

Science and Mathematics Education Centre

**The Development and Implementation of a
Multimedia Program that Uses Analogies in Senior
High School Chemistry to Enhance Student Learning
of Chemical Equilibrium**

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Doctor of Science Education of the Curtin University of Technology.

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CURTIN UNIVERSITY OF TECHNOLOGY
SCIENCE AND MATHEMATICS EDUCATION CENTRE
CANDIDATES STATEMENT

I certify that the thesis entitled “The Development and Implementation of a Multimedia Program that Uses Analogies in Senior High School Chemistry to Enhance Student Learning of Chemical Equilibrium” and submitted for the degree of Doctor of Science Education is the result of my own work, except where otherwise acknowledged, and that this Thesis (or any part of the same) has not been submitted for a higher degree to any other university or institution.

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Date _____

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This work would not have been possible without the support of my family who have sacrificed much in lost time and household maintenance. This thesis is dedicated to my wife, Cheryl, who would always listen to me, even if she didn't know what I was talking about. To my children, Mark, Scott and Elena go my thanks for putting up with the lost hours with a minimum of complaints and to my constant typing companion, Blossom the dog, perhaps there will be more time for walks now that this is completed.

Abstract

In this thesis, you will find a review the development process of a multimedia presentation designed to assist the teaching of chemical equilibrium using analogies. The objective of this thesis is to report on the process of designing animated analogies and the subsequent employment of these analogies in a teaching program for grades 11 and 12 students. This thesis describes a case study in the effective use of technology in the classroom based on established research in the field of analogical thinking. The work begins with a review of relevant literature from the fields of constructivism, collaborative learning and multimedia in education. The design phase of the research sought to discover if analogies for chemical equilibrium could be successfully transferred to a multimedia presentation on a computer. The subsequent testing of the software endeavoured to discover the most appropriate teaching strategies and if the use of such a program could enhance the learning process for students. The work resulted in a completed CDROM with full teaching program included which you will find attached to this thesis. The results indicate that the experience was a positive one and that there is some evidence to show increased ability in the students in their attempts to understand a conceptually difficult area of chemistry theory.

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List of Abbreviations

CDROM	Compact disk read only memory
CSCCL	Computer supported collaborative learning
CSCW	Computer supported cooperative work
CSILE	Computer supported intentional learning environments
GIF	Graphics image format
HTML	Hypertext Markup Language
IMM	Interactive multimedia
NSW	New South Wales

Preface

*Be not the first by whom the new are tried,
nor yet the last to lay the old aside
(Pope, Essay on Criticism, II, 335)*

To commence this thesis, I would like to introduce myself, the researcher, to the readers. I have been teaching science and computing for 22 years in NSW high schools and at TAFE colleges. My students have been mostly of high school age but at TAFE their ages have ranged from 17 to 70. Originally trained as a science teacher, my fascination for new technology led me to be an early adopter of microcomputers. I am currently network administrator at my school and, in addition to teaching a variety of classes, maintain over 120 computers. My interest in science teaching had been maintained through lively discussion with my colleagues but I realised that being out of touch with recent research severely limited our ideas on the best way to teach certain topics. I decided to embark on the Masters program at Curtin mainly through curiosity and a scholarly interest. It was actually an accidental reading of the course details in the newspaper that led me to Curtin. I am certainly indebted to the Federal government for making these courses available at little cost.

The beginning of the course opened my eyes to constructivist theory and the avalanche of research in the last two decades. Most of my teacher colleagues had little idea what I was talking about so I began to wonder about how much theory work is translated into the classroom. As I continued the course work component, I became more interested in the use of technology for teaching science. Participation in online discussion groups showed me the potential for the use of computers to enhance the learning process. The school offered me an upgrade to the Doctoral degree and although my time was heavily taxed already, I tentatively accepted the extra workload. The search for a thesis topic and study area was not too difficult. The lack of suitable software for teaching chemistry, and the price of existing software, was a constant source of frustration. I began to look for ways in which sound educational theory could be converted into valuable, cheap software. The field of analogical thinking continued to interest me and I could see an avenue to pursue.

This thesis is a history of how I developed software to assist in the teaching of some aspects of chemical equilibrium. The process was accompanied by an attempt to produce a teaching program to compliment the software and make it as

effective as possible. The end result is a complete package on CDROM which accompanies this thesis.

Geoff O'Brien

CHAPTER 1

Introduction

Overview

The study presented in this thesis focuses on the viability of producing analogies that utilize multimedia software on a computer as the transmission platform. Previous studies on the effective use of analogies in science teaching have been concerned with more traditional forms of analogies such as verbal, textual and pictorial forms or some combination of these. I have been unable to find examples in the literature of analogies produced as software for use with a computer. The literature review, found in chapters 2-5, presents research findings from diverse fields that are considered relevant to this study. The areas of interest involve constructivist theory, collaborative learning, the use of technology in learning, multimedia design, use of analogies in teaching, and the teaching of equilibrium theory. The results section provides an accurate description of the design and implementation phase of the project with a number of test groups. The reader will read of a development process that occurred in response to feedback from the target groups and a gradual change in the methods employed. As there were no precedents to this specific study, the research program became a journey of discovery for both myself, as teacher/researcher and my students.

The first chapter describes the research problem and summarises the rationale and methodology. The second chapter looks at the use of multimedia in education and the types of programs that have been introduced in the last decade. The third and fourth chapters look at current theories of learning in science and their relationship to the employment of multimedia design in education. In particular, theories of situated cognition, cognitive flexibility and collaboration using computers are highlighted as important principles to be pursued. The fifth chapter deals with theory surrounding the use of analogies and some of the practical applications that have been documented. A summary of research on the teaching of chemical equilibrium precedes a description of the methodology used. The documentation of the case itself occurs in chapter seven, which describes the development of the software followed by its implementation and evaluation in the classroom. Chapter eight concludes the thesis with discussion about the study and its relevance to previous findings. Final

comments attend to the limitations of the study and some suggestions for further research.

Introduction to the research

My experiences in 20 years of teaching have left me rather dissatisfied with the effectiveness of my teaching on the performance of average and below average achieving students in their attempts to learn chemistry. In my experience, their struggles to understand abstract and complex ideas have long been a source of frustration on both sides. Students were unable to learn certain concepts and the strategies that I had been using were not working very well. I had used analogies often when I had no other resources available and when students clearly appeared to be struggling. The students seemed to like many of the analogies but I had thought they were either not particularly useful or that they had little impact on overall understanding. The power of the analogy in linking the familiar with the unfamiliar is, in my mind, an attractive tool for introducing concepts. The use of computers and multimedia technology has become an equally attractive tool and I believe using multimedia to present analogies is a fruitful direction for research in chemistry teaching.

The research problem and research questions

The project undertaken was designed to produce a practical synthesis of research from a number of perspectives in science education. The theories under scrutiny look at multimedia use, analogical thinking, constructivism and collaborative learning. There is an extensive body of research to draw upon. The task is to solve a practical problem, i.e., teaching aspects of the chemistry course more effectively, while integrating elements of best practice from existing research. Three specific research questions provide a summary of the problem that is being posed.

1. Can multimedia analogies be developed to improve the way that aspects of chemical equilibrium are taught?
2. What specific teaching strategies need to be developed to accompany the software that most effectively challenge and stimulate student thinking in the classroom?

3. How effective are the software and teaching strategies in enhancing learning about chemical equilibrium in senior chemistry?

The reason to pursue these novel ideas stems from an underlying belief that a situation will improve as a result of its implementation. Firstly, I am interested to know if it is possible to successfully transfer analogies to a multimedia platform. Producing a finished product satisfying all design criteria would be the first step. Some measure of success would be a ready acceptance by the students and a positive response to the learning experience. A key research question asks ‘will it make a difference?’ With this program, I am hoping to foster the collaborative process and stimulate discussion at a metacognitive level about the nature of learning in chemistry. It is my aim to determine whether or not students think they understand why we use analogies in learning and appreciate the role that analogies can play in the development of intrinsic knowledge. The following background information outlines the process by which I have arrived at these questions and some of the reasons for the research program.

Background to the research

The use of analogies in the senior chemistry classes that I have taught has been a fairly traditional one. Often the first use is that of a verbal analogy, trying to create a mental picture that has some relevance for the student. An example is chemical bonding where a couple exchange wedding rings (electrons) and then walk off hand in hand, bonded together. If the analogy were more suited to a picture, I would draw something on the board to illustrate the idea or use one of the pictorial analogies in the textbook. In addition, scattered throughout the text are a sprinkling of written analogies that could be used. In some cases, I asked students to act out analogies. An example is tossing plastic balls to each other to simulate a bond. I did not really know whether any of this was working and had no way of measuring the effectiveness or otherwise. Until I began studying for a further degree, I was unaware of any theoretical or practical research into the use of analogies and any conclusions based on this work. I believe we develop our own styles of teaching based on our perceptions of effectiveness with a certain group at a certain time. We are not often consciously aware of the value of a microteaching technique, such as the use of analogies, to the overall education of the individual.

The introduction of computer technology into the classroom has become an imperative of the government in NSW and the task has fallen upon teachers to find effective use of the tool. Initially, looking at chemistry, the prospect of new programs with innovative graphics and large amounts of data seemed an exciting idea. I could see great potential in having interactive, searchable databases on the Periodic Table, the modeling of chemical reactions with 3D graphics, simulations of chemical reactions through videodiscs and animations. The power of visualization is an attractive feature of multimedia productions and one that can be exploited to improve the understanding of students. I looked forward to being flooded with software from companies keen to move into the area. The result to date has been a little disappointing. Many programs proved to be little more than textbooks translated into CD-ROM format with a few animations added. Some simulation programs proved difficult to manipulate or were a poor imitation of an established laboratory experiment. Some of the software, however, was very good and worth using. The problem was the availability of computers and the generally high cost of purchasing site licenses.

In an attempt to improve the use of analogies in the classroom, I decided to attempt production of analogies in multimedia format with animations, sounds, video and hyperlinks that would have a far greater effect than any casual use of analogies without previous preparation. I decided that it would not be good enough to just produce some simple animations and leave it to the teacher to use them in any way they thought fit. I wanted to integrate theoretical underpinnings of the effective use of analogies in a collaborative setting. It was important to choose a section of the chemistry course that provided sufficient challenge to the learner to make it a valuable exercise. It also had to be an area that would translate well into a series of analogies in multimedia format. Chemical equilibrium fitted the criteria well in my opinion and changes to a system at equilibrium became the specific focus area.

Rationale

This project is an example of curriculum development through action research. The learning activities would be designed to address a perceived learning problem in the domain-specific area of chemical equilibrium. The research procedure involves cycles of planning, implementation, and evaluation of teaching activities to ensure effective student learning (Driver & Scott, 1996). The research program

would include constructivist principles to ensure maximum student engagement in the learning process (see Chapter 3). The project is designed to investigate and evaluate the suitability of a specifically designed computer program as a teaching method in chemistry.

The problem was reduced to a rather specific set of needs. The software that would be produced provides visualizations of analogies based on changes to equilibrium systems. In particular, the focus would look at Le Châtelier's principle and how students might better predict the response of a system at equilibrium to changes imposed on that system. The software would need to engage the students and encourage collaboration and discussion of the ideas involved. The program also would have to provide analogies that would be useful to a broad cross-section of students and be sensitive to any ethical issues regarding race or religious beliefs. To assist the teaching process, ideas of a teaching sequence and scaffolded worksheets also would need to be produced. It was also important that the design of the software was firmly grounded in existing research. As will be seen in the literature review chapters, there is a wealth of research conducted in the last three decades to provide a sound basis for new programs in the classroom.

Methodology

The methods used in the development and testing are the subject of a later chapter (see Chapter 6). The research takes the form of a case study, which looks at the overall process from formation of initial ideas, through the development process, implementation in the classroom, evaluation and program refinement. Careful documentation of interactions with students will provide much of the data to assist in this process.

Significance of the study

This is a practical application of previous research on teaching with analogies. Both theoretical and classroom studies have pointed to methods of effective use of analogies in teaching. This project is an attempt to provide teachers with a model for this research work based on best practice. The work is also an attempt to use new technology in the classroom for the benefit of the learning situation. If successful, this program can become a basis for a new micro-teaching methodology in which teachers can learn about fostering collaboration through the

novel use of technology. Teachers have been provided with sophisticated computing equipment in recent years and the use of this equipment is constrained by the need for suitable applications. It is important that we progress in our use of technology as we explore novel methods of teaching. A failure to make good use of new technology would be a waste of a potentially valuable teaching tool.

Limitations

The nature of the analogies used is a principal limiting factor in the effectiveness of the lessons. There is no guarantee that all students will accept or relate to the analogies in the program. It would be a very difficult task indeed to produce universal analogies that are applicable in all situations. If students are to intelligently discuss the analogies presented then they will first need a basic understanding of the context of the analogy. There may well be cultural and environmental factors that impede this understanding. The technology itself is a limiting factor. The availability of quality hardware and software to run the program is still a question mark in some schools. The software that I have used to produce the graphics and animations limits their quality and effectiveness. In addition, my ability to actually author the software is a limiting factor.

A further problem is the way that other teachers may administer the program. The group dynamics in each class are different and this program relies on a collaborative approach both within the groups of students and between the teacher and students. The discussion of the nature of an analogy will not work if the group is not cooperative. In my own classes, I hope to be able to encourage the sort of rapport needed to benefit from collaboration but there are no certainties in teaching. As author and researcher, with a vested interest, there can be no guarantee of impartiality, although the research methods that I have designed to ensure that all data are recorded and reported with equal weight and attention given to the notion of triangulation, which is described in a later chapter, should compensate for perceived bias. Another limitation is the change in the syllabus that occurred within the timeframe of the research. This was an unforeseen complication that required a change in emphasis in the teaching program and limited the effectiveness of the content of the CDROM. This is discussed in detail in Chapter 7 and Chapter 8.

Summary

This brief introduction has provided a framework for the structure of this thesis. It has provided an overview of the research program and its theoretical basis. The research questions have been presented in context and the background to the research has shown how the rationale was developed. The significance of the study and a brief discussion of its limitations round off the chapter and provide some direction for the thesis. The next chapter looks at the use of multimedia in education and some key design principles for producing effective software programs for use in teaching.

Chapter 2

Multimedia in Education

Introduction

Multimedia is a tool of the nineties. With the expansion of computer power and ready access to multimedia in schools, there has been a ready acceptance of the technology by students. However, my experience in schools has shown me that teachers have not been so swift to adopt the use of computers in their everyday work. It will take time before computers become commonplace tools used regularly to aid the delivery of learning materials. The adoption of this type of technology is dependent on the availability of multimedia computers and the software that complements them. As the development of computing technology into schools is a relatively recent phenomenon (after 1995), much of the existing research into their use depends on data collected on older systems that may not translate readily to current computer use. It is my intention to present a summary of the research on the development and effectiveness of the use of multimedia in education. This chapter addresses some of the important aspects from the first research question about the design and development of multimedia tools in teaching. I have limited the scope of the chapter to those works that refer to constructivist principles and in particular how learning theories have influenced the use and design of multimedia in the classroom. Some of the earlier studies may not be specifically applicable to the modern world but I believe there is merit in their findings and should be incorporated here.

The development of multimedia tools

Firstly, a working definition of common terms is necessary. Gayeski (1993) defines multimedia as

a class of computer-driven interactive communications systems which create, store, transmit, and receive textual, graphic and auditory networks of information. (p. 4)

According to Wiburg (1995), there are further definitions for two important subsets of multimedia

hypertext, which is software consisting of networks of related fields that can be accessed randomly by icons or search strategies, and *hypermedia*, which adds video clips, graphics, or audio files to hypertext. (pp. 59 - 60)

In looking at the principles behind the design, we find that the first multimedia instructional designers worked from a traditional behaviourist approach (Wiburg, 1995). Using the theories of such psychologists as B.F. Skinner

these designers believed that if knowledge was broken into its appropriate parts and presented sequentially, and if reinforcement for correct responses was provided all students would learn from the properly designed material. (p. 60)

Of course this is a simplistic approach and ignores much of the recent work on constructivist theory and multiple learning styles, but it was a logical, if tentative, approach into an unknown area. Constructing a sequential, rewarding program that stimulates the users is probably a valuable tool. However, one of the real virtues of multimedia and hypermedia is lost in this approach, namely the ability for students to explore and construct their own reality and understanding from the stimulus material that takes individualised instruction to a new level.

As Wiburg (1995) points out,

Motivation increases when students have opportunities to work cooperatively, have some choice in their pathways through an activity, and find the user-interface design easy to follow. The best programs provide choices for teachers and students, including options for navigating through the information. (p. 60)

Those choices would include the ability of students to either browse everything or use an efficient search strategy for specific information. Simply presenting information using hypertext and/or hypermedia is not, in itself, a guarantee of positive learning outcomes. According to Wiburg's literature review (1995), students will learn the most if they are provided with navigation tools such as hypermaps and specific search strategies to locate the required information. Students are also said to be more effective learners when they can create their own connections between the files provided. The software must have a clear pattern of organisation to enable them to do this.

A further factor to be considered is how individual learning styles are catered for when using hypertext. Some people operate well in a linear, convergent environment and the freedom of choice in using hypermedia may adversely affect their progress. A divergent thinker, on the other hand, may benefit greatly from the ability to construct his/her own learning path. Much of the early multimedia

programs involved interactive video discs which used a common characteristic known as *anchored instruction* (Bransford, et al. 1990). The model developed for anchored instruction is designed to help students develop useful knowledge rather than inert knowledge. At the heart of the model is an emphasis on the importance of creating an anchor or focus that generates interest and enables students to identify and define problems and to pay attention to their own perception and comprehension of these problems. In this way, students can be introduced to information that is relevant to their anchored perceptions. The major goal of anchored instruction is to enable students to notice critical features of problem situations and to experience the changes in their perception and understanding of the anchor as they view the situation from new points of view. Bransford and his coworkers (Bransford et al. 1990) believe that video-based anchors provide a distinct advantage over other forms. The information on video is a much richer source than print media and provides dynamic, moving events that facilitate comprehension.

Computer-controlled video systems allow access at the speed relevant to each student. Random links between data can make the learning experience non-linear and more meaningful to the individual. It is important to consider how students interact with the software. Research has established that students come to the learning situation with alternative conceptions in science that are tenacious and difficult to modify. Conventional instruction methods often fail completely to alter these conceptions. (Duit & Treagust, 1998, p. 5)

The employment of constructivist principles in software design may be a rich field for development (Schwier, 1995). The idea that a program needs to consider the perceptions and previous experiences of the students, including culturally shared perceptions, provides a new level of difficulty and challenge for the designer. Learners are most likely to use multimedia programs if the information presented is relevant to their goals and experiences. To this end, multimedia programs may evolve as some sort of resource database in which students are either free to create new information or are guided to produce valuable conclusions. It could well be that the systems could evolve that can guide the student along the path from fully structured information to unstructured exploration.

From an educational point of view, programs should be a challenge to the user and present novel, rich problems that involve a synthesis of current information and a move towards a more sophisticated understanding. Much of the existing

software relies too heavily on presenting information in small chunks followed by positive feedback and the next logical (to the author) section. In one research project involving high school physics students, it was observed that the students' interaction with the program was often superficial. The students were observed to flick from screen to screen prematurely and they did not engage deeply in thinking about the problems being presented (Yeo et al. 1998). (In six years of teaching computer studies, I have also experienced the problem of students being off task when using the Internet as a research tool. This would appear to be a common problem in all subjects). It certainly presents a challenge to educational designers to be able to focus and harness student curiosity to produce a positive outcome for all parties. Multimedia and hypermedia can present their own distractions. If the graphics or video presentations are too complex or overly stimulating then the focus of the material being presented may be lost. There is often a tendency to provide "infotainment" and to try to keep pace with the commercial media who use sophisticated computers and large teams of software engineers (Squires, 1996). It is hard to predict the future of this area but it is a wise move not to underestimate the importance of its contribution.

Madian (1995) provides a good summary of some current issues with multimedia production and design. He argues that multimedia programs are not the replacement for most sections of the curriculum; they cannot involve all the senses and do not allow for many important manual tasks. He argues that teachers should be a little more critical in adopting the technology. Are students actually doing something to enhance their thinking and general skills or are they simply learning more computer skills? When students design their own multimedia, is the emphasis on how it looks or what it does? The multimedia format can actually discourage students from thinking deeply about content. It may be that the students become so obsessed with their presentation that the facts might get in the way. Madian presents a common argument about the perceived desocialising influences of computer programs. If children are interacting with machines for long periods of time then they are not being given an opportunity to interact with society. Multimedia programs should be enriching experiences but not at the expense of cultural and social development.

If we use multimedia as a development tool then it is suggested that some hard questions need to be asked of the designers.

Where in multimedia is the thinking - the prewriting research, the formulating and exploring, the composing and revising? As in teaching writing, the success of multimedia productions requires developing a sense of quality in the student-creator through discussion, comparison, modelling, a passion to communicate ideas that matter, and good peer feedback. (Madian, 1995, p. 18)

Madian argues further that there are a whole range of strategies already in place in schools to develop student collaboration and thinking. Students develop ideas through talking, writing, music, drama, art, sculpture, debate and other strategies. Why use multimedia if it is not appropriate or as good as the current tools? We should be extending all the senses and not narrowing the focus within the limits of a computer program. While there is some aspect of the Luddite thinking in this approach, there is value in the words: 'All things in moderation' that provides a code for good living and is equally applicable to education. The development of technology is accelerating and we need to use the positive aspects of this technology to improve our work as educators. A cautionary note along the way is necessary to focus the debate but a solidly-based educational program is the goal for all. If multimedia can deliver a focussed, beneficial program, then it should be developed.

The use of hypermedia as a means of communication of ideas

As computer software evolved from text-based information processors to a graphical-user interface, designers saw the opportunity to create embedded links in their programs. The mouse was used as a navigational device that allowed users some freedom to jump around the program and explore with more freedom of choice. The use of hypertext was pioneered by Apple computers with their hypercard program that allowed a series of screens to be linked and related to each other using a simple scripting language built into the program. This approach was adopted by other computer platforms and eventually became the basis for communication over the Internet using Hypertext Markup Language (HTML) (World Wide Web Consortium, 2001). Using links built into pages, the authors could either dictate the direction they wanted users to follow or provide a range of choices with more user freedom. In its simplest form, it is used to link related screens, i.e., page 1 followed by page 2. In its most complex form, it allows multiple linkages with a high degree of choice given to

the user, e.g., a diagram of the digestive system with links giving in-depth information about each part and further links to Internet databases and contacts with scientists. HTML has been adopted by the public as the standard for transmitting information over the Internet as it provides easy navigation and appears intuitive to most users. In the classroom, I helped introduce many students to the Internet and found little instruction was necessary to produce proficient users of the interface. Some important questions need to be asked about the use of hypertext and why it evolved as the de facto standard in communication. What is it about hypertext that appeals to designers and users alike? Is there evidence to show that it is an effective tool for learning?

Dede and Palumbo (1991) proposed that there were some intuitive reasons for excitement about hypermedia. Original computer databases were no more than electronic card systems. Spoken and written speech, photographs and movies, like the databases, represent linear transmission of ideas, a sequence fixed by the author. Human long-term memory, they argue, is not similar to a database, but rather it is an elaborate web of associations where the brain builds patterns to suit the situation. The inherent flexibility of the brain is a key to generating ideas and effective communication. Our mental models have much richer associations than any formal hierarchical system set up by a programmer. Hypermedia provides a chance to depict some of this complexity, giving it an instant appeal to designers looking to mirror the functions of the brain. If they remove the effort required by the user to translate the information and provide their own associations, then the cognitive load should be reduced and the learners can focus solely on the subject under consideration. Less internal preprocessing should be a real help to the learner.

Dede and Palumbo make the point that problem solving often involves reducing a large problem to a series of smaller, less complex sub-problems that can be more easily mastered. These sub-problems are then linked to other parts of the problem to provide generalisations that may be useful in solving the original question. Hypermedia can provide links to these smaller sub-problems and provide a framework within which the larger problem can be more easily tackled. This represents a lessening of cognitive load that should enhance the ability of users to assimilate and manipulate ideas. Hypermedia gives us a tool to represent and navigate through complexity. The authors make an important point about the design of such programs. Hypermedia interfaces should provide a consistency in structure

for all users who require that the same commands apply across different programs such as common keys being used for basic functions. An example is the Integrated Office suite from Microsoft that has many common tools across a variety of programs. For hypermedia, it would mean that all links are activated in the same manner. It is important that cognitive load in the operation of the software be minimised so that full attention can be given to the problem under consideration. This can be achieved by consistency in design of the primary navigation tools. If all the sources of data are accessed through the one interface then the process will be greatly simplified. (Schwier & Misanchuk, 1993)

Dede and Palumbo (1991) define knowledge as integrated information that can be used to achieve a goal. The development of information systems on computers uses hypermedia to represent complex knowledge architectures. They propose that the key to knowledge building involves using interrelationships to transform information into knowledge and hypermedia gives us the platform to allow this to happen. Hypermedia may also make knowledge easier to communicate as well as represent. In the fields of computer-supported cooperative work (CSCW) and learning (CSCL), hypermedia is often chosen as the representational media. When people work and learn together in small groups or as a larger group connected remotely to the same network, they engage in sharing of mental models and group decision-making processes. The ability of hypermedia to associate ideas and provide links in these situations serves to reduce the cognitive load and can shift the emphasis to the collaborative process. Hypermedia environments also provide flexibility for the user in knowledge creation. The developer creates a web of information for navigation by the user. If new knowledge is formed in this process, the whole web does not have to be rewritten to accommodate it. Only new links have to be added to build a bigger picture. This parallels human memory associations, in that we build our knowledge base from prior experiences and do not continually have to reconstruct schema to explain new knowledge.

While there are several reasons to be optimistic about the use of hypermedia, it has to be remembered that any constructed tool has its limitations. Hypermedia does have comparable aspects to human memory but it is a much simpler system. The hypermedia system is a way of presenting data but it usually does not make an attempt to turn that data into useful information. The user is not required to become actively engaged in interpretation and learning. There is also often no requirement

that information needs to be synthesised to provide an answer to a specific query. Simple answers are usually provided with a click of the mouse. There are also problems related to the designer of the programs. Links have to be provided by the author and therefore rely heavily on the interpretation of the author. Links that may be intuitively obvious to one user may be confusing to another. Often there is no specification as to the nature of the relationship between sections of the program and no rationale for its existence in the first place. In contrast, human memory is highly associative and reflective on the types of relationships it creates. Human memory can also function using incomplete inputs and interpret structures successfully in this circumstance. Hypermedia can be made to parallel memory processes but does not approach the processing capability of the brain and its ability to process information. Dede and Palumbo make the conclusion that presenting information on a computer screen is an inadequate pedagogical method, as it does not fully address the problem of knowledge transfer or knowledge construction in the individual. They suggest that knowledge-systems, where the users interact to construct new knowledge and build their own learning environments, are a fruitful direction to pursue with this type of media.

The value of instructional multimedia systems

The ideas of Dede and Palumbo are echoed by Romiszowski (1992) who looked at some of the issues in the development of successful interactive multimedia (IMM). In considering the value of any piece of courseware, he takes the constructivist view that the best program is related to the depth of internal processing required by the learner and the quality of thinking demanded of the learner. The reality of hypertext is that no author can predict the level of association of all the users and a better method of design is to concentrate on offering the learner the opportunity to engage in the work at a demanding level. He would like to see both learner and teacher engaged in deep-level conversational dialogues, both actively participating in sense-making. He claims that most multimedia is very much surface-level processing requiring simple responses. There are fundamentally two different sorts of IMM – those providing instruction and those for information dissemination. Instructional IMM systems involve the teacher, who presents the information, evaluates the learning and then attempts to improve the learning outcomes. This teacher can be part of the system, an electronic tutor, or a person or a combination of

both. Information dissemination IMM systems are content driven and rely heavily on good presentation and design to allow learners to extract the information. There is no evaluation mechanism built in or means to take remedial action to improve learning. In education, Romiszowski argues, most IMM products are information dissemination tools, whereas in the training area, most products are instructional in nature. They are designed to teach a skill, evaluate the learning and provide feedback. This balance should be changed in schools to provide better quality learning experiences with IMM.

In addition, Romiszowski notes that even in specific training courseware, the level of response required is quite shallow, often restricted to selecting items from a menu, and fails to encourage deeper thinking. He makes the following observation:

There may be whole areas of human thinking that are not only dependent on the analysis, organization and manipulation of knowledge but are also highly dependent on personality and emotional traits that may well be beyond the capabilities of replication within computer software. (p. 66)

Perhaps the field of artificial intelligence may eventually be able to incorporate the complete role of the teacher but software to date has not been designed with this level of sophistication. The emotional element in teaching should not be ignored in instructional systems. The role of the teacher is vital in providing some impetus for learning. If the student is not motivated to learn in the beginning, it doesn't matter how good the courseware is designed. Romiszowski cites a model for instructional design, first described by Keller (1983), that involves four stages – Attention, Relevance, Confidence and Success. The students' attention can be gained by stimulating media and passionate presentations. The students must then see the direct relevance to their study pattern and be given confidence that they can succeed. When they do succeed, students need appropriate positive feedback to ensure continued learning. IMM can certainly provide the stimulus and designers should consider putting an exciting presentation at the beginning of their program. In addition, methods of self-evaluation to build confidence and a feeling of success should also be incorporated.

Design principles for multimedia software

Park and Hannafin (1993) adopted a different approach to multimedia design based on existing research in psychology and pedagogy. They developed a total of

20 principles and implications for the design process. Their table is reproduced faithfully here as it provides an excellent example of how learning theory (up to 1993) can be linked directly to design implications for IMM.

Table 2.1: Design principles for IMM (from Park & Hannafin, 1993, pp. 68-69)

Principle	Implication
1. Related prior knowledge is the single most powerful influence in mediating subsequent learning.	Layer information to accommodate multiple levels of complexity and accommodate differences in related prior knowledge.
2. New knowledge becomes increasingly meaningful when integrated with existing knowledge.	Embed structural aids to facilitate selection, organization, and integration; embed activities that prompt learners to generate their own unique meaning.
3. Learning is influenced by the supplied organization of concepts to be learned.	Organize lesson segments into internally consistent idea units.
4. Knowledge to be learned needs to be organized in ways that reflect differences in learner familiarity with lesson content, the nature of the learning task, and assumptions about the structure of knowledge.	Linkages between and among nodes need to reflect the diverse ways in which the system will be used.
5. Knowledge utility improves as processing and understanding deepen.	Provide opportunities to reflect critically on learning and to elaborate knowledge; encourage learners to articulate strategies prior to, during, and subsequent to interacting with the environment.
6. Knowledge is best integrated when unfamiliar concepts can be related to familiar concepts.	Use familiar metaphors both in conveying lesson content and designing the system interface.
7. Learning improves as the number of complementary stimuli used to represent learning content increases.	Present information using multiple, complementary symbols, formats, and perspectives.
8. Learning improves as the amount of invested mental effort increases.	Embed activities that increase the perceived demand characteristics of both the media and learning activities.
9. Learning improves as competition for similar cognitive resources decreases and declines as competition for the same resources increases.	Structure presentations and interactions to complement cognitive processes and reduce the complexity of the processing task.
10. Transfer improves when knowledge is situated in authentic contexts.	Anchor knowledge in realistic contexts and settings.
11. Knowledge flexibility increases as the number of perspectives on a given topic increases and the conditional nature of knowledge is understood.	Provide methods that help learners acquire knowledge from multiple perspectives and cross-reference knowledge in multiple ways.

Table 2.1 (cont.): Design principles for IMM (from Park & Hannafin, 1993, pp. 68-69)

12. Knowledge of details improves as instructional activities are more explicit, while understanding improves as the activities are more integrative.	Differentiate orienting activities for forthcoming information based upon desired learning; provide organizing activities for information already reviewed.
13. Feedback increases the likelihood of learning response-relevant lesson content, and decreases the likelihood of learning response-irrelevant lesson content.	Provide opportunities to respond and receive response-differentiated feedback where critical information is involved, but avoid excessive response focusing when incidental learning is expected.
14. Shifts in attention improve the learning of related concepts.	Differentiate key terms, concepts, and principles through cosmetic amplification, repetition, and recasting.
15. Learners become confused and disoriented when procedures are complex, insufficient, or inconsistent.	Provide clearly defined procedures for navigating within the system and accessing on-line support.
16. Visual representation of lesson content and structure improve the learner's awareness of both the conceptual relationships and procedural requirements of a learning system.	Provide concept maps to indicate the interrelationships among concepts, and hypermaps to indicate the location of the learner relative to other lesson segments.
17. Individuals vary widely in their need for guidance.	Provide tactical, instructional, and procedural assistance.
18. Learning systems are most efficient when they adapt to relevant individual differences.	Interactive multimedia must adapt dynamically to both learner and content characteristics.
19. Metacognitive demands are greater for loosely structured learning environments than for a highly structured one.	Provide prompts and self-check activities to aid the learner in monitoring comprehension and adapting individual learning strategies.
20. Learning is facilitated when system features are functionally self-evident, logically organized, easily accessible, and readily deployed.	Employ screen design and procedural conventions that require minimal cognitive resources, are familiar or can be readily understood, and are consonant with learning requirements.

This set of principles provides a design platform that can be employed to guide the program developer to produce software based on established research findings.

Squires (1996) explores the implications for design of educational IMM from a constructivist view of learning. He points out that constructivism is not a single well-defined theory of learning, but rather:

a framework of ideas and theories which all share the same basic premise that people learn through a process of building and adapting concepts through personal experience. (p. 1)

Learning experiences need to be active, developed in authentic contexts and relevant to the social context in which learning occurs. The collaborative process is central, as it allows learners to share and test ideas amongst their peers. For the tasks to be authentic, they should promote ownership by the learners with the implication that IMM software should promote a high degree of learner control both in program function and in choice of activity. Squires also suggests that project-based activities should be promoted through the software to encourage a diverse range of tasks requiring higher-order thinking skills. In addition, IMM software is ideally suited to providing the user with multiple perspectives. If learners are experiencing difficulty in following the program as set out by the designers, then they should have alternate representations or pathways to explore the concepts in ways that better suit their abilities and perspectives. Learners should have the chance to develop their own ideas and experiment with their learning. IMM is a rich environment and it is ideally suited to providing both rich and complex environments. Squires argues that simplistic, contrived learning situations that are tailored to prescribed learning outcomes do not challenge the learners to explore and experiment. Realistic tasks are inherently complex and this should be reflected in the design of software.

The effectiveness of multimedia use in the classroom

There are three traps that designers of IMM need to avoid. The first of these is the 'superficial complexity trap' (Squires, 1996). IMM is often superficially complex as a collage of text, graphics, video and sound. It might look impressive but if it doesn't provide intentional links between content and the choice of media then it does not have a sound educational focus. It is important to include a variety of learning functions throughout the program that include opportunities for reflection, expression and observation distributed between appropriate media forms. The media form should be chosen on its ability to best convey a particular learning situation. An example is the use of video, which is a good choice for conveying a teacher's ideas. It is, however, a poor substitute for the teacher in person and it does not give the students the chance to interact and express their own ideas. To avoid the superficial complexity trap, designers need to be mindful of the educational needs of their target audience and employ media that fulfill those needs. Too much complexity can serve as a distraction and unwittingly increase the cognitive load of the learner.

Squires' (1996) second design obstacle is called the 'passivity trap'. The danger here is that learners are conceived as passive recipients of the multimedia collage. Multimedia can be in danger of mimicking television and this is the antithesis of constructivist learning where an active role in sense-making is required. There are three ways in which the passivity trap can be avoided. One can use the practice of 'omission design' to deliberately leave out parts of the multimedia environment. Learners can be induced to complete the missing sections by interacting with background information in the program. A second approach is to involve the learners as multimedia authors. Using a storyboard approach and having the learners guide the construction process drives an active participation by the learners. A third approach is to encourage collaboration among students and teachers. The use of educational IMM in the classroom usually occurs in a social setting where interactions, both on-task and off-task are continually occurring. If the IMM encourages discussion and argument then the passivity trap can be avoided.

The 'fantasy trap' is Squires' (1996) third design problem for IMM. Modern computers can produce realistic worlds through virtual reality but it is not possible for designers to mimic the complexity required to replace our view of the world. Real environments are inherently complex and by narrowing the view we produce an impoverished environment that may be detrimental to the learning process. To avoid the fantasy trap, the setting must be sufficiently complex to allow authentic learning experiences and it must match the real world in a number of aspects to allow the learners the opportunity to transfer their experience to real-world examples.

All three of these traps need to be considered by designers of educational IMM to satisfy the needs for authenticity and complexity in the constructivist learning paradigm. While the work of these authors provide sound design principles based on current learning theories and educational psychology, the question of how effective we are at turning theory into practice needs to be evaluated. Dillon and Gabbard (1998) have reviewed the quantitative literature on the effectiveness of hypermedia as an educational technology. Their findings have significant implications for future designs of learning experiences with IMM.

Dillon and Gabbard restricted their study to those papers that were primarily quantitative in comparing test scores and actual achievements in assessments. Wholly qualitative studies were not included in their search for hard data with adequate controls to gauge objective outcomes. Their stated aim was to find out what

the learners were doing with the programs and their relative effectiveness. The authors looked at three major themes in which IMM is supposed to make a significant difference. The first of these was comprehension of presented materials. The argument is that hypermedia can improve comprehension through its capability to improve structured access, enable rapid manipulation of data and give learners greater control of the process. The results from this section of the study are, at best, inconclusive. Most test groups did not show a significant difference to control groups throughout a wide variety of tasks. Where improvements were claimed to be due to the presentation through hypermedia, the situations represented limited tasks where substantial searching or manipulation of visual data was involved. If the goal is to improve learner comprehension, then the use of hypermedia is not supported. The authors suggest that the problem may be caused by the inability of the software designers to organise information in digital form in such a way that it exploits the cognitive capabilities of learners to link and organise new information.

The second theme that Dillon and Gabbard considered was the important idea of learner control. One of the advantages of hypermedia is the control that it allows users in the method by which they access information. In their analysis of five published studies, the authors found that differences emerged based on the ability levels of the test subjects. Lower ability students found the most difficulty adapting to increased control and decision-making. In general, the ability to control the pace and delivery of information did not prove to be a significant factor in measuring learner outcomes for most groups of students. There did, however, seem to be a small advantage in these studies for higher-ability students. The third major theme looked at individual differences among learners, in particular the learning styles exhibited by the test subjects. It had been claimed that learning styles are crucial mediating variables that need to be considered when explaining any observed effects of hypermedia. In terms of learner ability level prior to the program, the papers assessed confirmed that high-ability learners benefited most and that low-ability students showed a decrease in performance. It was postulated that the increased learner control had overwhelmed the low-ability group and significantly interfered with their learning.

The authors point out that learning styles are considered independent of ability levels and perhaps by catering to specific learning styles the hypermedia may be more effective. They looked at studies involving field dependence versus field

independence, passive versus active learners and deep versus shallow processors. This section of the review proved extremely difficult, as it is not easy to isolate learning styles and test them in a hypermedia environment. There may well be important implications for designers but the studies show inconclusive findings about any benefits at this stage. There is some evidence to support the idea that some hypermedia applications have the ability to support low-ability learners and it is suggested that future technology can best be designed to target specific learner groups.

Dillon and Gabbard conclude that the evidence does not support the generally euphoric reaction to the development of hypermedia in education. It would seem that the benefits of hypermedia lie in very limited areas for specific tasks. Manipulating the form of delivery produces mixed results and educators should not pin their hopes on a single form of delivery providing great breakthroughs. The strength of hypermedia lies in tasks that require rapid manipulation of complex material, the overlaying of images or running animated simulations to deliver the information. Although they did not test it, the authors state that combining technology with innovative classroom practices, discretionary collaboration and self-paced learning may offer further advantages. They suggest that more research is needed to understand the various components of learning tasks in order to identify those tasks best suited to hypermedia intervention. The design variables are not well enough understood nor are the influences of individual differences in the learning process. They also support the idea that learning with media as opposed to learning from media is a fruitful area for research.

Summary

We have seen in this chapter how the use of multimedia has progressed from video-based anchors to interactive hypermedia environments with an emphasis on how a student might control the learning process through choice within the program. A number of authors have attempted to enunciate design principles for multimedia based on established learning theory. There is a solid base provided for novice designers to produce computer-based learning tasks that can be effective and worthwhile. The evaluation of the use of multimedia in the classroom shows that we are yet to establish a clear rationale for effective use and that the benefits are not clear. There is a need for more research to discover the type of software required for

specific learning tasks and also to develop tools to measure that effectiveness. In the next chapter, I will present in more depth how established learning theories can be related to the development and use of multimedia in the classroom. In particular, the chapter focuses on the theories of constructivism and social constructivism and their relationship to how software- learning programs have been produced.

CHAPTER 3

Some Current Learning Theories and Their Relationship to Multimedia/Hypermedia use in Education

Introduction

Multimedia authoring tools in current use put the mechanics of building software within the reach of most educators. It is not very difficult to produce professional looking programs to suit a purpose. The process of design, as we have seen, is much more difficult and producing effective learning tools needs to be guided by sound, well-researched ideas about the nature of learning in science. This chapter looks at several current learning theories that are integral to the process of building learning tools that can be effective in the classroom. The chapter is designed to provide further foundation for the initial research question and also helps to answer the second question related to effective teaching strategies. The sequence followed traces the beginnings of constructivist principles based on the work of Piaget through to the modifications proposed by Vygotsky and others who show how learning may best take place in the social setting of the classroom.

Constructivism

The search for an explanation as to how learning takes place in science has been a feature of the cognitive sciences in the last few decades. The early views of science education were based on the behaviourist view that knowledge could be transferred intact from teacher to student. The learning experience was primarily a passive experience with little effort required by the student. Teachers prepared lectures and often used a variety of media to get their message across. The main type of assessment was some form of test at the end of the topic with little emphasis placed on the existing ability of the students. There was a dichotomy between rote learning and meaningful learning that separated teaching approaches (Novak, 1978). The early work of Piaget questioned this passive approach as he and his co-workers sought to understand the process of conceptual development.

