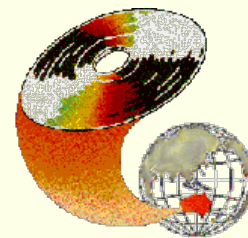# Hypermedia design for enriching conceptual understanding in chemistry

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Background

Hypermedia and Interactive Multimedia (IMM) are part of the lexicon of descriptive terms currently being used for Computer Aided Learning (CAL). In the literature, universally accepted meanings of these terms have yet to be agreed upon, however, most researchers in the field agree that hypermedia and IMM have the following general aspects in common.

1. The learning environment is computer driven but may be linked to other devices, such as video disc players and CD-ROM drives.

2. The software is able to provide the learner with access to text, audio, graphics, and video in an integrated, interactive learning package (Preece & Davies, 1992; Gayeski, 1992).

3. The learner navigates through the database created by the software by means of icons or other search strategies.

Some researchers (Dede, 1992; Thomas & Knezek, 1990) differentiate between hypermedia which, they claim, has the capacity to be accessed by the student in a highly individualised manner that enables the student to decide their own path through the informational matrix, whereas IMM does not. However, Reeves' (1992b) broader definition of IMM includes software that is "designed with linked nodes of information to allow users to access the information according to their unique needs and interests"(p. 47). For Reeves, therefore, hypermedia and IMM are synonymous. In this study, the definition that will be applied is that which focuses on hypermedia, in Reeve's broader sense of IMM, with the emphasis upon the "linked nodes" combined with the ability to access information according to a student's "unique needs and interests".

The vast educational potential of hypermedia is illustrated by the claims of John Sculley, in the foreword to a book titled *Interactive Multimedia* (Ambron & Hooper, 1988):

> Teachers and students will command a rich learning (multimedia) environment that, had you described it to me when I was in school, would have seemed entirely magical. Imagine a classroom with a window on all the world's knowledge. Imagine a teacher with the capability to bring to life any image, any sound, any event. Imagine a student with the power to visit any place on earth at any time in history. Imagine a screen that can display in vivid colour the inner workings of a cell, the births and deaths of stars, the clashes of armies, and the triumphs of art. And then imagine that you have access to all of this and more by exerting little more effort than simply asking that it appear. It seems like magic even today. Yet the ability to provide this kind of learning environment is within our grasp. (Sculley, 1988, p. vii)

However, is it really going to be that easy? David Clark (1992), in his paper *The future of interactivity: Is it really a hardware issue?,* argues that much of the currently available software is *technology driven* and avoids addressing the problem that teaching and learning are essentially human activities. He argues for innovative interactive programs that can make better use of teachers as the primary teaching resource by providing mechanisms for students to determine what constricts their comprehension and then making this information easily available to teachers. Innovative software design would enable students to identify areas of conceptual difficulty which then allows both students and teachers to focus more quickly and more

effectively on the problem.

Reeves (1992a) has criticised earlier CAL packages because the instructional design models employed in their design are based upon the *objectivist tradition,* or the view that knowledge exists in a perfect form as a separate entity, or truth, that has to be *absorbed* by the learner. The underlying epistemology of this pedagogical approach is based on the *behaviourist view,* whereby if knowledge is broken into small enough pieces, then learning will take place. Rather, Reeves (1992a, 1992b) sees the need for the design of hypermedia programs to be based upon sound pedagogical foundations of contemporary cognitive psychology, especially the *constructivist model.*

An examination of the literature and a review of CAL packages associated with the teaching of chemistry, including the current award winning programs from IBM (Kagan, 1992), provides evidence that the objectivist tradition has not succeeded in delivering hypermedia that lives up to its promise. Duffy and Jonassen (1991), Reeves (1992a) and Spiro, Feltovich, Jacobson, and Coulson (1991) argue for constructivism as an alternative epistemology for instructional design and evaluation. In particular, this study will be based on Resnick's (1989) constructivist principles of contemporary cognitive theory which she applies to the instructional design of hypermedia:

1. Hypermedia should be developed from the premise that learning involves knowledge construction rather than knowledge absorption.

2. The learner makes use of existing knowledge upon which he or she constructs new knowledge. Therefore, hypermedia should be based on the principle that learning depends on the learner's prior knowledge and experience.

3. Hypermedia designers should recognise that learning is highly tuned to the environment in which learning occurs and should design programs accordingly.

