Committee for the Advancement of University Teaching

FINAL REPORT FOR A 1995 NATIONAL TEACHING DEVELOPMENT GRANT

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1) Identification

Name of Project Leader(s)

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Project Title

Design of a pool of constructivist tasks for learning chemistry

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Key words or phrases that describe the project

Thinking tasks; deep learning; teaching for understanding; organic chemistry; thermodynamics; chemical education

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2) Project Summary

Over the last twenty years or so, science education researchers have developed some rather ingenious ways of probing student understandings. In more recent times, some of these types of task developed for probing understanding have been recognised as having value as strategies for improving student learning, largely because they demand reflection and even struggle by students to make sense of the subject matter.

While it is one thing to have descriptions of such instructional tasks, the practising teacher needs to have access to specific examples in their field and at the appropriate level. The purpose of this project has been to devise a pool of such tasks applicable to undergraduate chemistry courses which can be used in a variety of ways: (i) "as is", (ii) modified to suit particular purposes, or (iii) as examples to assist in the construction of similar tasks. A pool of 140 "thinking tasks" have been devised, mainly in the areas of equilibria in aqueous solution, organic chemistry and thermodynamics.

3) Suggested Applications

The "thinking tasks" devised in this project are directly applicable "as is" or with modification in undergraduate chemistry courses - although some may also be useable in secondary schools. As exemplars of various types of task, they have the potential to assist teachers of any of the sciences to construct tasks more specific to their purposes.

The tasks are designed to encourage "deep learning" by students and are particularly appropriate where lecturer-student and student-student discussion is used. In particular, these "thinking tasks" might require students to clarify their understanding of a concept, to differentiate between concepts, to construct linkages between concepts or topics, or to understand the purpose of the steps in a laboratory procedure. Consequently they are suitable to use during tutorials, although it is also sensible to use any one of these tasks (some are more appropriate for the purpose than others) as the starting point for a lecture. Some have been designed for use as stimulation exercises in pre-work for laboratory sessions, and all could be used in assignments. Given that their origins lie in strategies to probe understanding beyond the superficial and algorithmic demands of many examinations, most of them can be used as examination questions.

4) Output

The final product is a compilation of invented tasks that has been published as *Thinking Tasks in Chemistry: Teaching for Understanding*. It comprises four parts:

- Part 1: Equilibria in aqueous solution (52 tasks)
- Part 2: Organic chemistry, (29 tasks)
- Part 3: Thermodynamics (35 tasks)
- Part 4: Miscellaneous (25 tasks)

Because of the size of this compilation in "hard copy" format, and the cost of reproducing entire sets, the publication will be made available on diskettes (in Word for Macintosh format).

5) Major Objectives of the Project

The major objective of the project has been the invention of a pool of "thinking tasks" that is useable directly by teachers of undergraduate chemistry courses. Each of the tasks can be used "as is", modified to suit particular purposes, or as examples to assist in the construction of similar tasks. The driving force behind the achievement of this objective has been a desire for strategies that challenge students intellectually, that encourage reflection upon meaning and give students the opportunity to see the subject from new perspectives. The ultimate aim is achievement of "deep learning" so that student understandings go beyond the recall and algorithmic levels.

At the heart of the project is the recognition that chemistry is a very complex, concept-rich area of study with an extraordinary degree of interdependence amongst the concepts and between the concepts and the "facts". Far from being a subject that can be presented and learned in a linear sequence, even for professional chemists knowledge consists of partial understanding of each area of the field (variable form person to person, area to area) with changing number and strength of linkages between the areas. As our partial knowledge in one area advances, this allows illumination that leads to enrichment of our partial knowledge of other areas, as well as perhaps to an increase in the number and intensity of recognised links between areas. Which in turn ………ad infinitum.

This view of learning chemistry recognises the enormity of the challenge facing teachers and, more particularly, the enormity of the challenge facing students. So much so that perhaps it is not surprising that many students learn to play the "game" of rote learning, regurgitation of definitions and key phrases without understanding, and blind use of algorithms to disguise their highly compartmentalised knowledge. The science education research literature abounds with evidence that for many students the transmission model of instruction has severe deficiencies. Gross student misconceptions have been found to be quite common. Furthermore, research has shown time and again that conceptions - including misconceptions - are extremely resistant to change

Largely because of the exposed deficiencies in the transmission model of instruction, instructional designers are turning to "constructivist" views of knowing and learning, which recognise the uniqueness of each person's knowing, and how each person comes to know. According to this perspective, knowing is the individual reality that each person constructs as a result of interpreting their experiences. This project has as its basic postulate that worthwhile learning only results from a struggle to construct meaning from our experiences, in the light of previous understandings.