Piaget theorised that learning takes place through three processes – assimilation, accommodation, and equilibration. Assimilation is the process of acquiring new knowledge where the inputs basically fit the existing cognitive

structure. Accommodation is the process of restructuring existing cognitive structures, adapting to the new knowledge, when the inputs do not fit. Equilibration is the process of reconciling differences between new and existing knowledge when a cognitive conflict has occurred in the accommodation phase (Novak, 1978). When a student experiences a concept or idea that produces a cognitive conflict then that student is said to experience 'disequilibrium'. It is this disequilibrium that causes the student to go beyond his/her present state in search of new solutions (Brown & Desforges, 1977). Assimilation and accommodation must occur continuously in the process and are always intimately related. The basic underlying idea that each individual has an existing knowledge base and all new information has to be accommodated within that framework formed the basis of the ideas of constructivism.

In their review of learning theories, Duit and Treagust (1998) provide the following summary:

At the heart of this constructivist view is the idea that the conceptions held by each individual guide understanding. A further key aspect of this view is that knowledge about the world outside is viewed as human construction. A reality outside the individual is not denied; rather, it is claimed only that all we know about reality is our tentative construction. Accordingly, learning is not viewed as transfer of knowledge but the learner actively constructing, or even creating, his or her knowledge on the basis of knowledge already held.

(p. 8)

If one is to follow Piagetian pedagogy, there are certain features of the instructional process to be incorporated. Students should be encouraged to actively explore and experiment with the learning environment; hands-on work promotes exploration and provides students with the opportunity to understand the world in their own way (Lovejoy, 1995; Musk, 1995). Teachers should provide for social interaction in the classroom so that the alternative concepts of other students reduce the egocentric behaviour of individuals. In addition, students have the chance to learn in a context that may be culturally different and, therefore, provide conflicts to existing structures not anticipated by the teacher. Teachers should endeavour to have students voice their internal conflicts and attempt to analyse the source of alternative conceptions. By asking students to explain their conceptions, a more accurate diagnosis can be made of inconsistencies in their thinking (Gunstone, 1995; Hand & Prain, 1995;

Vance & Miller 1995). Teachers also need to be aware that certain underlying mental structures need to be present (facts or procedures) for students to be able to understand the nature of internal conflicts. If there is insufficient base knowledge then the whole lesson may be wasted. Finally, Piaget was convinced that thinking abilities progressed in well-defined stages and that a certain amount of maturity is required to master certain constructs. By relating hypotheses to concrete, real-world objects, the teacher can make ideas more readily apparent to the students (Novak, 1978).

Mainstream constructivist approaches of the 1980s and 1990s have focussed on a conceptual change approach where “learning of science concepts and principles usually involves major restructuring of students’ already-existing preinstructional conceptions.” (Duit & Treagust, 1998, p. 11). It is generally held that students’ conceptions and science conceptions are formed in different frameworks. Students generally do not speak “science” to each other in social settings. The science classroom is similar to a foreign-language room as much of the new knowledge is difficult to assimilate and is couched in its own culture. Hence, it is not likely that science concepts can replace everyday concepts within the students’ everyday framework.

Conceptual change approaches therefore hold that the aim of science instruction is not to replace everyday views but to make students aware that, in certain contexts, science conceptions are much more fruitful than their own conceptions. (Duit & Treagust, 1998, p.11)

The design of a teaching program from a constructivist stance needs to start with an analysis of what is known or believed and then develop a suitable pathway to follow. The teacher’s aim is to provide experiences that challenge current conceptions and promote a classroom atmosphere that encourages a willingness to think critically. If students have no desire to change their conceptions, they will usually make excuses for the alternative provided by the teacher. Strongly held beliefs are unlikely to be changed because a teacher wishes it. The key is that the learning process has to be driven by the student; effective learning conditions must support conceptual change. It is difficult to clearly state all the variables that should be considered when designing an instructional setting for conceptual change but the classroom climate and power structures in the room should be conducive to changing concepts. Rigid hierarchical schemes are not relevant here. The lessons need to

include the individual by taking into account his/her motivation, interests and beliefs. This also should apply to the teacher. If the teacher has no interest or belief in the subject, it will be less effective for the students (Duit & Treagust, 1998).

The use of multimedia to assist the process of learning from a constructivist viewpoint is an emerging field with some researchers attempting to develop practical guidelines. However, the problem with using multimedia to support constructivist learning situations is that those situations are not easily definable.

Constructivism believes (sic) that learning outcomes are not always predictable and that instruction should foster, not control, the processing of the learner....Constructivists emphasize the design of learning environments rather than instructional sequences...They do not seek to predetermine a sequence of instruction or a prescribed set of activities and thought processes by the learner. Rather they seek to provide a supportive environment in which the learner can interpret at least a simulated reality in order to better understand that reality. (Jonassen, 1994, p. 35)

Many multimedia computer programs developed in the 1990s follow a tutorial - based procedure with students progressing in levels or step-wise fashion. Hypercard stacks provided some freedom of navigation and a more random learning sequence and approached learning more from a constructivist stance. It would seem that the best applications were those that designed microworlds where students could explore an unknown environment and learn how that environment operated (within the designers' constraints). A possible advantage of computer simulations is the speed with which laboratory tasks can be achieved. Instead of having long delays as practical exercises are conducted, students are able to see results quickly and modify the test conditions to suit their own hypotheses and changes, thereby providing more time for discussion and absorbing ideas that conflict with their personal constructions.

Jonassen (1994, p. 37) has provided some broad design principles that follow a constructivist model. In summary, there are three broad areas to be accommodated in a successful design model.

1. An environment that supports the construction of knowledge which (a) is based on internal negotiation to stimulate the process of accommodation as outlined by Piaget; (b) is based on social negotiation to share the process; (c) is facilitated by

exploration of real-world environments and the creation of new environments providing relevance and interest to students; (d) results in mental models being produced.

2. A meaningful, authentic context for learning and using the knowledge they construct should (a) be supported by real-world case-based problems containing authentic tasks that would be encountered in real life practice; (b) require students to understand the thinking processes involved in that context; (c) be modeled for learners by skilled performers but not necessarily expert performers.
3. Collaboration among learners and with the teacher, who is more of a coach or mentor and not a purveyor of knowledge, should engage and facilitate social negotiation. It should provide an intellectual toolkit to facilitate an internal negotiation which is necessary for building mental models.

Clearly, this is a difficult task for designers. The factors to be incorporated will require a lot of planning and research in real classroom environments to see where computer programs can fit in. Jonassen (1994) places emphasis on social processes and social negotiation, an emphasis derived from a different view of constructivism known as social constructivism that emerged from the writings of Vygotsky which is explored more fully in the next section.

Social constructivism

The idea that students actively construct their own ideas based on previous experience provides a useful framework for the development of learning situations. However, there is a further consideration for constructivists that needs to be addressed. Vygotsky (1978), who is widely acknowledged as the author of social constructivism, and his co-workers were largely concerned with the circumstances that would best facilitate learning and questioned the accepted fundamentals of learning that existed at the time. He writes

In experimental investigations of the development of thinking in school children, it has been assumed that processes such as deduction and understanding, evolution of notions about the world, interpretation of physical causality, and mastery of logical forms of thought and abstract logic all occur by themselves, without any influence from school learning. (p. 79)

Vygotsky questions the independent development of the thought processes as proposed in Piaget's 'extremely complex and interesting theoretical principles' (p. 80). Prior to Vygotsky's work there were three accepted ideas of the relationship between development and learning. The first holds that development must occur first and then learning can follow. If a child is not at a certain level of development then he or she cannot possibly hope to understand and assimilate lessons at that level. With this position, development always outruns learning and therefore precludes any part that learning has in development. The second position is that 'learning *is* development' (p. 80) - the process of learning is completely and inseparably blended with the process of development. Here development is taken to mean the elaboration and substitution of innate responses. Any acquired response is considered either a more complex form of or a substitute for the innate response. Learning and development coincide at all points in this process.

The third theoretical position is simply an attempt to combine the first two. Development is assumed to be based on two inherently different but related processes, each of which influences the other. Maturation is the first of these and this depends on the development of the nervous system. The other is learning that, in itself, is a developmental process. The processes that make up development are mutually dependent and interactive. Maturation makes learning possible and learning stimulates and advances the maturation process. Arising out of these ideas is the value of a general education.

The idea that acquiring skills in languages or knowledge of an ancient civilisation provides transferable skills to other areas has been a common theme of classical education curricula. The fact that the subject taught is possibly irrelevant to the life of the student does not influence the theory here. It is assumed that there are certain mental capabilities that function independently of the subject material at hand. The learning process and the maturation process serve to develop these independent capacities that are then available for use across a range of experiences. However, research has shown that the mind does not quite work in this way. Learning how to do one specific task does not automatically presuppose the ability to complete an unrelated task.

Learning is more than the acquisition of the ability to think; it is the acquisition of many specialized abilities for thinking about a variety of things...According to this view, special training affects overall development

only when its elements, material, and processes are similar across specific domains; habit governs us. (Vygotsky, 1978, p. 83)

Theorists such as Koffka and the Gestalt school hold to the third perspective and assert that the influence of learning is never specific. They argue that:

The learning process can never be reduced simply to the formation of skills but embodies an intellectual order that makes it possible to transfer general principles discovered in solving one task to a variety of other tasks. From this point of view, the child, while learning a particular operation, acquires the ability to create structures of a certain type, regardless of the diverse materials with which she is working and regardless of the particular elements involved. (Vygotsky, 1978, p. 83)

These theorists believe that development is always a larger set than learning. Once a particular operation is mastered, it is then assimilated into a larger structural principle that can be applied to other areas. One step in learning leads to two developmental steps and learning and development do not advance at the same pace.

All three ideas of learning and development have merit but Vygotsky prefers to substitute his own ideas on the learning process, believing that from a child's very first day, learning and development are intricately linked. Children's learning starts long before they attend school and that any learning a child encounters at school has a previous history. This is essentially the constructivists' view. Vygotsky points out that there are some important differences between school and non-school learning. At school, the philosophy of the education system and the ability of the teacher place constraints on the learning process. The development level of the child and how that is matched to specific learning tasks is the key to the process. In many learning situations, the child's actual development is measured by a series of standard tests. The results of these tests are then used to determine what that individual should be learning. The fault in this process is that the measuring process only tells us the stage of development already reached, it does not provide any measure of the potential for future development or suggest lessons to develop the child's abilities. Vygotsky introduced the notion of the 'zone of proximal development' to suggest that development is the key to understanding how learning should progress.

It is the distance between the actual development level as determined by independent problem solving and the level of potential development as

determined through problem solving under adult guidance or in collaboration with more capable peers. (p. 86)

Vygotsky asserts that while there is a limited and measurable number of things a child can do on his or her own, there is also a large body of tasks that the same child can achieve through coaching, imitation and interaction with peers. The limit of the zone of proximal development is the level of task that is beyond the student regardless of the quality of coaching or imitation. It is really a measure of those processes that are in an embryonic state in the maturation process and are able to be developed in the current instruction cycle. To understand a child's mental development, we need to clarify both the actual development level and the zone of proximal development.

Vygotsky characterises learning in humans as a social venture by which children grow into the intellectual life of those around them. Using imitation and guidance in a collective or collaborative activity enables children to push into the zone of proximal development and show real progress.

We propose that an essential feature of learning is that it creates the zone of proximal development; that is, learning awakens a variety of internal developmental processes that are able to operate only when the child is interacting with people in his environment and in cooperation with his peers. Once these processes are internalized, they become part of the child's independent developmental achievement. (p. 90)

The most important feature of Vygotsky's idea is that development lags behind the learning process. Learning triggers the production of zones of proximal development. As the child ventures into these zones within their social setting, the child's mental development continues. While the relationship between learning and development is quite complex and no single theory could provide a complete explanation, Vygotsky hopes that his theory will provide a model for changing classroom practice to accommodate a more efficient development phase. The key is social interaction whereby all learning and development is grounded in and intricately linked to the social setting of the child's development.

In the classroom, there are a number of actions that can be used to support the perspective of learning and development as espoused by Vygotsky. Doolittle (1998) has produced a list of such actions which are summarised as follows:

Teach using whole and authentic activities: These should be genuine activities, not contrived to fit an artificial situation. Teaching component parts as isolated activities should be avoided. Students should see the big picture.

Create a need for what is to be learned: Desire to learn is essential in a child's quest for knowledge and relevance.

Create classroom exercises that require social interaction: The classroom activities should incorporate group interaction and push the developmental levels into the zone of proximal development.

Provide opportunities for verbal interaction: Language allows children to articulate and internalize their thinking. It enables critical scrutiny of the ideas of others and thus furthers individual development.

Monitor student progress: Teachers must be satisfied by the progress of each student and make sure that the material is challenging them.

Scaffold: Initially students should be presented with tasks that challenge them. Each task should require that they seek outside assistance to complete the task. As they progress, the level of assistance should be lessened to encourage them to take responsibility for their own learning.

Provide opportunities to demonstrate learning independently: Once mastery or behaviour approaching mastery becomes evident, students should be given the chance to complete the task independently. This can provide a means of assessment for the teacher.

Instruction must precede development: Learning activities should be aimed at the upper end of the zone of proximal development to lead the student to new knowledge and skills. If the lesson material is not challenging the student then it is not encouraging development.

Foster both behavioural and cognitive change: Students should be encouraged to construct their own mental representations of tasks and be required to exhibit certain behaviours in the planning and execution of the tasks.

The key implication for the use of computer technology, from a social constructivist viewpoint, is that learning will best be achieved in a collaborative environment. The use of computers in the classroom should be a social activity in which the nature of the activity challenges the students and motivates them to actively engage in the learning process. There should be opportunity for discussion amongst the peers and some motivation for further research.

Cognitive flexibility

Multimedia is a ready-made framework for *cognitive flexibility* in learning. Spiro and Jehng (1990) considered the value of using hypertext in providing cognitive flexibility for advanced knowledge acquisition in ill-structured domains. They define cognitive flexibility as the ability to spontaneously restructure one's knowledge in many ways, in adaptive response to radically changing situational demands. Ill-structured domains are defined in terms that require two conditions to be fulfilled. The first specifies that the case or example typically involves the simultaneous interactive involvement of multiple, wide application conceptual structures. There would be multiple schemas, perspectives or organisational principles and each of these would be individually complex. The learning domain involves both concept and case complexity. Secondly, there is an irregularity across cases that are nominally of the same type. There exists variability in conceptual incidence and how the concepts interact and the application of knowledge contains a certain irregularity.

Spiro, Feltovich, Jacobson and Coulson (1992) offer a theory of learning and instruction based on constructivist principles that emphasises the real-world complexity and ill-structured nature of many knowledge domains. Any effective approach to instruction must simultaneously consider several inter-connected topics, namely, the constructive nature of understanding; the complex and ill-structured features of many, if not most, knowledge domains; patterns of learning failure and a theory of learning that addresses known patterns of learning failure. In this way, the development of an instructional hypertext system could promote successful learning of difficult subject material.

Spiro et al. further argue that the characteristics of ill-structuredness found in most knowledge domains present serious obstacles to the attainment of advanced learning goals (such as the mastery of complex concepts and the ability to use instructed knowledge independently in novel situations). They believe that these obstacles can be overcome by shifting the constructivist orientation of the learning situation. Instead of an emphasis on memory retrieval of intact, preexisting knowledge, they see an alternative constructivist stance that emphasises the flexible reassembly of preexisting knowledge to adaptively fit the needs of the new situation. By using

theory-based hypertext systems, it is possible that the instructor can introduce flexibility in delivery that closely mirrors the requirements of the students.

The crux of the argument is that special problems occur when students are placed in situations of advanced learning and complexity. There is a tendency by instructors to oversimplify the theory and provide poor transference to real life examples. Spiro et al. argue that the instructional design has to be more flexible and that oversimplification needs to be avoided. There is, they argue, a definite gap between introductory instruction and the mastery of a subject through advanced knowledge acquisition and transfer of that knowledge to novel situations. They argue that the strategy of compartmentalisation of knowledge and recall of discrete sections works well in well-structured domains but it blocks effective learning in more intertwined, ill-structured domains which require high degrees of knowledge interconnectedness. In well-structured domains, the instructor can focus on general principles that have a wide scope of application across cases. In ill-structured domains, the same principles can lead to misunderstandings as the cases can have quite different requirements to understand them fully. Well-structured domains can usually be integrated with a single, unifying representation. Ill-structured domains require multiple representations for full coverage. Spiro et al. offer, by example, the use of a single analogy to a familiar concept or experience. They found that a single analogy may be of assistance in the early stages of learning but it actually interferes with more advanced treatments later on. Using a single analogy for a complex concept will always provide limited usefulness. It is better if the students are made aware of the limitations of the analogy if it is to be revisited when studying more complex examples of the same concept. The authors found that certain strategies that produce initial success for more modest goals of introductory learning may later impede the attainment of more ambitious learning objectives. Any work that involves evaluation of the effectiveness of analogies needs to incorporate an appreciation of this perspective, especially when working in an ill-structured domain.

In an earlier article, Spiro et al. (1990) argue that the use of hypertext and linking in general promotes more advanced cognitive structures and improves student understanding. They believe that a computer, using flexible, hypertext delivery systems, is ideal for fostering cognitive flexibility. They argue that traditional texts, lectures and computer-based drill programs cannot deliver the required flexibility to

deal effectively with subject material that requires some degree of cognitive flexibility.

Their design of hypertext environments is not just a random linking of words and phrases to provide an ill-structured environment. They advocate that the links and the many ways that material can be interpreted be carefully considered before the program is developed. In this way there is a guiding hand behind the structure that the students may not necessarily discover until after they have mastered the course. Spiro et al. (1990) argue for a premeditated criss-crossing of ideas and substantial themes that are linked. Their conceptual landscape should include a large number of case examples of a given conceptual structure in use. The student is then able to choose examples that appeal to him/her. In this way the student is acting as editor-in-chief of the learning program as he/she rearranges the course elements to focus on the conceptual structure that is being emphasised at the time. The student does not have to rely on the possibility that a real case or example will be presented by the teacher. With a wide range of examples, the student can see cross-case variability and begin to address the problem of ill-structuredness. In addition, any single issue can be seen in relation to a larger number of issues and so be integrated within a larger framework. The treatment of conceptual variability is one aspect of a more complete approach to learning in which diverse aspects are theoretically united.

The constructive process should go beyond the aim of a retrieval of knowledge structures from memory. To progress beyond the current concept being taught, there should be an independent, flexible, situation-specific assembly of the background knowledge structures themselves that can lead to the production of non-linear, multiple access learning environments. If this is successful in complex, advanced, ill-structured domains, then it should certainly be relevant to a highly structured chemistry course that contains much subject complexity. It provides one alternative to traditional instruction that may prove useful to some teachers and students. Spiro et al. conclude that their work is moving towards a systematic theory of hypertext design that includes flexible instruction techniques. This theory they have dubbed random access instruction, which in turn should guide the design of non-linear computer learning environments referred to as cognitive flexibility hypertexts. It is simply a set of principles designed to improve transfer of concepts in ill-structured knowledge domains.

Situated cognition

The theory of situated cognition centres on the concept that learning is inextricably linked to the context in which it occurs and exploits the inherent significance of using real-life contexts in learning (Brown, Collins & Duguid, 1989). There is a perceived need to provide experiences in authentic contexts that emphasise the processes as opposed to the outcomes. Advocates of situated cognition believe context in learning is a key component because individuals think and behave differently in everyday environments as opposed to controlled or contrived situations in schools. Choi and Hannafin (1995) argue that students are often poor at solving everyday problems using formal thinking skills taught in schools. They believe that there is a gulf between academic cognition or thinking in highly ordered, compliant situations and everyday cognition or practical, informal situations. In formal learning, the emphasis is on systematic problem solving, often using abstractions from reality. It is assumed by the teacher that the procedures taught in this situation will be sufficiently robust to allow transfer to novel situations, especially practical applications. However, Rogoff (1984) found that individuals tend to apply practical strategies rather than formal, bottom-up methods. In everyday situations, individuals often use concrete referents and tools extensively, making sure they refer continuously to the specific context (Choi & Hannafin, 1995).

Formal learning promotes a uniform understanding and usually does not allow unique methods. For students to develop the abilities of experts, they require authentic, real-life contexts to work on. Authentic tasks are coherent, meaningful and purposeful and they represent the ordinary, everyday practices of a community (Brown, Collins & Duguid, 1989). Authentic tasks are problem-based. In order to solve the problem, students need to use a variety of resources productively. They must look at appropriate strategies and often modify their approach as the situation drives their intent to solve the task at hand (Collins, Brown & Newman, 1989). If one accepts that formal learning can inhibit transfer of cognitive skills to everyday situations, then situated learning can provide those practical tasks that are more likely to promote such a transfer.

In addition to promoting the use of practical abilities, the knowledge that is taught (or learned) also should be set in a meaningful context. In real problems, the students should come to appreciate that remaining flexible and applying knowledge

in different ways can overcome difficult situations (Choi & Hannafin, 1995). However, deciding on the content to be included in a specific exercise can be a difficult process. As has already been pointed out, abstract, formal knowledge and skills may fail to transfer effectively to novel situations. Just as important, though, we need to realise that domain-specific knowledge can also fail to transfer to dissimilar cases. The key to the problem is to develop teaching and learning strategies that provide a level of generality that allows application in many settings. In addition, students should be trained in self-monitoring and analysis of the thought processes that produced successful outcomes, that is, metacognitive skills. A practical approach that involves providing content that reflects similar concepts would demonstrate how knowledge could be applied in different circumstances.

The use of analogical reasoning depends on the ability to recognise similarities in different contexts. The Cognition and Technology Group at Vanderbilt (1993) found that, by employing contextually-anchored videodiscs in both Mathematics and Science, students were better able to solve problems that were analogous to the original. They reasoned that analog and extension problems help students to develop flexibility in their thinking and more readily extend their knowledge to related areas. In addition to the use of analogs and extension sets, the use of contrast sets is also a valuable tool. A contrast set is a group of related concepts that begin with large differences and progress to finer distinctions (Bransford, Franks, Vye & Sherwood, 1989) allowing the novice student to build up a larger set of experiences in the domain being investigated. Novices need to acquire the ability to detect important, substantive aspects of varied contexts to better understand how new situations are similar to, and different from, those previously encountered (Choi & Hannafin, 1995).

Cognitive apprenticeship

A subset of the theory of situated cognition is the idea of a cognitive apprenticeship. If we treat students as apprentices, then there are differences in the tactics employed to teach various concepts. Typical apprentices in trades are subject to learning in the field from a mentor who helps them acquire skills through a combination of observation, coaching and practice. The apprentice is able to create mental models, develop scaffolds to assist understanding and gradually become self-reliant (Winn, 1993). Formal learning, which has largely replaced apprenticeship

schemes, has developed its own strategies that are often divorced from the mentor-apprentice setting. There is insufficient attention paid to the reasoning processes and strategies that the expert employs in real-life situations (Choi & Hannafin, 1995). Cognitive apprenticeships are designed to emphasise the relationship between content and processes that experts employ to perform complex tasks.

Similar to situated cognition, the apprentice needs to experience real-life tasks and be able to observe the expert's approach to the problem and the strategies employed (Brown, Collins & Duguid, 1989). The thought processes involved need to be made overt and more accessible to the apprentice. In return, the apprentice's thought processes need to be made available to the mentor for analysis. What sort of strategies can be employed to develop a cognitive apprenticeship and support the principles of situated cognition? Students require ongoing, interactive and continuous facilitation to support their personal constructions of meaning in the tasks that they experience. If students are assisted to internalise information, then we are promoting higher order, metacognitive skills such as self-monitoring, correction, self-regulation and self-assessment (Choi & Hannafin, 1995). This facilitation has assumed several forms in the classroom.

Modelling physical processes and thought processes underlying the performance of a task are key features of cognitive apprenticeships (Collins, Brown & Holum, 1993). Through modelling, students can observe those processes that are normally invisible and begin to see what is happening and why it is happening. The provision of scaffolding is important to the development of cognitive structures. A scaffold is a tool to support the student in a particular task that assists him/her to accomplish a task not otherwise possible. It supports and simplifies a task as much as possible to enable students to manage the learning process better and achieve the required outcome (Choi & Hannafin, 1995). A practical example would be teaching a student to write laboratory reports in a standard format. Each section can be represented in boxes on a page with some clues as to what is required in each section. After the student has mastered the procedure, the scaffold is no longer required. The amount of scaffolding required depends upon the ability level of the student and the complexity of the task but it should always be set just beyond the level that a student could independently manage. This is reflective of the work of Vygotsky and the 'zone of proximal development'. It is necessary to keep developing the student by providing a challenge to his/her current abilities.

As with most learning situations, cognitive apprenticeships require coaching, guiding and advising (Brown, Collins & Duguid, 1989). These strategies are employed as required to ensure the ongoing development of the students' cognitive skills. Collaboration is a key tool as most instruction occurs in a social setting and a group can provide important conversation that is needed to create and modify the beliefs of individuals. Brown, Collins & Duguid state that collective problem-solving, the employment of multiple roles by the learners, the confrontation and correction of misconceptions and the opportunity to experience collaborative work skills are all positive features of group learning. This is the rationale behind the computer-supported collaborative learning discussed previously.

A further strategy is the use of fading which involves gradually reducing the level of support over time to promote independent achievement by the student (Collins et al. 1991). Students need to acquire strategies that move them from being dependent on the mentor to a self-regulating expert. Practical implementation often involves the use of cognitive tools to enhance learning. Tools can take various forms such as calculators, dictionaries, databases, spreadsheets, simulations and communications tools (Tobin & Dawson, 1992).

Assessment of the effects of situated cognition

Justification for the use of the techniques of cognitive apprenticeships and the ideas of situated cognition needs to be provided in the form of relevant assessment procedures. If students are to progress to self-regulation and independence, they need to have a series of tools that reinforce the process they have undertaken and give them a measure of achievement. If there have been a number of strategies used in solving real-life tasks, then the assessment procedures should reflect this by looking at assessing the diversity and complexity of learning (Choi & Hannafin, 1995). Firstly, progress and achievement should be measured against an individual's goals. Assessment should be self-referencing and focus not only on performance outcomes but also on diagnosing cognitive processing components, strategies and knowledge underlying performance (Collins, Brown, & Newman, 1989). Situated learning environments have as their goal the ability to transfer knowledge and skills flexibly across related platforms. The assessment needs to see if this has been successful by stimulating students to think about new situations and use the cognitive tools acquired to solve problems. The measures of learning should reflect flexibility and

diversity and not become fixed reference points. The way we assess various groups should directly relate to the types of tasks they were experiencing and should look at their ability to provide well-reasoned arguments to support their solution.

Assessments also should look at the ability of the student to generate new ideas and not just select alternatives from those provided. The emphasis is on the processes that students use to create solutions and what they create in that process (Collins, 1990). Assessment should be embedded in the task, not a separate entity at the end. Students require continuous feedback through ongoing assessment so that they can diagnose what they need to more fully understand the task. Assessment should be integral and authentic (Collins, 1990). Students need to be able to demonstrate the processes they undertake by communicating effectively the results to others. There are a number of assessment tasks that can be used in situated learning environments. Portfolios, performance assessment such as practicals and design of related materials (such as analogies), and concept maps are some of the tools that can provide measures of achievement.

In conclusion, situated learning emphasises the recognition by the individual that he or she is growing and learning and teaches them to recognise this through metacognitive skills that allow reflection and self-regulation. The use of authentic tasks that are complex and ill-defined stimulates the student to retrieve the required knowledge and skills or seek assistance to find those skills. The ultimate test is how well those skills transfer to novel situations and how well the student has progressed in applying new knowledge and skills.

Summary

This chapter has served to demonstrate the evolution of ideas about learning from the general development theories of Piaget and Vygotsky, through to the specific types of learning situations created by cognitive apprenticeships and situated cognition. There are many specific guidelines to ensure that a designer can produce learning tools that are soundly based on active classroom research. The key for the designer is to understand the nature of the learners and how to successfully engage them in meaningful construction of knowledge and skills. The next chapter looks at collaboration in the classroom. In particular, the focus is on how computer-based learning can be designed to improve collaboration among participants in learning tasks.

Chapter 4

Computer Supported Collaborative Learning (CSCL)

Introduction

This chapter looks at the nature of collaboration in the classroom and its importance in the learning process. The role of the participants is examined as well as the use of effective communication strategies to enhance learning. The use of computer-based tools and how they might best be employed provides an interesting debate about how teachers and learners can work together to improve the depth of understanding through technology. This chapter is primarily concerned with the second research question as it explores effective teaching methods for small groups.

Collaborative learning

Collaboration is a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem. The use of computer software to encourage collaboration and cooperation among learning groups provides a rich field of research. A number of workers in this area have looked at the most effective ways in which to design the software and provide tutorial support for the teachers and students. Collaboration has a sound theoretical base in educational psychology. For example, O'Malley (1995) is concerned with learning theories and how they relate to computer system design to support collaborative learning. O'Malley compares the sociocognitive theory derived from the work of Piaget and the sociocultural theory derived from Vygotsky in relation to this important field. In his earlier work, Piaget emphasised the importance of social interaction on individual development. Social interaction is a necessary condition to progress from egocentric to decentred thinking as well as the development of formal thought. It provides conflicting ideas that enable an individual to progress. As stated previously, Vygotsky sees that all individual development has its origins in social processes. Discussion is all-important, as it is the basis for inner dialogues that reflect thought and action. If groups are attempting to coordinate perspectives or co-construct hypotheses to arrive at a joint solution then they are able to progress in a manner fundamentally different from the way Piaget proposed. There is a causal relationship between social and individual processes.

One of the key concerns for educators designing materials for collaborative learning is the composition of small groups. If we are to follow the ideas found in the early work of Piaget, then it is important for the group members to consist of peers with differing perspectives. To provide cognitive conflict that leads to the accommodation of new knowledge, Piaget believed that the group should consist of individuals with equivalent intellectual abilities. Having peers of higher ability would lead to some attempt at dominance by the more able over the less able. However, from a Vygotskian perspective, it is essential to have peers of differing ability to provide experts within the group. There seems a clear dichotomy in the two schools as to the nature of the differences in the group formation but also clear agreement that difference is the key ingredient. Verba and Winnykamen (1992) studied peer interaction using a model-building task. They found that progress was made in cases where pairs were of unequal general ability and in cases where pairs were of unequal domain expertise. In pairs where the domain expert was the higher ability child, the interaction was in the form of tutoring or guidance. In pairs where the novice was the high ability child, the interaction was more collaborative and involved joint construction.

In determining whether or not the age (or development) of the individuals was an important factor, Azmitia (1988) found that in pairs of five year-olds, when novices were paired with experts in a model building task, there was a significant improvement in the novices both during and after the interaction. If the groups were of equal ability, they did not find significant improvement. The author found that the most important factors in the learning process were guidance by the expert and observational learning by the novice. Conflicts proved a negative influence. Azmitia argued that conflict may play a part in the learning processes of older children but in preschoolers they may lack the skill to sustain discussions of alternative processes. Clearly, age is an important consideration when designing collaborative groups and the nature of the learning task. Of course, Piagetian theory puts constraints on the abilities of students at different ages and maturation levels. It is not clear whether the social interaction leads to the decentration needed to obtain benefit from collaboration or whether the individual must have progressed sufficiently before collaboration can successfully occur.

In searching for a way to reconcile the varying ideas of Vygotsky and Piaget, Rogoff (1990) points to a fundamental difference in the philosophy of the two

schools. Vygotsky has focussed on acquiring understanding and skills. Piaget has emphasised changes in perspectives and restructuring of existing concepts. Rogoff suggests that tutoring or guidance may be a necessary condition for the Vygotskian approach whereas collaboration between peers of equivalent intellectual ability may better foster the Piagetian approach. The structure of dyads or groups may well depend on the learning outcomes one is interested in. For skill acquisition, peers of unequal ability would be better. For conceptual change, similar ability peers would be the path to pursue. Clearly, group design is a very important part of the collaborative process and the composition of learning groups in relation to the task is a key consideration.

It has also been suggested by Kruger (1993) that the debate about conflict versus cooperation is a non-issue. In situations where the partners disagree and in situations where they cooperate to find a new solution, individuals are always faced with some difference between their prior conception and an alternative conception of the task. By providing a situation where conflict arises and where new solutions are able to develop should allow the individuals to progress.

Further, Howe et al. (1990) found that there was no relation between a jointly constructed solution and individual post-test results. Children in a group with differing views progressed more relative to children in groups with similar views. This was regardless of the solution obtained in the interaction and supports dyads of differing abilities. Rogoff (1990) believes that there is intrinsic value in individuals working with peers in a social learning activity because the individual is functioning with a shared understanding. The individual's use of this shared understanding at a later time is usually not the same as what was constructed jointly. It is, more often, an appropriation of the shared activity that reflects the individual's understanding and involvement in that activity. The participation in the activity leads to an individual construction and, thus, new learning.

Tao (1998) provided further insights into the process by conducting research with a group of Year 10 students working on a computer mediated physics task. In the study of the students' conversations within the group, Tao made the observation that co-construction of knowledge was indeed evident during peer collaboration. However, this new knowledge was not always persistent. Tao believes that the students must undergo a further stage involving personal construction to ensure a conceptual change that is stable over time. Personal construction is a private process

that a student must commit to on a regular basis. Tao found that those students who progressed in their knowledge were aware of their alternative conceptions and were able to clearly state the conceptual change that they had undergone. Tao does say that the interaction with peers and the teacher during the task is an important component of the process, thus supporting the ideas of Vygotsky in the social nature of the learning situation. It is the nature of the final personal construction that determines the effectiveness of the learning and the teacher and peer group may have very little influence over that process.

The nature of the task also lends itself to different types of cognitive development. According to O'Malley, the literature suggests that collaborative learning can produce a variety of gains – both in general abilities as well as more domain specific skills. There is sufficient diversity of ideas to make it quite difficult to find a key list of general principles to design effective supportive environments. Some tasks lend themselves to sharing information better than others and it is up to designers to consider the nature of their task initially to ensure it is suitable.

Roschelle (1996) attempts to show how collaboration can lead to convergent thinking by members of a group. It is clear that there are many areas of theoretical science where opposing ideas can both provide acceptable explanations of observed phenomena. Indeed, it is the ability of science to accommodate these perceptions and apply tests to them that strengthens the discipline. Students bring to the learning situation their own ideas about the world and may have misconceptions that are stubborn and not easily modifiable by traditional teaching methodology (Eylon & Linn, 1988). The question for Roschelle was 'How can two (or more) people construct shared meanings for conversations, concepts and experiences?' (p. 209)

Roschelle observes that scientific collaboration shares many of the features of everyday social interaction. An example is the incorporation of turn-taking structures to negotiate meaning. Where scientific work varies is in the production of visible displays that represent the world at an intermediate level of abstraction and the interplay and recombination of metaphors drawn from experience to construct explanations. In science learning, conceptual change is seen as a process of learning to register deep features of situations and restructuring systems of physical metaphors. Roschelle, like Goldman (1974), is an advocate of providing means for conversational interactions to construct relational meanings. This conversation can contribute to increasingly sophisticated understanding of a concept in a rich learning

environment. He provides a proposal for a process that, using prior research as a basis, provides a pathway to facilitate convergent thinking.

The four primary features of the proposed process are: (a) the construction of a deep – featured situation at an intermediate level of abstraction from the literal features of the world, (b) the interplay of metaphors in relation to each other and to the constructed situation, (c) an iterative cycle of displaying, confirming, and repairing situated actions, and (d) the application of progressively higher standards of evidence for convergence. (Roschelle, 1996, p. 211)

The convergence occurs through a cycle of displaying, confirming and repairing shared meanings. He argues that convergent conceptual change is achieved incrementally, interactively and socially through collaborative participation in joint activity.

Roschelle's case study involved an analysis of the interaction between two students and a computer physics simulation on vector analysis. In looking at the interaction, he makes special note of the importance of social interaction in the learning process.

Throughout the episodes, one finds constant evidence of the design of utterances as social acts. The students responded to utterances with mutual concern for shared knowledge, exerting deliberate effort to create convergence and avoid divergence. (p. 225)

Roschelle concludes that his study supported the four - step process outlined above as a method which students used to overcome the problems of prior knowledge and divergent thinking. He further argues that the mainstream cognitive research on science learning should focus attention on convergence. He is an advocate of situated cognition that is not constrained by teacher views or narrowly defined software. He believes that social constructivism can occur in a classroom through convergence that is free of the interpretations of designers. In other words, learners can be provided with a piece of software designed to evoke social interaction and involve the teacher in the process where he or she is a participant and not a lecturer. This, he believes, is the ideal situation for rich conversations to provide convergence of ideas.

Roschelle argues that convergence is a logical complement to current learning theories. He believes that the ideas of Piaget and Vygotsky provide a platform for the study of collaboration, but they do not sufficiently address the observed patterns of

behaviour that he recorded in his study. Vygotsky was concerned with the idea of scaffolding by an expert peer or peer tutoring. Piaget described the collaborative situation as a means to provide disequilibrium or conflict. They do not directly address the benefit of mutually contributing to shared knowledge to construct a common understanding as he had observed. Roschelle states:

The domain of collaboration is diverse and each perspective can offer valuable insights and tools for analysis. As research about learning as cognitive and social progresses, it is imperative that differing accounts of relationships among conceptual change and collaboration are actively questioned, elaborated and investigated. (p. 245)

The development of computer support tools

In the process of developing computer support tools in an educational setting, Koschmann, Kelson, Feltovich and Barrows (1996) have developed a set of guidelines that provide an outline of a methodology for successful design:

How would one undertake a theory-based approach to the design of CSCL tools? We argue that such a project should progress through four steps: making explicit the instructional requirements that serve as design goals for the project; performing a detailed study of current educational practice with regard to these goals; developing a specification based on the identified requirements and limitations of the instructional setting, and the known capabilities of the technology; and producing an implementation that allows for local adaptation to instructional practice. (p. 83)

The design process should be informed from the beginning by some model of learning and instruction. The designer should be able to articulate the educational considerations from the earliest stages of the design. An educational model allows the designer to evaluate the success of the innovation and also it provides a framework to evaluate the current instructional setting to reveal where the current practice falls short of the goals for the proposed model. Upon completion, the analysis identifies the current practice, its shortcomings, and where the technology can best contribute.

Debate in the 1980s and 1990s about perceived failures in the education system is often centred on the lack of robustness in the knowledge base of students, in that

students often learn facts out of context and have difficulty applying their knowledge to new situations (Koschmann et al., 1996). Students also lack the ability to reflect on their own learning and continue the learning process after they leave school. A major concern throughout education systems is how to deal with the knowledge explosion of the late twentieth century (Koschmann et al., 1996). A common response is to expand the curriculum to accommodate new ideas but not give any more time in the classroom. The result is that existing ideas are taught more superficially with less time for reflection and connection to other work. Memorising isolated facts is a short-term strategy that does not contribute to a rich knowledge base (Koschmann et al., 1996). In simple, one-step processes, it may not be necessary to have more than a basic factual knowledge but most real-life situations are ill-structured and complex requiring adaptable knowledge. Students need to have the necessary tools to deal with novel situations in the field. It is the seeming lack of these intrinsic tools/abilities that has researchers such as Koschmann concerned.

Educational administrators often tout the idea of the life-long learner, but it is rarely achieved, most likely due to the way that schools are set up. If the school's teachers and administrators focus on a transmission method of delivery and do not instill curiosity and ownership in the students, then they will not automatically acquire the desire/attitude of a life-long learner (Koschmann et al., 1996).

Koschmann et al. enunciate six principles of effective learning and instruction.

Principle of Multiplicity: This principle sees that knowledge is complex, dynamic, context-sensitive, and interactively related. Instruction should promote multiple perspectives, representations and strategies because single representations can often miss the richness in concepts and cases providing misleading simplification.

Principle of Activeness: Learning is an active process requiring mental construction on the part of the learner. Instruction should foster cognitive initiative and effort after meaning. The effective learner is driven by a need to know and is able to identify what needs to be learned in light of context. Real-world problem solving, then, demands activeness in the form of aggressive inquiry, reasoning, and reflecting. An effective instructional method should promote activeness in learning through self-direction, goal setting, problem finding, problem solving, and self-testing, and should engage the learner in problem solving that requires the aggressive

inquiry, reasoning, and reflecting demanded of ill-structured problems and knowledge domains.

Principle of Accommodation and Adaptation: Learning is a process of accommodation and adaptation. Instruction should stimulate ongoing appraisal, incorporation and/or modification of the learner's understanding. What one understands and subsequently remembers about any educational experience, whether text-based or direct experience, is a function of the learner's previously existing knowledge and beliefs with respect to that experience. The outcome of any learning experience, then, is a function of the mutual adaptation of learner to experience and experience to learner. This has three implications for instruction: Instruction should take advantage of the learner's prior understanding as a rich foundation on which to build; it should allow for ongoing monitoring of the learner's understanding in order to make midcourse corrections and to challenge erroneous ideas; and it should promote the development of cognitive flexibility so that appropriate adaptation occurs. Instruction must, therefore, be flexible. Skilled instructors are constantly assessing the understanding of their students to detect deficiencies, to challenge misconceptions, and to encourage deeper exploration of complex topics that students feel they already know. Such instructional behaviour serves as a model for the kind of self-questioning from which essential metacognitive skills of learning develop.

Principle of Authenticity: Learning is sensitive to perspective, goals, and context, that is, the learner's orientation, goals and experiences in the learning process determine the nature and usability of what is learned. Instruction, therefore, should provide for engagement in the types of activities that are required and valued in the real world. The context in which learning occurs can affect the learner's ability to retrieve and apply knowledge. Students must see that what they are doing is useful. (One of the problems with high school chemistry lies in students' not seeing the usefulness of conceptual knowledge. For example, with nuclear reactions we often use real-life examples such as the Hiroshima bomb. However, without first-hand experience of such a reaction, or its removal in time from their experience, the example may well be as abstract as the concept and provide further barriers to learning.) Instruction, therefore, should be organized around real-world problems in order to induce orientations to learning that are congruent with subsequent knowledge use, a central theme of theories of situated cognition and a fundamental principle of problem-based learning. The learner should be spared from engaging in

activities that are only meaningful in an instructional context (i.e., *schoolwork* in its most pejorative sense) and that are wholly disconnected from the concerns of the real world.