Non-computer multimedia technology, such as video, 35 mm slides, and overhead projectors, has been used for a considerable period of time in the teaching of chemistry in schools and universities. However, the use of CAL as a learning tool has been minimal. Although efforts in the past have been made to develop chemistry packages that utilise computer based multimedia in laboratory practice (Rasmussen, 1980) and *live* experiments and course work (Brooks, 1985), these packages have focused on relatively passive video technology, rather than on interactive microcomputers. One of the main educational problems of these chemistry packages is the inevitably linear, book like sequencing of the content. With a book, nevertheless, the individual learner is able to select chapters or pages as desired. However, many CAL packages lack this fundamental accessibility. Linear sequencing constrains access to the content of a program and limits its educational effectiveness by failing to cater to the range of learning needs of individual users.

This research and development study aims to overcome this pedagogical problem by designing a hypermedia program that provides non-linear sequencing of content. The aim of the program will be to enable individual students to gain access to the program appropriate to their specific learning needs.

Hypermedia and conceptual development

How can hypermedia be utilised to enable non-linear access and facilitate students' conceptual development in chemistry? Firstly, we consider the pedagogical problems associated with linear stack design of hypermedia programs.

The problem of linear stack designs

Fisher and Mandl (1990) argue that hypermedia programs come into existence only when the learner perceives and interprets them. The quality of interaction is determined by (1) the skills that learners bring to the situation, and (2) the degree to which the program has been designed to support the interaction. Therefore, the design criteria that support these assertions are very important. Dan Shaver (1991), one of the doyens of HyperCard scripting, in *The complete book of HyperTalk 2,* provides models for linear

HyperCard stack design which have been used widely by hypermedia designers. For example, the hypertree model (see Figure 1) is a commonly form of stack design that is linear in organisation.
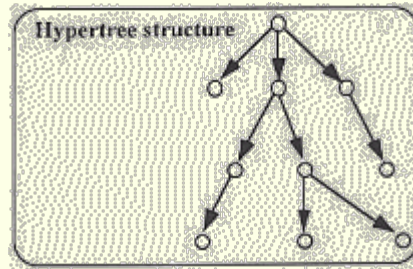

Figure 1: Hypertree structure
(Cortinovis, 1992, p. 49)

The hierarchical hypertree model (see Figure 2) is a development of the basic hypertree structure that reflects behaviourist pedagogy. That is, the designer reduces the content to a set of prescriptive pathways along which all students are routed regardless of their individual learning needs and interests. Although behaviourist pedagogies are regarded as outmoded by educational researchers, the hierarchical hypertree model is used widely in program design.

In their paper, *Creating interface metaphors for interactive multimedia,* Hedberg and Harper (1992) argue that the advent of sophisticated authoring packages combined with recent advances in personal microcomputer design has created a situation whom the educational computer packages developed in the recent past have outstripped the design models employed to produce them. As hypermedia becomes more complex, the problem of navigational demands placed upon the learner become more pressing (Perkins, 1991; Roselli, 1991). Questions that include, "where am I?", "where do I go next?", "where have I been?", and "is there anywhere else to go?", become additional *conceptual baggage* for the learner.
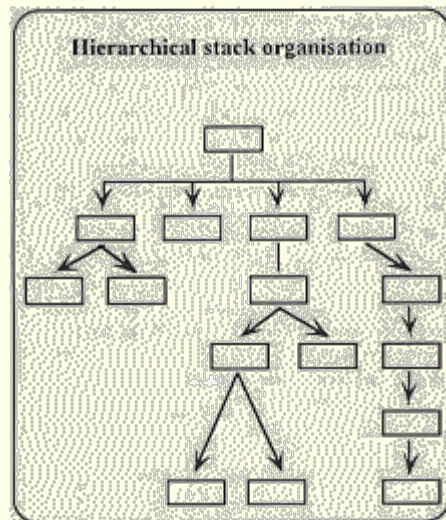

Figure 2: Hierarchal stack organisation
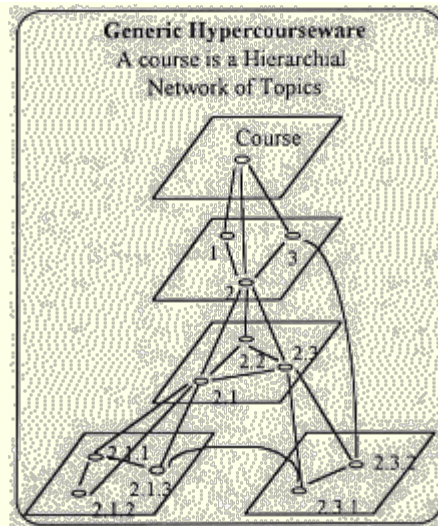(Shaver, 1991, p. 355)

