**Interactive Teaching and Testing Tutorials**

**for First Year Tertiary Chemistry**

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**Abstract:** This paper reports on the writing, development and trialling of ChemCAL, an interactive computer-based tutorial package for the teaching of introductory and first year tertiary chemistry. ChemCAL software was prepared using TutorialTools, a Hypercard™-based application designed by one of us (PAF), Macromedia Director™ and Quicktime™. ChemCAL uses on-screen video and animations, a range of question formats and three levels of direct response to students; it also has built-in logging that provides two-way feedback to both students and course supervisors. The total package has been used to provide interactive teaching and feedback to a large class where the effectiveness of traditional tutorials has proved limited; it has obvious applications for self-paced open learning. The results reported here refer to the use of ChemCAL as a tutorial base for a complete two-semester first year tertiary chemistry course.

**1 Introduction**

 This work has evolved from our earlier applications of computer technology for the teaching of elementary chemistry [McNaught, 1993][Fritze, 1994][Grant, in the press]. During semesters 1 and 2, 1994, forty 60-75 minutes ChemCAL sessions were prepared and delivered to 150 students in a first year chemistry stream in the Science Faculty at The University of Melbourne. In this paper we report on the structure of these computer aided learning (CAL) packages, the range of chemistry covered and an analysis of student feedback on the material presented. The material constitutes a complete yet flexible curriculum package that is now available for Macintosh computers in a trial edition on CD-rom.

**2 The Educational Environment**

 The ChemCAL packages were developed initially for a tertiary course in which the students have a weaker than average background in Chemistry. In 1994, approximately 90% of the 150-strong class had successfully completed the final year of secondary school chemistry where they had achieved results in the 35 - 55% raw score range; 10% of the class had not attempted the final year of secondary school chemistry.

 Having been developed for use with what is essentially a terminal year of chemistry, several of the modules have already been successfully adapted for use with mainstream chemistry courses servicing ca. 1000 students. The full 1994 course was delivered as follows: In each **two week period** there were:

6 large group lectures (group size ca. 150)

3 x 70 minute interactive CAL tutorial sessions in a 40 station Macintosh Quadra computer laboratory (group size ca. 35)

1 x 60 minute conventional tutorial (group size of ca. 35)

1 x 20 minute test with feedback in following week's practical session

1 x 3 hour practical laboratory class (group size ca. 16)

**3 The Educational Philosophy**

 The aim of this project is to develop CAL material that is strongly interactive, can be used with student self-pacing and is designed to assist learning by:

*\* using illustrative techniques that cannot be mimicked by printed materials, such as animations and film clips.*

*\* imposing on students the discipline of continually having to respond to questions as a condition for progressing through the material.*

*\* providing hints and explanations on request as an integral part of the questioning process thereby simulating, in part, the role of a personal tutor.*

*\* providing immediate feedback of the student's level of understanding together with suggested remedial action where appropriate*

*\* providing feedback to the course supervisor of student rate of progress through the material, thereby quickly identifying problem areas in the course*

 We have not assumed that CAL packages will or can completely replace the printed or spoken word as a vehicle for teaching chemistry. As an obvious example, we have judged it inappropriate for the mathematical development of the simple equations relevant to the study of chemical equilibrium to be developed 'on-screen'. For many students, the printed page may well remain a preferred method for initial study and comprehension of much of chemistry.

The programs we have developed have the following specific features:

(i) They provide animations or Quicktime™ movies to illustrate teaching points. eg., a procedure in volumetric analysis; the illustration of the critical point of a pure substance; the absorption of radiation by atomic or molecular species.

(ii) An animation can be followed by questioning based on the teaching point of the animation, that may require careful observation of the animation.

(iii) The course concepts are systematically referred to and then tested with graded on-screen questions. Feedback is provided at three levels in the form of a

**HINT** that can suggest a method of approach, followed by a complete....

**SOLUTION** for the student who is unable to complete the task; finally, there is a detailed....

**EXPLANATION** that is provided on request. In normal operating mode a question must be attempted before a solution can be revealed; however the order and timing of feedback can be configured to suit particular needs.

(iv) The programs can be run in 'test-only' mode either for student self-testing or as a component of final assessment.

(v) The 'screens' of which the individual packages are composed can be readily selected and re-sequenced so as to accommodate changes in course content and emphasis.

 Note that these ChemCAL packages provide the opportunity for self-paced learning of material for a whole course. One of the encouraging features of the project has been the demand from students to make available extra times at which they may review material done earlier in a semester; the provision of adequate access thus becomes in part a timetabling issue which leads quite naturally to self-paced learning within the context of a conventional University study.