Principle of Articulation: Learning is enhanced by articulation, abstraction, and commitment on the part of the learner. Instruction should provide opportunities for learners to articulate their newly acquired knowledge. Articulation as used here denotes giving utterance to force a cohesive explanation and interrelating of concepts and relationships. As a pedagogical activity, articulation can take a variety of forms, including generative summation and the production of analogies, predicting outcomes of events on the basis of understanding and developing implicated questions about the learned material. Such activity serves a number of useful functions: it enhances retention, it illuminates the coherence of current understanding, it sensitizes knowledge points for impact by subsequent feedback (e.g., predicting an event makes the subsequent observation of results more powerful), and it forces the learner to take a stand on his or her knowledge in the presence of peers, making a commitment that calls for assessing and evaluating that knowledge and setting the stage for future learning. Articulation serves another important function: It provides a mechanism for abstracting knowledge from the context in which it was acquired, thus increasing its utility. Abstraction is especially difficult, context-sensitive, and limited in scope in ill-structured domains. In order to abstract principles from the various contexts in which they are embedded, the learner must view the cases from various perspectives, assembling and reassembling, to establish relationships and sort out which elements are generalizable and which are context specific. This cognitive effort provides practice in cognitive flexibility. Articulating constructs and relationships forces the effort, with the added bonus of subjecting the outcome to observation and critique.

Principle of Termlessness: Learning of rich material is termless. Instruction should instill a sense of tentativeness with regard to knowing, a realization that understanding of complex material is never completed, only enriched, and a lifelong commitment to advancing one's knowledge. If complex knowledge is approached appropriately, one does not learn, one is learning. Because knowledge changes meaning with context, values, perspectives, and new learning, learning must be dynamic and active to accommodate these changes. Instruction, then, should promote the development of a disposition toward and competence in initiating, reflecting on,

and directing learning in response to the dynamics of the domain..... The learner must develop a sceptical certainty with respect to his or her knowledge base. This sceptical certainty is enhanced as learners are exposed to a variety of perspectives and opinions, both expert and nonexpert.

In summarizing these principles, Koschmann et al. (1996) state that

developers of instructional software (CSCL-related and otherwise) must try to accommodate variability across classrooms by designing their systems to be sufficiently flexible to support differences in local patterns of use. Indeed, the best tools may be the ones that can be reinvented by their users, that co-evolve with practice referred to the divergent ways in which identical software tools were used by students and instructors in different settings as realizations. We must recognize that the emergence of a variety of such realizations does not constitute a dilution of the original design, but rather, an enrichment through creative use. (p. 118)

The role of the computer – some examples

Computers are tools that can mediate communication between learners. Computers can be used to provide simulated environments, which act as a stimulus or catalyst for discussion of competing solutions. The software also could be used to test predictions but would only be relevant to collaboration if participants were required to make their predictions fully explicit and come to some agreement through explanation and justification. This type of activity assumes a passive role for the computer and an active role by the participants. However, the act of interacting with a computer may at the same time change the nature of the activity itself. Many see the computer software in a more proactive role. Roschelle and Teasley (1995) argue that the interaction with the computer actively mediates collaboration by providing a means for disambiguating language by establishing shared referents. If all participants are viewing the same cues in the same context then the meaning of the author should be less ambiguous. In addition, the software can produce conversational turns, help to resolve impasses, invite interpretations within acceptable limits that lead to the generation of new ideas. The creation of new, shared ideas and interpretations takes the computer from being merely a stimulating tool to a tool that can mediate interaction.

Roschelle and Teasley designed their research to look at the process of collaboration rather than the theory behind it. They take the premise that collaboration is a key feature of learning and look at a specific case closely in order to examine how the collaboration proceeds. They establish a clear dichotomy between collaboration and cooperative problem solving. In a cooperative situation, each member of the group is responsible for separate small parts of the problem, a division of labour. Collaboration differs as it becomes a mutual engagement of participants in a coordinated effort to solve the problem at hand.

These authors also operate on the assumption that collaboration is a synchronised activity in a face-to-face situation; the shared conception of a problem is fundamental to their work. Their philosophy, based on this and other research, is that we require a negotiated and shared conceptual space that has been constructed externally to the learner. What is required is a mediational framework of shared language, situation and activity that promotes the collaborative thinking and interaction.

The role of the computer in this process, which is central to their arguments, is as a 'mediational' resource that stimulates conversation and provides clues to and visualisations of problems. In studying the progress of a small group of students interacting with some physics software called the Envisioning Machine, they remark on the students' use of both language and action to overcome an impasse. The students occasionally converge in their ideas but there is a significant difference in their theories and actions and they require a conscious effort to keep progressing. Learning does not take place by simply putting two heads together. They require stimulation and motivation to contribute actively to the process. Talk is the cornerstone of collaboration. The language used must facilitate a shared understanding.

So how do resources provided by the computer support collaboration? From their studies, Roschelle and Teasley provide the following suggestions:

- The computer is a means for making language less ambiguous. The use of technical terms and carefully designed application of those terms on the screen should ensure that the students are talking about the same thing.
- The computer software has the potential for resolving an impasse. Experimenting with the computer can lead to more correct interpretations.

- The computer software invites and constrains students' interpretations. It leads the students down certain paths and ensures that they do not focus on extraneous matters.

The researchers postulate that their research methodology is a path to deeper understanding of collaboration and could lead to better design of resources to support collaborative learning.

A more radical view sees the tools and representations provided by the computer as participants in the interaction to provide an active example of distributed cognition. An example is the project reviewed by Scardamalia and Bereiter (1996). The use of computer technology in classrooms has been questioned often as most teachers try to mould new technology to fit their existing teaching methods. Scardamalia and Bereiter label this process as reinventing the familiar with educational technology.

With new technologies, student – generated collages and reproductions appear more inventive and sophisticated – with impressive displays of sound, video and typography – but from a cognitive perspective, it is not clear what, if any, knowledge content has been processed by the students. (p. 249)

These authors proposed a system that created an enabling technology in which students could effectively use their time to develop new knowledge in a collaborative setting. It was known as the CSILE project – Computer Supported Intentional Learning Environments. Intentional learning is defined as those moments when a student is actively trying to achieve a cognitive objective rather than doing school-type activities. In using the CSILE tools, the authors hoped to engender a process of expertise in which progressive problem solving becomes the norm. They also tried to restructure a small section of the school as a knowledge-building community with the hope that this would extend across the institution. The idea behind the project is a communal database system that, once established, becomes the basis for further knowledge building.

The process of becoming an expert, they argue, is ignored in the design of course delivery in schools. Educators should take into account social structures, group dynamics and the knowledge that students bring to the classroom. They should make the knowledge objectives obvious and use them as the focus of the unit. They should provide opportunities for the teacher to model his/her expertise and show the techniques required in becoming an expert. For computer technology to become an

integral part of this process, it needs to find a place in the system that is not traditional – neither didactic nor activity-centred.

Scardamalia and Bereiter advocate the creation of knowledge-building communities in schools. Using apprenticeship models and the study of highly effective research groups at university, they believe that students in schools can form collectives, in which knowledge becomes a product, enjoying an existence independent of the individual knowers. To achieve this end, a certain amount of restructuring is required. We need to look closely at the social processes in the school and how we can best organise learning groups to maximise knowledge-building opportunities. Technology provides the facilitative infrastructure to drive the process. Studies with a development group on the CSILE program showed that students were able to demonstrate an improved depth of understanding and an improved understanding of the learning process itself. The use of a computer bulletin board system and database allowed students of all standards to contribute to collective knowledge. There were some simple rules applied to the system. Before comments were published, they were subject to peer discussion and review. The teacher also was involved in this process and the work produced has the important feature that it contributes new knowledge or insight. The students designed their own learning objectives and then worked towards a collaborative understanding of the learning field.

This is a rich area for further study and suggests that schools can indeed be restructured into knowledge-building communities. The use of the Internet has the potential for global communities and learning on a much wider scale.

A further example supporting collaborative learning ideas is research by Tao (1997) that involved Year 10 students working collaboratively in dyads on a variety of computer simulations in physics. The aim of the study was to investigate whether and how collaborative learning at the computer fosters conceptual change. The main source of data was the study of student conversations while working collaboratively coupled with a series of pre-, post-, and delayed post - tests. Tao makes the distinction between shared knowledge developed through collaboration, which can be judged through conversations and short - term test results, and personal construction which can be judged by delayed post - tests. Once new knowledge has been identified by the individual and accepted, it is then necessary for the individual

to assimilate the knowledge and make it part of the permanent body of concepts. This is a metacognitive process and is a skill that needs to be developed.

The results of this study showed that social construction of knowledge took place in peer collaboration and in many cases led to student's conceptual change in relation to the specific task. Tao found that this change was not stable over time for many students and concluded that those students who reverted to alternative conceptions or did not retain a conceptual change were unable to make personal sense of the information. While they were able to develop new knowledge collaboratively, these students needed the continued support of the group to sustain the ideas. Students who were successful at internalising the information were found at interview to be self-aware and able to state the cognitive change they had undergone. They also claimed that they constantly tried to understand and make sense of what they had learned. This research provides positive support for computer supported collaborative learning as a vehicle for the social construction of knowledge and questions how effective the process can be if the students lack the metacognitive skill and desire to incorporate the new knowledge as a personal construction.

CSCL: The role of the participants

The students are the principal users of any software designed for course delivery. There is a sound theoretical basis and collection of practical case studies to clearly define the role of the students in the collaborative process. Howe et al. (1990) present arguments based on specific studies involving the teaching of physics in secondary and primary schools. The authors cite the observations of Wellington (1988) about the trends in physics education in the UK in the late 1980s. Wellington suggests that there are three identifiable categories of knowledge building that comprise a complete science education. The first category, Knowledge that, comprises the facts and phenomena that make up the traditional content-led approach to physics education. This approach is said to be flawed because of its 'didactic character, its removal from real-life experience and its use of assessment methods that enabled rote learning to flourish' (p. 150). The second category, Knowledge how, comprises skills, processes and abilities that formed the basis of process science courses that became popular in the late 1980s and through the 1990s. However, the idea that one can teach skills in isolation from other types of knowledge is

questionable because it is based on the mistaken assumption that the development of scientific skills can be divorced from the acquisition of other types of knowledge.

The third category, Knowledge why, comprises theories, models and concepts that are represented by the higher categories of Bloom's taxonomy. This is a concept-led curriculum that should take central place in course design. Wellington is careful to maintain that we should not emphasise any of the three categories at the expense of others. However, there is a clear implication that the teaching of knowledge and skills should take place within a framework of developing scientific theories, models and concepts as these provide the context for everything else.

The actual implementation of a curriculum that is capable of achieving a balance between the types of knowledge and provides real learning needs to ensure that the learners' pre-existing ideas are confronted by empirical evidence that attempts to lead the learners to a better explanation. Changing students' conceptions through a scientific process of making predictions, testing predictions and constructing an explanation of observed phenomena can make permanent changes (Howe et al., 1990). The key feature is the making of predictions that will be formed from prior experience and should mirror student alternative conceptions. If these are made individually, without group discussion, it is too easy for the learner to hold on to their conceptions and explain their experimental tests as anomalies or experimental error.

In the group situation, there is no easy escape. If all the participants are required to make predictions, and there are significant differences amongst members of the group, then progress towards new knowledge-building will be more significant. Members of the group must defend their concepts and it is the process of defence that, when alternative concepts differ, is thought to be advantageous. It is the degree of equilibration that produces the internal conflict that decides the extent of useful information. In looking at their study group, Howe et al. (1990) argue that it is more effective for the group to comprise individuals with different preconceptions, which can promote effective learning. The evidence from the single study by Howe et al. (1990) with a computer microworld learning system provides solid evidence to support this stance.

The application of constructivist ideas has implications for the design of CSCL. Prior to any educational interest in collaboration, it had been assumed that tasks must involve the formulation and testing of predictions and the explanation of

experimental results. Should this process produce results that conflicted with predicted results, then the subsequent reinterpretation will promote conceptual change. Once collaboration is introduced as an extra dimension, tasks that involve predicting, testing and explaining are taken as given. The key conclusion about the computer system is that it must oblige the students to make their predictions fully explicit and then come to agreement.

Howe et al. (1990) conclude that in forcing an elaborated, step-by-step process in the representing of predictions on a computer screen, computer software may have a unique role to play. The computer plays the role of a structured information resource. Computer-based tasks allow us to ensure that the students' experience is not haphazard, both in terms of task structure; since moving to each stage of the program may be made dependent on appropriate responses to the stage before, and in terms of task content; where a range of items, impractical to handle in any other way, may be specifically tailored to challenge known alternative concepts. Moreover, these facilities allow us to design tasks that not only promote conceptual development, but which in addition teach explicit procedural skills, and provide experience with a range of relevant phenomena.

CSCL and collaboration

Collaboration in the classroom does not occur because the teacher says it should. The introduction of a computer and some attractive software does not ensure effective learning. Planning for collaboration and designing software to suit a target group are key features of CSCL. One of the most important aspects of group work is to involve all the students in conversation about the topic. Goldman (1996) found that a resource-rich computer environment supported students in their efforts to make sense out of science concepts. The level of participation in conversation was enhanced by such a resource. Goldman's study, based on high school physics labs using a program called Dynagrams to stimulate student involvement in learning about optics, is strongly linked to her beliefs about learning using the theories of situated cognition and social constructivism. In summary, learning is viewed as an on-going participation in communities of practice. In the science community, this participation would entail sharing the understandings of others, the work they do, and the meaning that science has for them in the wider community. Learning means participating and not being part of a passive transfer from teacher to student.

Learning is not a possession, but a long-term result of participating in the activities of a community during which participants collaboratively make sense and organize their knowledge and other concerted behaviours to resolve emergent dilemmas.

Goldman argues being a part of a conversation about the concept is essential for the students. The activities we participate in and subsequent communications are the vehicles for sense - making. To facilitate active learning, Goldman set out to create an environment where

students would have opportunities to engage collaboratively in inquiries that challenged them to have conversations about what was happening while pacing themselves through the procedures of the science (hypothesizing, observing, experimentation, explanation). (p. 57)

Goldman and her coworkers conducted field tests of the software and were surprised by the results. Instead of seeing a concentrated, collaborative learning situation, they found that a significant amount of the time students engaged in conversation and interaction was not directly related to the topic. The surprising conclusion was that the groups needed this social interaction to occur to enable conversations about the physics problems. They required this foundation of purely social interaction in order to develop a basis for task-oriented discussion. Goldman makes the following conclusions about establishing successful science learning environments:

It seems clear that the students were capable of accomplishing cognitive work in group settings, provided that they were rich in resources, props, and opportunities for conversation. The students' search for resources was clear. When students engaged socially, they sought each other, the assignment sheet, and occasionally the teacher. When they engaged in science, they sought each other, the assignment sheet, the simulator, the teacher, and their prior knowledge. The social glue is a factor in the production of the science learning. (p. 74)

So, in order to maximise collaborative learning, as educators we need to provide rich resources that free the teachers and students from the lecture - demonstration type lesson and introduce opportunities for social engagement. The old adage that students' social lives are best left outside the classroom door may need a rethink by teachers.

O'Malley (1995) continues:

The notion that computers can be used to provide more authentic activities for learners fits in with theories of "situated learning", inspired by sociocultural theory. (p. 292)

She quotes Lave, who argues that learning should be a process of legitimate peripheral participation, where learners engage in activity that is genuine science, for example, and not doing artificial or pretend problems in order to learn science.

Computers can provide this sort of authentic experience by giving students access to the same information and tools that working scientists use.

The instructor holds a key role in the delivery of any education paradigm and CSCL is no exception. The special circumstances of collaboration and the use of a computer interface require a sound understanding of the variety of teaching methods and the most suitable approaches to the classroom management. The use of computers as passive tutoring systems is not justified in this context. There is a need to balance teacher and student interactions with the software to produce an inclusive environment for learning.

Tobin and Dawson (1992) echo the thoughts of others when they claim that the teaching of science is rooted in objectivism. The idea that knowledge is an independent entity that can be learned objectively still pervades the modern classroom. If we, as teachers, can put enough knowledge in students' heads then we can expect to produce knowledgeable and wise students. The idea that knowledge has a separate existence is foreign to those of the constructivist school. The act of trying to learn is a personal construction that modifies new material in light of previous experience. It is not possible to divorce prior constructions from new concepts. If the learner is the key to knowledge construction then we can improve the process with a learner-centred curriculum and classroom (Tobin & Dawson, 1992). The issue of teacher control is an important one for both teachers and curriculum designers. Designers need to convince teachers to relinquish some of their control and hand the responsibility to the students, who need to be given sufficient incentive and reason to adopt an active learner role and accept the responsibility. This represents a significant shift in the culture of schools (Tobin & Dawson, 1992).

A number of computer-based tools have been developed to assist teachers in curriculum delivery but many of these tools are little more than tutorials on disk and do not seek to address the problem of learner-centred focus. Tobin and Dawson

describe the ScienceVision project, a collection of interactive video disks, computer software and resource booklets. This project was designed to stimulate small group inquiry by providing material that is linked intuitively by video, databases and experiments. The students decide the path their research takes and ultimately decide what is learned and the depth of that learning. The use of hypermedia to jump to necessary parts of the program is the key to providing a certain amount of flexibility and autonomy for the group. Whilst judged a success by the participants, the authors are sceptical of a significant, system-wide change. They believe curriculum designers will need to adopt more of the constructivist ideology before this type of learning system becomes a focus for the educational process.

O'Malley (1995) concludes that it is a difficult task to design computer-supported learning environments because there are many factors to be carefully integrated. She provides some guiding principles in concluding her article. The technology is not neutral in the design process as it can often change the very nature of the user's task. The designer needs to concern himself/herself with an analysis of the context of the learning situation and then specify the requirements for the technology. Alternatively, the designer may also have to design the context itself rather than regarding it as a backdrop for design.

This approach would interpret the term interactive learning environment in its widest possible sense, which should include not only the design of the software itself, but also the learning activities, the role of the teacher, the type of interaction between participants and the organisational setting for collaboration. (p. 295)

CSCL and communication

Pea (1996) takes a broader look at the field of CSCL and begins by suggesting that most collaborative work designs are better described as 'collective' learning because truly collaborative situations are rarer than designers would like to admit. Pea makes the important point that we need to more fully understand the communicative process if we are to design effective tools for computer supported lessons. Communication is embedded in both social and material structures that are unique to the learning situation. The interaction between individuals involves non-verbal cues that are often essential to impart meaning. In the classroom, materials such as graphs, diagrams and symbols enhance communication. According to Pea, a

rich computer-based tool to support collective learning implies the need for highly interactive, multimedia conversational learning environments.

Two contrasting definitions of communication are a transmission view and a ritual view. As previously mentioned, transmission has been a dominant paradigm in the classroom as knowledge is apparently transferred intact from teacher to student. The ritual view is closely aligned to religious teaching where a group comes together to replicate the social mores and shared belief current at the time. It is difficult to justify an approach based purely on transmission or the absence of ritual in an educational setting (Pea, 1996). In addition, it is clear that ritual alone cannot be effective in education, as the educative process requires generation of new ideas. Pea makes the point that:

Learning is not only a conserving enterprise, which seeks ritual belonging in order to perpetuate sameness and tradition. It is a quest to expand the ways of knowing. It seeks to expand the problem niches to which past concepts and strategies and beliefs are applied. It must establish in its communicative activities the grounds for its own evolution. (p. 174)

Pea proposes that there is a third view of communication, the transformative. This view acknowledges that, in the educative process, the process changes both the student and the teacher (and other group members) itself. The teacher must respond in some way to the reaction of the student in his/her attempt to assimilate new information. This process can result in a transformation of existing practice that goes beyond the common body of knowledge.

Pea makes some telling points about the use of educational computing in the communicative process. He states that the transmission view of communication has been inherited by the educational community, without acknowledging either its commitments or its limitations. Intelligent tutoring systems are an example in which faulty conceptions on the part of the learner are diagnosed and supposedly replaced by the correct information in the tutoring section of the program. Instructional design methods for curriculum delivery always speak of ‘delivery’ of courseware, regardless of the media used. It is an implied transmission method. Pea continues:

Research on the effects of media on learning – whether computing, television, or writing systems – by their very framing of the question in terms of effects, also inherits the transmission orientation. This underlying communication perspective is no less apparent in various multimedia electronic books and

CD-I [interactive computer disk] paradigms now emerging, which profess that learning occurs by browsing, guided exploring, and other forms of exposure to information resources. (p. 175)

Pea states that the more recent views of educational communication in terms of conceptual learning conversations, cooperative learning, cognitive apprenticeship, communities of learning, knowledge building communities, and learning as legitimate peripheral participation, implicitly recognize the need for foregrounding a ritualistic view of communication. In those situations where the communication is primarily a transmission type, the aim of the educator is to use good strategies that ensure the correct information is transmitted to (or constructed by) the learner. However,

There is often lack of recognition that such communicative interchanges transform not only the child but also the expert in the communicative system, the teacher. The system is not one way with this transformative view but a two-way dynamic system. (p.175)

Pea rightly points out that teachers are not simply information broadcasters but are required to understand the thinking of the students in regard to new topics. This research task on the part of the teacher may even lead to the teacher gaining new understandings of the subject being taught. Students sometimes draw surprising inferences that change the teacher's viewpoint. Students often have trouble understanding the teachers approach and can be confused by the teacher's activities in the lesson. Pea offers a means for more effective communication:

For the social construction of understanding to take place, these interpretive activities are, of necessity, highly interactive conversational exchanges requiring conjectures, responses, and repairs for all participants to determine what is meant from what is said and done. This style of discourse is too rare in educational practice, but it certainly exists and can be sustained. (p. 176)

Educators have long accepted the use of a rich variety of media to stimulate learning conversations. Using a graph, text, films, photographs and other symbolic representations produces multiple interpretations in the learners based on prior experiences. However, it often takes more effort on the part of the participants to establish meaningful dialogue and interpretive activities to establish a common ground of understanding.

Towards distributed multimedia learning environments for transformative communications

Changes in communication technologies have opened up a number of avenues for remote delivery of courses. However, much of the design of these courses is geared towards the transmission model, supplying a video of a lecture or having limited feedback from participants by using simple question and answer formats. Much of the content on the Internet is transmission based with little interactivity. Pea questions the effectiveness of this type of learning, as it excludes the formation of small collaborative groups with which the teacher can interact. There is insufficient flexibility built into most current systems that need to involve the community of learners in knowledge building through transformative communication. Scardamalia and Bereiter's CSILE program is such a project.

Although much has been achieved in the development of the World Wide Web and communication technologies, Pea (1996) makes the important point that a definition or set of rules for interactive learning environments needs to be established.

We must begin to define a science of interactive learning environments that seriously embraces conversational and interactional analysis as a means of understanding the transformations of learner and teacher meanings that take place in and around computer-based technologies. (p. 179)

There are three developments required to provide this shift with substantial foundations.

One concerns the concepts of communities and cultures for learning. The second concerns integrating research on conceptual change and conversational analysis. The third involves addressing the design and technical issues necessary to advance testbeds for creating and studying highly interactive, distributed, multimedia environments. (p.179)

The first consideration will require a substantial societal shift in its ideas about learning communities. The establishment of collaborative networks for specific purposes will have to be supported by well-grounded research. There will need to be protocols established for how we connect and participate in networked communities. The second consideration requires the integration of current research into practical classroom activities. The way in which students interact and the conversations about

the learning process are the key features of collective learning. Pea has been active in developing computer-based software called Dynagrams (dynamic diagramming tools). In his study of the student interactions with the software, he was able to elucidate the roles of the students and the teacher in the interactive process. Other models and systems need to be incorporated with their ideas to set up optimal learning situations. The third consideration is to create successful learning opportunities that can convince teachers to adopt some of the ideas and attempt to create their own learning environments based on the research. Work with the Dynagrams project showed that students were actively engaged and on task more often and that their alternative conceptions were significantly reduced. The teacher also modified his lessons to try to eliminate the misconceptions once they were made clear to him/her.

Pea sees that by implementing distributed multimedia learning environments through telecommunications, learning communities can be created using proven software. It would be too hard for teachers to create all the tools needed because the key features of screen design, simulations, models and diagrams need to be carefully designed and tested in relation to the type of learning environment they create. At the moment, most communication is asynchronous via email or bulletin boards. Real-time communication via video conferencing can certainly provide advantages in forming a collaborative group. Clearly, much work is still needed to keep the development of distributed learning alive.

Intended effects with and of CSCL: Tracking learning in a new paradigm

Educators and researchers who have embraced CSCL have noticed that cognitive capabilities were not the sole influence on student learning. The social aspects of situations also play an important part. Investigating the use of computer software in the collaborative process is an important key in understanding the use of technology in education: Do the software tools encourage collaboration or are these tools an enabling technology? Student conversations should be monitored during the process and see if there is a positive influence being generated by the stimulus material. The basic question arises: ‘Do computers make a difference?’ and if so, ‘what is the nature of that difference?’ Kolodner and Guzdial (1996) provide a guide as to the value of the technology in promoting learning by addressing the issue of

transferability of learning. In all educational settings, the program designer should have something to say about transfer of concepts into novel situations. Students need to learn enough to make sense of a complex world and cope effectively with new challenges.

Educational technology is effective in the long run to the extent that its effects transfer to new situations – beyond the classroom and into actual practice. (p. 308)

A critical analysis of any new learning situation requires careful questioning. CSCL is no exception. Some of the considerations are:

What can be expected of the group after their initial CSCL experiences? What can be expected of the individuals who make up that collective – both on their own, and as part of other collectives? Are students learning the intended concepts and skills? Does the software facilitate using pedagogical methods that promote deeper and longer lasting learning? Are students better able to learn from their collaborations using the software? How dependent is future learning on having the software available? Can students collaborate with each other better after experience with the software? Does using the software promote a better attitude toward learning and knowledge building, one that prevails beyond software use? (Kolodner & Guzdial, 1996, p. 308)

The authors are generally positive about published attempts to use technology collaboratively. Pea and Goldman's Dynagrams and Roschelle's Envisioning Machine are seen as valuable exemplars because their visualizations were designed to make explicit those things that, traditionally, students have difficulty understanding. The CSILE project has merit in its attempts to instill deeper learning through a knowledge-building activity that incorporates collaborative processes. Using computers to support problem-based learning shows the value of authentic problems solved in groups to promote deeper learning. Computers can also be used to involve physically separated groups and provide collaborative online tools as well as stimulus material. Computers can provide a shared record-keeping space for collaborators to examine the work of others and make contributions to the collective. The group is seen as the focus for better learning and the technology as its aid.

In looking at the effects of working with CSCL, Koldner and Gudzial see learning as constructing a deep understanding of a concept, not merely being familiar with the concept. They argue that this is the fundamental difference in the objectives

of a traditional transmission-based classroom and a collaborative classroom. In traditional classrooms, there is a form of collaboration when students work in laboratory groups or on projects. The argument is that in traditional settings, the achievement of the task, often at a superficial or minimal level, is the goal (Kolodner & Gudzial, 1996). In collaborative groups, understanding and group learning are the ideals. CSCL should provide opportunity for reflection on what has been achieved. This reflective phase is important in deeper learning.

Of course, the implementation of this sort of system provides disturbing challenges to the traditional school system. The basis of most classes is the teacher setting a scene, exploring some concepts, making notes and basically telling the students the answers. Teacher education institutions and parent bodies may be uncomfortable with any model that shifted away from the way they were taught at school. The idea that students construct the knowledge without being told answers by the teacher is foreign to most educational authorities (Kolodner & Gudzial, 1996).

Kolodner and Gudzial see three key areas to enable CSCL to flourish and change the thinking of educators. The first area, school structure, indicates that effective use of new technology and administrative support is vital. Teachers need to be freed from tight constraints to allow them to experiment with different structures. The second area, teacher support, is important because teachers have little opportunity to learn formally and deeply about collaborative learning or innovative use of software. Teachers are notoriously conservative about changes to their work practice. One argument is that teachers need computer-supported learning environments too. They need to form collaborative structures to communicate new methodologies and examine case studies of new learning techniques.

The third area, software support, incorporates three features of the software that need careful consideration when designing for CSCL, namely, interface, representations, and function. Designing interfaces for learner's needs to take into account the possible prior experiences of the learner. Novices require more guidance and structure to succeed. However, this would not suit all learners, so there should be some flexibility of choices available. The interface must be integrated with the idea of collaboration and should seek to actively engage the students in a discussion of the program's intentions. The representation of the ideas in such a way as to promote extrapolation of data and discussion is also a key feature. However, there is no general agreement here as Kolodner and Gudzial state that:

Feltovich, Spiro, Coulson and Feltovich argue for the value of multiple representations, and Pea argues for students to be able to develop and manipulate their own representations. Too many representations are too complex, and too few offer few opportunities to discuss. (p. 314)

The software has to provide everything that the course designer intends. The function of the software is as varied as the designer wishes to make it. Kolodner and Guzdial (1996) have stated that some of the roles include:

- Promoting inquiry and sense-making, thereby promoting conversation
- Facilitating knowledge building, as in the CSILE project. Students are engaged by the culture of knowledge building, their sense of ownership of their own contributions, and the sense of accomplishment in seeing how they contribute toward the group's learning.
- Providing important record-keeping and/or external memory functions
- Enabling communication with distant communities
- Promoting the kinds of reflection that are facilitated by collaboration.

Collaborative experiences are uniquely suited for encouraging reflections of alternatives – alternative perspectives, alternative solutions, alternative critiques. Software that fits with the criteria set out in Cognitive Flexibility Theory uses the computer to encourage this kind of reflection on alternatives, even without the physical presence of the group.

- Supporting teacher planning and implementation of collaborative activities. The support includes project visualization and planning, descriptions of successful cases, a multimedia journal for recording personal successful practices, and a forum for communicating with other innovators.

What then is the future direction of CSCL? Kolodner and Guzdial offer some philosophical points. CSCL is a seamless merging of cognitive and social perspectives; concentrating solely on a cognitive approach or a social view will not constitute an effective learning experience.

By combining the social perspective with the cognitive perspective, CSCL has the potential to help us make important strides forward in helping us to understand how we might facilitate learning in real-world situations.....At its best, current CSCL takes into account cognitive and social needs in

learning, producing interesting and innovative software systems that support both. (p. 319)

This is obviously a good thing but more study is needed to answer several important questions that relate to both individual and group learning. We need to find out how effective the learning has been after using the software. Can we determine exactly what has been learned and is the new knowledge transferable? Because of the time that needs to be invested, CSCL is a paradigm that must replace the convention of learning a lot of things in a shallow manner. CSCL operates on the philosophy that less is more. It is more important to learn a smaller number of concepts and skills deeply than to learn a large set of facts in a shallower manner. Working in a collaborative manner is a skill that requires practice. It is also a perspective that many people can work more effectively than one person. If we are to promote the ideal of the lifelong learner then CSCL can play its part by developing the skills and perspective that encourages collaboration. More evidence is required to accurately assess the effects of CSCL in the classroom and to see if teacher training institutions adopt some of the key principles in their education courses.

Summary

This chapter has presented a number of arguments for the use of computer-based learning as a means of changing the way that students and their teachers approach the instructional process. There is a general consensus that well-designed computer tools can encourage collaboration that will lead to knowledge construction in a cooperative environment. The difficult parts of the process will be in the initial design and the training of teachers and organisations when they attempt to implement the programs. Research findings indicate that there is a general optimism towards this approach and improved knowledge by teachers of this field can certainly produce benefits in the classroom. The type of software-based tool that I have developed deals with the use of analogies to help explain Le Châtelier's principle as it applies to equilibrium systems. It was developed as a collaborative tool using the theoretical guidelines from the authors in this chapter. The next chapter deals with the theories of analogical thinking, the use of analogies in the classroom and the ideas behind the teaching of chemical equilibrium at high school level.

Chapter 5

Analogies and Chemical Equilibrium

Introduction

Judging the effectiveness of any teaching strategy is an important part of the evaluation process that teachers employ. There must be some good reason for adopting a teaching technique that significantly changes the normal pattern of operation in the classroom. The use of analogies to explain difficult concepts should be justified as an effective strategy before it is implemented. The first part of this chapter looks at how analogies might best be employed in the classroom and examines effective teaching techniques used to support their use. This analysis will provide more information to help answer the first and second research questions as effective design and implementation are discussed. The second part of the chapter looks at the teaching of chemical equilibrium specifically and some of the inherent difficulties involved in successfully understanding changes to systems at equilibrium. This last section is directly relevant to the first research question.

Analogical thinking

There is a significant body of research into the use and usefulness of analogies in teaching. A dictionary definition of an analogy describes the concept as: a relationship of similarity or likeness between two or more entities. For example, an analogy, or similarity, between the human heart and a mechanical pump has been argued. In logic, analogy is the name of an inductive form of argument which asserts that if two or more entities are similar in one or more respects, then a probability exists that they will be similar in other respects. Historically, analogies have been used for a variety of purposes. Literary analogies have been used to paint vivid word pictures. Scientific analogies have been used for explanatory purposes. In philosophy, Plato illustrated his ideas by the use of well-developed analogies. (Australian Infopedia 2.0, 1998)

The importance of this definition lies in the fact that an analogy must compare two or more entities. This is the feature that distinguishes an analogy from a metaphor. An analogy compares structures in two domains explicitly whereas a metaphor compares implicitly and does not aim to compare features of the two domains (Duit, 1991). In this sense, analogies are more functional in the instructional process. The use of

metaphorical language can add colour and interest to subject material but it does not provide a framework to assist knowledge transfer in the same way that analogical reasoning can.

Theoretical and practical support for the use of analogies

To use analogies in the teaching process, it is first necessary to justify their inclusion. If the teacher's reason for using an analogy is simply that it seemed like a good idea at the time then it probably would not stand close scrutiny. Very often an analogy might be quite acceptable but may fail in achieving the intended outcomes because of poor methodology in terms of mapping similarities and dissimilarities between the analogy and the scientific concept being taught. So what evidence is available to support the use of analogies?

Analogical reasoning has been the focus of research in many areas including artificial intelligence, creative problem solving and learning by example (Goswani, 1992). Analogies have been widely used in the history of science. For example, Archimedes was able to see the connection between water displaced from a bath and accurately measuring the volume of a gold crown. Analogies have been used to teach new ideas and relationships and also to assist in problem solving.

For learning to be meaningful, new knowledge must be integrated with existing knowledge. This is a complex process and involves the interaction of key cognitive processes including image formation, organisation and drawing analogies. As these processes interact, the mind is able to construct relationships among concepts (Glynn, Duit & Thiele, 1995). To a cognitive psychologist, the idea of reasoning by analogy is a core component of human cognition because 'it is involved in classification and learning, it provides a tool for thought and explanation, and it is important for scientific discovery and creative thinking' (Goswani, 1992, p. 1).

Problem solving by analogy provides a rich opportunity to carefully match ideas and relationships. A new problem can be tackled by using a familiar scenario or story. The success or failure of the analogy is dependent on a number of factors; for example, the age of the students is an important factor especially when dealing with young children (Goswani, 1992). Piaget used analogical reasoning to help establish boundaries between concrete and formal-operational thinking which occurred in the 11 to 12 years age bracket. His research showed that reasoning by analogy is a higher order thinking skill and is not usual in younger children.

The theory of analogies

Stepich and Newby (1988) approach the use of analogies from the theory of how the brain acquires new information. They state that

All knowledge is stored in human memory in terms of interacting cognitive structures..... labelled schemata knowledge modules propositions frames and scripts. The acquisition of new knowledge occurs via the active discovery and/or the development of schematic relationships among pieces of information and the integration into existing schematic structures. (p. 129)

They add that analogies will prove beneficial when new information is not readily related or subsumed within existing structures. It is a process of relating the new to the familiar.

Using an analogy facilitates effective encoding by providing a means of using existing knowledge to manipulate information. Learning by analogy is the process of selecting a schema already known to the learner, and using it as a guide to create a schema for the information to be learned. An analogy is not a schema for new information. Rather, it is a means of generating a schema for the new information, using an existing schema as a cognitive template. An analogy improves retrieval of information by providing an effective retrieval cue. According to Treagust et al. (1994),

an analogy is a process of identifying similarities between concepts. One concept is familiar and is referred to as the *analog* and the other is unfamiliar and is called the *target*. Usually the target relates to the scientific concept. There are features of the analog which are like features of the target and features which are unlike the target. (p. 1)

Figure 5.1 showing the comparison or mapping between analog and target is a useful representation of how an analogy works (see next page).

The advantages of analogies

An analogy aids the visualisation process in learning. An analog that the students are familiar with, or have seen, is valuable in helping them visualise abstract concepts. In addition, there can be a real world linkage when the presentation of a concrete analog facilitates understanding of an abstract concept by pointing to similarities with objects or events in the students' world. This process should promote meaningful learning. Analogies also provide a motivational function as the teacher is drawing

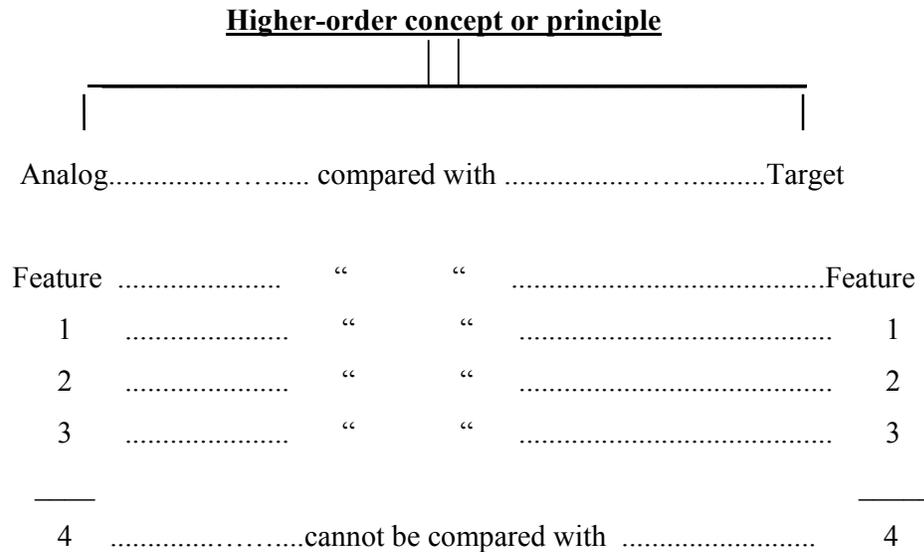


Figure 5.1: Relationship of the analog to the target (from Treagust et al. 1994).

upon the students' real-world experience; a sense of intrinsic interest is generated. If students are able to achieve a higher level of conceptual understanding than usual, this also can result in motivational gain. Construction of analogies encourages the teacher to consider the students' prior knowledge. Students' prior knowledge influences the way they perceive new concepts and it can be advantageous to consider what the student knows and how this knowledge can be utilised before teaching any concept (Treagust, 1995).

The constraints of analogies

Students are often unfamiliar with an analog, especially if it is centred upon the world of adults. This unfamiliar analogy may cause greater confusion and misunderstanding. Teachers should try to choose analogs that are familiar to their students or explain the analog to the students to help remediate this problem. Alternatively, open discussion in the class about the analogy will help the teacher identify where analog unfamiliarity may be a problem. The level of cognitive development of the student can influence the level of understanding required for the effective use of the analogy (Treagust, 1995). If students lack visual imagery, or knowledge of analogical reasoning or correlation reasoning, then the effective use of analogies is believed to be limited. In addition, those students already functioning at a high level may have attained an adequate understanding of the target and the inclusion of an analogy might add an unnecessary information load that could also

result in new misconceptions being formed by students (Treagust, 1995). In addition, the features of the target and analog that are not shared are often a cause of misunderstanding for the learners if they attempt to transfer them. When analogies are used during classroom instruction, discussion should take place to assist in defining the limitations of the analogy (Treagust, 1995).

Teaching sequence when using analogies

Stepich and Newby (1988) proposed a teaching sequence for the use of analogies. Their scheme, which involved constructivist ideas, was built on the following sequence:

1. What do the learners already know?
2. What is the nature of the specific learning task involved in the instruction?
3. Construction of the analogy.
4. Presentation of the analogy.

These authors believe that the placement of the analogy in the teaching sequence is a critical factor in its effectiveness. As analogies are designed to operate during the encoding of new information, they should be presented early in the instructional sequence. Once introduced, there should be time allowed for the students to compare the analog with its target. It is important that this time is factored into the instructional sequence and that it be adequate for the group involved.

Glynn et al. (1995) provided further elaboration on the model for teaching with analogies. They state that analogies may do more harm than good as teachers and authors often lack the guidelines and training to use analogies effectively. If the analogy is not useful, then the analogy may be a distraction or its ideas blurred with that of the target. The analogy and the target require similar features and the process of describing the similar features is known as mapping. This comparison can be either verbal or visual. It is important to realise that no analog maps onto the target perfectly. If the target and the analog were the same then they would be the same concept. The idea of an analogy is that the analog breaks down at some point. It is for this reason that teachers should provide a number of different analogs to students to improve their chances of understanding the concept (Glynn et al., 1995).

Glynn et al. further point out that it does not matter how well an analog maps to a target, the important task for teachers and authors is to make sure that the students are familiar with the analog before attempting to use it. For example, if a mechanical

pump is used to represent a heart, are the students aware of the functioning of a mechanical pump? In addition, if students overgeneralize and map non-corresponding features of concepts then misconceptions can arise. Effective teachers make systematic use of analogy and emphasise to students that analogical thinking is powerful, but limited, and that wrong ideas can arise when an analogy is carried too far. When teachers and authors use an analogy they should anticipate analogy-caused misconceptions and eliminate them by pointing out to students where the analogy breaks down. Teachers should engage their students in a discussion in which the limitations of the analogy are identified (Glynn et al., 1995). To formalise the process, Glynn et al. have produced a teaching sequence or teaching with analogies model as follows:

1. Introduction of the target concept
2. Cue retrieval of analog concept
3. Identify relevant features of target and analog
4. Map similarities
5. Indicate where the analogy breaks down
6. Draw conclusions

This series of steps is an attempt to make the teaching of analogies a planned, logical sequence that should ensure a worthwhile use of an analogy. However, the process is fraught with difficulties as the untrained teacher and the uninitiated student could certainly make a mess of what should be a structured approach. Finally, the same authors point out that it is advantageous for students to try creating their own analogies for a particular target. This process should increase the meaning for the students and increase their independence as learners.

The research to this stage has shown a distinct methodology needs to be followed in the use of analogies in the classroom. Most of the researchers build their schema on existing ideas and the common theme for the use of analogies is well summarised in the teaching with analogies model of Glynn et al. Given the well established mechanics and the processes and research used to establish them, the authors must have been convinced with their potential as effective tools in teaching and learning. Treagust et al. (1994) produced the FAR guide for teaching with analogies to further formalize the process of using analogies in the classroom. The guide was developed in cooperation with secondary school teachers in Australia and contained several practical examples for use in schools (see also Treagust et al. 1998).