Figure 3: Generic hypercourseware
(Siviter and Brown, 1992, p 167)

Siviter and Brown (1992) and Cortinovis (1992) recognise these problems and have attempted to overcome them by using a hypertree model of instructional design (see Figure 3) which reduces the conceptual and navigational problems by limiting the complexity of each node in the hypertree structure. This is achieved by creating mini hypermedias at each point, and a series of hierarchical topics (eg., 2, 2.1, 2.1.1) Nevertheless, the weakness of this design model is the set of prescriptive pathways along which all students must proceed. The model fails to address students' interests and individual learning needs. The solution to this problem lies in non-linear stack design.

The future: Non-linear stack design

Dede (1992) argues that the non-linear stack design of hypermedia has (1) an associative nature that more closely mirrors the structure of human long term memory, (2) facilitates the construction of students' mental models, and (3) has the potential to develop greater learner metacognition than does linear stack design. Hypermedia provides also a rich informational matrix that allows users to access information based on their individual needs ad interests (Reeves, 1992b). Although Shafer (1991) proposes a model for non-linear stack design (see Figure 4), this model has not addressed the problem of high cognitive complexity (Perkins, 1991) that such a design places on the learner.
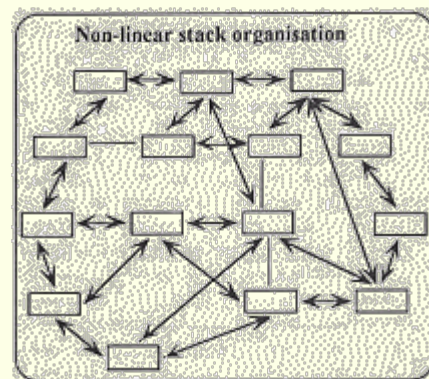

Figure 4: Non-linear stack organisation
(Shafer, 1991, p. 356)

In this study, a new model for hypermedia program design - the Hypermedia Concentric Conceptual (HCC) Model - has been developed. The model addresses the problems of hypermedia navigation by the use of an easily recognisable symbol - the circle. The model incorporates key principles of constructivist epistemology for enhancing students' conceptual understanding by recognising that: (1) knowledge is constructed by the

learner; (2) the learner uses existing knowledge to construct new knowledge; and (3) the learning is tuned to the environment in which it occurs (Resnick, 1989). The Hypermedia Concentric Conceptual (HCC) model is illustrated in Figure 5 with a number of possible navigational paths and conceptual levels outlined.
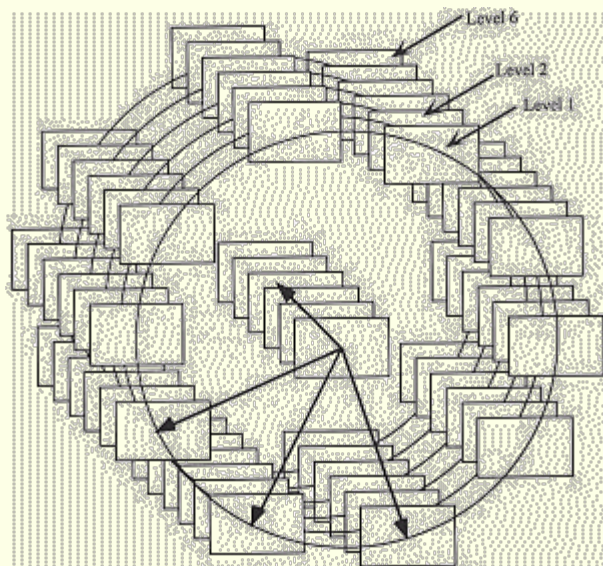

Figure 5: The hypermedia concentric conceptual model

The HCC model facilitates knowledge construction by incorporating students' *pre-instructional knowledge.* The first conceptual level of the informational matrix (Level 1) is designed from concept maps of the knowledge that students bring to the program. In this study, this information is being obtained directly from students during the formative design process (see research design section of the paper). The concept maps provide the basis for designing hypermedia links to subsequent conceptual levels (Levels 2-6) of the informational matrix. It is intended that students will construct their individual conceptual understandings as they navigate meaningfully from familiar starting points to other, more abstract conceptual levels in the program. Although six conceptual levels are indicated in Figure 5, the model is not restricted to this small number. The number of levels incorporated into the program will depend as much on the imagination of the designers as on practical constraints.