 An integral part of the project is the provision of written textual material keyed to the screens that are presented to the students. Data tables or references to texts or other print material (lecture notes, prac. notes etc.) can be provided on-screen as required - and in some cases the production of new text quite specifically keyed to the on-screen presentations is needed.

 The discipline imposed by the task of writing testing material covering the whole course was salutary. It required the constant asking of the question 'just what do we want the student to know as a result of presenting them with this material?'. Given that a standard introductory laboratory program is an integral part of the course, the only significant area of testing remaining that is not covered by ChemCAL is the testing of a student's ability to provide some verbal analysis and description of chemical concepts.

**4 CAL Question Styles**

Note that all the following question styles are supported by on-call **'Hints',** **'Solutions'** and **'Explanations'.**

The available question types are:

(i) *Checkbox responses:* These are the conventional true-false or multiple choice items which require a 'point-&-click' on the correct box. We believe that a battery of true-false items is, in general, preferable to multiple choice. The traditional multiple choice format has the disadvantage that the ratio of 'incorrect' to 'correct' material is usually 3 : 1 with the further drawback that the respondent usually knows that only one of the possibilities on offer is correct thereby assisting inspired guessing. The true-false option has the advantage that the student is required to make a clear decision on each item presented. A battery of true-false items can be grouped so as to avoid the problem that there are only two possible responses for each individual question.

(ii) *Problems requiring numerical responses:* These may require the student to use a hand held calculator and a worksheet to proceed through the appropriate steps of a problem so that the final answer can be entered either from the keyboard or from a 'point and click' palette. The result is then checked for correctness to a pre-determined level of significance. Standard exponential notation is used in both entering members and in displaying results, eg *N*A = 6.022E23 mol-1

(iii) *Problems requiring symbolic responses using standard alphanumeric symbols:* These responses might require the writing of a chemical formula, an electronic structure, a mathematical formula, a Lewis electronic structure etc. There are, in general, three different ways of entering the appropriate symbols:

 **a** placing the cursor in an appropriate location and using the keyboard

 **b** pointing the cursor at an appropriate location and clicking from a palette

 **c** dragging from a palette

In this type of problem, pointing and clicking is usually the preferred option although in certain cases, dragging is indicated - eg. when there is no obvious 'correct' order in which to place the symbols such as in placing the dots in a Lewis structure or the balancing of a chemical equation. Some students are observed to prefer direct keyboard entry and although this poses some additional technical problems it is an option we retain wherever possible.

(iv) *Problems requiring the placement of text:* **-** these might require the labelling of a diagram, the completion of a sentence or the provision of a correct interpretation of a diagram, animation or movie**.** The same three options listed under (iii) are available and the decision as to which option to use is determined by the nature of the question.

(v) *Problems requiring the establishment of a rank order:* - eg. the ordering of a set of operations needed to correctly carry out some process. Again the 'point-&-click' and 'drag' options are available including a special version of the drag option in which the objects (as labels) can be freely moved around within a defined field.

**5 User Response**

(i) *Student Opinion:*

Built-in options are provided at two different levels for students at tutorial sessions to record comments about:

**a A particular screen**. These comments can be entered directly from the keyboard and refer to the clarity and/or quality of an animation, a question, a hint or an explanation on a particular screen. They are typically no more than one or two sentences. Some typical examples (good and bad) from the first version of tutorial 6 in semester 1, 1994 are:

\* *perhaps a periodic table displayed would be useful* (this has now been done)

\* *NO HINTS AND NO HELP?!AAH!* (quite so - this was attended to)

\* *the motion is too quick to really see what is happening* (an animation has been improved)

**b A whole 60-70 minute session**. These comments are entered in two different ways

b1 on a pro-forma screen in which general opinions about relevance, interest level, degree of difficulty and other similar qualities can be expressed by choosing appropriate words by dragging and clicking from a palette. Student response was unambiguously positive. The words in the left hand column of the table below were available to be selected. The data shown in the table are a set of responses for tutorial 11, a session dealing with the nomenclature of organic molecules and are typical of the reaction to the ChemCAL sessions.

 Session in general Chemistry content Wording of questions

valuable 62 29 5

clear 15 14 45

want more 10 10 -

like 7 14 7

pleasing 10 15 6

too easy 1 - -

too hard 8 3 4

want less - - -

dislike 2 - 2

irritating 10 - 1

confusing 7 8 8

worthless 3 - -

b2 by simple typing comments into a field using the keyboard.