Analogies and chemistry teaching

Royer and Cable (1976) used written analogies in science to test their effectiveness with a group of students and found that the use of analogies, illustrations and concrete examples improved student performance markedly. Royer and Cable commented that the use of this technique is most effective with difficult subject material (hence we find analogies for the abstract ideas in chemistry textbooks) and argued that facilitative transfer should occur when the target material cannot be readily assimilated into existing knowledge structure. The analogy should establish a knowledge structure into which the difficult target material can be incorporated; that is, the analogy is a familiar real-world link.

In comparing the use of graphic analogies against a text-based approach for students who were studying aspects of electrochemistry, Rigney and Lutz (1976) designed tests to assess knowledge, comprehension and the ability of students to apply concepts in different situations. They found that external imagery results in better test results and more enjoyable learning. Students displayed a more positive attitude towards the lessons that involved the visual imagery.

Gabel and Sherwood (1980) investigated the usefulness of analogies in chemistry teaching comparing concrete-operational and formal-operational students in their ability to understand analogies and to apply those analogies. Their findings were less than encouraging in that they found more able students benefit more from extra practice problems than from using analogies. However, their work with concrete-operational students showed some improvement in their understanding after being taught with analogies. Their conclusion that this group benefits more than others is moderated by the fact that 48 % of the students in their study group did not fully understand 90% of the analogies used by their teachers. Gabel and Sherwood did not advocate the abandonment of analogies but suggested that if they are to be used then they would be better aimed at the weaker students and need to be redesigned so that these students better understand them.

Gabel (1998) contends that using analogies to solve problems in chemistry results in higher achievement on problems involving moles, stoichiometry and molarity but she again cautions that students often have difficulty understanding the analogs used. Obviously a variety of teaching strategies are required to involve the largest number

of students in the learning process but it would seem that, used appropriately, there is a place for analogies.

Chemical equilibrium and Le Châtelier's principle

‘Tout système en équilibre chimique stable soumis à l'influence d'une cause extérieure qui tend à faire varier soit sa température, soit sa condensation (pression, concentration, nombre de molécules dans l'unité de volume) dans sa totalité ou seulement dans quelques-unes de ses parties, ne peut éprouver que des modifications intérieures, qui, si elles se produisaient seules, amèneraient un changement de température ou de condensation de signe contraire à celui résultant de la cause extérieure’ (Henri Louis Le Chatelier, 1884)

This is the original version of the idea that Le Châtelier described as ‘très simple’ and it is the version that he defended as the only true form of his principle. A fairly literal translation follows:

A system in stable chemical equilibrium, when subjected to the influence of an external cause which tends to change either its temperature or condensation (pressure, concentration, number of molecules in unit volume), throughout or in only some of its parts, can undergo only such internal modifications which, if they occurred on their own, would bring about a change of temperature or of condensation of a sign contrary to that resulting from the external cause. (Gold & Gold, 1984, p.802)

Although a number of modifications have been suggested since 1884, the ideas expressed have survived almost unchanged. Le Châtelier thought the idea was ‘très simple’, but throughout time and under closer scrutiny it has proved to be anything but simple and far from correct. Le Châtelier's work was based on earlier offerings from his peers. In particular, van't Hoff's principle of mobile equilibrium plays a prominent part. J.H. van't Hoff (1896) had stated that ‘lowering temperature led to a displacement of the equilibrium position towards the state whose formation evolves heat’ (Gold & Gold, 1984, p. 803). His work, however, had a significant advantage over that of Le Châtelier in that he was able to put it in quantitative form.

In modern notation his equation is:

$$(\delta \ln K_p / \delta T)_p = \Delta H^0 / RT^2$$

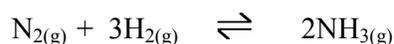
The corresponding equation that shows the dependence of equilibrium constants on pressure was formulated later by Planck and van Laar (Prigogine & Defar, 1954) and is:

$$(\delta \ln K_x / \delta p)_T = - \Delta V^\circ / RT$$

These equations are much more powerful than Le Châtelier's principle as they not only predict the direction of the shift in equilibrium, but also its magnitude. Most thermodynamicists have considered that Le Châtelier's principle is unimportant in the mainstream of thought because it lacks this quantitative treatment (Gold & Gold, 1984). However, the reality is that in high school texts and less advanced chemistry texts, it is Le Châtelier who prevails. Gold and Gold cite several reasons for the long survival of this less rigorous principle. For those technicians working in industry who may have poor mathematical skills it is a reasonable rule of thumb and this also applies to school students. The mathematical treatment can be quite daunting for those who have not yet reached that level. In addition, because it is such a simple and seemingly elegant explanation of complex phenomena, it suits man's beliefs in the search for some universal rules of nature (whether they exist or not). Whatever the reasons, the principle is alive and well with its innate problems not exposed to the novice student.

In certain circumstances, Le Châtelier's principle actually produces a result contrary to the observed reaction. There is no such inconsistency with the van't Hoff equations. Some workers have attempted to convert Le Châtelier's principle into a practical quantitative form that could be generalized but found the process overly complex (Prigogine & Defay, 1954). Other workers have found that Le Châtelier's principle fails to provide the correct answer in relatively simple situations.

Consider the following classic example for concentration effects:



It is true that the addition of a small amount of N_2 at constant temperature and pressure forms a little more ammonia but this is dependent on the initial mole fraction of N_2 . Above 0.5 we find that the opposite reaction occurs and less ammonia is produced. Surely a principle that is reliant on reaction conditions is not a principle at all. Many workers after Le Châtelier struggled to form a simple and general principle but failed (Gold & Gold, 1984). The equations of van't Hoff give a much more reliable prediction of changes in equilibrium systems.

Allsop and George (1984) are firmly of the belief that Le Châtelier has no place in the British Advanced level syllabus. They contend that misinterpretations would be rare if Le Châtelier's principle was discarded and replaced with the more mathematically correct view of equilibrium via the equilibrium constant. This is a compromise view as it does not need to involve the higher-level mathematics of van't Hoff and is also a part of the high school syllabus. Hackling and Garnett (1985) believe that a quantitative approach based on the equilibrium constant expression is essential for anything more than just rote learning of the principle. They proposed a teaching sequence that places the equilibrium constant work before Le Châtelier is mentioned. While it may be chemically more accurate to discard Le Châtelier, it would be practically impossible given the entrenched nature of the principle in introductory chemistry courses. What is needed is to understand the problems generated by using Le Châtelier's principle and then develop strategies to effectively deal with those problems.

In 1960, Driscoll outlined five reasons for students mistakenly applying the principle to problem solving. These were:

1. Using an ambiguous or faulty statement of the principle.
2. A lack of a thorough appreciation of the factors affecting the position of equilibrium.
3. A confusion between the *extent* of a reaction and its *rate* (how *far* it goes and how *fast* it gets there).
4. Attempts to apply the principle when the system was not in thermodynamic equilibrium.
5. A failure to consider the effect of a particular change on all equilibria which may be concerned with the reaction.

All these factors are likely to occur during the secondary school chemistry course and some care needs to be taken to minimise the common faults. Jordaan (1993) approaches the problem from a more general viewpoint. He believes that the problem is one of deep understanding (or a lack thereof) and describes four conditions that need to be met to satisfy the requirements for deep understanding. (Note: Jordaan uses the term Law but it can as easily be applied to tenets and principles).

1. To understand the concepts used in the law.
2. To understand the mutual interrelationships between the concepts and to be able to tell what the boundary conditions are within which the Law is valid.

3. To be able to state the law in his/her own words and also recognise an alternative formulation.
4. To recognise and/or give and/or construct simple applications of the Law.

Jordaan (1993) looks at ways in which Le Châtelier's principle can be interpreted to allow for all the conditions of understanding. He comes to the conclusion that the parameters of the general principle are too confusing and lead to misconceptions. He proposes that the use of pressure and volume changes in gas equilibria be eliminated in favour of Le Châtelier's original stance of only considering temperature and concentration effects. He produces what he believes is the closest statement that can be correctly interpreted by students.

If a non-isolated system in stable equilibrium is subjected to a change in the temperature or concentration of any of its reactants and/or products, a process (reaction) *may* occur within the system which will counteract the imposed change in temperature or concentration. (p. 12)

The word 'may' is necessary because of the exceptions that occur.

Given this improvement to the principle as a basis, Jordaan makes some suggestions to improve the depth of understanding. To better understand the concept he suggests that the language is a problem. It is a combination of lay terms and scientific terms and careful attention by the teacher is required to address this issue. To better understand the mutual interrelationships and be able to recognise boundary conditions it is important to introduce a number of different examples. Students should be familiar with varied cases and be prepared to interpret them as a response to temperature change or concentration effect. Jordaan hopes for an examination system in his country where ambiguities inherent in various applications of Le Châtelier's principle are eliminated by more specific questions. If we remove the possibility of multiple effects from the question, then applying the principle becomes a more straightforward process.

Research efforts in the classroom have reported methods to improve the understanding and achievement levels of students when attempting to solve problems involving chemical equilibrium. Comacho & Good (1989) looked at the problem solving strategies of novices and experts as they were given a range of tasks. They concluded that the path to effective problem solving is neither short nor direct. The transformation from novice to expert requires the acquisition of domain-specific knowledge and training in effective techniques. Comacho & Good reinforce the ideas

of situated cognition and cognitive apprenticeship as summarised by Brown, Collins and Duguid (1989). They provide some specific tactics to improve understanding. These include the provision of class time for both individual and small-group problem-solving efforts. The instructor should not assume that all students function at the same level and not all of the lesson should be lecture style. The instructor should search out misconceptions and deal with them as they arise. Students should be encouraged to discover inconsistencies in their arguments with frequent checking of their ideas amongst the group.

A common misconception among students is the distinction between the term “equilibrium” and the term “chemical equilibrium”. Gussarsky & Gorodetsky (1990) probed students’ understanding of the relationship between the two. They discovered that the common interpretation of equilibrium as a state of balance, much like a see-saw, interfered with understanding of chemical equilibrium. In attempting to translate the idea of equilibrium to chemical reactions, students often split the reaction into two sides so that the reactants and products were completely separated. The idea of a balance in a reaction led to a rather static view of chemical equilibrium. The dynamic aspect of continually interchanging species is often not well understood. Gussarsky & Gorodetsky recommended that the misconception in the two terms be highlighted by the instructor and actively assessed by the students. In attempting to distinguish between the two terms, it was hoped that they would better understand the concepts and how they differ. Niaz (1995) looked at the relationship between conceptual understanding and the ability to solve computational problems. He found that students who exhibited a higher level of conceptual understanding were also better at solving associated problems. He argued that students should be given exercises that require conceptual understanding prior to problem solving questions. He stated that at the time of writing it was commonly held that if a student was given computational exercises first that this would lead to conceptual understanding. His study provided evidence contrary to this idea. Niaz argues that teaching methods should initially focus on ways to improve conceptual understanding. The use of analogies is one method to achieve this.

A study by Huddle and Pillay (1996) was concerned with the abstract nature of the subject material when teaching chemical equilibrium. They identified eleven common misconceptions about chemical equilibrium that had been cited in previous studies. These misconceptions range from erroneous ideas about reaction rate

changes to being unable to clearly distinguish between the rate of a reaction and its extent. The terminology used in textbooks such as “shift” and “move to the right” have different contextual meanings for students. There is confusion about reactions that go to completion and reversible reactions. Huddle and Pillay stated that there is a need to address the abstract concepts by employing concrete analogies in the introduction phase. They question whether such concepts should be taught at high school level and believe that more descriptive tasks should be set that do not involve abstract thinking. They also advocate the use of small, cooperative groups to give individuals time to construct concepts for themselves and hopefully gain a deeper understanding of the nature of chemical equilibrium.

Tyson, Treagust and Bucat (1999), having considered the research to date, decided to look at data from Western Australian high schools and attempt to understand the difficulty involved in teaching equilibrium. They considered that the specific nature of the content was a significant factor because it is abstract with a high degree of linkage to other content areas of chemistry. To arrive at a correct conclusion, in many examples, the thinking has to be highly sophisticated, as the interpretation required of terminology and concepts is very specific. The language used in the topic often uses terms such as ‘shift to the left’ that may have more than one meaning in a student’s preconceptions. In using common terms, we may be holding the theory up to misconceptions that can impede learning. Just the word ‘equilibrium’ has a general meaning of ‘equal’ that has implications when interpreting reaction position. Tyson et al. suggest that terms like ‘equilibrium position’ and ‘equilibrium balance’ be avoided and that the class be focussed on the concentration of a particular species in an equilibrium mixture. Indeed, most examination papers have tried to eliminate confusion about the terminology by narrowing the question to the effect on a single species.

Tyson et al. provide three approaches to the teaching of equilibrium effects. These are Le Châtelier’s principle, the Equilibrium Law and reaction kinetics. All three can be used independently to predict changes in an equilibrium system but there are limits to their useability in the classroom. Le Châtelier’s principle may lead to the correct answer in specific questions but at the same time it may provide an incorrect scientific interpretation as to the cause. The Equilibrium Law will yield a correct answer but may take too much time and effort in cases where Le Châtelier’s

principle also yields the correct answer. Reaction kinetics may be just too abstract for some students to follow in many examples.

In a survey of teachers, Tyson et al. found 87% of them preferred to teach using Le Châtelier's principle ahead of more accurate, numerical methods. This is because it is probably 'très simple' as Le Châtelier himself reminded us. It is deceptively easy to apply and yet may lead to misinterpretation that the student is unable to explain. Tyson et al. also point out that students often fail to explain concepts because of a lack of visualisation skills. If students can focus on individual species and eliminate non-essential features then perhaps they can reach a chemically sound conclusion.



Figure 5.2: The water transfer model (from (Geddes & Jaipal, 1993 p. 3).

Geddes and Jaipal (1993) reported a case study in teaching for understanding using chemical equilibrium. They observed a teacher introducing equilibrium in a series of three lessons. The teacher knew from experience that multiple representations and grounding the concepts in the students' world were essential to maximise understanding. In addition, he found it important to go beyond the descriptive terms and talk about the molecular behaviour. He used a variety of methods from demonstrations using the water transfer model (see Figure 5.2), to textbook work, to a descriptive analogy for the process. His concern was motivating students to accept the theory in the context of their world.

In summary, Le Châtelier's original principle was concerned with looking at temperature and concentration effects. If we keep within these guidelines then the potential for misinterpretation is reduced. While misconceptions are common, it is

not necessarily an argument for abandoning Le Châtelier's principle altogether. There should be a teaching sequence for equilibrium change that covers the requirements of the various syllabi and at the same time exposes inherent problems that lead to confusion. To only use Le Châtelier's principle would be a major error. The underlying cause of the change is more important than correctly predicting the effects. To create a definitive teaching sequence and technique would indeed be a major achievement.

Summary

The teaching of chemical equilibrium requires the student to think carefully and in some depth to understand the nature of the changes that are occurring. There can be a number of sources of confusion and misinterpretation that will cause the student difficulty in understanding. The use of analogies to improve the way students think about equilibrium change appears to be a fruitful area for exploration. The next chapter outlines the methodology behind the research program which leads to a report on the case study itself.

Chapter 6

Research Methodology

Introduction

This research project involved a series of interrelated phases of design, development, implementation and evaluation. The boundaries between these phases became blurred as the software program was changed incrementally to suit observations made during each implementation phase. The program itself developed steadily over a three-year period. The methods of collection and analysis of data also changed over time to provide a variety of measurement tools (see Table 6.1). This chapter will provide a brief, general overview of the methods employed to produce the software program, information about the participants in the project, the types of data collected and an overview of the challenges faced by the teacher/researcher in the classroom in producing a case study.

Software design and development

The authoring language was Hypertext Markup Language (HTML) to provide a web site on CDROM with meaningful links between the various concepts in the text of the program. The graphics were produced using a paint program and then assembling the animations with a GIF animator. The initial task involved producing animated analogies to map to various aspects of the changes to systems that had reached equilibrium. The nature of the analogies changed over time, as did the text structure that surrounded them. The final lesson sequence reflected the criticisms and suggestions made by students, teacher colleagues and research students. The program design was heavily influenced by existing learning theories that were based on constructivist principles and guidelines for the use of analogies in teaching.

Implementation and evaluation

Sections of the software program were introduced to four separate groups of students over a three-year period. Feedback was obtained through teacher observations, student observations, assessment tests, taped lessons, and brief interviews and written surveys. After each trial of the program, modifications were made to the software to reflect the feedback. The HTML format proved to be relatively easy to implement but the GIF animations were quite a challenge in both design and production.

Table 6.1
Summary of Research Questions and Research Procedures

Research Questions	Data Type	Instrument Developed	Sample Selection Strategy	Data Collection Strategy	Internal Validity	Data Analysis
1. Can multimedia analogies be developed to improve the way that aspects of chemical equilibrium are taught?	Qualitative	Analogies created as motion clips (animated GIFS) with sounds added to pressure analogy. Questionnaire	Purposeful sampling	Observation, Taped lessons, Interviews, survey	Long term observation and repetition of tests and lessons	Description
2. What specific teaching strategies need to be developed to accompany the software that most effectively challenge and stimulate student thinking in the classroom?	Qualitative and quantitative	Survey questions	All answers were included	Survey, taped lessons, observations and interviews	Long term observation and repetition of tests and lessons	Statistical and description
3. How effective are the software and teaching strategies in enhancing learning about chemical equilibrium in senior chemistry?	Quantitative and qualitative	Survey questionnaire	Purposeful sampling. All responses tabulated	Survey, interviews, observation and interpretation of taped lessons	Long term observation, follow- up questions of students and repetition of tests and lessons	Statistical and description

Research population

The student participants were from senior chemistry classes at a comprehensive high school in NSW. The school population had decreased dramatically after 1993 because additional high schools were opened in the area. One of these schools became an academically selective school for the area and contributed to a drift of superior students away from their usual comprehensive high school (New South Wales. Department of School Education. (1991)). With a total population of approximately 800 students in Years 7-12, there are now, on average, approximately 70 students in Year 12. A typical chemistry class would have between 6 and 12 students in the final year although they would start Year 11 with anything up to 18 students. This is a typical group size for schools with this student population. Larger schools with populations above 1100 students in Years 7-12 would typically have classes with about 25 students. The academic results in chemistry over the previous few years have shown a population significantly below the NSW state average by more than one standard deviation (New South Wales. Department of School Education. (1996-98)).

The students in the first three groups presented in the case study had shown from their school assessments that they were little different in composition to previous years. Indeed, their final examinations supported the view that, in general, these students were below the state average in chemistry. They had all been taught chemistry as units of work in Years 7 – 10 and would be expected to be familiar with the Periodic table, simple word equations for chemical reactions, simple formulae and atomic structure. The specific makeup of each group were: Group 1: 6 students 4 male 2 female, Group 2: 6 students 4 male 2 female, Group 3: Two males, Group 4: 12 students 8 males 4 females. Group 2 was atypical in size as minimum classes would run with 5 students in most schools. These classes were also disadvantaged by having reduced face-to-face teaching time. As groups shrink below 12 the number of timetabled lessons is reduced. All of these student groups could expect to receive up to 40 hours less teaching in the classroom than their peers with larger class sizes in other schools. The students were mostly from a white, Anglo-Saxon population with the exception of three girls from South-East Asia in the fourth group. A few of the students were capable of achieving well but the majority found chemistry a difficult subject and struggled with key concepts. It was the lack of achievement that prompted the research efforts reported in this thesis.

Research data

The principal source of student data gathered was from transcripts of taped lessons that I had conducted while implementing the program (see Table 6.1 and Appendix D) and notes taken from lessons. In addition, written responses from students and answers to evaluation questions were employed. My personal observations and notes from interviews were used to supplement the lesson data. The final group was asked to complete a survey that was designed to more objectively test the types of data that had been gathered in the previous three groups. The surveys were collated into a spreadsheet program that produced a series of graphs to pictorially represent the findings. The findings are qualitative in nature and rely heavily on teacher/student interactions. The validity of the data relies on the repetitive nature of the task and the similarity in the findings from four different groups over a four-year period.

Evaluating the research methodology

The research presented here entails a case study of the impact of an innovative teaching approach with successive groups of students. I would like to describe several aspects of case study theory and show how this relates to my study. Merriam (1998) describes a case as a single entity, a unit around which there are fixed boundaries. The researcher must be able to define the boundaries in order to produce a single case. A case study is not limited to any particular methods of data collection or analysis. Any combination of data collection, including interviews, surveys, testing and observations can be relevant to the case. The case study focuses on a holistic description and explanation. The design of a case study is best suited to those situations where it is impossible to separate the variables from their context. Merriam states that it is

particularly relevant to describing an entity in qualitative, complex and comprehensive terms not infrequently as it unfolds over a period of time (p. 29)

The case study often focuses the way a particular group confront specific problems. As such they are usually problem-centred, small scale, entrepreneurial endeavours (Merriam, 1998 p. 29). The description of a case study is usually qualitative, using prose and literary techniques to provide a rich description of the incident. By using rich descriptions, often the researcher and readers can discover

new meanings which lead to a change in the way people think about a phenomenon. The key to a case study is not so much the methods employed but the questions asked and how those questions relate to the end product. The value of a case study lies in its uniqueness, the fact that it is providing data and meaning that other forms of research cannot produce. Merriam uses the words of Abramson (1992) to encapsulate the value of such studies:

First, since such data are rare, they can help elucidate the upper and lower boundaries of experience. Atypical cases....are essential for understanding the range or variety of human experience, which is essential for understanding and appreciating the human condition (p. 190).

I consider my study to be atypical as it was the only one of its kind of which I am aware. My case study is best defined as an evaluative one that involves description, explanation and judgement. The students in the fourth study were issued with a survey designed to evaluate their experience with the software. The results of this evaluation are to be found in the Chapter 7 on pages 134-138.

Merriam (1998) points out that there are a number of limitations that need to be considered in any case study. Firstly, there are often time restrictions that can interfere with the ability of the researcher to produce rich, thick descriptions. Secondly, case studies are only a small slice of experience. The researcher can tend to exaggerate the significance of the study or conversely oversimplify the data to produce some meaning for the reader. Thirdly, the researcher is often left to his/her own instincts and abilities throughout most of the research effort. There are no firm rules about how to analyse the data collected. Training in data collection and analysis is necessary but not always available to the isolated researcher. For this case study, I was fortunate to have had some experience provided by the preliminary course work and felt confident interviewing students. Finally, there is a perceived lack of rigour linked to the problem of bias introduced by the subjectivity of the researcher. It is necessary, then, to consider some of the problems faced by the teacher/researcher in gathering data while attempting to teach new information to students.

Wong (1995) highlights some of the problems that can occur when teachers attempt to conduct research in their classroom. The research process involves objective data gathering that can be in conflict with the moral responsibility of teaching a topic effectively. Often, it is necessary to pursue ideas with individual students at the expense of the group, setting up a moral dilemma for the teacher.

Wong's experience was similar to my own as he questioned the extra time taken with an individual at the expense of the group (p. 23). There were several occasions where I felt it was important to pursue an individual's ideas because they were leading to interesting insights related to my project. However, this produced an internal conflict as I could see the rest of the group losing focus and interest.

Wong asserts that when teachers act as researchers they often have to change the way they conduct their lessons to suit the type of inquiry (p. 26). One of the goals of my research was to investigate the collaborative process and group dynamics to determine if the software could act as a stimulus for focused discussions. This was not the typical classroom setting for my test groups, so they needed time to adjust to the new lesson structure. One of the more important adjustments, from my point of view, was the amount of teacher intervention in the process. As group leader, I had to make important decisions as to the pace of the lesson and when to encourage further student involvement. Wong also states that part of the dilemma is a moral duty to ensure that changes in classroom conduct are beneficial to student learning (p. 27). The principle goal of my project was to improve student understanding of difficult concepts. I was not convinced that the methods I had employed previously were very effective and I believed that some change was necessary.

A further problem was the collection of data. Using a tape recorder was the least intrusive device I could think to employ. It allowed me to concentrate on what the students were saying and on the lesson structure. Later analysis of the tapes provided time for reflection and produced some surprising findings. Making notes during the lesson was less effective and would often require further work after the lesson to provide more details from the hastily compiled summaries. Interviews with students were usually very good experiences as they provided time for reflection on the events from the lessons. The surveys also proved to be a useful tool as they provided time for the students to focus on the issues involved in the research (the students were given the weekend to return the surveys).

Knowing when to stop data collection was also important. I decided to finish the trials when the data collection was producing only small increments of new information in comparison to the effort needed to obtain them. The final group produced few new insights and I felt that I was not going to learn much more by continuing. The software had been refined to a point where I could not see any necessary changes and appeared to be effective enough to help me answer the

research questions. The repetition of a similar study over a number of trials also helped to overcome some of the bias of the researcher and, thus, increased the validity of the study.

Summary

My experience throughout this research project has convinced me that it is indeed possible to reconcile the differences between researching and teaching in a combined role under certain circumstances. Firstly, the time frame is important. The presentation of my lessons occupied no more than a week for any group. A brief, well-defined time frame can assist to accommodate both roles. The necessary lesson planning can ensure success if both the teacher and the students are prepared in advance for the changes in lesson style. The evaluative case study was the most appropriate form for this study as it could answer the research questions and produce rich data for further analysis. The software designed for this project was readily applicable to the test groups. The types of data collected should provide valuable insight into the working of the groups and provide some measure of their success or failure. The next chapter details the case study from its inception to its conclusion. It is an accurate picture of the process that was undertaken over the time period for the research.

CHAPTER 7

The Case Study

The case study offers a means of investigating complex social units consisting of multiple variables of potential importance in understanding the phenomenon. Anchored in real life situations, the case study results in a rich and holistic account of a phenomenon. It offers insights and illuminates meanings that expand its readers' experiences. (Merriam, 1998, p. 41)

Introduction

This chapter details the process of software development and the responses of the various test groups to its implementation. This chapter provides evidence for the effective use of multimedia analogies in the classroom in order to answer the research questions in Chapter 8. This chapter contains extracts from the data collected and some observations to accompany the data. Several screen shots of the software program are included to illustrate phases of the development. It is recommended that the reader peruse the accompanying CDROM to gain a more accurate picture of the functioning of the program prior to reading this case study. The chapter presents the study in chronological order from the initial phase through the four trials in the classroom.

The initial phase

The decision to investigate multimedia analogies arose from my desire to see computer technology incorporated into classroom learning. The chemistry software available at the time was some combination of information, graphics, tutorials, simulations of practicals and examination preparation. More sophisticated programs looked at reaction kinetics and 3D modelling. I was unable to find software that addressed my perceived need for integration of technology with learning. Simulations of experiments effectively replaced the same experiments in the laboratory and tutorial-type programs replaced tutorial booklets. Information CDROM packages replaced or supplemented textbooks. If computer technology was indeed new technology, then it should provide something new in its approach to interaction with the student. I was not convinced that there was any great value spending thousands of dollars in software that was not sufficiently innovative. As a

science faculty, we had collectively returned many CDROM trial packages for this very reason. The more sophisticated modelling packages were quite expensive and not really aimed at high school students.

The aspect of CDROM software that impressed me the most was the use of graphics, animations and video. This was clearly an area that could not be matched by traditional texts. At first, I thought simulations of laboratory practicals were most impressive, giving rapid results without the mess! However, I realized that these programs could not hope to replace a real-life experiment as a learning experience. For example, if you make a mistake, such as spilling potassium permanganate from a burette, your clothes and skin can suffer the consequences. On a computer, you only need a reset button to fix problems. The simulation does nothing to help the student prepare for a real laboratory environment. There are too many sensory attachments to laboratory experiences for them to be translated successfully to a simulation. The smells and sounds of a chemistry laboratory are invaluable cues in the learning process and chemistry is, after all, a practical subject.

How then is the use of a computer going to be of most benefit in the learning process? How does one integrate computers in the chemistry course smoothly and gain benefit from the experience? The computer is most commonly used for its more general capabilities. The construction of databases, spreadsheets, graphs and tables, as well as report presentation, are well-established tools for the student. The manipulation of data and making predictions using spreadsheets also can be extremely useful. What I was looking for was a teaching tool, a way to better present information to improve the learning process. The literature on the use of analogies suggested to me that if I could create animated versions of analogies then they would have an impact on the students and may enhance learning. The animated version should be designed to have more impact than verbal analogies and two-dimensional graphics. I thought that if I could successfully animate some of my own ideas, coupled with the ideas of others (textbook authors, academic researchers, classroom teachers), then I could produce something useful and the computer would become a necessary and integrated device in the classroom.

The choice of software development platform was a very important first step. I looked at the options based on my skill level with various programs. I initially considered Visual Basic from Microsoft, a standard programming language for Windows-based computers. I rejected this option because my level of expertise did

not allow me to start at the required level and I felt the time taken to learn the language would be better invested in thesis research. A second important consideration was that many computers in schools were Apple Macintosh and these would not run Visual Basic code created on a Windows-based machine. I also looked at a purpose built, education software authoring program called Toolbook II by Asymetrix. It could produce vector or path-based animations as well as impressive-looking tutorial material that included multiple-choice tests. It would have required less time investment to master but it, too, only produced programs for Windows-based machines. However, it did have one capability that drew my interest in that tutorial material could be prepared as web pages for distribution and use on the Internet. I had previously set up a web site and had a good grounding in using the software to create web pages. The language of the web is HTML (Hypertext Markup Language) and the obvious advantage was that it would run on any type of computer with an Internet browser installed. The program could then be made available to students regardless of the hardware purchased by their school.

The types of animations that are used on web pages are usually frame-based (or cel-based) types created with readily available GIF animators. GIF (Graphics Interchange Format) is a standard format that compresses bit-mapped images so that have a small file size. These files can then be joined together to create an animation series in the same way that cartoons are created. The whole series, once compiled by the GIF animator into an executable animation, will run in the web browser or other applications. The compiled file is small enough to be transmitted over the Internet with minimal download time. As I had originally intended that my program would run directly from a CDROM and not over the Internet, the final file size was not very important. The file transfer from a CDROM is typically much faster than the Internet using a Modem. Using this format, however, gives me the option of presenting the program over the Internet and, therefore, improving distribution and access. I had thought of incorporating some video sequences of the reactions used in the program, so using small animation files would leave a lot of space on the CDROM to add these later. As it turned out, I did not proceed with video images as I felt the animations kept the ideas simple and fulfilled my criteria for presenting the analogies. (Also, the videos would have been technically difficult for me to add, as I did not have the correct hardware to capture images.)

An exothermic reaction: Burning chips analogy

This analogy concerned chemical equilibrium and in particular, Le Châtelier's principle and the effect of temperature change on an exothermic reaction. I had described the specific analogy with a class before I had begun my course with Curtin University of Technology and was impressed by the reaction I had received from my students. The idea was based on a television commercial playing at the time where a woman leaves hot oil and chips on the stove while she makes a phone call and the pan catches on fire causing a panic. The analogy to an exothermic reaction seemed obvious to me, as I had spoken of fires as an example of an exothermic reaction (but not an equilibrium reaction!). The lid of the pot represented the change in temperature of the system and was supposed to represent heat applied.

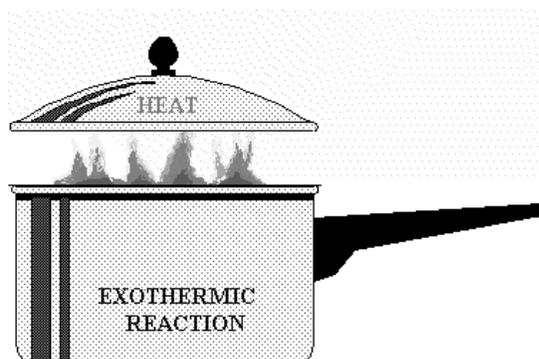


Figure 7.1: The burning chips analogy

The analogy was designed to draw on the students' experience of the television commercial and this provided relevance and something familiar to them. The animation seemed simple enough; a pot containing oil and chips which was to catch fire (exothermic reaction) and a lid applied to the pot diminishing or extinguishing the fire (the reverse reaction). The authoring process proved to be more challenging than I had expected. The individual graphic images took many hours to perfect and it was the time spent on this relatively simple task that made me realise that authoring a lot of animations would be beyond my time constraints. This was reinforced by my attempts to create a beginning page for the web site involving an animated title and a 3D animation of a mortar and pestle. This project took over two weeks, as I had to learn how to use the graphics software. My initial ambition was to produce sophisticated 3D graphics similar to those found in modern games.

I soon scaled back to two-dimensional frame-based animated GIF images. At the time, the memory usage of 3D graphics was very high and most schools would struggle with their current hardware to run the program successfully. The evolution of hardware since has negated this argument. Given that the graphic images were to be a stimulus for group discussion and not the underlying reason for producing the software, the time investment for fully three-dimensional graphics seemed inappropriate. It was the way that students dealt with the analogy, as much as how the multimedia analogy affected their learning that was important. If I could have paid a company to design and build the analogies then the product would have undoubtedly been more professional in its appearance but I did not know at the time if it would be the key factor in the success of the project. I decided in the end to settle for animations that were less demanding to author, but I hoped just as effective in delivering the educational message.

The FAR guide for teaching with analogies (Treagust et al., 1998) has a series of specific steps to be followed to optimize the use of analogies in the classroom. I followed these steps when integrating the animations into the program. I felt that the program should integrate theory closely with the analogy, so I created a split screen, first with the theory that I was attempting to teach followed by the analogy (see figures 7.2a and 7.2b).

An endothermic reaction: Melting ice cream analogy

EX01 - Microsoft Internet Explorer - [Working Offline]

File Edit View Favorites Tools Help

Back Forward Stop Search Favorites History

Address Go

Links


ENDOTHERMIC REACTIONS


$A + B + \text{HEAT} \rightleftharpoons C + D$
 OR
 $A + B \rightleftharpoons C + D \quad \Delta H = + X \text{ kJ/ MOLE}$

ANALOGY

Done My Computer

Start 4:50 PM

Figure 7.2a: Screen shot of opening endothermic reaction analogy

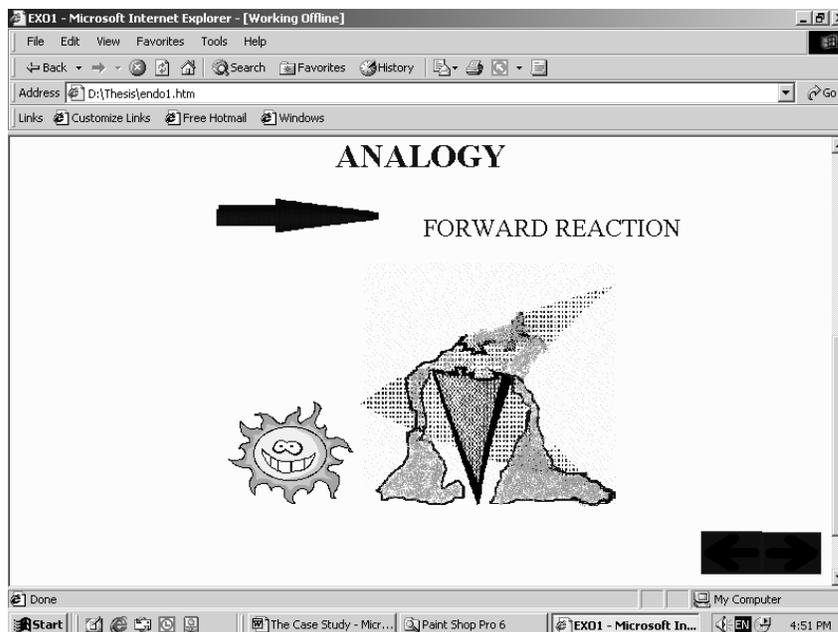


Figure 7.2b: Screen shot of opening endothermic reaction analogy

At all times the analogy can be easily related to the knowledge required by the student. The screen shots above show the first screen for the analogy of melting ice cream in an endothermic reaction. As the program was dealing with changes applied to an equilibrium system, a single animation would not suffice. Changes had to happen to the animation and the changes mapped to the concept. The screen shots in figures 7.3a and 7.3b show such a change being applied.

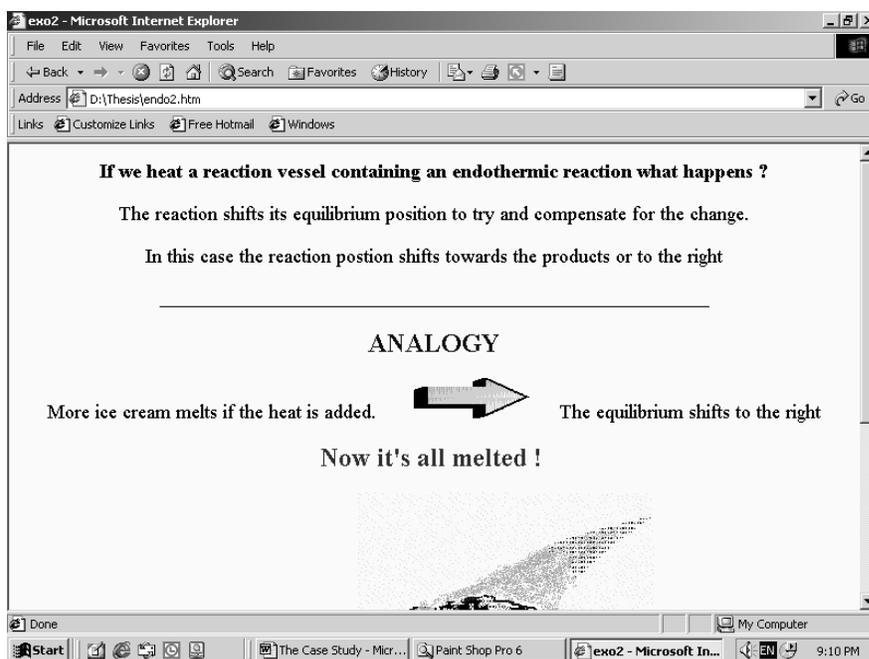


Figure 7.3a: Changing the temperature in an endothermic reaction

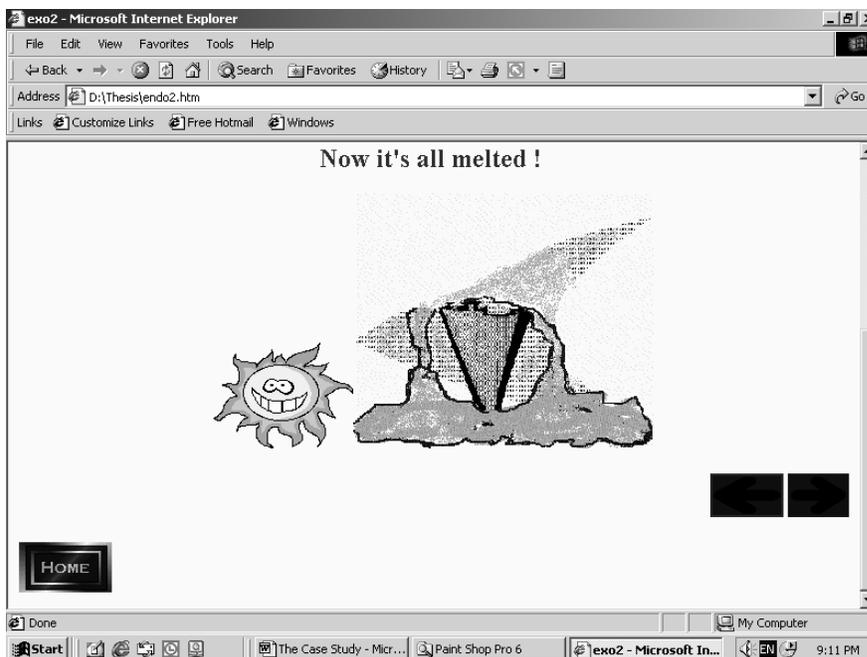


Figure 7.3b: Changing the temperature in an endothermic reaction

The idea of the analogy is that if we increase the temperature on a system containing an endothermic reaction at equilibrium, then the reaction would compensate by absorbing some of the applied heat and shifting the reaction towards the products. In this case more of the ice cream would melt. The next step in the sequence was to map the analogy to the target as seen in the table in figure 7.4.

ANALOGY	TARGET
ICE CREAM SOLID	REACTANTS
ICE CREAM LIQUID	PRODUCTS
SUN	DRIVES REACTION TOWARDS THE PRODUCTS

Figure 7.4: Mapping the analog to the target

An example problem was then provided to test the students' initial grasp of the idea. At this point, some discussion should ensue between the teacher and the group. This would then be carried over into the next section, which was the discussion of the faults in the analogy (see figure 7.5).

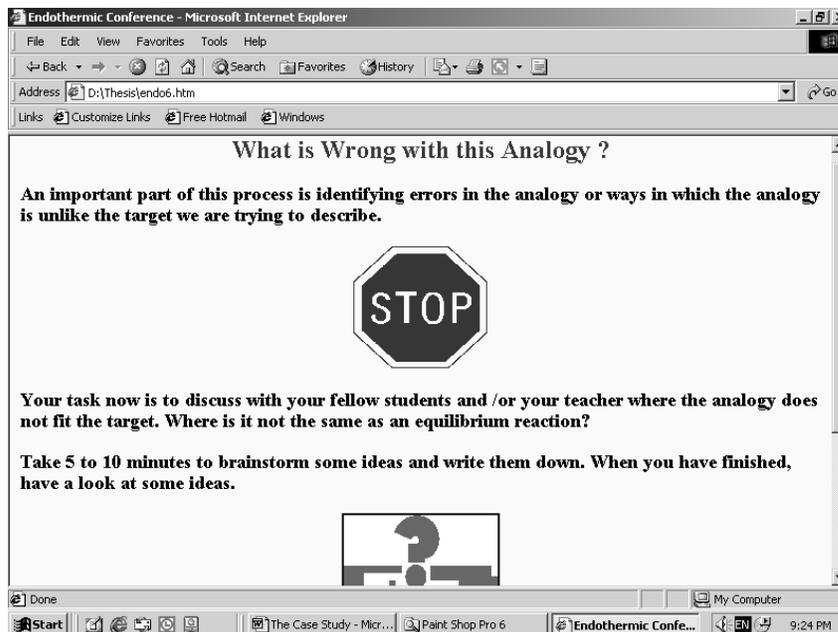


Figure 7.5: Prompt screen for the discussion of the analogy

Included at this stage are some suggestions of where the analog does not map well to the target (see figure 7.6). This is to be used once the discussion has concluded to see if the students understand the process and what is required in terms of seeing where the analog does not map correctly to the target. A perfect match between the analog and the target would mean that the analog is the target. All analogies break down at some point and I included the discussion section both on the CDROM and on the worksheet to emphasise the importance of a critical analysis of the analogy (see Appendix A).