The program design addresses Reeves' (1992b) requirement for *situated learning* by providing a rich informational matrix that is relevant to the range of experiences of the individual learners. Situated learning occurs when the design of a hypermedia program provides the contexts and association that allow students to generate connections between conditions and actions to solve problems, enabling die transfer of skills to other situations (Reeves, 1992)

Students will be able to navigate through the HCC program by making use of built in strategies such m contextual clues, guided tours, or colour which identify a particular conceptual path, and written directions to related concepts or positional information within the screen format (Hedberg & Harper, 1992; Siviter & Brown). An example of possible navigational paths is shown in Figure 6.
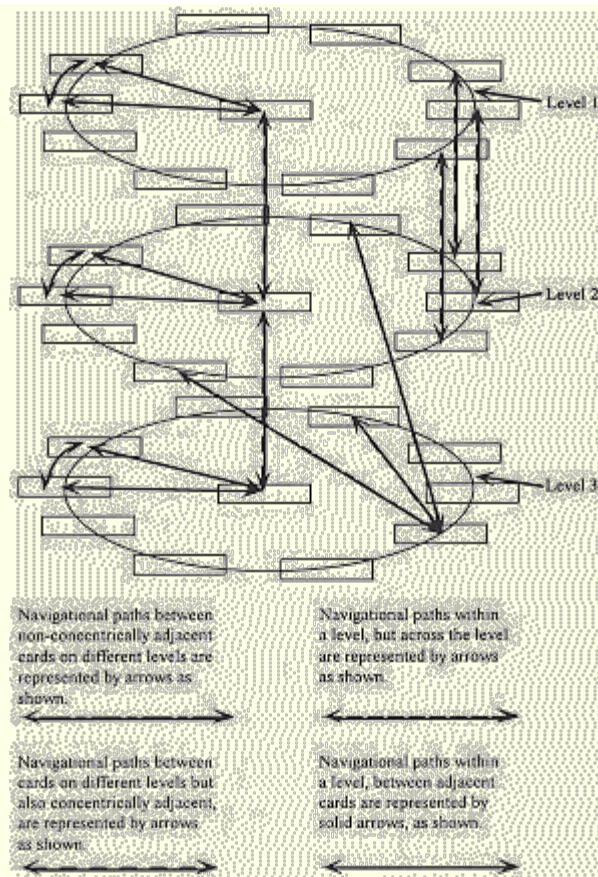
Navigational paths between non-concentrically adjacent cards on different levels are represented by arrows as shown.

Navigational paths within a level, but across the level are represented by arrows as shown.

Navigational paths between cards on different levels but also concentrically adjacent, are represented by arrows as shown.

Navigational paths within a level, between adjacent cards are represented by solid arrows, as shown.

Figure 6: The HCC model: Navigational paths

Purpose of the study

The main aim of this study is to develop, trial, and evaluate a hypermedia program based on very recent advances in computer software authoring systems, (ie, HyperCard, QuickTime and AddMotion). This software will facilitate the design of a program that enables access to information in a non-linear mode and that provides audio, video, graphics and text in a rich interactive informational matrix within a single microcomputer delivery platform. Although the HCC model can be applied in any field, for the purposes of this study it will be designed to significantly improve opportunities for learning important chemistry concepts amongst university aspiring secondary students who are studying university related chemistry courses in the senior years of secondary school.

The evaluation phase of the program will focus on students' attitudinal and conceptual development. Student criticisms of earlier CAL programs have indicated that the programs were repetitive, unexciting, and didn't relate closely to the course of study. This problem will be addressed by adopting a formative evaluation approach (Scriven, 1967) and, in response to the perceptions of the students, amending the program during the developmental phase. Students' conceptual development will be monitored by means of student interviews and a post-test of students' conceptual understandings of chemistry developed in conjunction with their use of the hypermedia program.

Research questions

The following research questions are guiding this research and development study.

1. What are the design factors of a user interface that enable students to interact effectively with hypermedia? The user interface is the manner in which the program is accessed by the learner and includes: (1) the procedure which enables the learner to navigate through the matrix of information; (2) the screen design; and (3) modes of interactivity available to the student (eg, opportunities to

copy, print, and add to, or personalise, the informational matrix, and to test concepts in simulations).