Over the last two decades, science education researchers have invented a range of ingenious tasks for the purpose of probing students' understandings. Recently, attention has been drawn to the potential of such tasks as effective teaching strategies because they require students to struggle with ideas in order to create their new knowledge. For example, these "thinking tasks" might assist students to see an overview of the subject matter, to clarify their understanding of a concept, to differentiate between concepts, to construct linkages between concepts or topics, to recognise meanings hidden by the jargon of definitions, to recognise non-examples as well as examples of a particular classification, to relate bulk properties to appropriate images at the sub-microscopic level, or to understand the purpose of the steps in a laboratory procedure.

While it is all very well to have descriptions of these useful teaching strategies, practising teachers need specific examples ready to use or to "borrow" from. The project reported here has created a large number of such tasks of many types. It is intended that a larger pool will be developed over the next few years and contributions have been invited.

6) Major Achievements of the Project

This project has lead to the construction of a pool of “thinking tasks” appropriate to tertiary level chemistry, mostly in the areas of aqueous solution equilibria, thermodynamics, and organic chemistry.
The types of task created during the course of the project include all of the following:

- Challenging the right answer
- Completing tables
- Concept mapping
- Conversations
- Decision flowcharts
- Dirty tricks
- Flowcharts
- Incomplete lecture notes
- Inserting sub-headings in text
- Interpreting diagrams
- Linking examples to principles
- Matching outcomes with origins
- Matching the reason with the instruction
- Relational diagrams (Venn diagrams)
- Reversing the task
- Scrambled calculation steps
- Scrambled instructions
- Selecting information from grids
- Sweller questions
- What data is necessary?
- Where and why is it wrong?

The set of tasks created during this project have been published as *Thinking Tasks in Chemistry: Teaching for Understanding*. This comprises 52 tasks in Part 1: *Equilibria in aqueous solution*, 29 tasks in Part 2: *Organic chemistry*, 35 tasks in Part 3: *Thermodynamics*, and 25 tasks in Part 4: *Miscellaneous*. The package is available on disk in Word for Macintosh format.

The most important evaluation component of this project has been the trialling of draft tasks with undergraduate students. This has had considerable influence on the design of many tasks. A considerable number of the tasks have been used in conjunction with tutorials and laboratory work at the first-year level within the normal teaching programme in the Department of Chemistry at the University of Western Australia. This has allowed evaluation of a reasonable sample of the tasks in terms of the students’ perceptions of the effectiveness of the tasks in making sense of various topics. As a result of this process, some tasks were re-designed and some re-assessment of the relative values of various types of task occurred.

Evaluation within the Department of Chemistry at UWA has continued during 1996. In addition about 20 people, Australian and international, have purchased the materials in recent months and most of these have promised to provide feedback.

The achievements of the project have matched the objectives - in terms of the direct applicability of the product, as well as in terms of the potential of the product to catalyse the development of more tasks - perhaps different in nature as well as relevant to different topics and different levels.

7) The Teaching Development

The project has already been shown to have a practical outcome since various lecturers in this Department have used particular tasks from the pool that has been created in their teaching. Furthermore, ideas for new versions of some of the tasks have been suggested, and some of the types of tasks been used as examples to create new tasks in other chemistry topics. So, as intended, the project has given rise to a product which has immediate applicability, as well as being a stimulus for further creative development.

By design, this project has not given rise to a programme which needs to be implemented as a whole (or not at all). Rather, the product is a resource from which samples can be used “as is” or with modification, by any of the lecturers, for any purpose that seems appropriate to them. This is happening, and some of the tasks are being used more than others.