If during group discussion the students were able to point out key areas where the analogy breaks down, then they would have progressed a long way towards understanding the true nature of the target. Furthermore, if students were able to visualize or create their own analogy for the same target idea then they will have shown an active, critical participation in the lesson. A display of critical thinking about analogies is one of the main aims of the program. The collaborative aspect of this work is also very important to its success or failure. An active group who are all contributing ideas should gain much more benefit from the process.

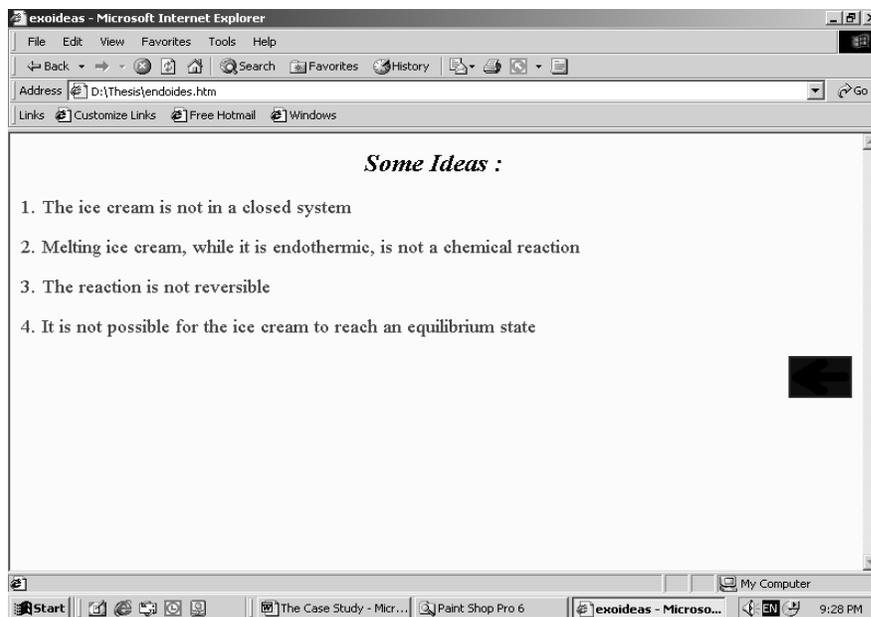


Figure 7.6: Suggestions about the analogy's mapping

Following a discussion of the concepts on the screen, some past examination questions and answers were shown to see how the examiners had tested the concept in the past and to give practice to the student group (see Appendix G). This work also provided a chance in the lesson for the collaboration established in the discussion to be carried over to collaboration in problem solving. I felt it important to ground the work in real examples to see if the students could use the analogy to help them understand the question and how the answer was derived. I intended to find out if the students had used the analogy during their problem-solving phase (by questioning) or if they had used other strategies. The examination questions provided a focus for the study of the analogy in the first place and therefore became an important part of the lesson sequence.

Having authored analogies to show the effect of temperature on exothermic and endothermic reactions, I asked two science faculty teachers at my school to peruse the analogies and the program to get some feedback on their usefulness. I was concerned that other teachers would not accept the analogies that seemed to work well in the classroom for me. Teacher A believed that the exothermic analogy was too complex and removed from the real situation. When he was trying to solve the problems on the CDROM, he used previous personal strategies and not the analogies. He was more impressed by the endothermic reaction analogy. He liked the idea of a physical change being mapped to a chemical reaction. He would like to find out what

is happening at the molecular level and would have liked a molecular type animation to supplement the analogy. Teacher B liked the simplicity of the idea and the structure of the computer presentations. He found no real problems with either analogy and was very positive in his comments. Having received some positive and negative feedback, I decided to trial the software with my chemistry class.

Testing in a classroom situation (trial 1)

Shortly before the Higher School Certificate (HSC) examination in 1998, I presented the completed sections of the program consisting of two equilibrium analogies (exothermic and endothermic reactions) to my Year 12 class. In their course they had completed a unit on equilibrium during term 1. Due to other duties, I had not taught the class this unit but I know that the unit was completed. To understand the class responses more fully it is necessary to have some background on their abilities. There are only eight students in the class and on the day I presented the analogies there were only three present initially before being joined later by three others. The best achieving students in the class are scoring only just above state average (60%) in their school-based examinations. Their knowledge of chemistry is best described as incomplete. Two of these students, I will call them student A (female) and student B (male), often proclaim their lack of ability in chemistry, especially in problem solving exercises. The third student present at the start, Student C (male), shows a degree of understanding but performs poorly in tests and seems frustrated by his inability to do well. He is scoring around 35 - 40 % in class tests.

Prior to the presentation the students were asked four questions and their written responses were as follows:

Question 1: What is equilibrium?

Student A: When the forward reaction equals the reverse reaction.

Student B: The forward rate of a reaction = the backward or opposite rate.

Student C: Equilibrium is when the rate of forward reaction equals the rate of the reverse reaction.

Question 2: What is Le Châtelier's principle ?

Student A: $K = \text{product/reactants}$.

Student B: $K = \text{products/reactants}$. (there was some collaboration between A & B)

Student C: Le Châtelier's principle = the equilibrium constant at a given temp and pressure.

Question 3: What happens when an exothermic reaction at equilibrium is heated?

Student A: Exo and endo is opp. The equilibrium will shift to the right. K will increase.

Student B: The forward reaction will increase. K will become larger.

Student C: Shift to the same side as the reactants.

Question 4: What happens when an endothermic reaction at equilibrium is heated?

Student A: (a combined response as read in question 3 above)

Student B: The backward reaction will increase. K will become smaller.

Student C: Shift to the products.

Comments:

Students A and B were helping each other and as they discussed the questions were clearly confused by the responses necessary. Student A did not mention rates of forward and backward reactions. Student B had a few attempts at predicting the outcome of altering the equilibrium and crossed out his responses, showing a lack of confidence and a certain amount of confusion. Student C, the underachiever of the group, actually showed more correct responses and a better understanding at this stage. All students understood that changes imposed on a system at equilibrium resulted in a shift of the equilibrium position but they did not associate this idea with the term “Le Châtelier’s principle”. In my mind, there was a clear basis for revision of the concept and pre-existing knowledge.

Preparatory Remarks:

The students were told that this was a program I had developed to help them and others to better understand key concepts in chemistry. I ran the program through a single computer monitor in front of them and I controlled the flow of the program to some extent. If they asked to see previous screens I followed their wishes. The first stage in our exploration was to follow the instruction screens about analogies (see figures 7.7a and 7.7b). The students were happy to accept the idea of an analogy and were prepared to understand that the analogy is not the real situation. I also stressed that it was their task to find where the analogy breaks down. At the screen presenting a brief summary of equilibrium key concepts, I was asked if there was a printed copy available. Clearly, there are strong ties to a piece of paper as opposed to a computer disk!

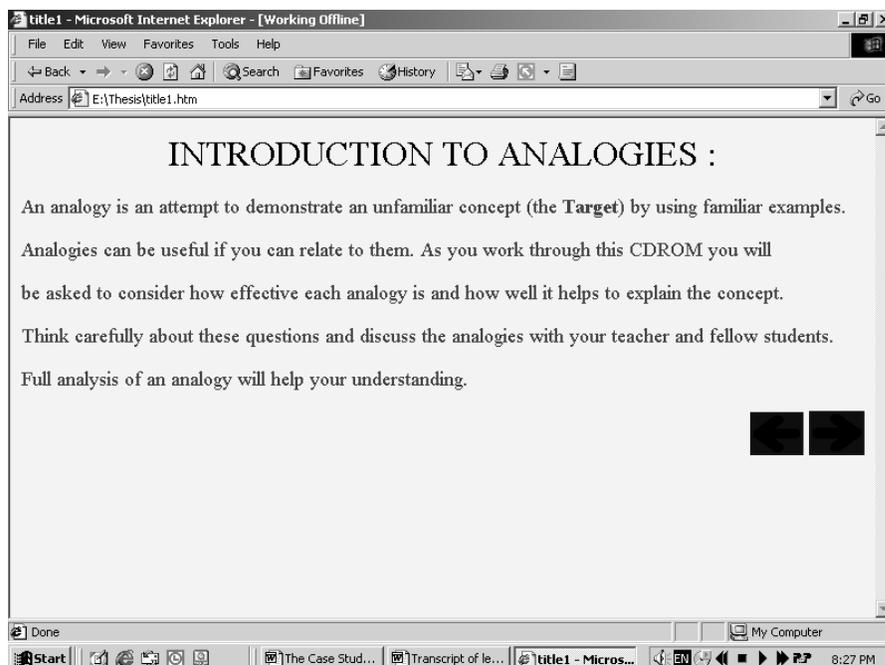


Figure 7.7a: Information about analogies screen shots

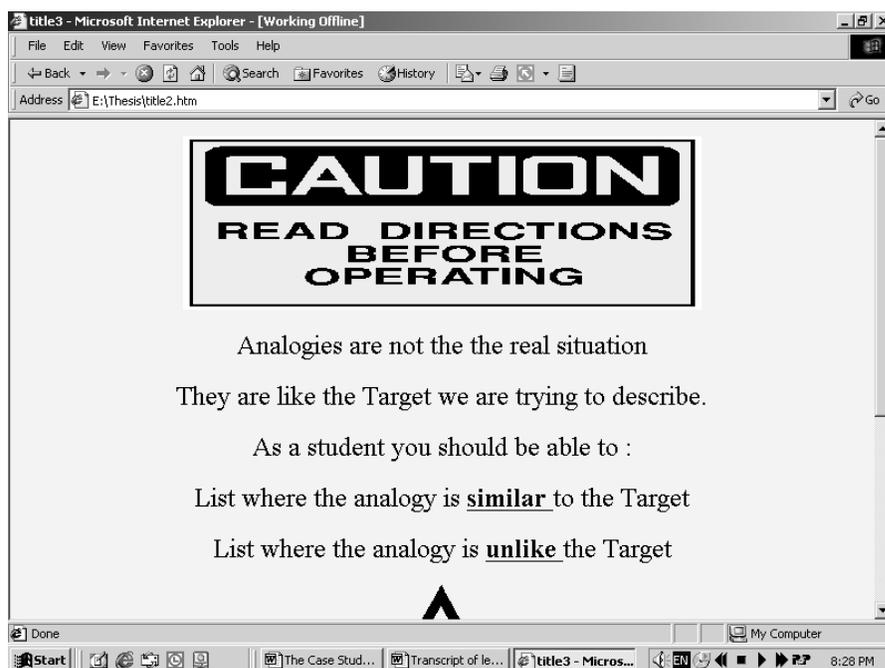


Figure 7.7b: Information about analogies screen shots

Reaction to the exothermic reaction: The burning chips analogy

I then proceeded to the first analogy on exothermic reactions. After the theory involving exothermic reactions was presented, I showed the analogy on the lower half of the screen. (Scroll down required. I found I had to reload the page as

the animation had stopped). This analogy of burning chips (see figure 7.1) drew a comment from Student A immediately that she didn't like it- she didn't think it related well to the concept. This was the same comment I had received from my colleague Teacher A. The other two students made no comment. We then discussed the problems with the analogy. The procedure seemed rather foreign to the students but with a little prompting they were able to identify three or four responses that showed they were beginning to develop the idea that there were failings in the analogy. We then went on to the examples and the exercises (see Appendix A). The students wanted to frequently revisit the first computer screen that showed the exothermic reaction equations. I consciously reinforced the analogy on the following screens before going back to the problems. I noted at the time that this exercise became one of co-operative learning and I gradually assumed a less dominant role, becoming more of a co-learner. There was a strong sense of collaboration in the room with the program being the stimulus material for this to occur. The students were able to complete the three exercises correctly by flicking between screens. There were no words crossed out or editing marks in their answers.

Reaction to endothermic reaction: The melting ice cream analogy

I then presented the second analogy on melting ice cream to model an endothermic reaction (see figures 7.2a and 7.2b). Again, I was surprised at the number of times they wished to go back to the original equation screen and the other screens. Following the presentation of the analogy they were asked to solve a problem involving the nitrogen dioxide/dinitrogen tetroxide equilibrium (see figure 7.12). This was a demonstration they had already seen prior to the presentation on CDROM but, surprisingly, they treated it like a new experience. The second attempt at pointing out the problems with the analogy was more successful and they were able to enunciate four faults with the analogy with less prompting; they responded to the questions with confidence and were able to produce the correct responses, although student B corrected his initial answer. This was due to the fact that the question is deliberately worded the opposite of the example presented earlier (see figure 7.13).

On completion of the sample questions, I asked the students to once again answer the four questions that were set as a pre-test. Their responses were as follows:

Question 1: What is equilibrium?

Student A: When the forward reaction equals the reverse reaction. (the same as the first response). (*My comment*: obviously the idea of rates of reaction did not penetrate the presentation for her).

Student B: The forward rate of a reaction = the backward or opposite rate. (the same as the first response).

Student C: Equilibrium is when the rate of forward reaction equals the rate of the reverse reaction. (the same as the first response).

Question 2: What is Le Châtelier's principle ?

Student A: When something is at equilibrium, you can predict how the equilibrium will react when changed.

Student B: no response

Student C: Is designed to predict how an equilibrium system will react when it is at equilibrium.

Question 3: What happens when an exothermic reaction at equilibrium is heated?

Student A: The equilibrium will shift to the left.

Student B: The backward reaction. K will decrease.

Student C: Reactants are favoured.

Question 4: What happens when an endothermic reaction at equilibrium is heated?

Student A: No written response. Verbally she told me it would shift to the right.

Student B: The forward reaction increases.

Student C: Shift to the products.

Student reactions to the computer models:

I then asked the students how they felt about the program and the use of analogies. The responses from the group (there were now six present) were very positive. They remarked that I shouldn't give the program to other schools before the HSC! They obviously believed that it gave them some advantage. They asked if there were any more examples on the computer. When I told them I was developing some more examples, I asked them if there were specific areas they thought might be useful. They were unable to supply specifics (they just wanted any help they could get at this stage!).

After the computer presentation, I showed the group a video that had been produced to present the same idea with analogies and models about equilibrium. Some of the analogies used were: the idea of the dance floor and people changing partners, the idea of the terrarium as a closed system and the traffic in city streets to explain molecular motion. Some of the ideas presented were well thought out and I thought a sound learning experience. The students were not so impressed. They made derogatory remarks about the actors and generally joked around while the video was playing. This was in marked contrast to their concentration during the multimedia presentation. The fact that I was leading the exercise with the computer is significant in this shift of attitude but it does not entirely explain their unwillingness to take the video seriously.

Comments about Trial 1:

Having worked with these students for almost two years, I was able to notice a distinct shift in their attitudes when confronted with what was to them a new presentation medium. The collaborative nature of the learning was a real bonus and one I intended to pursue in the development phase. Tutorial-type software that is produced for students to study at home or own their own in computer laboratories have been developed for single users with minimal teacher involvement. The programs are usually meant to be used by the students at their own pace but do not necessarily involve interaction with others. The fact that my program required responses (both verbal and written) seemed to me to be a really positive feature. We quickly became a small learning group and the students remained totally focused on the presentation for one hour. I now believe that there is a future for this type of media development that involves more than one user of the computer. The advent of modern projection equipment and therefore the ability to involve a small group of students provides the required technology. I believe that programmers need to become aware of the possibilities of this type of presentation.

From a theoretical viewpoint, this presentation was out of sequence. Typically an analogy is presented early in the instructional sequence and then used in the teaching of the unit concepts. The timing in this case was out of my hands as I had only developed the software at this time and well after their initial instruction on chemical equilibrium. Apart from this fault, based on the students' responses the whole process appeared to be overwhelmingly positive.

The second trial: First lesson

Work then began on a new analogy – the effect of a catalyst on equilibrium reactions. This analogy involved the idea of two motor vehicles taking alternate routes to reach a destination, the flatter route representing a catalysed pathway (see figure 7.8)

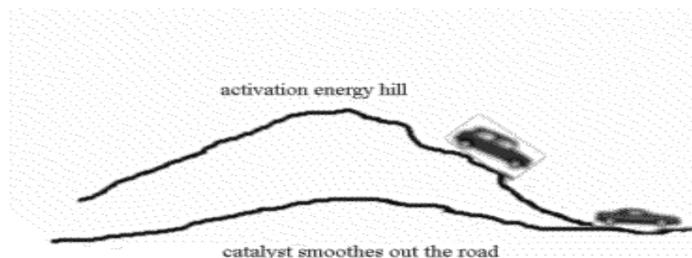


Figure 7.8: The catalysis analogy

Once I had decided on the format of the exothermic and endothermic analogies, it was fairly easy to fit a new one into the same sequence. Some further work was needed on navigation buttons and screen presentation to ensure consistency across the program.

The beginning of the next year (1999) presented the opportunity for me to test the software once more with a class group. This time it was as part of the teaching sequence and not a revision exercise. The situation was new to me as it was not my senior class that was the test group and I was not fully aware of their abilities or the degree of collaboration that existed within the group. Similarly, the students did not know what to expect from me. I explained the circumstances of my research program prior to the lessons and they were aware that they were part of a trial to see the effect of this type of teaching methodology. I did not tell them about my goal to achieve effective collaboration or the requirements of the program in this regard. Any discussions that then arose would be as part of their participation in the lesson and not as an artificial construct.

It was necessary to develop a teaching unit that would incorporate the use of analogies into the flow of the lessons in what seemed a logical sequence to me. Two one-hour lessons were designed to introduce the students to the concept of chemical equilibrium through a combination of theory and practical lessons. They carried out a

reversible reaction involving the hydration and dehydration of cobalt chloride and were given a demonstration of the $\text{NO}_2/\text{N}_2\text{O}_4$ equilibrium undergoing changes due to temperature. They carried out an experiment to see the effect of changing concentration on equilibrium involving the iron thiocyanate ion. The theory had included the information that for the general equation, $a\text{A} + b\text{B} = c\text{C} + d\text{D}$, that all species were present at equilibrium and that the rate of the forward reaction was equal to the rate of the reverse reaction. The distinction between equilibrium in a closed system as opposed to the steady state theory was also discussed.

The analogy of a sink emptying at the same rate as it fills was used for the steady state theory. This was presented as a verbal analogy as well as a pictorial analogy on the blackboard. I noted at the time that I thought this was a good way to start talking about analogies and specifically pointed out to the students that this was an analogy and how it was designed to evoke something familiar to help explain the unfamiliar. The introductory lessons were concluded with a brief introduction to Le Châtelier's principle and the idea that the position at equilibrium could be altered in some way by changing conditions. This led neatly into the use of the computer program. (Note: These students had previously studied chemistry for one year and I assumed that they were already familiar with writing chemical equations. Due to time limitations, I was unable to test my assumption prior to these lessons.)

The CDROM package was introduced in the third one-hour lesson. I set up a single computer monitor in the centre of the room and arranged the students in an arc facing the screen while I ran the program from a laptop, side on to the screen so that I could see all the students throughout the presentation. I placed a tape recorder next to the monitor to record all the conversations that took place regarding the program.

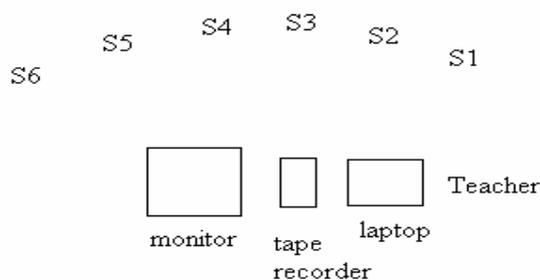


Figure 7.9: Seating plan for the second trial (There were six students labelled S1 to S6)

The permission of the students via a letter to their parents was gained before taping the lesson. The students were quite happy to be recorded in this process and some of them told me they were interested in my research program.

Although I had some nagging doubts about the analogy for an exothermic reaction with the burning chips, I decided to continue, as I could not think of a better analogy that I could have authored successfully. I felt that the real value of the analogy was not the analogy itself but the discussion that ensued from its use. If an analogy is poor in its mapping or complexity, this should be cleared up in student discussions and, therefore, promote useful learning. The following section is based on verbatim tape transcripts of the two lessons dealing with analogies that were presented. What follows are examples of classroom interactions and my analysis and interpretation of those interactions from my viewpoint as a teacher. The initial part of the tutorial program began with figures 7.7a and 7.7b showing an explanation of analogical reasoning and how students were to treat an analogy.

The initial part of the first lesson was largely teacher directed as students were stepped through the first screens of the tutorial. This, I believed was necessary to correctly orient the students towards the tasks to come and introduce the important concepts to be covered. It would be the discussion section about the analogy that provided the students with the opportunity to develop metacognitive skills in questioning their own thinking processes and develop their own version of the analogy. Further work could involve the students creating new analogies that better suited their thinking. During this introduction, I stressed the importance of the relevance of the analogy to the individual: "If it's something you're not familiar with, it's not going to help you at all." The students were also urged to think carefully and discuss each analogy thoroughly. Some notes on the theory of equilibrium that leads to the first of the analogies and follow-up exercises were given to the students. These theory notes about chemical equilibrium are reproduced in figure 7.10.

After discussing these notes carefully with the group, the students were asked to make some predictions about a closed system at equilibrium if subjected to changes in temperature or concentration. The first part of the collaborative process is designed to elicit student ideas about the nature of the equilibrium process.

(In all extracts of conversations from the taped lessons, T = teacher S# = student.)

EQUILIBRIUM
Some Facts

- * Many chemical reactions involve a competition between the forward reaction and the reverse reaction.
- * These reactions do not go to completion but reach a stage where the rate of the forward reaction is equal to the rate of the reverse reaction.
- * Equilibrium can only occur in a closed system.
- * To show equilibrium reactions on paper, they are written with a double arrow:

$$A + B \rightleftharpoons C + D$$

- * Le Châtelier's principle is designed to predict how an equilibrium system will react if changes are made to the system once it has reached equilibrium.
- * The following analogies are designed to help you understand these reactions to change.

Figure 7.10: Theory notes about equilibrium

(Extracts from taped lessons)

- T: So if you've got a test tube sitting on a bench, with a cork in it, and the system has reached equilibrium, so its forward reaction is the same as its reverse reaction, then what happens if we then stick a Bunsen underneath it?
- S1: It changes the position of its equilibrium
- T: Yes, and what happens if we add water to it?
- S1: It changes it
- T: Good. What we need are rules that help us make predictions as to how that system is going to change.

Reaction to the exothermic reaction: The burning chips analogy

The students were then shown the exothermic analogy screens and also directed to their worksheets where they copied the equations describing an exothermic reaction. The worksheets have been provided to assist the students in focussing on the key points (Appendix A). The analogy was then presented and the effects of a change of temperature explained through the use of the animation (putting the lid on the burning chips). The analogy was then mapped to the target before presenting the students with a practice problem to see how they were coping with the analogical transfer. Most students had little trouble answering the question, although one student struggled a little and relied on another student to explain it to her again.

The students were then led into the discussion of the analogy itself. To assist this process, I moved the computer screen back to the mapping of the analog to the target. The ensuing discussion involved a number of students and provided me with evidence of collaboration within the group that had not been obvious in the introductory lessons.

- T: Where else is it not like an equilibrium?
 S3: It's actually burning and therefore it's always changing, I'm not sure how to say it.
 S5: You mean like a transfer of the products out into the air, instead of into the mixture
 S3: An open system
 S1: And so, you are not getting a chemical reaction, an equilibrium.

This continued into a discussion of mapping the lid to heat.

- T: What about the lid, representing heat? How does that map?
 S5: It isn't heat
 T: It's not heat is it?
 S3: No it's just trapping energy
 T: Heat's an abstract thing isn't it?
 S5: It's just making it a closed system
 S3: It's not heating the system
 S6: The fire would go out, so there would be no reaction
 T: The fire would go out with no continuing reaction, excellent!

The students needed some prompting at this stage to talk about the idea of reversibility of equilibrium reactions. I noted from this that the teacher must form an integral part of the discussion to prompt the correct use of terminology.

- T: Yes, so what's the word? Reversible?
 S1: Reversible
 T: All equilibrium reactions are reversible, this one's not is it?
 S5: No, you can't really change the chips back.
 S4: Unless they're fat
 S5: Then they are not really going back, they are still cooked
 T: So you can't actually produce the chips you started with can you?
 S3: Once again it's not reversible in another way that if you took the lid away it would not burst into flames.
 T: Yes, so it's definitely not a reversible reaction

At this point, the students were asked to consider the possibility of creating their own analogies, ones that would work better for them. This theme of creating an effective analogy was repeated a number of times to stimulate further discussion. Once the discussion had covered most of the differences between the analog and the target, I then moved on to the screen that suggests my ideas as to how the analog

does not map to the target (Figure 7.6 is an example). The students were reminded that this was not a final step in the process. I believed that it was important to compare their responses with those of the designer of the program. There was a good correlation here and the students' answers covered the main differences mainly because they had been led to those ideas in the discussion. The students were unfamiliar with the processes required and the training in how to approach the first analogy was very specific in the hope that they would learn to expand their ideas spontaneously with subsequent analogies (see Appendix E, Example 1 for sample worksheet from a student).

The next step was to test the new knowledge using past examination questions as examples. All students were able to arrive at an answer at their first attempt and most answers were correct. Students aired their thoughts out loud asking for confirmation. One student who had struggled earlier needed the questions rephrased to assist her understanding. While the students were working one of them asked:

S3: So, in equilibrium is there an overall balance involving heat lost to the air?

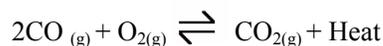
T: Yep, that heat is not continually being lost. Some of it is being reabsorbed to produce reactants. If you have this tube sitting on the bench at 22 degrees, it's just bouncing back and forward. One thing you notice about equilibrium reactions is that they have constant macroscopic properties. So what you are looking at doesn't change, so it looks like nothing's happening, but we know, in reality, that [at the molecular level] the reaction is bouncing back and forward inside.

This verbal exchange is evidence of engagement by a student looking for further elaboration of ideas; the clarification of conceptual ideas is an important step to a better understanding.

The next phase of discussion looked at the answers to the problems (see figures 7.11a and 7.11b) and it was clear from the increased interactions that the group was beginning to focus on the principles underlying the ideas of Le Châtelier. Some adjacent pairs of students were helping each other to understand the answers. Five of the six students answered correctly without prompting. The sixth student had the answer explained by another and had the opposite answer which she changed after this discussion. This question prompted discussion about balancing equations and the correct value of the enthalpy change relating to the number of moles of

reactants. One of the students had written the equation with 2 moles of NO and had not altered the enthalpy amount. This sort of question had led to other related areas of the topic and stimulated a clarification of this part of the theory.

Question 1. The following system has been allowed to come to equilibrium

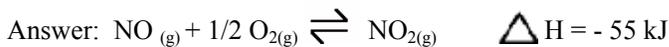


What would be the effect on the equilibrium concentration (increase, decrease, no change) of each substance in the system when the vessel is heated?

Answer: The reaction shifts towards the reactants. The $\text{CO}_{(g)}$ and $\text{O}_{2(g)}$ would increase. The $\text{CO}_{2(g)}$ would decrease.

Figure 7.11a: The first examination question for exothermic reactions

Question 2. Nitric oxide (NO) releases 55 kJ / mole when it reacts with oxygen to give nitrogen dioxide. Write the equation for this reaction and predict the effect of raising the temperature on the equilibrium concentration of NO.



The NO concentration would increase.

Figure 7.11b: The second examination question for exothermic reactions

Clearly thinking about the overriding concept, S4 commented: “I don’t understand how you can tell how you can predict the changes.” S3 then attempted to explain the concept to S4 but there remained some confusion in S4, which triggered a rather lengthy discussion between S3, S4, S5 and the teacher about the nature of change in an equilibrium system. It was considered important to pursue the difficulty of S4, as it was likely that some other students were experiencing the same confusion. In considering the exothermic reaction, S3 added at the end: “If it’s an exothermic one way [reaction] can we consider it endothermic the other way?” The thinking was showing an increased level of sophistication to which the teacher replied:

T: Yes. It just depends on which side of the equation the heat is. Typically for an exothermic reaction, the heat is one of the products. The way we write it on paper is the way we mean the reaction to go. We mean that the left-hand side

is reactants and the right hand side is the products. Even though it is a two-way reaction, we still distinguish those on paper.

- S3: So do we write an endothermic reaction with the products first? (So the heat is on the left)
- T: No, the products must always be on the right by convention.

Having exhausted most of the ideas about exothermic reactions, attention was turned to endothermic reactions. Some general information about the nature of endothermic change prompted this response:

- S2: So is that like where the heat goes into the bonds and when you break them up it's released and forms exothermic [an exothermic process].

Here the student was bringing in the issue of bond making and breaking as the cause of temperature change. Some recognition of this idea was followed by a return to focus on the analogy.

- T: Yes, its creating bonds that are attracting the energy in the overall process.

Reaction to the endothermic reaction: The melting ice cream analogy

The analogy of the melting ice cream was then presented (see figures 7.2a and 7.2b). The following exchange demonstrated that this analogy was more easily accepted than the exothermic one.

- T: What happens if we heat the ice cream some more?
- S1: It melts
- T: More ice cream melts if we heat it and the equilibrium shifts to the right. And the cone stays there but it just melts more of the ice cream.
- S1: That's quite good. I can see the reaction going from frozen to not frozen.

After mapping the analogy to the target (see figure 7.4), the group proceeded to the test example involving the temperature-dependant equilibrium between NO_2 and N_2O_4 shown in figure 7.12. (see Appendix E, Example 2 for student sample worksheet). Most of the group was able to answer the question without difficulty but student S4 was still struggling. She appeared to be unable to link effectively between the analogy and the target and failed to see through the surface imagery. She chose the brown coloured vessel because it reminded her of chocolate ice cream. The analogy was evidently not useful to this student. The discussion about where the analog does not fit the target involved more student talk than teacher talk. The work that had begun with the first analogy was now easily transferred to the second

analogy and the group was able to recognize the main attributes of an equilibrium system that were inadequately covered by the analogy. There was some discussion about whether the reaction was reversible: Some argued that re-freezing ice cream shows the analogy is modelling a reversible reaction while others argued that you cannot remake the ice cream in the cone to its original shape.

TRY THIS ACTUAL EXAMPLE :

CONSIDER THE FOLLOWING REACTION :

$$\text{N}_2\text{O}_4(\text{g}) + 59.2 \text{ kJ} \rightleftharpoons 2\text{NO}_2(\text{g})$$

colourless **brown**

How will the concentration of dinitrogen tetroxide change in an equilibrium mixture of the two gases if the mixture is heated ?

Before you go on write down your answer to the question

Figure 7.12: Initial example for endothermic reaction

One student tried to modify the analogy:

S3: If you did it in a container with the exact same shape then it would freeze back to the original

He followed this up with his own analogy.

S6: Let's get back to the melting of ice cream

S3: It should be like water and ice cubes

S6: I don't think this case is reversible

T: So do we have consensus on whether it is reversible. What sort of change is it?

S3: Well, it's a change of state

T: So we are dealing with physical rather than chemical change. Do we agree that it is probably not reversible?

S1: Because it is not a chemical reaction? Yes
(general agreement because you can't retrieve the original in its own form)

This exchange illustrated a desire on the part of the students to make the analogy work. In effect, they were constructing a better analog to fit the target. The spontaneous generation of a different, albeit very similar analogy, demonstrated a metacognitive process that became increasingly evident as the lessons proceeded. It became more obvious to me that most of the group had become immersed in the discussion and were actively engaged in sense making about analogies.

Student reactions to the analogies

The written responses by the students showed that they had acknowledged all the major differences between the analog and the target. The examination questions, which were then presented (see figure 7.13), were asked in the opposite manner to those examples in the computer program.

Test your knowledge

For each of the following reactions, state whether the reactants or the products would be favoured by lowering the temperature of an equilibrium mixture.

(a) $\text{H}_2\text{O}_{(l)} \rightleftharpoons \text{H}_2\text{O}_{(g)} \quad \Delta H = + 40 \text{ kJ}$

(b) $\text{CaCO}_3_{(s)} + 172 \text{ kJ} \rightleftharpoons \text{CaO}_{(s)} + \text{CO}_2_{(g)}$

(c) $\text{I}_{2(s)} + 7 \text{ kJ} \rightleftharpoons \text{I}_{2(\text{in alcohol})}$

Answer: In each case the reactants are favoured. Cooling an endothermic reaction at equilibrium will cause the reaction to compensate by shifting to the side that will produce more heat (the reactants or left side)

Figure 7.13: Examination questions for endothermic reactions

At this stage, S4 was trying to grapple with the analogy although it was encouraging that she had not given up. Reversing the way the question asked about endothermic reactions prompted a spontaneous discussion among the group. It seemed that the process of modifying the original analogy and creating a separate analogy had caused the students' thinking to wander and they needed to become focussed on the original. (In retrospect, I probably should have mapped the ice and water analogy as it arose). The following exchange provided some useful insights into the effectiveness of the analogies used.

T: The whole idea of the analogy is to give you something to hang your hat on. You're no longer looking at a chemical equation on paper that is just dry. So

when you're thinking about an endothermic reaction, it gives you a picture in your mind. Make it a little easier to understand.

- S3: The only problem with that is inventing an analogy for each individual thing, for endothermic, exothermic, addition of pressure and so on.
- T: Right. For endothermic/exothermic you could choose either the ice cream or the chips, as one is the reverse of the other. So if you like the ice cream better than the chips, you could use that one.
- S1: The ice cream is better than the chips because it is in some way reversible (even if it's not completely)
- T: What you've got to have is an analogy that you like. It's got to work for you. We've got to map an abstract concept to a concrete idea in your brain. So if you can find something to hang your idea on, it should make it easier for you to solve, not harder.

Some of the students believed that the use of analogies should be governed by two factors – frequency and appropriateness – and that it is a difficult process to develop analogies and that in some cases they might not work. I speculated at this point that using one analogy to describe two complementary processes could be a way to reduce cognitive load.

Lesson conclusion: Once the students had grasped the twist in the questions at the end of the lesson, they were able to correctly interpret them to produce an accurate answer. The end of the lesson provided an opportunity for some reflection among the group.

- T: The next lesson will focus on the catalyst in an equilibrium system.
- S2: I think of a catalyst as like a boxing match and the crowd urging them on, that's just what I think
- T: OK, that's good. You're thinking about your own analogies. Until you actually focus on the activity (creating analogies), you don't usually think of it as a way to approach a problem. So what did you think of that approach?
- S5: Good, a lot different
- S1: It was interesting
- S3: I learnt the difference, how it made you think what it wasn't, as well because the bad things were pointed out,
- S1: Sort of more obvious
- S3: Yeah, like it made it more obvious what it is, rather than what it isn't.
- T: Well once you can eliminate all of the extraneous bits, you can focus on what we are trying to learn which is what the equilibrium reaction does when its doing what its supposed to be doing.

Here the spontaneous generation of the analogy is a key indicator of the level of involvement by the students. Student S3 was the most engaged student and his comment on the process of dissecting the analogy shows that he understood what the program is trying to achieve. The generally appreciative tone of the comments was

an encouraging factor. It would seem that for some of the group this approach to equilibrium theory was a positive experience.

The second trial: Lesson 2

On the second day, the effect of a catalyst on an equilibrium system was the focus. I had decided to run this lesson a little differently by obtaining the group's existing ideas about the function of a catalyst in a chemical reaction and building on that as a foundation. We began by brainstorming the concept.

T: Firstly, I'd like you to write down your definition of a catalyst, what is it, what does it do?

Two typical responses were:

S3: A catalyst speeds up the process of a chemical reaction and supplies energy to the reaction often giving reactants the activation energy they need for the reaction to begin. The catalyst is (in the end) only a spectator.

S4: A catalyst is something that speeds up a chemical reaction but doesn't actually take part in the reaction.

The students were then asked to consider an equilibrium system and the effect of a catalyst on such a system.

S3: It might reach equilibrium quicker

T: What do you think S4? We have a reaction sitting on the bench basically at equilibrium and we pour in a catalyst, what do you think might happen?

S4: It might go to completion

T: Do equilibrium reactions go to completion?

S4: Um, no

T: What do you think S2?

S2: Hardly any effect.

T: And you, S5?

S5: It might reach equilibrium quicker

T: Yes, but remember, this reaction is already at equilibrium. We are looking at Le Châtelier's Principle here, trying to predict what changes may occur if we try to alter conditions at equilibrium.

S3: Well, because the catalyst affects the energy involved, it might shift the reaction one way or the other

T: So it's possible that a catalyst can shift the equilibrium?

S6: Say there's a gas involved, it may produce more gas because there's more energy.

T: Yes, anything's possible at this stage. I want to find out what's in your brains so that I can see where you're coming from.

So are we undecided? Do we not know what's going to happen in the vessel if we add a catalyst once it has reached equilibrium?

There was some general discussion amongst the students. Some were leaning towards the idea that the catalyst would shift the reaction one way, others were fairly

certain that it would have little or no effect and still others believed the catalyst was dependent on the system being studied.

I have included the whole exchange as it demonstrated to me that although their textbook definition was fairly accurate, as individuals they have difficulty transferring the concept to a practical situation. There are interesting examples of student thinking arising spontaneously as they try to link the familiar concept of a catalyst with the unfamiliar equilibrium system (cf S6 comment on the gas). S3 at this stage was becoming a little impatient and was keen to see an analogy. Within a short space of time, two lessons, the analogy had assumed a central role in the learning process.

S3: It depends on what the catalyst does in the reaction

T: It depends on what you think a catalyst is in the first place. It depends on your concept of what the catalyst is doing in the vessel.

S3: Can we see the analogy?

T: We'll get there, be patient.

Other students wanted to explore ideas further.

S2: What will happen in the vessel if we add the catalyst before it reaches equilibrium?

T: It will reach equilibrium, yes

S1: It will get there at a faster rate

S5: It might go past the equilibrium point

T: Past it? Can it go past the equilibrium point?

Before looking at the computer program, I decided to give them a practical demonstration of a catalyst at work. I had originally intended to show them at the end of the section on catalysis but it seemed more appropriate to give them a concrete example at this stage. The demonstration involved the degradation of hydrogen peroxide catalysed by manganese dioxide to produce oxygen gas. The students were able to observe bubbles of oxygen released rapidly after the addition of the catalyst. It is a reaction that occurs very slowly without the catalyst and as a demonstration it is unfortunate that students could not see anything happening before the catalyst was added. They were required to accept my explanation that there was indeed a slow reaction occurring and this was not entirely satisfactory from my viewpoint. The first screen, as seen in figure 7.14, that explored the role of the catalyst followed the demonstration. After explaining the concept, some further elaboration seemed appropriate.

- T: A catalyst does not affect the position of equilibrium, it only speeds it up to ensure that the equilibrium is reached faster. It is important to realise that the effect of lowering the activation energy ensures that both the forward and the reverse reactions are sped up. It's the same thing as trying to get across that a reaction is reversible. We usually look at a reaction like that (the peroxide/ MnO_2), we tend to see it get to the end faster and think that the catalyst is only working one way. What you have to get into your mind is that, in a reversible reaction, we are doing both. It is going one way and at the same time going the other way. So both the forward and the reverse reactions sped up.
- S3: Does the catalyst have an equal effect on the forward and reverse reactions?
- T: Yes, the catalyst has the same effect.

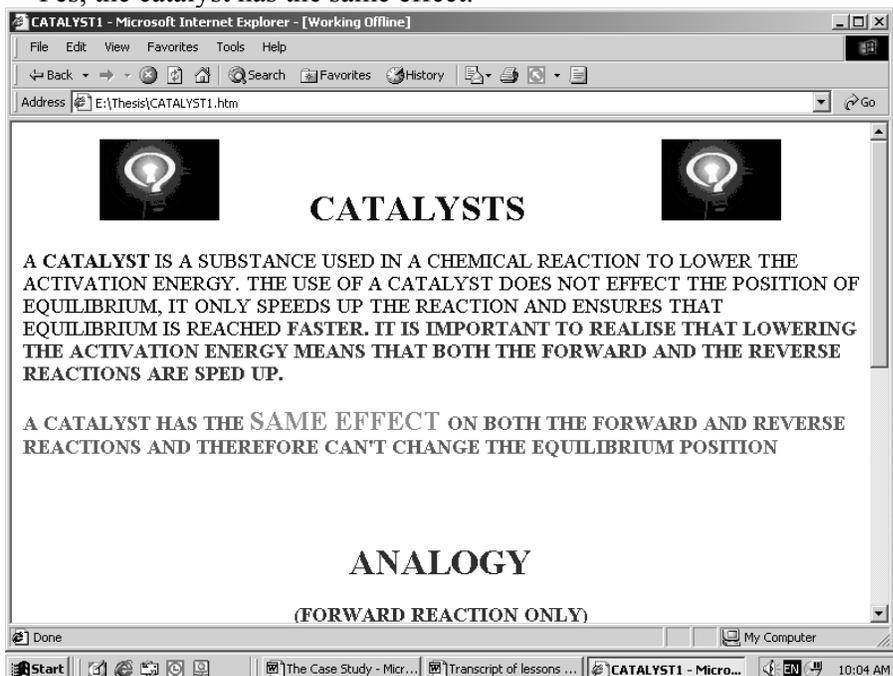


Figure 7.14: Initial catalysis screen

- While the students were completing their definition on a worksheet, student S3 provided his own insight into the use of analogies.
- S3: There's one other thing about analogies. The concept that you describe has to match the analogy. So, you have to think up an analogy that matches it well. I think that it should be your own.
- T: Yes, once you have seen somebody else's analogy and tested it against the concept, if you can personalise the analogy you're doing really well. If you can come up with an analogy that works for you and then state where the analogy is not so good or doesn't fit, then that's even better.

This student was showing a degree of self-direction and was already thinking about the appropriate use of analogies. The lesson suddenly diverged at this stage towards a discussion about the nature of memory and possible reasons for using analogies in

the first place. The idea that we have a limited working memory and that we need to construct schema to improve our thinking was raised.

S2 (interrupting): You mean like an eye test or something where you make up a little rhyme to remember a sequence.

T: Yes, rhymes are OK, but pictures are better and that's why these analogies are supposed to work better with graphics because you remember pictures better.

Other students joined in here:

S3: It works well with practical things because when we are doing a practical [experiment] we are seeing it as a picture as well as hearing it.

S1: And the weirder it is, the more you remember it

T: Of course, if it's strange it strikes you as strange so you tend to remember it. It's often easier to remember the odd things than those that are straightforward.

Perhaps some analogies should be working models rather than computer simulations. A model is a concrete representation of an abstract idea. For example, we often use different kinds of models – ball and stick or space filling- to represent atoms and molecules. Student S1 is providing perhaps another clue to effective analogy-making in that a bizarre analogy, something really striking, might be more effective.