These data are collated at the end of a tutorial session into a central file and can be printed out for scrutiny by the course supervisor. The examples shown below are a set of responses for tutorial 11, a session dealing with the nomenclature of organic molecules and are typical of the reaction to the ChemCAL sessions.

\* A good tutorial although I would like a printout

\* the session was informative but hard

\* we should have normal tutorials with a tutor going through questions. This allows students to have a better understanding of chemistry.

\* I would like more explanation of the finer points

\* very, very good. The best one yet....it made the understanding much better as I did not really understand.

(ii) *Student Navigation:*

 Student progress through a session is logged automatically and collated at the end of a tutorial session into a central file. The data can then be printed out for scrutiny by the course supervisor. Information available includes:

**a**  time spent on each screen

**b** frequency of consultation of hints, solutions and explanations

(iii) *Student Performance:*

**a** responses made to each question

**b**  whether and when a correct response is made

The typical printout below some student results for part of session 5, semester 1, 1994. The columns in the table show, in sequence, the title of a screen, the number of students attempting the screen, the number of questions on the screen, the average time in minutes taken for the screen and finally the fraction of correct responses to the items on the screen.

screen title number of attempts number of items average time ease

atomic orbitals 167 11 11.1 0.73

electronic structure of atoms 167 9 2.6 0.87

electronic structure of ions 167 12 7.3 0.86

elements in the periodic table 165 12 5.4 0.81

regions of the periodic table 1 164 10 2.8 0.82

regions of the periodic table 2 155 19 10.9 0.77

trends in ionization energy, groups 163 1 7.4 0.17

trends in properties, group 1 163 15 6.6 0.53

trends in ionization energy 1 159 3 3.7 0.69

trends in ionization energy 2 159 12 3.2 0.77

electron affinity of atoms 156 1 5.0 0.28

trends in electron affinity, groups 156 8 3.2 0.49

Note the very low 'ease' rating of 0.17 and 0.28 for two of the items. These were both single items over which students had spent appreciable amounts of time (7 and 5 minutes respectively). In subsequent editing, the 'Hints' available on these items were upgraded and the skill teaching in lectures has been intensified during 1995. Of special interest are items that have a very low ease level. One item in the table above scored only 0.17; such a low score leads one to question, not only one's teaching strategies, but also the need for teaching that particular skill. In this particular case, the problem turned out to lie more with the style and working of the question rather than with an intrinsic difficulty level.

(iv) *Tutor and Referee Opinion*

This project has involved the collection of professional opinions from tutors and other teaching staff as part of the evaluation process.

**6 Summary of Sessions Prepared**

 Each session has been designed to have a nominal duration 60 - 70 minutes. This is based on our experience of the rate of student progress as obtained from our student performance data. One obvious feature of these data is the wide variation in the time spent by students working through a session. We define a '60 minute session' as one that 75% of the class finish in the indicated time of 60 minutes.

 Sessions used and evaluated during 1994 were:

**Semester 1**

1. Introductory Diagnostic Test

2. Stoichiometry and the Gas Laws

3. Techniques of Quantitative Volumetric Analysis

4. Atomic and Nuclear Structure

5. Electronic Structure of Atoms

6. The Periodic Table and Atomic Properties

7. Solids. Liquids and Solutions

8. Spectroscopy

9. Molecular Structure and Shape. Applications of Spectroscopy.

10. Bonding in Molecules

11. Nomenclature of Organic Molecules

12. Bonding in Polyatomic Molecules. Molecular Conformation.

13. Chirality and Isomerism in Organic Molecules

14. Unsaturated and Conjugated Molecules

15. Calorimetry

16. Energy and Equilibrium

17. Phase and Heterogeneous Equilibria

18. Acid-base Equilibria.

19. Structures of Ionic Solids.

+ two practice tests

**Semester 2**

1. Rates of Chemical Reactions

2. Kinetics and Mechanism

3. Reaction Mechanisms

4. Conductivity of Electrolyte Solutions

5. Reactivity of Acids and Bases

6. Buffer Solutions

7. Solute and Solution Properties

8. Elementary Nmr Spectroscopy

9. Organic Acids and Bases

10. Nucleophilic Substitution Reactions

11. Elimination Reactions

12. Electrophilic Aromatic Substitution Reactions

13. Nucleophilic Addition and Substitution at Carbonyl Groups

14. Organic Oxidation and Reduction Reactions

15. Equilibrium Electrochemistry

16. Practical Electrochemistry

17. Occurrence and Extraction of Metals

18. Coordination Compounds

+ two practice tests

**7 References**

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