In similar vein, evaluation is less relevant to a programme as a whole than it is to the usefulness of each to the tasks - in relation to the specified purpose of each of them. The main purpose of evaluation in this project has been assessment of the quality and usefulness of each of the tasks in their various draft stages, with the purpose of guiding further design of the tasks. To this end, the students specified in the project application as Project Reference Group members have been helpful, as have several hundred undergraduates, particularly first-year students, who were not specified. The results of the evaluation process are the tasks themselves.

The following points are relevant to matters of publicity and dissemination:

- The project leader conducted a two-hour workshop on these materials at the 14th International Conference on Chemical Education held in Brisbane during July 1996. The workshop was attended by about 50 delegates and created considerable interest, with twenty people buying copies on diskette as a direct result of participation in the workshop. A two-page description is to be included in the Conference Proceedings, which will be sent to all 600 or more delegates, about half of whom were from overseas.

- A one-hour seminar describing the purpose and nature of the tasks has been presented to the Department of Chemistry at UWA, and the project leader has been invited to do the same at a forthcoming one-day conference organised by the Chemical Education Division of the Royal Australian Chemical Institute (WA Branch).

- Workshop presentations are planned for the 1997 Conference of the Australian Science Teachers Association (CONASTA) as well as at the annual conference of the Science Teachers Association of Western Australia (CONSTAWA). The materials will also be one of two main foci of an invited lecture tour of New Zealand in July of 1997.

- Copies of the materials will be sent for review to the editors of Chemistry in Australia (the monthly journal of the Royal Australian Chemical Institute), Chemeda: The Australian Journal of Chemical Education, and the Australian Science Teachers Journal.

- In addition, the Internet will be used in late 1996 and early 1997 to send descriptions of the project materials to members of every University chemistry department in Australia.

- A major problem with dissemination is that a “hard copy” of all four parts consists of about 600 pages. Low-volume production by photocopying consequently costs about $60 for each set, and this ignores labour costs and binding. A more streamlined version than the one included with this report is being produced, but even this will incur photocopying charges of about $40. Because of this, the materials are being offered on computer diskettes in Word for Macintosh format - but this is less attractive to potential users because it involves the activation energy barrier and financial cost of printing out the whole product. This is also a format less suitable for distribution to libraries.

An unforeseen problem that arose, concerned the use by the research assistant of software, which he found convenient for production of the considerable graphical component of tasks. This did not seem to be a problem when it was thought that the tasks would be disseminated as hard copy. However, when the cost of reproduction as hard copy was recognised, and the decision made to disseminate in electronic format, it was soon realised that many people did not have access to some of the software used (eg Claris Draw) and so during 1996 a considerable number of tasks have been re-produced in Microsoft Word (for Macintosh) format.

The university and the Department of Chemistry have provided all of the support that might be expected in the conduct of this developmental project. Nonetheless, the main difficulty in achieving the outcomes of this project were the need to make considerable inputs of time and intellectual endeavour, especially in terms of discussions with the research assistant as well as in student evaluation of tasks, over and above the departmental expectations of teaching and research. This has at times made the load unreasonable.

The final outcomes of the project matched exactly the intentions stated in the original proposal.

8) Personnel Outcomes

The six participants other than the Project leader that were specified in the application all played significant roles in the project - as sources of ideas as well as in evaluating tasks and in using tasks with their students for evaluation purposes.

Nominated Project Reference Group members Emeritus Professor PJ Fensham and Dr I Mitchell, both at Monash University, were hardly used because travel funds were not awarded and planned brainstorming sessions with these people became impractical. Professor Fensham was met at two conferences, but discussions were of a general nature only.

The involvement of undergraduate students in the evaluation process varied from one-on-one observation and interview while using a particular task, to the provision of tasks to 300 first-year students as laboratory pre-work exercises.

An enormous contribution to the production of materials both electronic and hard copy, and especially during 1996, was made by secretarial staff in the Department of Chemistry. This constitutes a “hidden cost” in the budget of the project.

9) Networks

Considerable interest was shown by delegates who attended a workshop on this project during the recent International Conference on Chemical Education.

However, although set of tasks had been created by early 1996, it is only just now that the complete set is available in Word for Macintosh format so that a more vigorous publicity campaign can be pursued.

As expressed previously in this report, the project has been supported by provision of computers, office space and secretarial assistance by the Department of Chemistry at UWA. The extent of secretarial assistance has probably amounted to about ten or twelve weeks full-time work.