The catalysis analogy was then presented to the students (see figure 7.8).

Mapping the analog to the target involved a discussion about activation energy. The students accepted the analog as presented but some wished to change it to better fit the target and in so doing had assumed a role as program designers.

T: What things are wrong with the analogy?

S6: There's two different cars.

T: Right, the cars are different.

S6: They should be the same.

S1: Their colour.

S6: Because the cars are just going on different roads. Should be the same.

S5: The cars are not a very good representation of a chemical reaction.

T: OK, why not?

S5: With the ice cream you could see that it was doing something, with the chips on fire you could see it was doing something, not with the cars.

S1: Perhaps they should change colour or something.

T: Yeah, they should change on the way through.

S1: Yeah.

S3: Yes that would show a reaction happening.

The ability of several of the group to see obvious problems in the mapping and then suggest changes to improve it demonstrated an involvement beyond the traditional learning process. Further discussion elicited a curiosity about the nature of a catalyst in an equilibrium system as illustrated by the following questions.

- S3: So what happens to a catalyst once it has reached equilibrium?
 S6: Does the catalyst at any point interact with the reactants but come out as itself at the end or is it always whole?

There was a brief attempt on my behalf to answer their questions but this was a diversion from the syllabus and while their questions required a fuller explanation, the time was not available here. This was a good example of the conflict between teacher and researcher as free time to explore concepts to their conclusion was severely limited. The next exchange was indicative of the level of discussion achieved by the group.

- T: So where else is this not like the equilibrium reaction? What were we talking about in the last lesson? What are the features of an equilibrium reaction?
 S5: It's not a closed system.
 T: Good.
 S3: It represents a rate change; it's not an equilibrium system like the others.
 S6: Yes every other analogy was also representing an equilibrium system.
 S3: So it doesn't relate to the first ones we did.
 T: Yes this is different.
 S6: It represents the amount of activation energy required to get where it wants to.
 S3: So it's a rate of change graph; so it's hardly an equilibrium.

This discussion was an important indicator that the students were seeing the value in analogies on a more general scale and were not confined to the equilibrium system. The ideas being raised were quite sophisticated at this level. However, the final exchange about the analogy seemed more superficial but also showed reflective thinking.

- T: Well where does the analogy break down? If we are trying to describe a change in the reaction progress rate, where isn't the analogy like the actual chemical reaction? We'll take it as a belief that it's not a closed system and that it's only showing you one direction and the cars aren't a reaction in there
 S5: There's no food involved. [like in the endothermic and exothermic reactions]
 T: No food, OK.
 S5: Drive us up to McDonalds and we'll have more ideas.
 T: It doesn't mean...because you can't think of a lot of things, some analogies are closer to their target than others.
 S2: Like the ice cream.
 T: Uh-huh, Some are good. Some are really close matching it.
 S3: Yeah, the ice cream one and the chips were representing the whole thing but this is only representing one part of the reaction, where the catalyst is involved.
 T: Yes, so we're narrowing again, the closer the analogy can match it.
 S3: Yes.

- T: The only rule here is that if the analog matches the target completely, it would be the target. So you would be looking at a catalysed reaction, which we are obviously not.
- S3: Realistically that's what the difficulty of chemistry is.

My interpretation of this exchange was that students were meaning to say that a simple analogy is the best and that they obviously relate to food better than any other stimulus.

The suggested answers were then presented to wrap up the discussion. I suggested that the catalyst was probably the bulldozer that flattened the hill rather than the small hill itself. Student S3 suggested that for different reactions the height of the hill could represent the actual activation energy and that a scale drawn on the side would give real values to the analogy. This would be a way to bring the analog closer to the target. Student S1 provided the expected range of written answers (see Appendix E, Example 3) but also worked on his own to produce a further analogy for catalysis that consisted of a mediator bringing two parties together to sort out their differences. This is an important example of the types of thought processes that were occurring in the group through the stimulation provided by the lesson material. If the

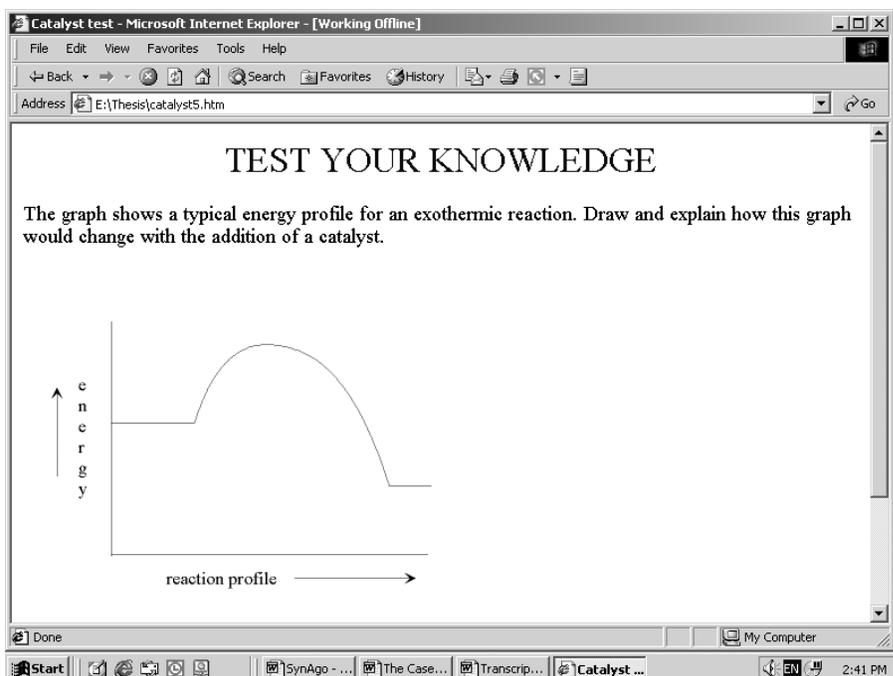


Figure 7.15: Catalysis examination question

students are challenged to create their own analogies, then some of them will respond immediately with their own creations. In this case, the student was not asked directly to produce any new ideas but instead took the initiative and found a better analogy

for him, one that, perhaps, made more sense. It was indicators like this that encouraged further use and development of the program. The final test question, shown in Figure 7.15, was then presented to the group. It proved to be the easiest for the students who gave correct responses without help.

In a concluding statement, I explained that I would have liked an analogy for pressure change. One of the students was able to suggest a room, containing people, in which the walls could move to simulate pressure. This spontaneous generation of an analogy, although incomplete, shows that the previous two lessons had served to enlighten this student as to the development and use of analogies in teaching and learning chemistry. The evaluation of the computer software and its use in the classroom was focused on the impact that it had on the students. It was clear from the discussions that the ice cream analogy was favoured and that the catalysis analogy was acceptable as long as adequate discussion was allowed. The burning chips analogy for an exothermic reaction caused too much time to explain clearly and needed replacing with something simpler and more easily understood.

A new computer-based analogy for exothermic reactions

While walking the dog and trying to get a little fitter, I had noticed how hot I had become and connected this heat with an exothermic system. The human body is after all a system that exists because of the heat produced and this could form the basis of an analogy. I developed the idea that if walking in mild conditions was acceptable, but still produced heat, then walking in hot climates would cause a person to think seriously about continuing the walk. This idea seemed to map the effect of heat in an exothermic reaction well and the ‘walking man’ analogy was born – as shown in figures 7.16a, 7.16b and 7.16c. In the first screen, a man in a suit steps out into a cool day and walks towards the park. As he leaves the city he finds himself in an arid region with hotter temperatures. The pace at which he walks begins to slow. He finds it too hot to continue so he returns to cooler conditions.

I had originally planned to produce analogies for a number of different concepts in chemistry but the production and testing of the computer generated equilibrium analogies proved extremely time consuming and convinced me to stay within the one area. I believed that this narrowing of focus would allow the production of a complete equilibrium package that would be of greater benefit in the

classroom.

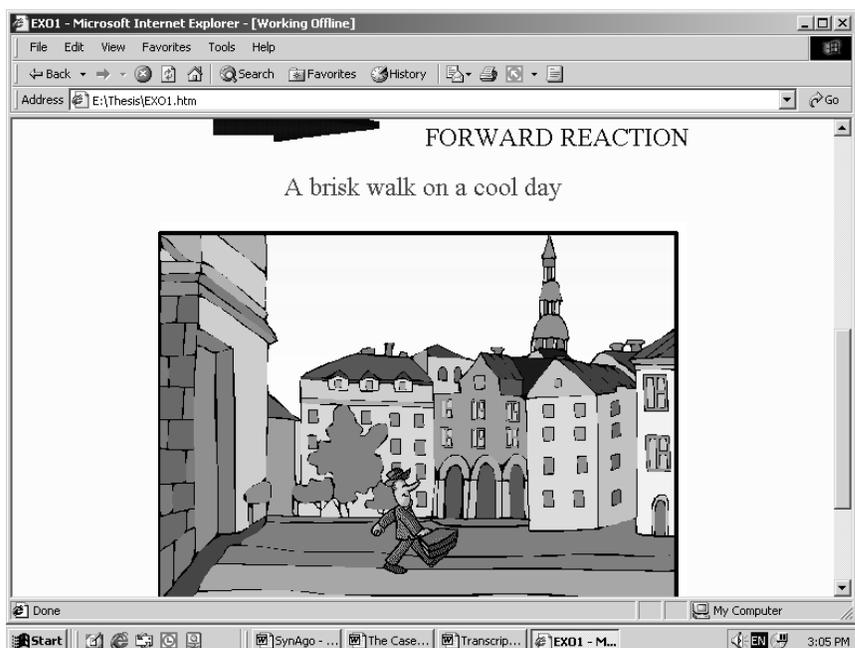


Figure 7.16a: The walking man analogy

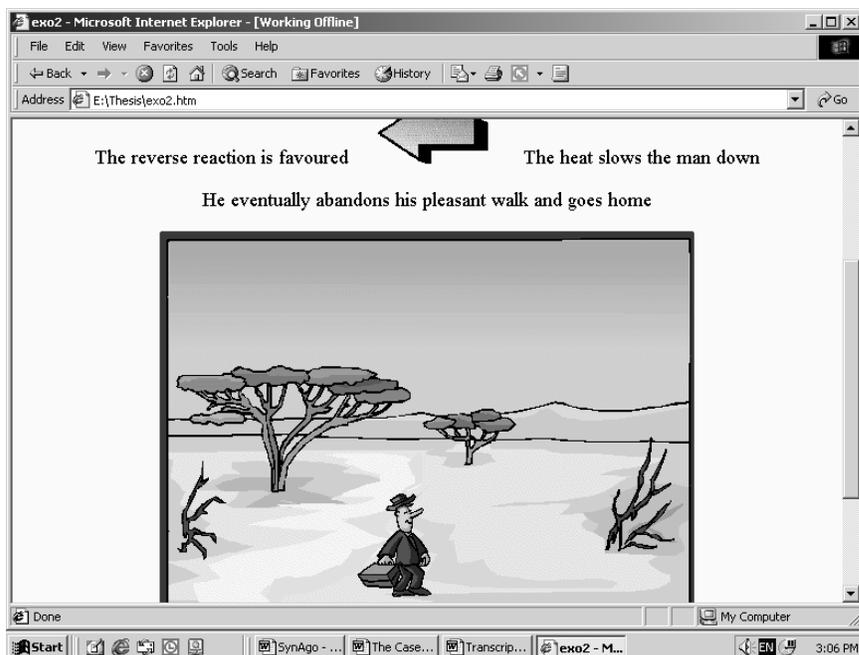


Figure 7.16b: The walking man encounters hot conditions

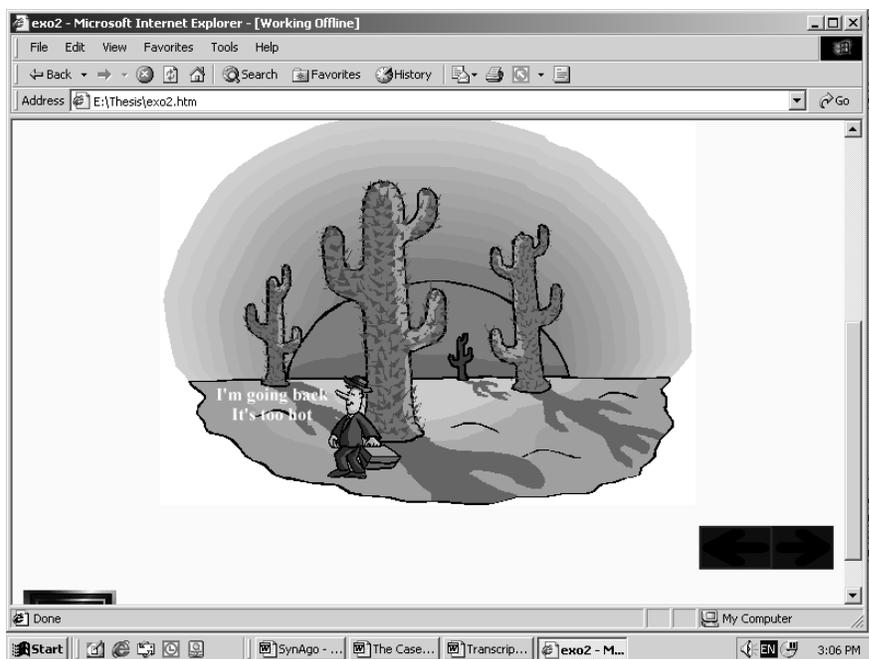


Figure 7.16c: The walking man in the desert.

The third trial

The software that now included the walking man analogy, along with a revised teaching sequence, was presented to two students (S7 and S8) at the beginning of the following year. I had been teaching both of these students for 12 months and was fully aware of their capabilities in chemistry. The analogies were used as part of the teaching program for the topic of chemical equilibrium, which was a new one for them. The physical arrangement was different as I was able to give them a computer each to browse the program and set up a small group around these computers. I followed a similar procedure to the previous group and introduced the topic with a demonstration of the reversible reaction involving the $\text{NO}_2/\text{N}_2\text{O}_4$ equilibrium, after which they completed practical experiments involving reversible reactions. The computer program was then introduced with an explanation of the use and purpose of analogies. I found that the presentation seemed to proceed much more smoothly than on previous occasions. Whether it was my presentation style, the fact that this was a pair of students or the change in design of the first analogy or some combination that caused the change, I really could not tell. The students were readily accepting of the walking man analogy and both thought it made sense. Their general responses were that the analogy was familiar and a reasonable way to present the

idea. The students had to be led through the process of discussing the first analog and its mapping to the target. They were only able to find four main discrepancies between the analog and the target. This analog seemed a closer match to the target than the burning chips and there was much less confusion on their part. One of the students, S7, appeared to grasp the concepts easily and both he and I were able to help the other student, S8, understand the ideas better. Student S8 was less confident but highly engaged in the discussions. The level of discussion proved to be very similar to the previous test group and for the first analogy the main differences between analog and target (see figure 7.17) were all identified by the students with a little prompting.

The ice cream analogy for endothermic change also was well received. The discussion produced some new ideas:

S7: It's not a closed system because someone could eat it!

S8: You can't measure the heat input

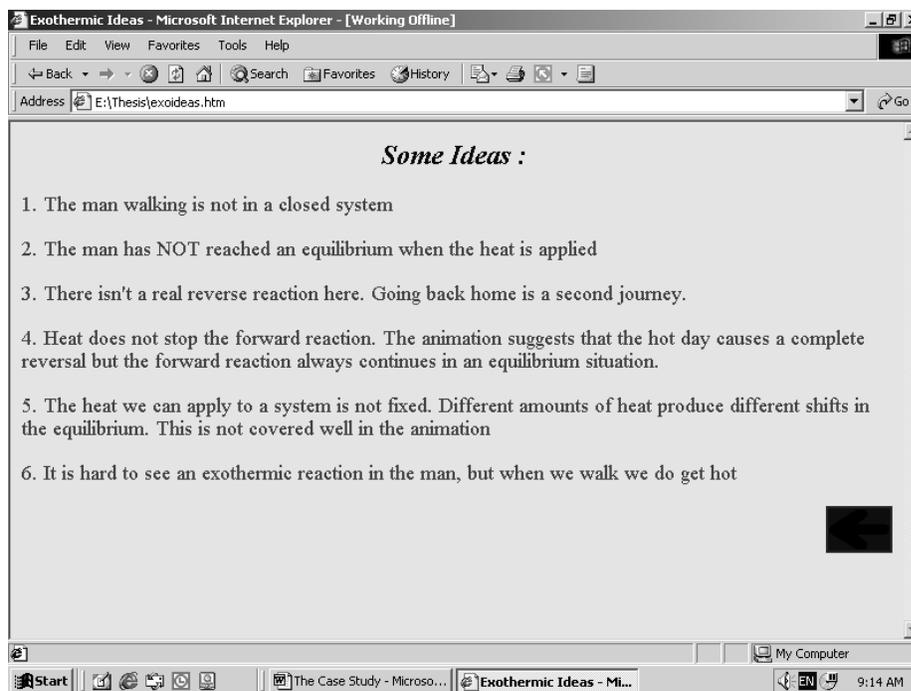


Figure 7.17: Ideas about the walking man analogy for an exothermic reaction

It was significant that neither student stated that it was a physical change involved in melting. When this was pointed out to them, they understood the difference but it did not appear to be an important part of the discussion for them. The catalysis analogy also was well received and the major differences between the analog and the target were elicited with little prompting. When the students were asked for their opinion of

the computer program, they were both positive and thoughtful and were genuinely impressed with the ease of the learning process for them. I mentioned that I was looking for analogies from other areas that would translate well into this format. Subsequently, the students in this conversation suggested the following analogies:

1. Metallic Bonding: A large car park with clearly defined rows and a thief running between cars with a bag of valuables.
2. Ionic bonding: One parent gets custody of the child in a divorce settlement.
3. Polar bonding: A car travelling along the highway towing a trailer. Both cars are carrying luggage. The extent of the polar bond is determined by the amount of luggage and the way it is distributed between the cars.
4. Covalent bonding: Two parents walking down the street with a child between



them holding hands.

For the students, the process of generating analogies seemed to be a natural extension of what they had learned. They had no difficulty in dealing with analogies and were able to produce original examples such as these when asked. The remainder of the second lesson was taken up with the hydrogen peroxide catalysis demonstration in the laboratory. Both students performed well on the test questions at the end of each section, so I was then interested to see their performance in the major examinations on this section of work. S7, it was subsequently noted in the half-year examination, scored full marks in questions directly related to Le Châtelier's Principle. S8 did not gain full marks but his performance on those questions was significantly better in relation to his performance on other types of questions. S7 was able to achieve 65% and S8 55% on the whole paper. In general terms, their understanding in this area was measured to be better than in other areas.

The second trial involving students S1 to S6, in my opinion, took too long to complete. I believed that analogies should be a component of the lesson and not the dominant feature of the unit of work. The purpose of this program was to help students understand an abstract concept better so I tried to speed up the process and present all three analogies in a one hour lesson. The discussion phase took a little

longer than this and I found myself using part of the second lesson with S7 and S8 to finish the catalysis work. These discussions took a little longer because I was researching as it proceeded (Wong, 1995). I wanted to know more about the students' thought processes than would normally be allowed by the course constraints. This type of teaching also requires a certain amount of training so that the students know what to do in the discussion phase. Once they are familiar with that process, then the subsequent analogies take less time and the learning becomes more time efficient.

Computer-based analogies for pressure, volume and concentration

Le Châtelier's principle is used in high school chemistry as a predictive tool for all the changes that can occur in an equilibrium system. While my review of the extant literature and analysis in Chapter 5 of the effectiveness of using Le Châtelier shows decreasing validity outside temperature and concentration effects, I still deemed it necessary to provide a complete set of analogies to draw upon in the classroom. Consequently, analogies for concentration, volume and pressure effects were required. The difficulty, as with the previous examples, was finding suitable analogies that would translate well into animations. Consultation with Professor David Squires from King's College in London, when he was a visiting scholar at the Science and Mathematics Education Centre at Curtin University of Technology in July 2000, led to a slight shift in my approach to design. The key principle, it seemed, was simplicity. The analogy should not place a significant cognitive burden on the student. It should merely stimulate and guide the student towards a deeper understanding of the concept.

An analogy for pressure: Using other doctoral students at Curtin University as sounding boards, a number of ideas were considered for a pressure analogy. Applying pressure to the whole system was the difficulty here. One could easily design the classical piston or syringe analogy where applying pressure to the plunger would force an aggregation of molecules. This idea was rejected because it is actually what I would do in a laboratory. I believed that the analogy should come from the students' real world and not from the formal classroom setting. I finally settled on a variation of the fish tank analogy. The tank was to contain two different types of fish (correlating to the reactants) and a place where the two types could associate close together (representing the product). This was achieved by having a

rock ledge in the tank under which the fish could congregate. The initial screen of the pressure analogy is shown in figure 7.18a. Pressure on the system came in the form of a cat, which enters making cat noises and jumps on top of the tank. Many of the fish respond by swimming under the rock ledge as shown in figure 7.18b.

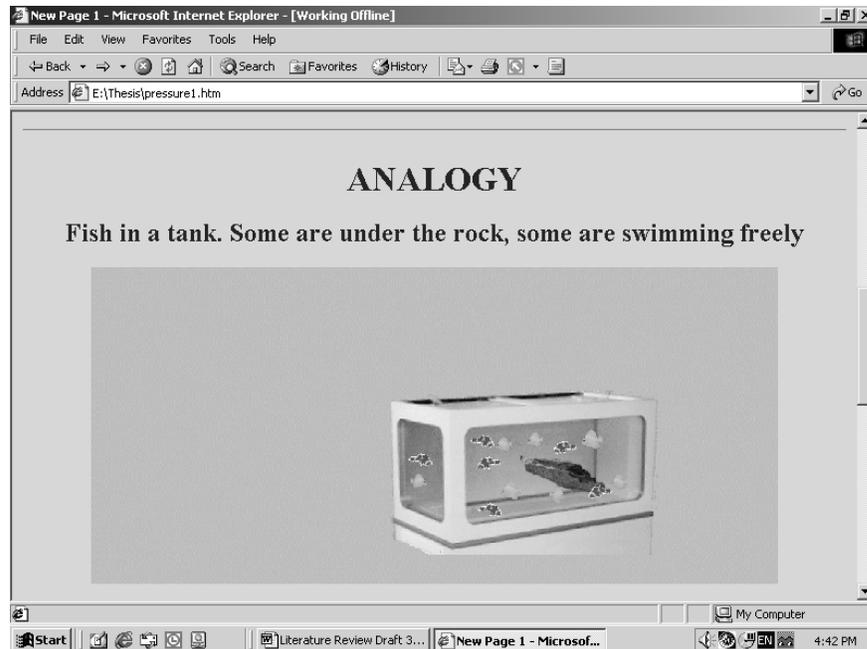


Figure 7.18a: Initial screen of pressure analogy

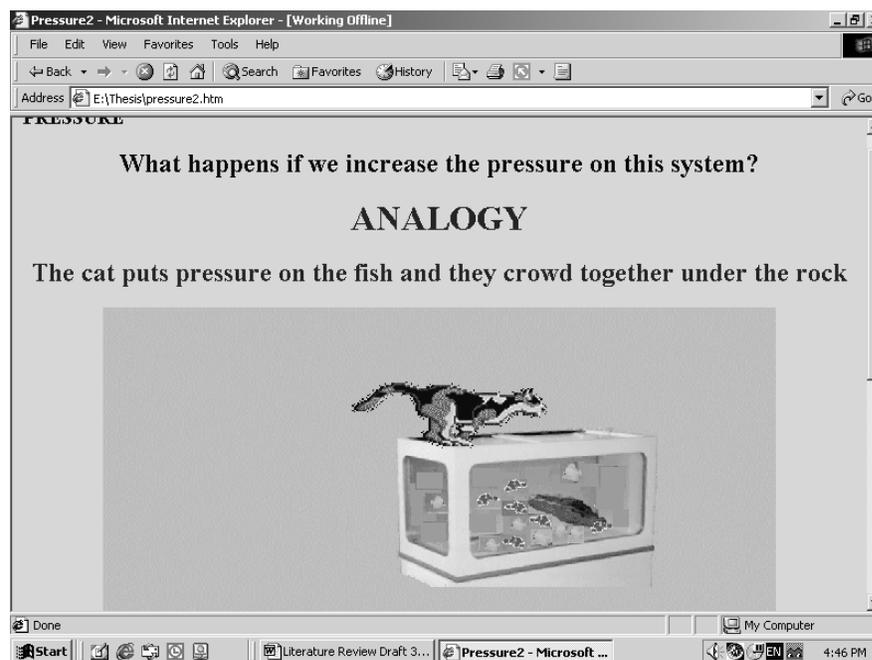


Figure 7.18b: Pressure applied by the cat!

This analog of the cat maps easily to the target, the pressure on the system, with the main discrepancy encountered being the lack of a different product. It is also important to point out to the students that the type of pressure applied by the cat is psychological and not the sort of pressure found in chemical reactions (force per unit volume). Fish swimming close together does not correspond to something new in the tank (see figure 7.18c). This does, however, provide a good starting point to the discussion about the value of the analogy in learning chemistry concepts by the students. If the mapping is not very accurate, the students should be able to identify those areas where it is deficient and hopefully understand the target much better.

The screenshot shows a web browser window titled "Analogy VS Target - Microsoft Internet Explorer - [Working Offline]". The address bar shows "E:\Thesis\pressure3.htm". The main content area has the heading "HOW DOES THE ANALOGY RELATE TO ITS TARGET ?" and a table with the following content:

ANALOGY	TARGET
Fish Swimming Freely in tank	Reactants A and B
Fish crowded under rock	Product C
Cat jumping on tank	Pressure applied to system

Below the table is an image of a cat sitting on top of a rectangular fish tank. The tank contains several fish and some rocks.

Figure 7.18c: Mapping grid for pressure analogy

An analogy for volume: The volume analogy was the result of some reverse thinking. Starting with the molecular level concept of decreasing the volume in a gaseous equilibrium and looking for everyday correlations, I finally settled on a robot filling a large container with boxes of two different colours. When the first row was filled, a second row was started. Any pair of red and yellow boxes together represented a product. The first two screens of the volume analogy are shown in figures 7.19a and 7.19b. Reducing the volume by decreasing the container size led to more boxes in the double row being formed as they squeeze into a smaller space (see figure 7.19b). This represents more product being formed as the volume is decreased at constant pressure.

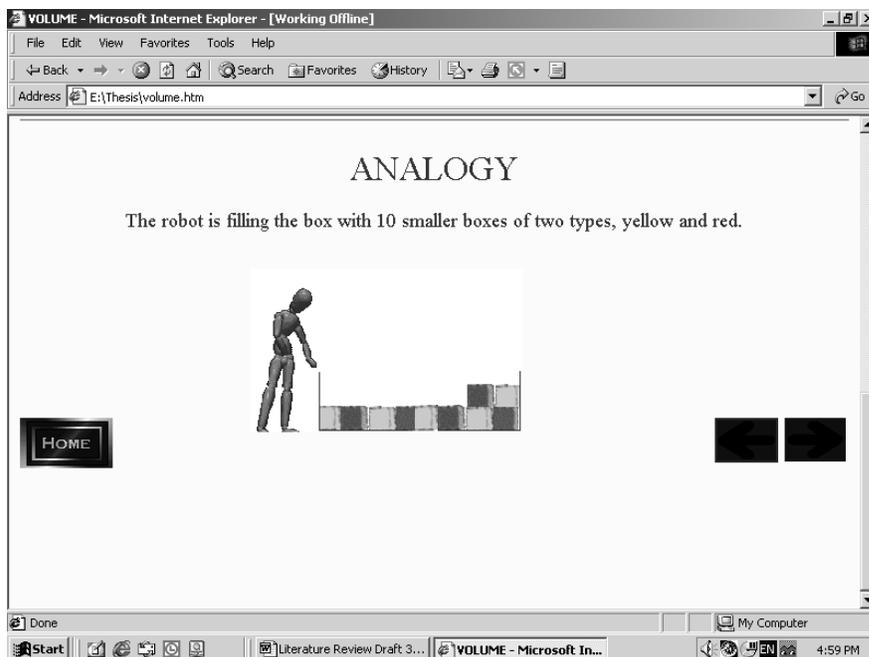


Figure 7.19a: Volume analogy screen 1

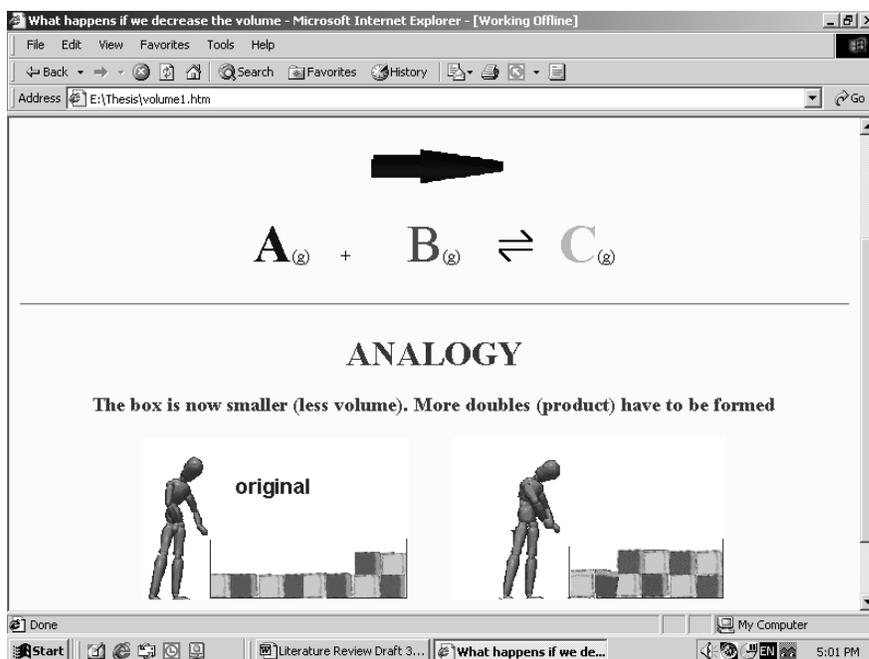


Figure 7.19b: Volume analogy screen 2

This analogy seemed to be simple enough and sufficiently removed from a laboratory situation to be acceptable in its design features. While students may not have seen a real robot sorting material, it did not seem a stretch of the imagination for them to superimpose a person doing the same if necessary. Should a student be able to modify an analogy, this is a sign that the student is engaged in active understanding of the underlying chemical concept. The mapping of this analogy,

seen in figure 7.19c, was very similar to the pressure analogy so it appeared to well suit the format of lesson design used in the previous analogies.

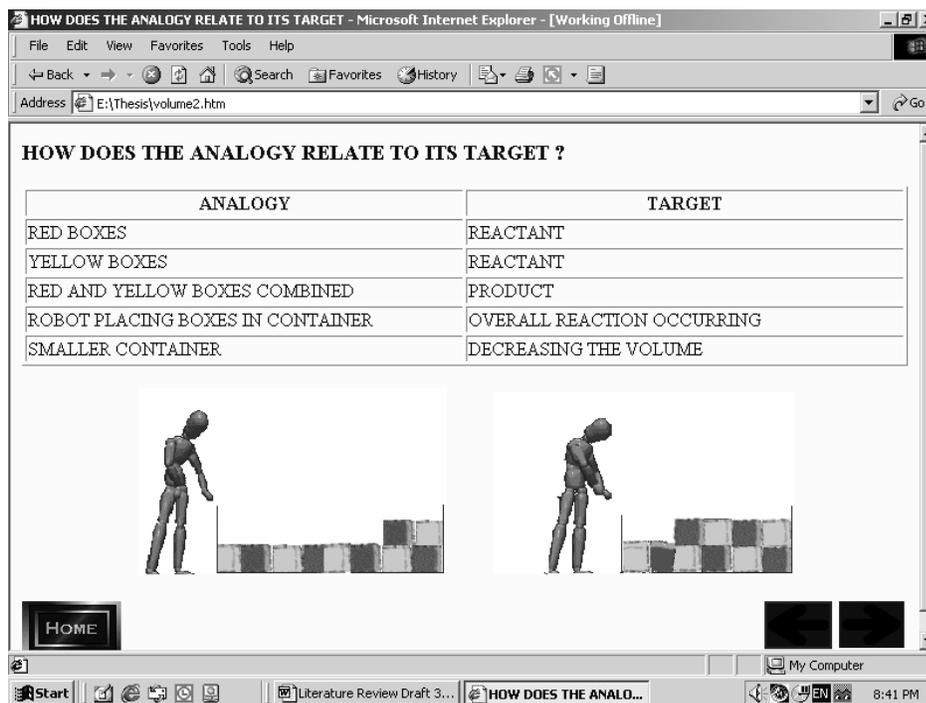


Figure 7.19c: Mapping the volume analogy with the target

The robot and boxes analogy used for volume changes should prompt a number of responses when the group are asked how well the analogy maps to the target. Figure 7.20 is a reproduction of the text from the program that is used to reinforce the student ideas after their discussion period.

Here are some suggestions about the robot and boxes analogy:

1. It is not a closed system. The boxes can fall out of the container.
2. The product is not a new substance, just two boxes on top of each other
3. It doesn't show what happens if the volume is increased
4. It is a physical rearrangement, not a chemical reaction
5. The equilibrium is not dynamic, reactants are not exchanged for products.

Figure 7.20: Ideas about the volume analogy

The examination questions and answers are reproduced in figure 7.21

TEST YOUR KNOWLEDGE

1. The following system has been allowed to come to equilibrium :



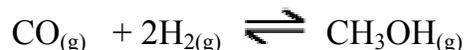
What would be the effect on the equilibrium concentration (**increase**, decrease, no change) of each substance in the system when the volume is doubled and allowed to re-establish its equilibrium?

2. Consider the reaction:



What would be the effect on the Chlorine concentration of an equilibrium mixture if the volume of the reaction vessel were decreased?

3. A key reaction in the manufacture of methanol is



Predict the effect of decreasing the volume of the reaction vessel on the yield of methanol. Explain your answer.

Answers

1. The equilibrium concentrations of carbon monoxide and oxygen would increase. The concentration of carbon dioxide would decrease. The reaction shifts towards the reactants, as there are more moles on the reactants side, more space for the molecules to expand into.

2. The chlorine would increase, as there are fewer moles on the product's side.

3. The methanol concentration would increase as the reduction in volume favours the fewer number of moles on the product's side of the reaction.

Figure 7.21: Examination Questions and answers from the volume analogy

An analogy for concentration changes: Concentration effects also fitted well with the robot analogy. The original animations were modified to show how adding more of one reactant (yellow boxes) affected the product. As the yellow boxes were added they paired up with red boxes forming more product. In this case the size of the container did not change indicating no change in volume and the pressure was assumed to be constant. Figure 7.22 shows the second screen of the analogy with the robot having added more yellow blocks to make more product. The mapping of the analog to the target was identical to the volume analogy. The ideas raised about how

the analogy breaks down are the same as those seen in figure 7.20 with the one exception being the word “volume” in example 3 being replaced by the word “concentration”. This completed the set of analogies and necessitated a further round of testing in the classroom to assess the overall program.

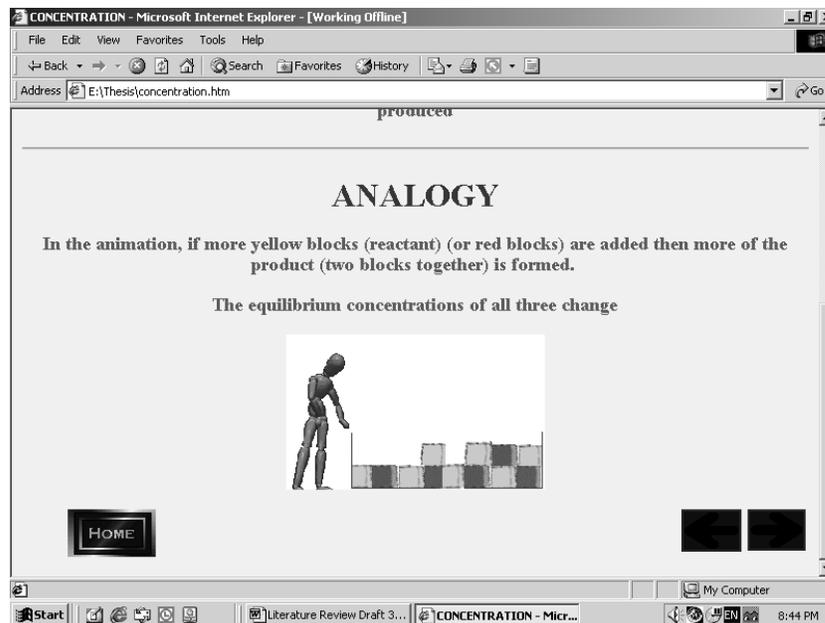


Fig 7.22: Concentration analogy

Final development of the CDROM: In order to complete the CDROM, I decided to add some extra resources that I thought might have been relevant. If the CDROM is to be used by other teachers and researchers then I believed some additions were necessary. Firstly, I included an essay that I had written summarizing the research evidence for the effectiveness or otherwise of using Le Châtelier’s principle and the equilibrium constant in the teaching of equilibrium change (see Chapter 5 – Chemical equilibrium and Le Châtelier’s principle). Secondly, some tutorial fact sheets and examination questions were included for students to print as summary sheets (see CDROM). Thirdly, an advanced tutorial on equilibrium from the University of Wales that I had found on the Internet was included for high achieving students (see CDROM). If the software package was to be used by the teacher, I included a questionnaire for both students and teachers to see if I could get some objective feedback (see Appendices B and C). Apart from determining if there was a perceived benefit from using the package, I also wanted to examine if their knowledge of the use of analogies and their level of collaboration and participation had changed. As a teacher/researcher, I had observed noticeable changes in the levels

of class discussion and interest of the class groups. It would be interesting to obtain views from other groups. I also included a questionnaire for teachers who reviewed the software but did not go on to use it (see Appendix C). The final production of the CDROM involved designing a cover, a set of instructions, final versions of the questionnaires and the burning of the CDROMs for distribution.

The fourth trial

With the finished product in hand, I began testing its effectiveness with a new group of students. There were 8 students from Year 12 present for the whole of the lesson sequence, but 12 were enrolled in the class. The lesson sequence spanned three one-hour lessons and it was very difficult to accommodate the other students who attended only one or two of those lessons. If they had missed the introduction, they would struggle to pick up the flow of the lessons and the rationale. To put these lessons in context, in 2000 the NSW Education Department had introduced sweeping changes to the HSC curriculum. Equilibrium theory was no longer taught as a discrete topic but was included where needed in acid/base theory and Industrial Chemistry. It was only a minor section of the acid/base topic that these students were currently studying. The only concept they were required to learn was the effect of concentration in equilibria involving buffers in natural systems. The remainder of the equilibrium topic had been included in an elective featuring Industrial Chemistry and these students were not intending to take that elective. I realized that I now had a complete set of analogies that were no longer directly relevant to the new syllabus for this group of students. Nevertheless, I proceeded with the lessons in a somewhat abbreviated format with the hope that I was not wasting precious time needed for examination preparation. I knew that equilibrium was still covered at university level but it was a difficult decision for me to stop a certain point with half an explanation and tell them that is all they need for this examination. There is a great deal of content in the new syllabus and it allows little time for in-depth teaching and teaching for understanding.

I began with a similar teaching sequence but focused the work around concentration effects with some coverage of temperature changes and catalysis. We briefly touched on the pressure and volume effects at the end. The focus on concentration was not necessarily a bad thing for my research, as I had not tested the robot analogy at that stage. We began with a practical lesson on reversible reactions

in the same manner as the previous two groups. The hands-on approach is a good way to have all students involved and experiencing the reactions as they happen.

The second lesson began with an outline of equilibrium theory that tied in the results of the experiments. Being conscious of the time and curriculum constraints produced a much quicker coverage of this basic theory. I felt that I needed to get into the program as early as possible. The screens that described analogies were given a brief viewing and discussion. The first analogy covered was the concentration robot analogy. As with previous groups, it took the class some time to understand what was happening and to understand their role in the process. The analogy itself seemed well received and the discussion, while very much led by myself, elicited much of the problems with the analogy. I had noticed three students among the eight who were very quiet in the lead-up lessons. They were sisters who had joined the school from Singapore at the beginning of the year. Two of them would not speak directly to me and worked through the older sister who explained concepts to them and provided some minimal feedback. During the discussion phase of the software, I found it impossible to draw these three into the group discussion that was dominated by two boys and one girl who had been at the school for five years. While they did not join in with the rest of the group, these two reserved students did manage to work out the correct answers to the test questions and seemed to understand the concepts.

The third lesson involved the walking man-exothermic reaction analogy and the catalysis analogy using the cars. The results of the discussion on the mapping went well with a noticeable increase in participation rate by the students, other than the three girls from Singapore. The students were growing more confident with their responses and were feeling free to contribute to the analysis of the analogies. There was evidence of metacognitive processes as one student asked why we should 'go this way' to understand a simple concept. He was not sure that using analogies and spending the time required by the program was an efficient use of his learning time. I explained that maybe it would not be such a simple concept if we did not use analogies. The lesson sequence concluded with a brief look at the other analogies and a distribution of survey sheets to each student. I relied on these surveys to provide a more objective analysis of the classroom dynamics during the teaching sequence. It was encouraging that the students were quite keen to be involved in the research program and promptly returned the survey forms after the weekend. I was impressed

with their studious attitude and reflected that students should be more involved in all aspects of their learning program.

Analysis of student surveys

The students were first asked to state their age and sex (see Appendix B for full questionnaire). The questionnaire contained 12 questions with a response rating from 1 (low) to 10 (high) on the issue being addressed. The group of six females and two males whose ages ranged from 16 to 18 years were asked how long they had been studying Chemistry and to give an honest assessment of their ability level on a scale of 1 (struggling to cope) to 10 (competent in all areas) (see figure 7.21). The interesting finding from the question about the length of time spent studying chemistry was that two of the three girls from Singapore had only been studying Chemistry this year for about two months. The older girl had already completed much of the English A-level course and the Chemistry A-level course. The other five students had completed Year 11 and were two months into their final year of secondary school. Only seven of the eight students responded showing that the students rate themselves average or slightly above average. This was a good test group from my viewpoint - the type of group the program was designed to target. If the students found little difficulty with the course or if they were all hopelessly lost on the basic foundations of the chemistry, then it would certainly not be relevant for my study.