2. How can constructivist epistemology be incorporated into the instructional design process of hypermedia program development?

3. How does prior knowledge and experience with computers influence the manner in which a student interacts with the program and other students?

4. Does the program enable students to develop sound conceptual understandings of chemistry?

Research design

This study will develop, trial, and evaluate a single hypermedia program using an interpretive case study approach (Erickson, 1986; Merriam, 1988). Reeves (1992a) strongly recommends a "multifaceted approach to research, including the conducting of intensive case studies and the application of computer modelling" (p. 185). The study comprises two parts, namely, a developmental phase, in which the program is designed and formatively evaluated, and a trial and summative evaluation phase, in which the effectiveness of the program is assessed.

Developmental phase

The program focuses on the Western Australian Tertiary Entrance Examination Chemistry course, and uses the Periodic Table as the starting point for the development of important chemical concepts by upper secondary school students. It incorporates colour animation, colour video sequences, and sound and textual data, in order to enable students to obtain non-linear access.

The process of program development is being carried out using a formative evaluation strategy (Scriven, 1967) which involves the trial students. Formative evaluation strategies will include:

1. Concept mapping of students' prior conceptual understandings in chemistry.

2. Classroom trialling of the program, which includes classroom observation and interviews with selected students for feedback and future design directions.

Also incorporated within the program will be an invisible structure that monitors the students' use of the program, and provides data on (1) the duration of student examination of particular screens, (2) all requests that the student makes of the program (eg, print or save), and (3) the pathway that a student uses to access the informational matrix.

Trial and summative evaluation phase

The hypermedia program will be trialled in a local senior secondary high school which has a computer laboratory furnished with 20 Macintosh LC Computers and standard RGB monitors. The participants will comprise an intact class of Year 11 Tertiary Entrance Examination Chemistry students. It is intended that the program will be used in place of the conventional mode of instruction for a period of three weeks.

The summative evaluation phase will examine students' perceptions of their interaction with the program, and students' conceptual development in chemistry. Data collection will involve:

1. A post-test of students' chemistry conceptual understanding. The instrument (a standard written test) will be developed and trialled with a group of Year 11 students in another school.

2. Use of the Constructivist Learning Environment Survey (CLES) (Taylor & Fraser, 1991), to determine students' perceptions of the constructivist nature of the program.

3. Interviews with selected students to obtain perceptions of program *useability*.

4. Tracking software to monitor the manner in which the CAL program is accessed by individual students.

5. The researcher's participant-observer field notes of classroom use of the hypermedia program.

The interpretive data analysis will constitute a synthesis of quantitative and qualitative data. Analysis will be ongoing during data collection activities and will generate assertions to guide its focus.

Significance of the study

The world of hypermedia has reached a stage where its educational potential can be realised. The use of a single screen, video compression, and interactive non-linear learning modes can be combined to provide a powerful learning and teaching tool. The new technology offers the potential for the creation of learning environments that are more responsive and relevant to the learning needs of individual students (Darby, 1992). With skilful development of CAL programs, the teaching of chemistry can be enhanced to provide valuable experiences that were previously unavailable to students, such as particularly hazardous or difficult to perform experiments, the teaching of laboratory techniques, and important industrial manufacturing processes.

This study will provide significant contributions to understanding how interactive microcomputer environments can be utilised to improve conceptual understanding in chemistry, a subject which is central to university science related courses. The availability of high quality, user friendly CAL programs also is likely to accelerate the demand for further program development in alternative tertiary education modes, such as distance education, external studies, and service courses which are expanding in response to growing demands for tertiary science related education throughout Australia. In these times of decreasing budgets, hypermedia offers a cost effective manner to teach large groups of students (Gladwin, Margerison & Walker, 1992).

The HCC model can obviously be extended beyond conventional educational parameters, and even beyond educational parameters themselves. It would be as appropriate in a computerised store directory as it would be in an industry based training program.

Any expressions of interest in the development and/or application of the HCC model would be well received by the authors.

Related support and research grant

This research and development study has been supported by a grant from the Apple University Development Fund (AUDF) which has supplied a suitably modified Macintosh IIci and required software for the researcher to aid in program development. Additional technical and software support has been made available by the Curtin University Engineering Department and Image Technology in Technology Park and Curtin Computing Consortium.

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