final presentations. No single outcome was universally selected in either SLP and so the teams did not have to listen to repetitive arguments. This may be due to the judicious design of open-ended exercises, to the prejudices the teams develop during Stage 1, or to a combination of these factors.

We noted considerable improvements in team performance over the course of the exercise.This was particularly evident when comparing the oral and written reports produced in Stages 1 and 2. We take this as an encouraging sign of the effectiveness of the feedback and guidance provided at the intermediate session/s. Students also become notably more comfortable with the concept that decisions have to be based on incomplete data in Stage 2, rather than attempting to accumulate all the data, as might typically be their approach during Stage 1.

The peer assessment only occasionally produced any variation of the *individual* marks from the *team* mark. When this happened there was a tendency to give very high marks to the above-average contributors. We felt some moderation was required in these cases. In general, the peer marking was effective in identifying the non-contributors, with other team members usually getting close to the team mark. We have some evidence that peer marking can result in above-average marks for some individuals who, from the plenaries, appeared to be making a below-average contribution. We think this is an important observation since it reminds us that the tutors may underestimate significant behind-the-scenes contributions made by some individuals who do not shine in public.

Tutor input

Even with short reports (typically, we have imposed a six-side limit on written reports and 10 minute limit on oral presentations), the time involved in assessment is appreciable and rises in proportion with the number of teams. Also, it is highly beneficial to run the exercises with two tutors, largely for purposes of second marking of oral and written reports. In these circumstances, we estimate that a class of 25 students (in 5 teams) requires a total of *ca*. 15 hours commitment from the course tutor (including six contact hours) and *ca*. 12 hours from a second tutor, including the plenary sessions, assessment and preparation. This is a similar time commitment to demonstrating and marking a typical laboratory course with, we feel, the tutor's input providing a higher level of intellectual stimulation than is usually provided in the lab. Additionally, the SLP requires no technical support, junior demonstrator or technician time associated with a practical course.

Student feedback

Running the exercises with a small group, as in Warwick, and with the benefit of two tutors, allowed for considerable interaction with individuals. This resulted in interactive and enjoyable plenary sessions with the teams often engaging in lively debate about the decisions their 'rivals' had taken. The feedback from students was extremely positive. Of the seven who returned the post-exercise questionnaire, six 'strongly agreed' with the statement 'I would recommend others to attend a similar course' and the other respondent 'agreed'. Further comments provided an endorsement of the style and content of the exercises:

'I did this course because I thought it would be a doss! In fact, it was hard work but the time just flew by.'

'I wish more of my courses had been like this.'

'I learned more chemistry in this course than I did in almost all of my others.'

At York, in spite of the large class size, the plenary sessions were still encouragingly interactive and lively with good levels of participation in the brainstorm sessions. We noted the same conspicuous improvement in performance between the stages of the SLP, as at Warwick, and the larger class-size seemed to enhance the experience of giving oral presentations.

Twenty-three students completed a questionnaire at the end of the course. (This return of ca. 35% is in line with other course questionnaires.) Fifteen of the 23 students completed the boxes inviting free responses and 13 of those comments were critical of the timing of the exercise. Similar verbal comments were also received. In future it will be possible to arrange the exercise at a more appropriate time. The discontent with the timing has almost certainly adversely affected the students' perception of the value of the course. Some evidence for this comes from the response to Question 1 (' How valuable is an exercise of this type?'). Students were asked to rate their answer on a scale of 5 (high) to 1 (low). The numbers of responses were as follows:

Score	5	4	3	2	1
No. of responses	3	5	2	6	7

Seven of the fifteen students who rated their score at 3 or less also gave written comments. All of these comments were strongly critical of the timing of the exercise and were often accompanied by remarks such as that made by a student who gave Q 1 a score of 1:

'the exercise should take place early in the third year, or even the second year'

Our conclusion that the student response to questions is not an accurate reflection of the value of the exercise is confirmed by our analysis of Question 2. This question asked students to score (on the same scale of 5 to 1) whether the exercise had helped them to improve or develop six specified skills. Table 5 shows the six questions, together with the average of the scores assigned by all 23 students and also the average assigned by the seven students who gave a score of 1 to Question 1. The latter scores are remarkably high considering that these students indicated that the exercise had little or no value. This analysis, together with the written comments, provides a strong indication that a number of students had effectively answered Question 1 as if it were 'did you enjoy this exercise?', and that they had responded negatively to this largely due to the timing issue. Furthermore, we believe that the timing issue also led to a number of students responding less favourably to Question 2 than they might otherwise have done. We base this on Clow's observation[13] that students' perception of the value of a whole exercise can be greatly affected by their dislike of one particular aspect. More directly, we had a series of semi-structured discussions with a number of individuals and groups of students at a social function held to mark the end of the course. Feedback obtained in this way was generally much more positive even when we targeted students who had clearly demonstrated their discontent throughout the exercise.

Our discussions have revealed that many students do recognise the importance of key skills and realise that the ability to demonstrate having developed and used them is crucial to their future careers. We conclude that the kind of exercise described here provides a substantial contribution to this process whilst also introducing important elements of additional chemistry. We are now in the process of making our own exercises available, upon request, as fully-documented materials with complete tutor's notes and recommendations which expand upon many of the issues raised here.

Table 5: Average student response to questions

	Rate how well the group exercise gave you the opportunity to:	*Mean score* (all 23 respondents)	*Mean score* (7 students scoring 1 for Qu. 1)
(i)	improve your ability to think creatively	3.1	2.4
(ii)	improve your ability to retrieve information	2.5	2.0
(iii)	develop your time management and planning skills	2.8	2.6
(iv)	improve your report writing skills	2.7	2.7
(v)	improve your presentation skills	3.4	3.1
(vi)	develop team-working skills	3.2	3.0

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