Question 1: Give an honest assessment of your ability in the Chemistry course so far. (1 - Struggling to cope 10 - Competent in all areas)

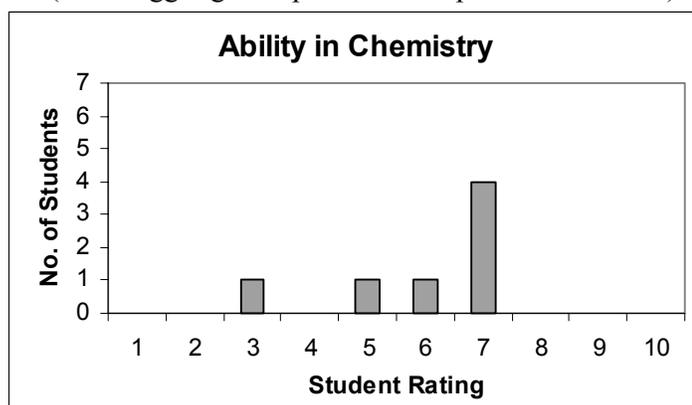


Figure 7.23: Student's own rating of their ability in chemistry

The students were then asked about their prior awareness of the use of analogies in their lessons. As I would have expected, most of the responses relating to prior knowledge of analogies were in the low range (see figure 7.24). Rarely do classroom

teachers have the time to explain the way they teach and reasons for using a variety of techniques. Often the use of a metaphor or an analogy to help explain a concept would occur at the instant of teaching.

Question 2: Before the lessons, rate your knowledge of how analogies are used to help teach you. (1 – Totally unaware 10 - A very good knowledge)

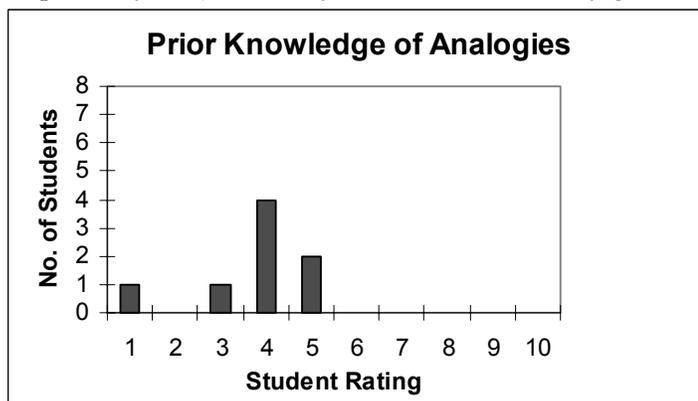


Figure 7.24: Student rating of prior knowledge of analogies in class

The next question was included to get an idea of the experience of analogies with regular teacher. Most of the responses were in the lower range (see figure 7.25). This survey was given after the lessons so they would have had a good understanding of the nature of analogies and how their teacher might employ them. They might not be aware of the range of analogies available to their teacher and verbal analogies may be used only briefly to emphasise an idea. The higher ratings were interesting here. Perhaps these two students were more conscious of the teacher's methods than the others or they mistook other forms of teaching for analogy.

Question 3: How often does your chemistry teacher use analogies to explain things? (1 – Not at all 10 – Very often)

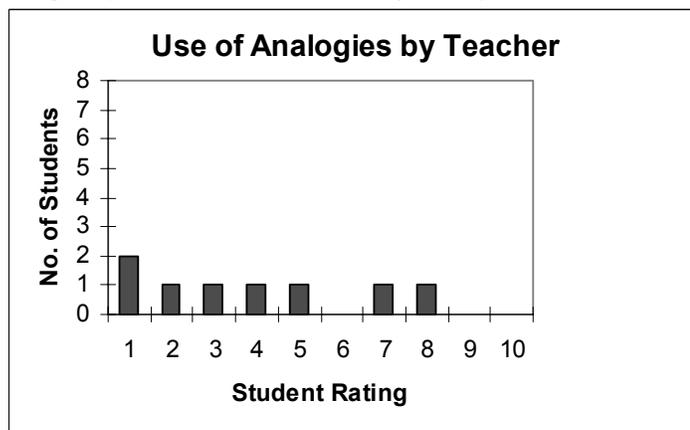


Figure 7.25: The prior use of analogies by the teacher

The use of analogies by their regular teacher and the authors of their textbooks are quite common. In talking with their teacher, he felt that he often used the techniques of metaphor and analogy to make abstract ideas easier to understand. His demonstrations would often involve models to explain behaviour at the molecular level.

The students were then asked about their prior experience of equilibrium theory.

Question 4: Before these lessons, rate your knowledge of equilibrium and how changes affect equilibrium systems.

(1 – No knowledge 10 - Very well established)

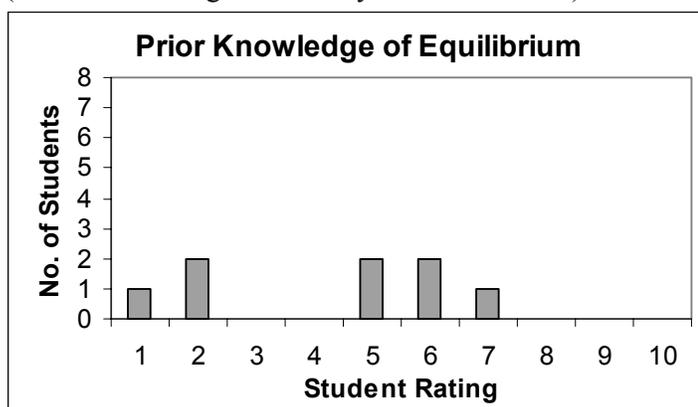


Figure 7.26: Students' prior knowledge of equilibrium theory

The three higher ratings were from the girls from Singapore (see figure 7.26). This topic had not yet been covered in Year 11 with the rest of the group.

The next two questions were concerned with the level of collaboration in the group.

Question 5: While using the program, you were asked to discuss how effective the analogy was in describing the real situation. Rate your level of participation in the discussions.(1 - Did not contribute 10 - Very active)

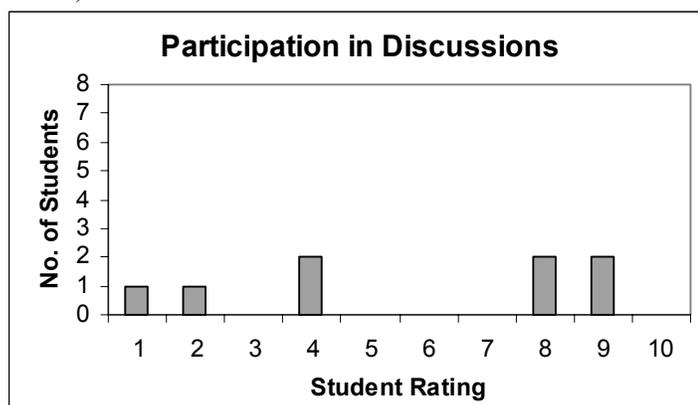


Figure 7.27: Level of participation in class discussions

This result was anticipated as the discussions had been dominated by three or four students, especially the two males in the group (see figure 7.27). The collaborative aspects that the program was designed to promote were not in evidence here across the group. Group dynamics is an important feature of any collaboration but due to time constraints, a further analysis of the group was not conducted. The next question should have been asked first as it was a measure of their usual participation in class discussions. One of the aims of the teaching program was to engage all the students in a fruitful discussion about the analogies. In this group it proved a difficult exercise, as a number of the students were quite reluctant to speak out.

Question 6: Rate your usual level of contribution in class discussions.
(1 – Do not contribute 10 – Always involved actively)

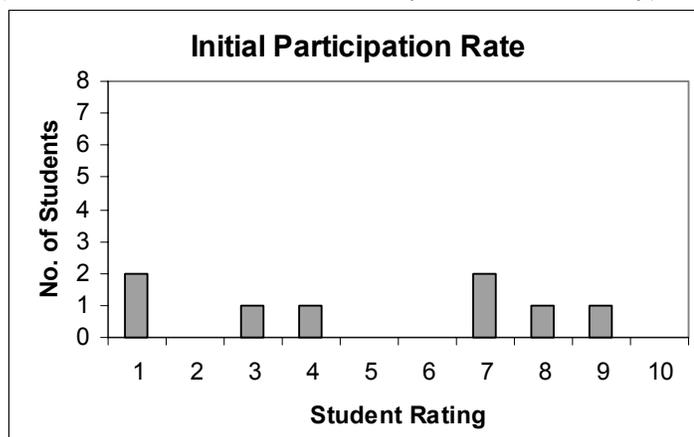


Figure 7.28: Students' usual level of involvement in class discussions

This distribution was fairly similar to their involvement in the discussion of analogies although there was slight improvement in the rating for the lower rating students (see figure 7.28). There was no real improvement in collaboration or discussion level here. I would attribute some of this result to the speed at which the lessons were presented and the need to quickly finish the discussion phase to save time.

Question 7 dealt with how the analogies were employed in teaching. This idea is subjective as no tests were conducted to see how well they understood the analogies. The students were not asked specifically to give their feedback on how well they were going during the lessons. General questions aimed at individuals towards the end of each lesson gave indications that their understanding was progressing and that the use of analogies was beneficial but the package itself

focused on the outcomes of the unit and tested the examination concepts. It is a question that deals with the metacognitive aspects of the use of analogies as the students are required to reflect on their own thinking processes.

Question 7: After going through the lessons with the package, do you think that your understanding of analogies has increased?

(1 – Not at all 10 – A great deal)

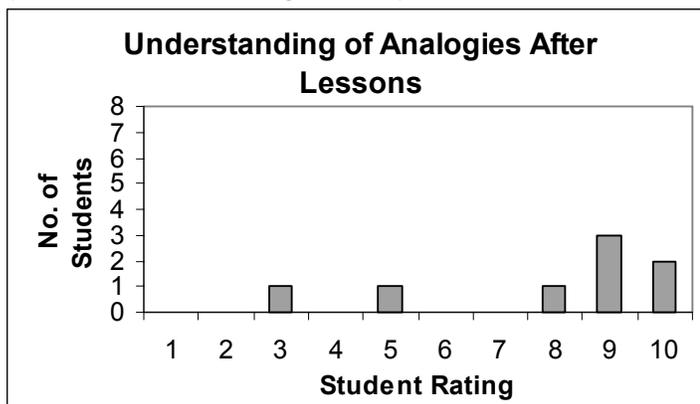


Figure 7.29: Post-lesson understanding of analogies

All responses showed a significant understanding of analogies after the lessons (see figure 7.29). It showed that most of the students had been thinking about the analogies themselves and considering the role of analogies in the learning process. The next question dealt with the specific knowledge covered by the analogies. This result was very positive as all members of the group felt that their understanding had increased significantly (see figure 7.30). The original reason for producing the software was to improve the quality of learning in equilibrium theory and the data supports an improved position.

Question 8: After going through the lessons with the package, do you think that your understanding of equilibrium and Le Châtelier's principle has increased? (1 – Not really 10 – A great deal)

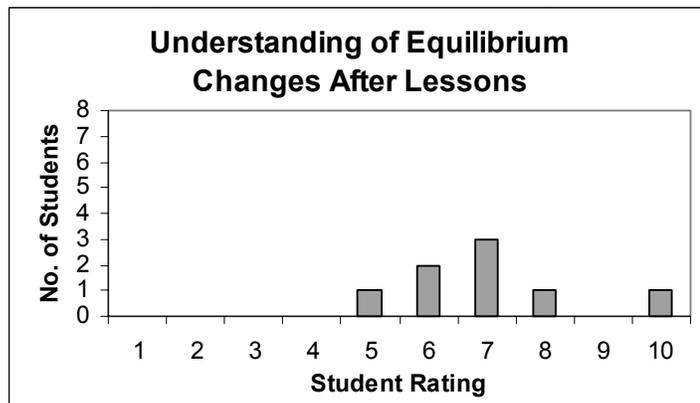


Figure 7.30: Post-lesson understanding of equilibrium concepts

The last four questions were designed to obtain feedback on the use of this approach in teaching this topic. The result here was also positive and showed that the students related some of their success in the test questions to their employment of the animated analogies (see figure 7.31).

Question 9: Did the animated analogies make it easier for you to remember the effects when you were doing the test questions for each section?
(1 – Not really 10 – Yes)

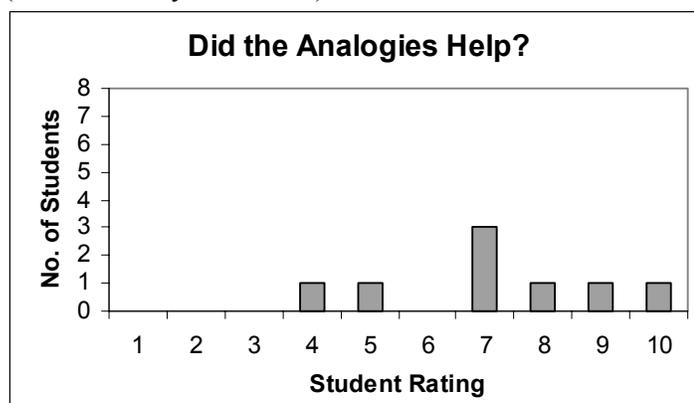


Figure 7.31: Did the multimedia analogies assist understanding?

This is the first measure of the effectiveness of the teaching program. The general acceptance of the use of analogies in this setting indicates that there is a reason to be optimistic about the learning outcomes where multimedia analogies are applied. This survey is reflective of previous trials where the students were very positive about the way that the analogies had influenced their thinking in this topic. Only one student rated the usefulness of the analogies below 50% on the scale, the same result as in figure 7.29 when the students were asked if they understood the use of analogies in teaching. This result is also evidence for the suitability of design of the analogies for their target group. The students did not complain about the analogies and there was no indication that they were experiencing any comprehension problems.

This survey was completed after a weekend and showed that the analogies themselves persisted, at least in the short-term for the students. If there had been no impact on the students then there would have been little reason for them to remember the animations to the level that they obviously did (see figure 7.32). The survey question asked for their recall to be highly specific and be able to remember the details in each of the analogies. It is significant that the animations contributed to their level of recall. Two students from earlier groups with whom I had the chance to

speak some six months after this short teaching program were able to recall some of the analogies. One of them still remembered the analogy she had constructed at the time and the chemical theory to which it related.

Question 10: What is your level of recall of the analogies at this stage? For example, if I were to mention an endothermic reaction, can you recall the analogy used in the package without difficulty?
(1 – Very low recall 10 – High level of recall)

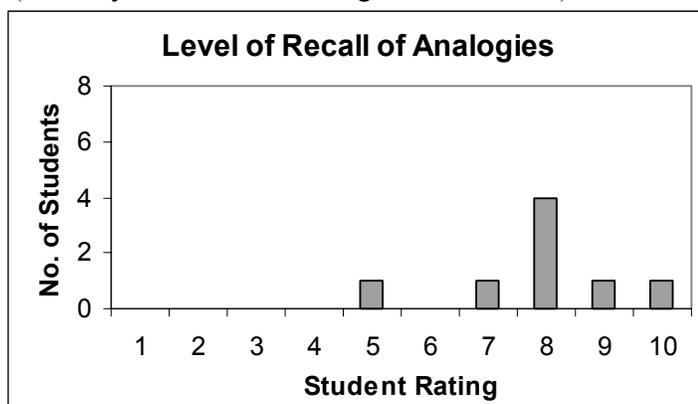


Figure 7.32: Level of recall of analogies

The next question was designed to evaluate the students' thoughts on the teaching methodology. This result, where the majority of the students considered the approach to be effective, was pleasing as the method of teaching was a major component of this research (see figure 7.33). If the students like this form of presentation then it should have a positive effect on their learning outcomes.

Question 11: Rate this approach to teaching this particular section of the topic.
(1 – Not very good 10 – Really effective)

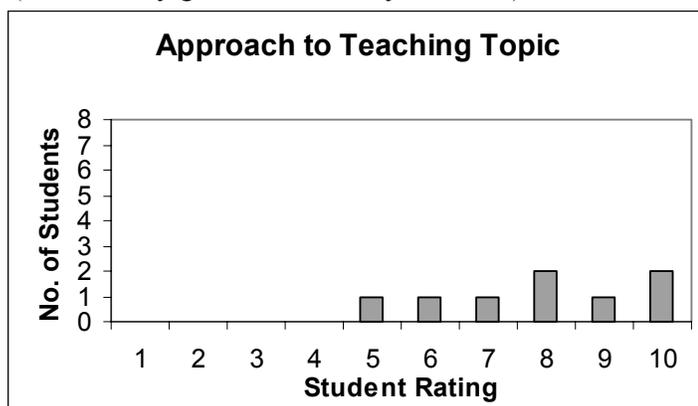


Figure 7.33: Student evaluation of teaching methodology

The next question is really a corollary of the previous question and the result was very similar (see figure 7.34). The very positive rating given by the group shows a broad acceptance of the approach. The reasons for this acceptance may lie in the

novelty of the approach and the way that the group was included in the learning process or it may be that it suited their learning styles.

Question 12: Did you find the use of the CDROM a benefit to your learning?
(1 – Not really 10 – Highly beneficial)

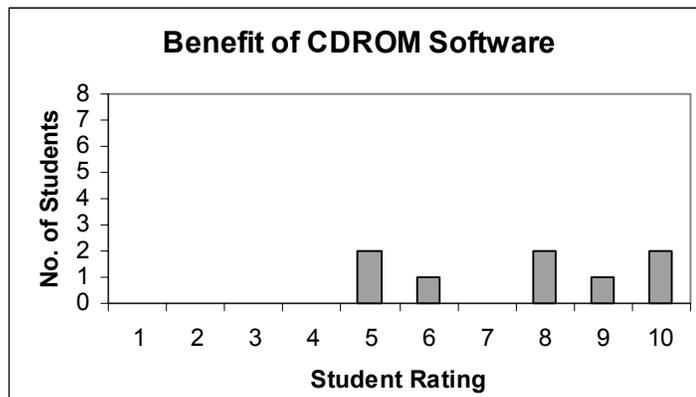


Figure 7.34: Benefit of using CDROM package

Some additional questions were asked regarding which analogy they thought the most effective and which the least. These were really questions about the design of the program and a bid to seek improvements. I discovered that there was no pattern at all. Different students liked different analogies. This was no surprise, as analogies have to be internalised and it is a very personal experience. The key to the use of analogies is in the discussion phase where students can see that the analogy is merely a vehicle to help understanding. The analogy itself can be anything that works for the students and they are not all going to like the same analogy if given a choice by the teacher. The students also were asked if they were able to produce an analogy of their own while thinking about the ones that had been presented. Two of the group replied that they could do this but two other students were unsure. This is again a positive finding as some members of the group were prepared to consider the analogies and produce their own in a thought process beyond that normally required in the classroom.

Summary

The development process produced significant changes to the software in response to perceived needs and analysis of the evaluation by students and others. The testing of the final product showed that it was now mature enough to reflect its original design parameters. The package was self-contained and appeared to be an effective teaching tool. The variety of data gathered generally supported the use of

the software in the classroom. The development process involving design, authoring of the software, testing, evaluation and refinement is demonstrated over the course of this investigation. I found, essentially, that the data gathered in the last trial was confirmatory of previous trials and that no new ideas were arising from the test group. For this reason, I decided to finish the testing and development phases at that point. The final chapter is designed to show how the research is linked to theory, the limitations of the research and some suggestions for further study. It will examine how the various ideas from previous research have been combined to produce the finished product. It will show how the use of analogies in combination with multimedia design can be used to produce a teaching tool that is easy to use and incorporates examples of best practice within a constructivist framework.

CHAPTER 8

Summary, Response to Research Questions, Limitations and Suggestions for Future Research

Introduction

In this chapter I would like to relate the theoretical basis of the thesis work to the design and implementation phases of the software production. The final version of the software package contains examples of best practice in the use of analogies as well as attempts to improve the collaborative nature of learning within the group. The software design is, I believe, a step forward in the use of analogies in the classroom. Following the identification of the domain-specific problem, the process involved a development cycle where solutions were designed, tested and evaluated. The results of the testing and evaluation provided the impetus for subsequent refinements and modifications.

Driver and Scott (1996) investigated curriculum development through a research program that involved the same development cycle. They argue that this method is a legitimate form of research that takes into account the perspective of both the students and the teachers involved in the process. Curriculum development, from a constructivist viewpoint, must consider what the students are gaining from the experience. Field-testing is the only way that researchers can gain first-hand knowledge of the learning process and how a specific program impacts on students.

This chapter responds to each of the research questions as it looks at the implementation and effectiveness of the program. The chapter concludes with a discussion of the limitations of the program and some suggestions for further research.

The design platform

In the second chapter, research on the effectiveness of using multimedia in the classroom has produced some clear guidelines for the design process. While acknowledging the criticisms of multimedia as it developed in the early 1990s, I feel it is important to take the best aspects of the new technology and use these to advantage. Madian (1995) has genuine concerns about adopting technology without first assessing what is to be omitted from the educational setting. If we are to replace certain traditional activities with computer-based learning, then the design and

implementation phases require research and validation. There is no doubt that any technological change that encourages superficial learning should be avoided and that time for collaboration, discussion and reflection needs to be a central component of lesson design. Teachers are entrusted with the implementation of any new designs in the classroom and should be critical reviewers in the process. The point that Madian is missing from his paper is that any new concept in learning is an exciting experiment with potential benefits beyond the vision of the designers. The challenge is to integrate the new with the established practices and improve the quality of delivery. The chemical analogies that I have developed are a complement to the more traditional approaches of classroom delivery. They are designed to encourage thinking, collaboration and reflection.

The use of HTML as the authoring platform, with its associated hyperlink language basis, was driven by the technology available in schools and the suitability to the task. If teachers and students in other schools wish to change or add information in the program, it is a simple procedure to use a web page authoring program to make those changes. The original software can be used as a template for developing other analogies in chemistry. This approach provides a measure of flexibility for the user and supports the idea of Dede and Palumbo (1991) that hypermedia environments should encourage students to create their own knowledge. The idea of cognitive flexibility in learning is a recurring theme in the literature dealing with hypertext and hypermedia. Spiro et al. (1992) argue for the freedom of the learner to construct his/her own links and associations in an effort to negotiate ill-structured domains. My software provides a degree of choice for the user in that they can navigate through the program with some choice as to the type of analogy to be studied (the Main menu) and then a choice as to the pace of learning and going back to various screens to revise information. If the classroom teacher gave his or her students a chance to experiment with the software, sections may be arranged into a better sequence. I finally settled on the current sequence after several trial presentations over a number of years. I deliberately included a fixed sequence for each analogy with limited branching, as I believed that this work was focused on a specific, narrow area with a need for compartments for each analogy. It is possible to alter the links and allow students to flick between analogies more easily but there did not seem to be a sound educational reason for doing this.

The design principles

Although written as a synthesis of research up to 1992, the design principles of Park and Hannafin (1993) still appear to be relevant to current settings. Their implications for software design in a constructivist framework provide a checklist to evaluate the validity of the program. It is not possible in a program dealing with such a specific area to cover all aspects of learning theory but I believe it is important to show how several features of the software design are tied to sound research principles. The active linking of prior knowledge to new knowledge is a cornerstone of constructivist theory. It is important that students can integrate existing knowledge structures with new experiences. Often in chemistry teaching, the students have only had about 12 months or less focusing on chemical ideas before they are asked to consider equilibrium ideas. This does not necessarily provide a solid base to build on, as much of their early work involves atomic theory, periodic table and bonding.

There is, in my experience, little chemical base knowledge for chemical equilibrium. The analogies I have designed draw from familiar, real world experiences in an attempt to overcome the lack of background from the chemical world. During the testing of the software, one of the important questions asked of the students was their impression of the analogies. Most of the students were of similar age and from the same ethnic and social backgrounds and the students accepted all of the analogies as familiar ideas. The fact that individuals showed a preference for different analogies did not detract from the simple observation that the analogies were well suited to the target group. When asked to produce their own analogies, several students produced ideas that were not very different from the originals and were a predictable fit for the background of these students (typically white, Anglo-Saxon, from low to middle income families). The students readily associate with consumer goods and services such as ice cream, businessmen, robots stacking cartons and well equipped fish tanks in homes. Their own analogies involved such things as cars in large car parks and a boxing match. A different culture where consumerism is not so dominant would require simpler, more relevant analogies.

Park and Hannafin's Principle 7 (see table 2.1) states: "that learning improves as the number of complementary stimuli used to represent learning content increases". This idea was included in the software design by providing dual representation on the same screen. The symbolic reaction is shown to illustrate

conventional theory and the analogy is also shown. The symbolic representation is included in two forms to give students a choice that better suits their understanding of the theory. In the analogy looking at gaseous equilibria, a further animation has been included to give an alternate pathway for understanding. It is hoped that adjacent, multiple representations will improve the comprehension for students. The next principle (8) deals with the amount of mental effort in which the student must invest in relation to the learning goals. The idea is that apart from engaging the student, there is a need to demand that the student focuses on the task and becomes an active participant in an attempt to understand the task. The discussion phase of the analogy satisfies this requirement. The students become critical analysts in the process although there is still a role for the teacher to ensure that all students adopted an active role.

An important design consideration for interactive multimedia (IMM) is the need to reduce cognitive demand for similar features of the program (principle 9). Computer software is ideally suited to this by using consistent screen design features common to all pages. I have employed the same basic structure for all the analogies and the same navigation structures. The ease of navigation effectively reduces the cognitive load as moving between screens is learned quickly and becomes more of a subconscious activity. Also, the way each analogy is introduced and applied is very similar to reduce the cognitive load involved in understanding the setup of the program. My findings were that once each group had received some initial training in the first analogy, they were much more independent in tackling subsequent analogies. This factor helps to explain why the student interactions became more collaborative in nature and their thinking more sophisticated as they worked through the lessons (see pages 107 -121). Once the mechanics of using the program were mastered, it left the students free to concentrate on the information being presented.

Principle 10 (p.18) states that transfer improves when knowledge is situated in authentic contexts. This principle is a brief statement of the theory of situated cognition in which learners experience tasks that are coherent, meaningful and purposeful. The tasks are embedded in everyday practices of the learner's community and provide an intrinsic relevance. The use of real problems to deliberately avoid a formal learning situation where the material is contrived for a purpose is a key feature. The relevance to my program is that the analogies are designed to be realistic examples from the students' own experiences. As already

stated above, the analogies are well matched to the type of community in which the students live. The value of the analogies should be judged against this background. The question should be asked as to the degree that each analogy is embedded in the real world and how well that is appreciated by the students. My study suggests that the analogies fit the ideas of situated cognition rather well.

Principle 12 deals with knowledge integration and subsequent understanding. Some methods are suggested that have been found to be successful in practice. In particular, to help understanding there is a need to provide organizing activities for information already reviewed. One of the features of my program was to add problem solving at the end of each analogy to test the students and to organize their thinking around actual past examination questions. This section of the program was primarily designed as an evaluation tool to see if the program was effective. I realized that it also provided a means to assist the students in organizing their ideas such that they comprehended the concept with more permanence.

The next principle (13) deals with the concept of feedback. If the students are given the chance to provide regular feedback on the progress of the lesson then they are less likely to be off task discussing irrelevant material. As part of the teaching sequence, I suggest that regular questioning about the nature and effectiveness of the analogies should be a feature. The program itself provides discussion and questioning but there is scope for further interaction among students and between the teacher and the group. Principle 17 deals with the level of guidance required by a student group. It is suggested that the teacher needs to provide tactical, instructional and procedural assistance to all students. I think that one of the benefits of a well-designed computer program is that it can contain all the necessary cues and instructions for the majority of students and all that needs to be considered is the rate at which an individual can comprehend the program's objectives. The software in my program has adequate instructions and should allow most users to understand its structures. To ensure this happens, I have required that the teacher be a part of the learning group and this provides further assistance to those who may be struggling with the concepts.

Squires (1996, p. 20) makes several important points about general design features in the use of multimedia. He echoes the thoughts of previous researchers regarding authenticity and ownership of the tasks. While he maintains that the best designs are often the simplest, he cautions against simplistic software designs and

contrived situations. Many difficult areas of study are inherently complex and designers need to echo the appropriate level of complexity in their design. The software should challenge the learner and draw them in to the problem. Squires' three traps of producing overly complex collages, television-like transmission programs and unreal representations of reality are avoided by my program design. Squires stresses the collaborative nature of learning and that the software should encourage group discussion. This is a constant theme throughout constructivist literature and a key feature of my program design.

Dillon and Gabbard (1998), in their appraisal of the effects of hypermedia in the classroom, struggled to find a positive correlation between the use of such software and improved outcomes. They correctly pointed out that learning styles of individuals would have a significant impact on how well each learner fared. As I progressed through the implementation and testing phase, I was not consciously aware of the learning styles of my students and I did not carry out any diagnostic tests to try and discover them. However, I did take into account their responses to the program design and changes that were made to the program would have been subtly influenced by the methods employed by the learners to understand the work. They also point out that the ability level of the learner determines how effective the software package can be. I have deliberately aimed the software at students who were seen as being average and below average achievement in high school chemistry so that I could target those who have difficulty with abstract thought and require assistance in the form of alternative representations. The overall acceptance of the program and performance in the diagnostic questions indicate a not insignificant success rate (see pages 103, 104, 114, 115, 122, 141 & 142). Dillon and Gabbard state that at the present stage of development, hypermedia programs should be limited to very specific tasks combined with innovative classroom practices and collaboration. Their work supports my findings from the classroom.

Collaborative learning

Collaborative learning supported by computers is an important emerging field. The comprehensive literature review in Chapter 4 shows how various researchers have come to similar conclusions. Koschmann's six principles echo the constructivist stance and provide a sound theoretical basis for the design of software. The common themes of active learners engaged in authentic tasks with structured

collaborative activities are restated here. The “envisioning machine” of Rochelle and Teasley (1995), the CSILE project of Scardamalia and Bereiter (1996) and the study by Tao (1997) provides examples of the variety of ways in which a computer might be employed to improve learning outcomes. My experience in Australian schools is that most software packages were either poorly designed and/or too expensive for most schools. The value of the early studies shows what is possible with some innovative thinking and provided me with an impetus to design a program with a specific application in mind. The nature and structure of the collaborative group are important considerations when assessing the impact of technology. Some groups are better suited to positive discussions about the work and will drive the learning process. Other groups will have individuals who may sabotage the learning effort and restrict the function of the group.

I was impressed by each group of students that tested the software. The program did not make great demands of them but they seemed to enjoy interacting with each other and the level of conversation showed that they were clearly on-task most of the time and making significant intellectual gains (see pages 105-119).

The work of Goldman (1996) provides further insight into the role of conversation in learning. She found that a certain amount of off-task social conversation was necessary for collaborative learning to progress. The teacher, as a facilitator of learning, needs to recognize that not all off-task work is counterproductive. Students need to establish a group rapport and the teacher needs to support that endeavour. O’Malley (1995) states that learning is enhanced when the teacher considers the whole learning environment that includes the type of activities, the nature of group interactions, the software design and the role of the teacher. My software does not take into account group dynamics but the instructions stipulate an active co-learning role for the teacher and a requirement for detailed discussion. As with any classroom situation, there are many factors that govern the effectiveness of any learning program. The teacher involved needs to be aware of how group interactions can enhance (or inhibit) a learning task.

The relationship to broader learning theories

My early readings suggested to me that social constructivism is closer to my desired philosophy than any other model. Much of my teaching career has followed a gradual development from transmission-type models to a constructivist model that

involved more investigation of the existing knowledge of the students. I had learned that it was more effective to back away from a dominant position and let the students' control the pace of their work. The social nature of the classroom can be both an aid and a hindrance in achieving curriculum outcomes. The need to guide social interaction to create a positive atmosphere is an important factor in student learning. Vygotsky found that student learning drives the development process by producing transferable skills useful in novel situations. The analogies software that I have produced provides a framework that other teachers can use to develop their own analogies. Students can also be encouraged to place their analogies within the framework. Ensuring that there is adequate social interaction as well as time for problem solving and feedback gives the student a chance to be reflective about their learning. This should enhance their skills in tackling novel situations and engender the sort of metacognitive abilities found in active learners. The best features of the software are the planned collaboration, scaffolding, use of familiar situations for analogies, practice examples, feedback and the involvement of the teacher within the group. I trust that my investigations have contributed positively to the development of learning techniques in the science classroom. Science teachers certainly have powerful tools available and we need to ensure that they are used effectively.

The chemistry

The teaching of equilibrium theory at high school level is dependent on a number of factors. The concept has a high cognitive demand and requires students with well-developed thinking skills. In the NSW high school syllabus there is a requirement for Le Châtelier's principle to be taught and examined. In chemical terms it is a less than adequate explanation for the changes that occur in equilibrium systems and in some cases it is incorrect. Jordaan (1993) sees value in limiting the use of Le Châtelier's principle to temperature and concentration effects. This would leave the volume and pressure effects to a numerical treatment using the Equilibrium Law. I have included a tutorial on the CDROM that approaches equilibrium theory using the Equilibrium Law as its basis. All textbooks used in secondary schools include both treatments. There is some debate among researchers as to the correct teaching sequence and whether the numerical treatment should precede the qualitative approach of Le Châtelier (Tyson et. al. 1999). I do not believe there is a place for teaching reaction kinetics to average students. It requires a high level of

abstraction to transfer mental models of molecular behaviour to theory questions. Exceptional students may benefit but time constraints would prove to be detrimental to their overall performance. There is a lot of work to cover for the HSC examination. The teacher needs to make a careful examination of the student group to determine the best approach. The student groups that I have dealt with during this research can cope well with the predictive abilities of Le Châtelier's principle in simple examples. I believe it to be a valid approach if the examination questions are to remain uncomplicated. I believe that the use of well-structured analogies can be a benefit in these situations. The reduced emphasis on equilibrium theory in the latest syllabus suggests that most teachers and students struggle to find the best way to understand the nature of change.

How well were the research problem and research questions answered by this study?

The initial goal that had been set was to produce a practical solution to a problem that includes a synthesis of current learning theories relevant to the area of study. The diversity of research into constructivist and collaborative learning suggested to me that it would be very difficult to draw all the ideas together and make some sense out of them. However, it soon became clear that much of the literature presented the same theme with a common philosophy as its base. The key features were the level of involvement by the learner, the enthusiasm of the teacher and the use of appropriate tools and teaching strategies. Once these general principles became clear, they provided the scheme upon which to build a solution.

The first research question asked: Can multimedia analogies be developed to improve the way that aspects of the chemistry course are taught?

I believe that the research has shown that analogies can be translated into multimedia, although the process is difficult and time-consuming. I do not believe that the analogies themselves will improve the teaching and learning of equilibrium in schools; rather they also require the specific teaching strategies that were developed within this program to help achieve the goals.

The second research question asked: What specific teaching strategies need to be developed to accompany the software that most effectively challenge and stimulate student thinking in the classroom? I believe that this question was answered by the research. Teaching strategies emerged with the development of the program so that a well-structured sequence arose. My intention that a more

collaborative and cooperative classroom would be fostered was supported by the findings, albeit with small student numbers. There was some evidence of metacognitive processes by some of the students. Most of the students expressed positive attitudes towards the teaching approach and were very clear on the role that analogies play in learning. Using past experience as a guide, I found that the ability of each of the study groups to solve problems improved and that they were more capable of verbally explaining changes in chemical systems at equilibrium.

The third research question asked: How effective are the software and teaching strategies in enhancing learning about chemical equilibrium in senior chemistry? This question can only be answered by investigating individual responses to the software program. As already stated, for many students in this study the experience was positive and enjoyable. The ability to concentrate on the problem at hand and discuss various aspects of each analogy shows that students are focused on the task and keen to seek solutions. There is evidence of a confident approach by most students when asked to solve the problems that deal with chemical equilibrium. I believe that this microteaching technique has the potential to benefit targeted groups of students and enhance the learning process for them and their teachers.

Limitations

As mentioned in Chapter 1, there are a number of areas of concern that may limit the effectiveness of the project.

The nature of the analogies: In terms of the nature of the analogies, the targeted student groups accepted the format and the animations used. The presentation of the program in the classroom proved to be successful and the single screen at the front of the room an effective method of focusing the attention of the group. It would still be possible for each student to have their own workstation, but there may be a problem with the collaborative discussion phases because of the physical seating arrangements. The quality of the graphics and text did not prove to be detrimental to the presentation. The analogies themselves proved a limiting factor for some individuals in each group. Linking the analogy to the target proved to be quite difficult for some students and the way that they attacked the practice problems did not guarantee success. It is probable that some students were confused and/or distracted by the analogies, which impeded their learning. If they did not actively

participate in the discussion phase then they would not benefit fully and their depth of understanding would be affected.

The number of students per group: The principal limitation of this study is the small number of students in total that participated. The group sizes for the two larger groups were, I believe, the correct size. A larger group would make it more difficult to engage all the students whilst a smaller group may not have sufficient variety to stimulate discussion. I found that when there were only two in the group that the discussion phase was more limited and involved more talk from the teacher. The program proved to be effective in terms of learning outcomes for the two students as they had a good grasp of the use of analogies and solving problems in chemical equilibrium. The effective use of this program in a larger class would be as a small group activity for students in the average to below average achievement range. The teacher needs to be able to concentrate on the group interactions and analysis of the analogies.

The designer and teacher as researcher: A further limitation is that the designer and author of the software carried out all the research. While I was able to gain other researchers' opinions at conferences, I have been unable to get another teacher to trial the software at this stage. As a teacher/researcher the difficulties of marrying the two roles must make the process less objective and more difficult to assess. I have used taped lessons, interviews and surveys to increase the objectivity but there is always the subjective interpretation of the data that cannot be ignored. The way that the software is used in the classroom was also influenced by the aims of the research. Another teacher may not be very interested in collaborative learning and the software may then lose its effect.

The change in the syllabus: The program was designed for the syllabus at the time and covered a section of the unit of work on equilibrium. A new syllabus was introduced before the fourth trial and this syllabus integrated equilibrium into various topics. It was no longer an individual unit and time did not allow the teaching of the complete unit of work on the CDROM. This was very disappointing considering the time taken to develop the software. The nature of the learning material is still the same and the syllabus expects a working knowledge of equilibrium changes but these have to be seen in relation to the theme being taught. It would be necessary to modify the software to fit it better into the new work. More relevant examples are required.

Suggestions for future research

The most obvious research program would be to visit other schools and assist other teachers to present the lessons. The research would involve gathering data through taped lessons and surveys to gauge effectiveness. As a full-time teacher I am currently not in a position to do this. Further research could involve further refinement of the current analogies and the production of further analogies for different topic areas or different subjects. It would also be interesting to see how analogies could be used in primary school teaching. The nature of the analogies and the way that younger students interact with them is a fruitful area for development. In addition, virtual reality systems are now becoming available and with them we have the ability to create sophisticated situations in which students can become part of the analogy. This would be an exciting avenue of thought to pursue.

Appendix A

Worksheet to Accompany Equilibrium Analogies Computer Program

1. Exothermic Reactions:

An exothermic reaction is:

A general equation can be written as follows:

Answer to test problem

List ways in which the analogy is NOT like the target:

Answers to the questions:

1. _____

2. _____

3. _____

2. Endothermic Reactions:

An endothermic reaction is:

A general equation can be written as follows:

Answer to the test problem

List ways in which the analogy is NOT like the target:

Answers to the questions:

a. _____

b. _____

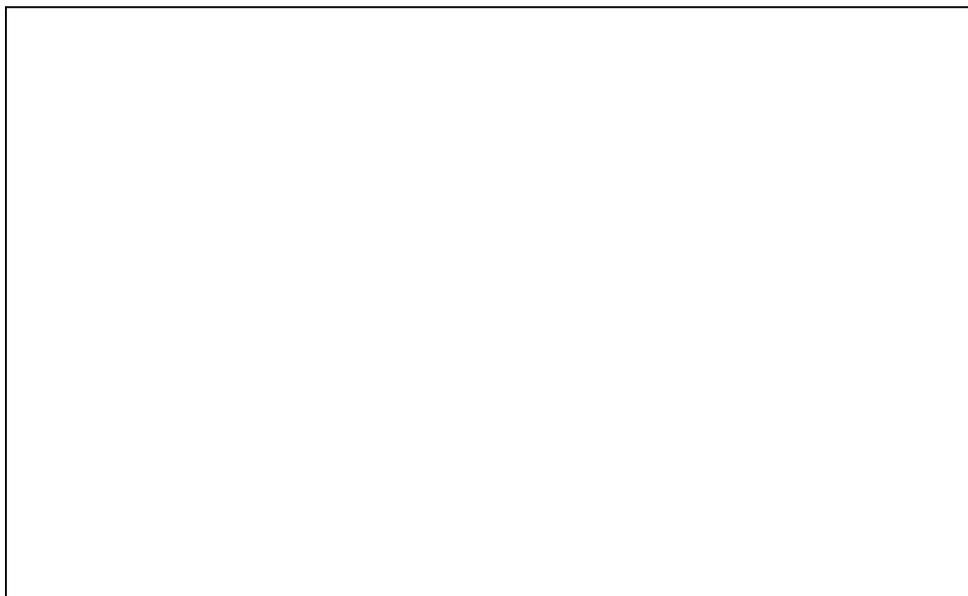
c. _____

3. Catalysts:

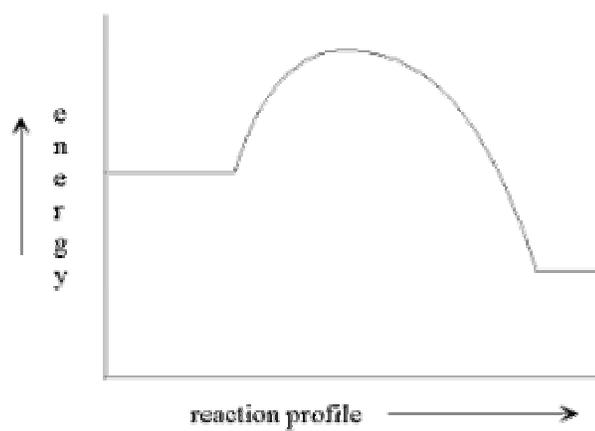
What is a catalyst?

What Effect does a catalyst have on the equilibrium reaction ?

How is the analogy unlike the target?

**TEST YOUR KNOWLEDGE**

The graph shows a typical energy profile for an exothermic reaction. Draw over the top of this graph to explain how this graph would change with the addition of a catalyst.



4. Concentration Effects

Answer to first question

How is the analogy unlike the target?

Answers to test your knowledge questions

1. _____

2. _____

5. Volume Effects

Answer to the example

How is the analogy unlike the target?

Answers to test your knowledge questions

1. _____

2. _____

3. _____

6. Pressure Effects

Answer to the example

How is the analogy unlike the target?



Answers to test your knowledge questions

1. _____

2. _____

3. _____

Appendix B

Student Questionnaire

(All information collected is to be used to assess the effectiveness of this teaching approach. Please do not put your name or personal details on this form. Hand it back to your teacher for return to the author)

Background Information:

Student's age: _____ Sex: _____

How long have you been studying Senior Chemistry? _____

On the scale below, give an honest assessment of your ability in the Chemistry course so far: 1 = struggling to cope 10 = competent in all areas

1 2 3 4 5 6 7 8 9 10

Specific Information about the CDROM package.

Before the lessons, rate your knowledge of how analogies are used to help teach you. (1 = totally unaware 10 = A very good knowledge)

1 2 3 4 5 6 7 8 9 10

How often does your chemistry teacher use analogies to try and explain things? (1 = not at all 10 = very often)

1 2 3 4 5 6 7 8 9 10

Before these lessons, rate your knowledge of equilibrium and how changes affect equilibrium systems. (1 = no knowledge 10 = very well understood)

1 2 3 4 5 6 7 8 9 10

While using the program, you were asked to discuss how effective the analogy was in describing the real situation. Rate your level of participation in the discussions. (1 = did not contribute 10 = very active participation)

1 2 3 4 5 6 7 8 9 10

Rate your usual level of contribution in class discussions. (1 = do not contribute 10 = always involved actively)

1 2 3 4 5 6 7 8 9 10

After going through the lessons with the package, do you think that your understanding of analogies has increased? (1 = not at all 10 = A great deal)

1 2 3 4 5 6 7 8 9 10

After going through the lessons with the package, do you think that your understanding of equilibrium and Le Chatelier's principle has increased?

1 = not really 10 = A great deal

1 2 3 4 5 6 7 8 9 10

Did the animated analogies make it easier for you to remember the effects when you were doing the test questions for each section? 1 = not really 10 = yes

1 2 3 4 5 6 7 8 9 10

What is your level of recall of the analogies at this stage? For example, if I were to mention an endothermic reaction, can you recall the analogy used in the package without difficulty? 1= very low recall 10 = high level of recall

1 2 3 4 5 6 7 8 9 10

Which analogy did you find the most effective? _____

Which analogy did you find least effective? _____

Were you able to come up with your own analogy that you thought was better and easier for you to remember? _____

Rate this approach to teaching this particular section of the topic (1= not very good 10 = really effective)

1 2 3 4 5 6 7 8 9 10

**Did you find the use of the CDROM a benefit to your learning?
1= not really 10 = highly beneficial**

1 2 3 4 5 6 7 8 9 10

Appendix C

Teacher Questionnaire (not using the package)

1. How many years have you been teaching chemistry _____
2. When teaching equilibrium theory involving changes to equilibrium systems, do you use Le Chatelier's principle as your primary method? _____

Any comment? _____

Have you read the paper on the CDROM about the problems with Le Chatelier?

YES NO

Do you think there is a need among some of your students for a more effective way to teach this topic?

YES NO

3. Rate your use of analogies in your chemistry lessons (this includes any sort of analogy - verbal, diagrams, written) 1= not used 10 = very frequent use

1 2 3 4 5 6 7 8 9 10

4. Rate the level of interaction of your class with each other during theory lessons.

(In which they would discuss chemistry with each other) **1 = no interaction 10 = active interaction at all times**

1 2 3 4 5 6 7 8 9 10

5. Rate your own understanding of the use of analogies in teaching **before** looking at the package (1= no understanding 10 = excellent)

1 2 3 4 5 6 7 8 9 10

6. Rate your own understanding of the use of analogies in teaching **after** looking at the package (1= no understanding 10 = excellent)

1 2 3 4 5 6 7 8 9 10

7. Rate the suitability of use for multimedia analogies in this format in the classroom

1 2 3 4 5 6 7 8 9 10

8. Can you see potential for producing your own analogies in this format? **YES NO**
If not, could you give reasons?

Any further comments you would care to make?

Teacher Questionnaire (using the package)

1. How many years have you been teaching chemistry _____
2. When teaching equilibrium theory involving changes to equilibrium systems, do you use Le Chatelier's principle as your primary method? _____

Any comment? _____

-
3. Rate your use of analogies in your chemistry lessons (this includes any sort of analogy - verbal, diagrams, written) 1= not used 10 = very frequent use

1 2 3 4 5 6 7 8 9 10

4. Rate the level of interaction of your class with each other during theory lessons.
(In which they would discuss chemistry with each other) **1 = no interaction 10 = active interaction at all times**

1 2 3 4 5 6 7 8 9 10

5. Rate the level of interaction of your class while using the CDROM package **1 = no interaction 10 = active interaction at all times**

1 2 3 4 5 6 7 8 9 10

6. Rate the level of understanding of analogies of your class after using the package
(1= no understanding 10 = excellent understanding)

1 2 3 4 5 6 7 8 9 10

7. Rate your own understanding of the use of analogies in teaching **before** using the package (1= no understanding 10 = excellent)

1 2 3 4 5 6 7 8 9 10

8. Rate your own understanding of the use of analogies in teaching **after** using the package (1= no understanding 10 = excellent)

1 2 3 4 5 6 7 8 9 10

9. Rate the effectiveness of the approach of using multimedia analogies in teaching this section of the topic (1= not useful 10 = very effective)

1 2 3 4 5 6 7 8 9 10

10. Were some students able to produce their own analogies while discussing the effectiveness one on the CDROM? _____

Any further comments you would care to make?

Appendix D

Transcript of taped lessons from trial 2

Transcript of lessons. Feb 1999.

The following transcript is a presentation of two one-hour lessons using the computer based analogies program. These two lessons were part of a teaching sequence for the topic Chemical Equilibrium. Prior to these lessons, the students had been introduced to the concept of equilibrium through a combination of theory and practical lessons. They had carried out reversible reactions and had seen a demonstration of the $\text{NO}_2/\text{N}_2\text{O}_4$ equilibrium undergoing changes due to temperature. They had carried out an experiment to see the effect of changing concentration on equilibrium. The theory had included the information that for the general equation, $a\text{A} + b\text{B} = c\text{C} + d\text{D}$, that all species were present at equilibrium and that the rate of the forward reaction was equal to the rate of the reverse reaction. The distinction between equilibrium in a closed system as opposed to the steady state theory was also discussed. The computer based analogies program was designed to introduce the concepts of how a chemical equilibrium could be changed by altering the conditions of the reaction vessel. The initial part of the tutorial program began with an explanation of analogical reasoning and how students were to treat an analogy. Some theory on equilibrium leads to the first of the analogies and follow-up exercises are provided. It is the discussion section about the analogy that provides the students with the opportunity to develop metacognitive skills in questioning their own thinking process and developing their own version of the analogy. Further work involved the students creating new analogies that better suit their thinking.

The initial part of the first lesson was largely teacher directed as students were stepped through the first screens of the tutorial. This, I believed was necessary to correctly orient the students towards the tasks to come and introduce the important concepts to be covered.

Transcript : (T = teacher talk S = Student talk (S1, S2, S3 etc))

T: Here, an analogy is an attempt to demonstrate an unfamiliar concept, which is called the target, by using familiar examples. Analogies can be useful only if you can relate to them. If it's something you're not familiar with, it's not going to help you at all. As you work through the program, you will be asked to consider how effective each analogy is and how well it explains the concept. Think carefully about the questions and discuss the analogy with the teacher and your fellow students. Full analysis of the analogy will help you understand it. Now, remember analogies are not the real situation. They are like the target we are trying to describe but as a student you should be able to list where the analogy is similar to the target and where the analogy is not like the target. What we are going to try to do is look at the example try and work out where it is like what we are trying to describe and where it is not like what we are trying to describe. So, it takes a bit of brain power on your part and you have to get involved with it so we'll be having discussions as we go. (Next screen – a look at equilibrium. This involved going through each point briefly in an attempt to recall the required base information to proceed to the principles exposed in the main part of the program)

T Now, here are some facts that we have been going through over the last few days. Now these are just some basic summary of the stuff about equilibrium first up that you should have read the information in your textbooks. Many chemical reactions involve a competition between the forward reaction and the reverse reaction. If you want a copy of these notes we can print them off for you. These reactions do not go to completion but they reach a stage where the rate of the forward reaction equals the rate of the reverse reaction. And that's a definition of equilibrium. The rate at which it gets to the end is the same as the rate that it's going back to the beginning. We are not talking about the position of equilibrium; we are just talking about forward and reverse reactions. They are competing at the same rate. So as much as the products are being formed, the reactants are being formed at the same rate. That's what equilibrium is. Important point, equilibrium can only occur in a closed system, it can't be open to the universe it's got to be isolated somewhere. We write equilibrium equations with a double arrow. And then we talk about this principle, this is what we will be referring to, Le Chatelier's principle, (after this guy, a French man.) It's designed to predict how an equilibrium system will react if changes are made to the system once it has reached equilibrium. That's also important for you to remember. We are going to look at a system once it gets there, if we try and change it, what happens? So if you've got a test tube sitting on a bench, with a cork in it, and the system has reached equilibrium, so its forward reaction is the same as its reverse reaction, then what happens if we then stick a bunsen underneath it?

S1: It changes the position of its equilibrium

T: Yes, and what happens if we add water to it?

S1: It changes it

T: Good. What we need are rules that help us make predictions as to how that system is going to change.

So the first one we are going to have a look at is how does temperature change affect an exothermic reaction? Firstly, we will do a little revision. What is an exothermic reaction?

S2: Where heat is produced

T: So an exothermic reaction is one where heat is a product, it produces heat and the system would be seen to be getting hotter. So heat is a product and we can write it in two ways. On your worksheet you can fill in the details. Write it on your sheet, both the definition and the two ways you can represent the equations. One where heat is included in the reaction and the other in delta H format.

S3: Is that the enthalpy change?

T: Yes, that is enthalpy, the change in heat. The delta is change, the H is the heat content or enthalpy and it is always written with a minus sign. Alright, delta H is minus something kilojoules per mole, that's how we represent an exothermic reaction. This is the accepted method for the HSC but a lot of people have trouble using the minus sign (or plus sign), so it might help you to remember that the heat's in the reaction as a product.

So we are talking about a reaction here that gives off heat. We are now going to vary the reaction conditions. We've got the equilibrium reached in a sealed system and we are going to change the temperature conditions. So, on the next screen here is an analogy for the forward reaction. The analogy is a runaway forward reaction, the chips have caught fire. So, it's an exothermic reaction. What's he going to do? He's going to ring his missus. And she says... 'just put the lid on!' Now, the lid in this analogy is adding heat to the reaction and what the heat's doing is forcing the

reaction back towards the reactants, towards the chips before they caught fire. Up here (top half of the screen), if we heat a reaction vessel containing an exothermic reaction what happens? The reaction shifts its equilibrium position to try and compensate for the change. In this case, the reaction position shifts towards the reactants or towards the left. So the reverse reaction is favoured. The heat or the lid forces the reaction back towards the chips. So if we look at the analogy again, applying heat to an exothermic reaction drives it back towards the reaction. What I want you to think about is that if this analogy is useful to you, to remember the analogy when you do the problem solving section.

So how does the analogy relate to its target? (next screen). The burning chips are the exothermic reaction. The lid is the heat applied and applying the lid drives the reaction back towards the reactants. That is the three mappings there of that analogy. Here's an example. Hydrogen gas, Iodine gas in equilibrium with HI. It's an exothermic reaction. The question is how does the concentration of hydrogen iodide change in the equilibrium mixture of these three gases if we heat the mixture. There's no space on the worksheet so put the answer at the bottom. Think about the analogy, if that helps you. You don't have to say how much each of them changes. Just tell how the concentration of this one changes, what will happen to the HI if we heat that mixture.

(One student, S4, is unable to form an answer so the three choices – decrease, increase or no change are offered to the student and the concept explained individually. She still finds it difficult to offer a solution. S3 offers an answer and part explanation to S4, he tells her that the HI will decrease because the reactants are favoured in this case)

Once all students have answered, the teacher continues:

T: As the reaction is exothermic, heating the reaction would shift the equilibrium towards the reactants, so this would lead to a decrease in the HI. Let's have a look again at the analogy. The one thing about analogies is that they form a picture in your brain. They are supposed to connect with something you are familiar with and if they don't do that then they are not useful. So what we have to do now is discuss the analogy and try and work out where it is good and where it is bad and see how that relates to what is going on in your brain. We are going to discuss together where the analogy doesn't fit the target. Take 5 to 10 minutes to brainstorm and write them down, then we will look at some of the suggestions in the program (Move back to the screen that shows the mapping of the analogy to the target)

Considering what an equilibrium reaction is, where does that not fit into the scheme of an equilibrium reaction? Where do the pot and chips not match what we know about a chemical reaction?

S3: It's an open system.

T: Alright, let's jot these down as we go. It's not a closed system is it? The pot's on the stove with other interfering things. The heat is going away so it's continuing to drive in one direction. Certainly it's an open system. Where else is it not like an equilibrium?

S3: It's actually burning and therefore it's always changing, I'm not sure how to say it.

S5: You mean like a transfer of the products out into the air, instead of into the mixture

S3: An open system

S1: And so, you are not getting a chemical reaction, an equilibrium.

- T: So we're not keeping everything in are we? Everything is not staying in the pot.
- What about the lid, representing heat? How does that map?
- S5: It isn't heat
- T: It's not heat is it?
- S3: No it's just trapping energy
- T: Heat's an abstract thing isn't it?
- S5: It's just making it a closed system
- S3: It's not heating the system
- S6: The fire would go out, so there would be no reaction
- T: The fire would go out with no continuing reaction, excellent!
- OK so two things, not a closed system and putting the heat on would put out the fire, so the reaction would go out so its definitely not a...
- S6: reaction in the water
- T: No, what's typical, what did we say the other day that's typical of an equilibrium reaction? All of them are what, what can they do?
- S1: They can swing one way or the other.
- T: So they are all?
- S1: Not going to go to completion
- T: Yes, so what's the word ? Reversible?
- S1: Reversible
- T: All equilibrium reactions are reversible, this one's not is it?
- S5: No, you can't really change the chips back.
- S4: Unless they're fat
- S5: Then they are not really going back, they are still cooked
- T: So you can't actually produce the chips you started with can you?
- Have you got that one down?
- How else is it not like the target? What else about the reaction is not like the reaction type we are trying to achieve?
- S3: Once again it's not reversible in another way that if you took the lid away it would not burst into flames.
- T: Yes, so it's definitely not a reversible reaction
- Another part of this process is that you can create your own analogies, ones that work better for you. The problem with working with ones that have been created for you is that it is not necessarily something that you identify with so well. So, after we've been through this one we'll have a few minutes to see if you can come up with an analogy for yourself or how you might map an exothermic reaction. I might even get you to spend some time at home on it.
- So let's have a look at what the program suggests are problems with this analogy. (Move to that screen).
1. The burning chips are not a closed system
 2. They are not at equilibrium when the heat's flowing. The whole idea of Le Chatelier's principle is that the system is allowed to come to equilibrium before you make the change
 3. The heat's not a substance like the lid is.
 4. The heat doesn't stop the forward reaction. The animation suggests it puts out the fire.
 5. The heat we can apply to the system is not fixed. Different amounts of heat produce different shifts in equilibrium. So, just having one big blanket heat applied doesn't actually show what we can do in the lab, we can add little bits of

heat, lots of heat, we can even take heat away. We can cool it down and maybe see the reverse of the reaction.

All right, let's see how you are going picking up the ideas. Right, there are three questions for you. Write your answers on the sheet.

(All students present were able to answer the three past exam questions correctly at the first attempt. Students aired their thought out loud asking for confirmation. One student who struggled earlier needs the questions rephrased to assist her understanding.)

Question from S3 while working on problems

S3: So, in equilibrium is there an overall balance involving heat lost to the air?

T: Yep, that heat is not continually being lost. Some of it is being reabsorbed to produce reactants. If you have this tube sitting on the bench at 22 degrees, it's just bouncing back and forward. One thing you notice about equilibrium reactions is that they have constant macroscopic properties. So what you are looking at doesn't change, so it looks like nothing's happening, but we know, in reality, that the reaction is bouncing back and forward inside.

(Question 3 is then scrolled on to the screen and read out.)

OK there's the reaction in question 3, HCl and Oxygen reacting to form water and chlorine gas and 120 kJ. What would be the effect of the chlorine concentration if we heat the reaction vessel at equilibrium?

(A clarification required by the student)

S2: Is that H₂O gas or liquid in that reaction

T: It's a gas, it's very important in the HSC that you put in the states of matter as different states have different energy associated with them. You will be given states in the exam to use.

T: OK, the answers. Has everyone got their answers ready.

The first one produces an increase in CO and O₂ and a decrease in the CO₂.

(A pair of students engaged in mutual discussion of the answer, one explaining to the other.)

Now for the second one, I'm not too concerned if you got the equation wrong because we are looking at the equilibrium change. But it is important to note that if you wrote the equation with 2NO's then you have to double the delta H.

(To S3) What did you have for your equation and delta H?

S3: I had 2 NO and 55 kJ

T: Well, that is incorrect as you need to double the heat. The heat quoted in the question is per mole of NO so you need 110 kJ.

T: So the NO concentration would increase in the second one. If we heat it, it pushes the reaction back to the reactants. In the third one, for the same reason, the chlorine decreases. We'll come back to that a few times. Generally, that sort of question is part of a HSC question when they ask you predict the shift in equilibrium.

S6: So, basically a question would say how would this exothermic or endothermic reaction perform if...

T: Those three questions you have just completed are typical of the HSC.

What you have to get straight in your mind is how the system changes once it reacts. I'm hoping that for some of you, you'll remember the analogy.

S4: I don't understand how you can tell how you can predict the changes

(S3 then attempts to explain the concept to S4 but there remains some confusion in S4).

T: (a further attempt to explain the concept) Have a look at this reaction again. What happens, as a general rule, is that the reaction changes to compensate for things that have been put on to it. So if I add any one of these four things, the reaction will change to use up the stuff I've added.

S3: So you put more of this in (explaining again to S4)

T: So it would push the reaction this way. So if we put heat into the reaction, the reaction will try and compensate for that heat by using it up. To do that, its got to drive the reaction this way because going from right to left, towards the reactants, causes that reaction to reduce the amount of heat. So by putting the lid on it, by pushing it back with the heat I push it back towards where it started from.

S4: So what happens if I pull the lid off?

T: In that case both of those would increase

S4: And the reactant?

T: It would decrease.

S3: (spends some time here going over it again with S4)

T: (looking at S4's notes) So, you need to add there that the reaction shifts its position to try and compensate for the change

S5: So nothing really stays the same.

T: It stays the same provided you don't try to change the system. That's what an equilibrium is. For a reaction in test tube sitting on the bench at the same temperature with a cork in it and nothing is added or removed, then all the concentrations stay the same. They are continually going back and forwards but to look at it you can't see any change. What we're saying here is, what happens if we come along and heat that? What would that do? And if it's an exothermic or endothermic reaction then you will get a compensatory change, it will change itself somehow.

S3: If it's an exothermic one way can we consider it endothermic the other way?

T: Yes. It just depends on which side of the equation the heat is. Typically for an exothermic reaction the heat is one of the products. The way we write it on paper is the way we mean the reaction to go. We mean that the left-hand side is reactants and the right hand side is the products. Even though it is a two-way reaction we still distinguish those on paper.

S3: So do we write an endothermic reaction with the products first? (So the heat is on the left)

T: No, the products must always be on the right by convention.

OK let's have a look at an endothermic reaction. Same concept but here we have a different analogy, maybe one that you can understand a little better. We begin with the facts about the equilibrium. This is the last bit you probably haven't got yet. Le Chatelier's principle is designed to predict how an equilibrium system will react when changes are made to the system once it's reached equilibrium.

Endothermic reactions. Turn over your sheet. Generally these are ones that get colder. They are cold to the touch because what they do is that they are sucking heat out of the environment. So if you put your hand on an endothermic reaction it feels cold because it sucks the heat out of your hand when it goes in the forward direction. So an endothermic reaction one which, in the forward direction, absorbs heat.

S2: So is that like where the heat goes into the bonds and when you break them up it's released and forms exothermic.

T: Yes, its creating bonds that are attracting the energy in the overall process.

The overall difference is that when we write the endothermic equation we put a positive sign on the delta H. which shows the heat is put in. (Students could not see the colour contrast on the screen)

If you try and remember in the exam the snowman at the top of the screen because the endothermic is getting colder. It might help you remember. You can think of the candles for the exothermic reaction.

Let's have a look at an analogy for an endothermic reaction. Here's the forward reaction, melting ice cream. We are putting in heat and we are driving the ice cream to distraction and turning it into goo. Just like the recent add they've got about the car without air conditioning. Alright, what are we going to do to this reaction? We are going to heat it. If we heat a reaction vessel that's got an endothermic reaction happening in it, and it's reached equilibrium, so it's not melting anymore. What happens if we heat it some more?

S1: It melts

T: More ice cream melts if we heat it and the equilibrium shifts to the right. And the cone stays there but it just melts more of the ice cream.

S1: That's quite good. I can see the reaction going from frozen to not frozen.

T: Alright, well let's have a look at how it fits (by viewing the mapping screen). The solid ice cream is the reactant. The liquid ice cream is the product. The sun is the heat driving the reaction towards the product. That's the mapping.

Let's have a look at an example (next screen). This is one that you've seen as I showed you last week with the nitrogen dioxide and the dinitrogen tetroxide, the N_2O_4 .

Here's the reaction. N_2O_4 plus 59.2 kJ of heat, that was the reaction we were doing in the flask, to give you two NO_2 's. The N_2O_4 is colourless and the NO_2 is brown. How would the concentration of this one, the N_2O_4 , change in an equilibrium mixture of the two if we heat it? – Write your answer on the bottom of the sheet again. Think about the analogy, driving the reaction forward gives more melted ice cream. The reaction shifts its equilibrium to compensate for the change. In this case, the reaction shifts towards the product or the right. Here's our example again. What happens to this N_2O_4 , the colourless one.

(Talking to S4 who is still struggling a bit) Which one of these is the ice cream?

S4: The brown one.

T: Why is that?

S4: It reminds me of chocolate

T: Think about it. If we add heat to it, it changes the ice cream. What happens to the ice cream?

S4: It melts

T: So if the ice cream is the N_2O_4 , then what happens to it when we heat it.

S4: It decreases. (S4 is still unable to link between the two properly to arrive at the correct prediction for the colour of the reaction vessel).

T: Ok, so let's have a look at the answer screen. The mixture would get darker. A decrease in the N_2O_4 , as we push it to the right, and it would go to a light brown colour. It wouldn't go all the way (to dark brown on the screen) because that's all NO_2 . It would be some intermediate colour between the two.

Ok, before we do some examples, let's do the same thing. Where does this analogy not work, where is it not like an equilibrium system?

S1: Its not closed. It's not an equilibrium system

T: Right, that's one

S3: It's not actually an equilibrium

T: That's true

S1: Like, there's no reaction going on.

S3: It is reversible, because you can freeze ice cream

- S1: You can freeze ice cream (at the same time)
- T: Right. Would it come back to be the same state as the original ice cream?
- S3: Yes
- T: Would it look like the original?
- S6: Not the same shape.
- S3: Like, if you did that with chemicals, they wouldn't necessarily be the exact same shape.
- T: Fair enough, they would be a different form. So is it reversible?
- S3: I still say yes
- S1: Yes, I agree.
- S3: If you did it in a container with the exact same shape then it would freeze back to the original
- T: Ok. We are looking at where it's like and not like it. We are interested in where it's not like it but we are also interested in where it's like it, how well it maps to the original. You've obviously come up with some similarities, which is great. What other ways is it not like the equilibrium?
- S5: Ice cream is tasty. If we eat chemicals we die.
- T: OK, real ice cream
- S3: If you change concentration or pressure it's still going to be the same, so no other effect on it would make a difference
- T: We are trying to isolate it down to one factor but, yeah, if we change other things like pressure or concentration that's not going to change it much.
- S1: Well you can always change them and add that to what happens.
- T: In the HSC they won't give you three different things and ask for the combined effect. They will usually stick to one factor like we are here.
- S6: Let's get back to the melting of ice cream
- S3: It should be like water and ice cubes
- S6: I don't think this case is reversible
- T: So do we have consensus on whether it is reversible. What sort of change is it?
- S3: Well, it's a change of state
- T: So we are dealing with physical rather than chemical change. Do we agree that it is probably not reversible?
- S1: Because it is not a chemical reaction? Yes
(general agreement because you can't retrieve the original in its own form)
- T: So, let's look at what we've got so far and compare with the program. There are four ideas here. The ice cream is not in a closed system. Melting ice cream is not a chemical reaction. The reaction is not reversible. It is not possible for the ice cream to reach equilibrium in an open system. Well you certainly got the lot there.
- Now some questions to see how well that sits with you. For each of the following reactions you have to state whether the reactants or the products would be favoured by lowering the temperature.
- S4: Lowering?
- T: This question is slightly different from the analogy. What's going to happen to this reaction here if we decrease the temperature. Think about this one the ice cream and this one's the melted ice cream. What happens if we make it colder?
- S4: I'm really not seeing the ice cream
- T: Alright, think about the ice cream. The left hand side's the ice cream, the right hand side's the melted ice cream. Which one do we get? More reactants or more products?

(Some discussion among the students to determine a consensus for the answer. They continue discussing and ignore the teacher's attempt to pull them up and give a decision. Discussion proceeds for 3 to 4 minutes. Some more directed questions aimed at individual students seeks to coax a final answer. S2 is confused and seems to have lost concentration. The difference between liquid water and solid water has become a major difficulty for some in the group. It seems the analogy has removed them so far from the real world that they find it difficult to apply the concept to actual examples. The teacher decides to revisit the purpose of using analogies and how they might relate to the task at hand)

T: The whole idea of the analogy is to give you something to hang your hat on. You're no longer looking at a chemical equation on paper that is just dry. So when you're thinking about an endothermic reaction it gives you a picture in your mind. Make it a little easier to understand.

S3: The only problem with that is inventing an analogy for each individual thing, for endothermic, exothermic, addition of pressure and so on.

T: Right. For endothermic/exothermic you could choose either the ice cream or the chips as one is the reverse of the other. So if you like the ice cream better than the chips, you could use that one.

S1: The ice cream is better than the chips because it is in some way reversible (even if its not completely)

T: What you've got to have is an analogy that you like. It's got to work for you . We've got to map an abstract concept to a concrete idea in your brain. So if you can find something to hang your idea on, it should make it easier for you to solve, not harder.

S3: For questions in equilibrium involving energy, will we have to work out values ourselves?

T: No, you'll be told. They are only testing one concept in a question, so they will give you the other details.

OK, let's look at the answers to these questions.

In each case the reactants are favoured. Cooling an endothermic reaction will cause the reaction to compensate by shifting to the side that produces more heat. When we go towards the reactants, we are actually producing heat. An endothermic reaction absorbs heat when it goes towards the products. So what I have done is twisted the question away from a straightforward one because that is what they do in the HSC exam.

They will try and get at it from a different angle to make sure that you really know what you are talking about with the concept.

The next lesson will focus on the catalyst in an equilibrium system.

S2: I think of a catalyst as like a boxing match and the crowd urging them on, that's just what I think

T: OK, that's good. You're thinking about your own analogies. Until you actually focus on the activity (creating analogies) you don't usually think of it as a way to approach a problem.

So what did you think of that approach

S5: Good, a lot different

S1: It was interesting

S3: I learnt the difference, how it made you think what it wasn't , as well. Because the bad things were pointed out,

S1: Sort of more obvious

S3: Yeah, like it made it more obvious what it is rather than what it isn't.

T: Well once you can eliminate all of the extraneous bits, you can focus on what we are trying to learn which is what the equilibrium reaction does when its doing what its supposed to be doing.

Thanks very much for that, that was great.

SECOND DAY>

T: Firstly, I'd like you to write down you definition of a catalyst, what is it, what does it do?

OK, we'll just go around quickly and see what you've written.

S1: A thing that speeds up a reaction without affecting or becoming involved in the products formed

S2: a chemical which speeds up the reaction process between chemicals

S3: A catalyst speeds up the process of a chemical reaction and supplies energy to the reaction often giving reactants the activation energy they need for the reaction to begin. The catalyst is (in the end) only a spectator.

S4: a catalyst is something that speeds up a chemical reaction but doesn't actually take part in the reaction.

S5: A catalyst is something used in a reaction to speed it up by lowering the activation energy

S6: something added to a chemical reaction to speed it up without bearing any result on making any change to the result.

T: OK, so we've got two attempts there. One is the bland definition of a catalyst and some people have tried to explain how a catalyst might work. I'm talking about things like energy, providing activation energy or whatever. So basically you have some grasp of the idea of the word so that's really good. How would you think a catalyst would affect, say we have a reaction at equilibrium, what would you suspect a catalyst would do?

(a pause for thought)

S3: It might reach equilibrium quicker

T: What do you think S4? We have a reaction sitting on the bench basically at equilibrium and we pour in a catalyst, what do you think might happen.

S4: It might go to completion

T: Do equilibrium reactions go to completion?

S4: Um, no

T: What do you think S2?

S2: Hardly any effect.

T: And you, S5?

S5: It might reach equilibrium quicker

T: Yes, but remember, this reaction is already at equilibrium. We are looking at Le Chatelier's principle here, trying to predict what changes may occur if we try to alter conditions at equilibrium.

S3: Well, because the catalyst affects the energy involved, it might shift the reaction one way or the other

T: So it's possible that a catalyst can shift the equilibrium?

S6: Say there's a gas involved, it may produce more gas because there's more energy.

T: Yes, anything's possible at this stage. I want to find out what's in your brains so that I can see where you're coming from.

So are we undecided? Do we not know what's going to happen in the vessel if we add a catalyst once it has reached equilibrium?

(Some general discussion amongst the students. Some are leaning towards the idea that it will shift the reaction one way. Others are fairly certain that it will have little or no effect. Others believe it is dependent on the system being studied)

T: (to the students in the little or no effect camp) Some of these guys are trying to tie in ideas about energy that we discussed yesterday with the endothermic and exothermic reactions. Maybe if it affects the energy, it might affect the way it swings.

S4: The catalyst is a spectator

S3: It depends on what the catalyst does in the reaction

T: It depends on what you think a catalyst is in the first place. It depends on your concept of what the catalyst is doing in the vessel.

S3: Can we see the analogy?

T: We'll get there, be patient.

S2: What will happen in the vessel if we add the catalyst before it reaches equilibrium?

T: It will reach equilibrium, yes

S1: It will get there at a faster rate

S5: It might go past the equilibrium point

T: Past it? Can it go past the equilibrium point?

S3: It says here in the book that a catalyst enables the reaction to reach equilibrium faster

T: I don't want you look in the book yet. I want to know what's in your heads.

OK, I was going to do this at the end but I'll show you a catalyst in action.

This is hydrogen peroxide, a non-stable substance. It does form an equilibrium in the bottle, but if we leave the lid off and let it sit there, it breaks down spontaneously to form water and oxygen (Writing the equation on the board). If the system is left open it would keep going to the right and form water – a very expensive bottle of water. We can speed this process up. It is an equilibrium, you won't drive it completely in one direction, there will always be a little of some substances left. This is the catalyst, Manganese dioxide. When added it does.... That (bubbling)

S1: All those little bubbles are oxygen

T: Yes

Now you can see from that reaction that it is a lot faster than the peroxide just sitting on the shelf.

S3: So what's the manganese dioxide doing

T: It's helping the peroxide to split apart

OK we'll now look at the computer program giving us an analogy for the role of a catalyst

(Screen 1) A catalyst is a substance used in a chemical reaction to alter the path a reaction takes. This path requires lower activation energy. So, what it's doing is providing an alternate pathway for that reaction to travel along. That alternate pathway is easier to traverse than the original reaction. So, you would use a catalyst in a reaction where you can't get something to go or it takes too much energy to get it to start and is not economical. A catalyst does not affect the position of equilibrium, it only speeds it up to ensure that the equilibrium is reached faster. It is important to realise that the effect of lowering the activation energy ensures that both the forward and the reverse reactions are sped up. It's the same thing as trying to get across that a reaction is reversible. We usually look at a reaction like that (the peroxide/ MnO_2), we tend to see it get to the end faster and think that the catalyst is only working one way. What you have to get into your mind is that a reversible

reaction, we are doing both. It is going one way and at the same time going the other way. So both the forward and the reverse reactions sped up.

S3: Does the catalyst have an equal effect on the forward and reverse reactions?

T: Yes, the catalyst has the same effect.

Now write on your worksheet the effect a catalyst has on the equilibrium reaction.

S3: There's one other thing about analogies. The concept that you describe has to match the analogy. So, you have to think up an analogy that matches it well. I think that it should be your own.

T: Yes, once you have seen somebody else's analogy and tested it against the concept, if you can personalise the analogy you're doing really well. If you can come up with an analogy that works for you and then state where the analogy is not so good or doesn't fit, then that's even better. As I said the other day, it's to give you something to hang your hat on. If you're struggling up there and it's just an equation in space, it gives you something practical to hang your hat on. It's a bit like memory techniques. If you go to a course that teaches you to memorise items better, they work through a visualisation process where you imagine things. If you wanted to remember a 7 digit number, which is right at the stretch, 7 digits is about the limit for most people....

S2: (interrupting) You mean like an eye test or something where you make up a little rhyme to remember a sequence.

T: Yes, rhymes are OK, but pictures are better and that's why these analogies are supposed to work better with graphics because you remember pictures better. If you say, you've got a working memory that can remember anywhere between five and eight things and that's the difficulty with chemistry. A chemistry problem, typically from the HSC, will have anything up to ten or twelve variables written into the question and you have to develop ways of putting three or four of those things together in a predefined scheme so that you're only dealing with less than 8 things when you're answering the problem.

S3: It works well with practical things because when we are doing a practical we are seeing it as a picture as well as hearing it.

S1: And the weirder it is the more you remember it

T: Of course, if it's strange it strikes you as strange so you tend to remember it.

It's often easier to remember the odd things than those that are straightforward.

Getting back to the memory thing, if you wanted to remember a seven digit number, some of the techniques are, like, to remember a tree with a big banner and the number written on the banner. Or you imagine 7 cups and you put 1 number in each cup.

Alright, let's have a look at the analogy. OK this is an analogy for the forward reaction only. On the analogy you can see that we have two different paths for the cars to take. This is the activation energy hill, and this is where the catalyst smoothes out the road and makes it quicker for the cars to get to the end. That analogy there shows that by smoothing out the activation energy, which is what the catalyst does, the bottom reaction reaches the end faster. They run backwards but they do that a bit too quickly. Let's have talk about the analogy. How does the analogy relate to it's target? The hill is the original reaction with the higher activation energy. The flatter road is the catalysed reaction with a lower activation energy. The cars represent the reaction progress rate.

S5: So, does the catalyst lower the activation energy?

T: Yes, it provides an alternative pathway for the reaction to go down, which is easier, in both directions. If we go back to our original definition, there, you see that a catalyst is used in a reaction to alter the path a reaction takes and that new path requires a lower activation energy.

This question appears in the HSC every 2nd year.

S3: Was it in last year?

T: No, so probably this year. Usually it is a multiple choice question. They give you a nice long complicated reaction you haven't seen before. It looks really awful and it's got energy in it and all sorts of things and one of the choices is no effect and that's the right answer.

S4: That's the right answer for an equilibrium question?

T: it'll be written as an equilibrium, I'll show you some questions later.

Alright, here we go, same again, what's wrong with the analogy? Where does the analogy not work. I want you to come up with some ideas. Think of the cars, think of what we are trying to describe, why is it not a perfect match. What things are wrong with the analogy?

S6: There's two different cars

T: Right, the cars are different

S6: They should be the same

S1: Their colour

S6: because the cars are just going on different roads. Should be the same.

S5: The cars are not a very good representation of a chemical reaction.

T: OK, why not?

S5: With the ice cream you could see that it was doing something, with the chips on fire you could see it was doing something, with cars

S1: Perhaps they should change colour or something

T: Yeah, they should change on the way through

S1: Yeah

S3: Yes that would show a reaction happening

T: It's supposed to map, according to the analogy, the cars are the reaction progress their not showing what goes on in the reaction itself but that's the rate at which the reaction is progressing. So it's supposed to map. So, where else does it not fit an equilibrium reaction?

S4: It doesn't go back

T: Doesn't reverse? Good. Well we're only showing you one direction, so we're not actually showing you a reversible reaction as such.

S3: So what happens to a catalyst once it has reached equilibrium?

T: It keeps working

S3: With a catalyst in a normal reaction...

T: What's a normal reaction

S1: A + B gives C

T: A reaction that goes to completion? Is that normal do you think, based on what we have been doing for the last few days?

S3: No

T: Is it normal to find a reaction going all in one direction

S3: No its not

S1: Well it's what we're used to doing

S3: From that, I'm guessing that the catalyst doesn't actually interact.

S6: Does the catalyst at any point interact with the reactants but come out as itself at the end or is it always whole.

- T: Does it change its shape?
- S6: yes, does it change at all
- T: Generally not, generally it's providing a surface area the reactants can react on and the products can react on. It's like a mediator. It brings the parties together so they can sort their differences out. Not often, I don't know of examples where it actually changes and then reforms, not to say it doesn't exist, but I haven't heard of any obvious ones.
- So where else is this not like the equilibrium reaction? What were we talking about in the last lesson? What are the features of an equilibrium reaction?
- S5: It's not a closed system.
- T: good
- S3: It represents a rate change, it's not an equilibrium system like the others.
- S6: Yes every other analogy was also representing an equilibrium
- S3: So it doesn't relate to the first ones we did
- T: Yes this is different
- S6: It's represents the amount of activation energy required to get where it wants to.
- S3: So it's a rate of change graph so its hardly an equilibrium
- S6: Why is the activation energy in the middle?
- T: Well where does the analogy break down? If what we are trying to describe is this, a change in the reaction progress rate, where isn't the analogy like the actual chemical reaction? We'll take it as a belief that it's not a closed system and that it's only showing you one direction and the cars aren't a reaction in there
- S5: There's no food involved
- T: No food, OK
- S5: Drive us up to Mcdonalds and we'll have more ideas
- T: It doesn't mean...because you can't think of a lot of things, some analogies are closer to their target than others.
- S2: Like the ice cream
- T: Uh-huh, Some are good. Some are really close matching it
- S3: Yeah, the ice cream one and the chips were representing the whole thing but this is only representing one part of the reaction, where the catalyst is involved.
- T: Yes, so we're narrowing again, the closer the analogy can match it
- S3: Yes
- T: The only rule here is that if the analogy match the target completely, it would be the target. So you would be looking at a catalysed reaction, which we are obviously not.
- S3: Realistically that's what the difficulty of chemistry is.
- T: OK, let's have a look at some of the answers I came up with.
- Cars only go in one direction, whereas equilibrium we know is two ways. The system is not closed, a truck could come along the other way and stop the whole thing. The catalyst would probably be the bulldozer that flattened the path under the hill, not the flattened hill itself
- S6: Ah!
- T: The flattened hill's the path it goes on. The catalyst causes the lowered activation energy. The cars are not reacting with anything, we talked about that and it's not likely you can generalise about the advantage given one reaction path over another. The difference in the car's arrival time is fixed in this animation. But you can't generalise for all catalysed reaction how much faster one's going to be. That

animation shows the difference but a different reaction might have a much bigger difference or have them close together.

S3: You could create one for each reaction you do and use quantities.

T: You could with numbers and graphs, and they have been produced for actual reactions.

If you turn over the page, here is your test question. It is an energy profile for a reaction. This is how the energy changes as the reaction proceeds to the right. I want you to draw and explain how this graph would change with the addition of a catalyst. I want you to actually draw the new reaction path over the top of this graph. I want you to think about the start and finish points and the energy.

(pause)

Let's have a look at one that I drew.

Yours can be slightly different to that. The thing is that the time reach equilibrium will be quicker, so we'll get to the products a bit quicker and the activation energy will be lower. Both those things have to appear as features of your graph. You will see in the HSC that this is a typical question (this is taken from a past paper.) I think it fits the car analogy pretty well because you can think of the hump as the hill and if you've got a flatter hill, it's pretty easy to get where you are going. Even if yours wasn't exactly like that, at least if you got it lower you are going to score some marks. Completely correct, its got to finish early, but as long as you've got the lowering effect then you've got the effect of a catalyst on that reaction. (All students were able to show this)

I would like to do one on pressure but I haven't got an analogy yet

S3: Perhaps you could have a room with four walls and people inside then you could move the walls in to show more pressure.

Appendix E

Examples of Student Notes

Worksheet to Accompany Equilibrium Analogies Computer Program

1. Exothermic Reactions:

An exothermic reaction is: one where heat is a product/Heat is produced

A general equation can be written as follows: $A+B \rightleftharpoons C+D + \text{Heat}$
 $A+B \rightleftharpoons C+D \quad \Delta H = -X \text{ kJ/mole}$

List ways in which the analogy is NOT like the target:

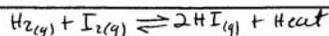
BURNING CHIPS IN POT.

NOT A CLOSED SYSTEM
 THERE IS NO CONTINUING HEAT. - (the fire would go out when the lid is put on)
 NOT REVERSIBLE - (can't get the original chips back).
 WASN'T IN EQUILIBRIUM TO START WITH.

effect of Cl_2 concentration if we heat the reaction vessel.

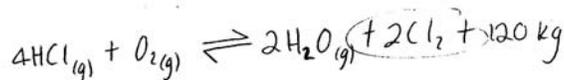
Answers to the questions:

1. CO_2 would decrease, O_2 & CO would increase ✓
2. ~~decrease~~ increase $2NO(g) + O_2 \rightleftharpoons 2NO_2 \quad \Delta H = -110 \text{ kJ}$
3. concentration would decrease



$H_2 + I_2$ - go back to the form of the reactants.
 - decrease the concentration of HI. ✓

$2NO(g) + O_2 \rightleftharpoons 2NO_2 \quad \Delta H = -110 \text{ kJ/mol}$ - what happens to NO if we heat it

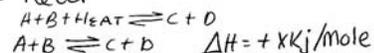


Example 1

2. Endothermic Reactions:

An endothermic reaction is: one that draws heat from the environment.
~~Draws~~ Absorbs heat

A general equation can be written as follows:

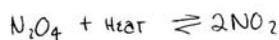
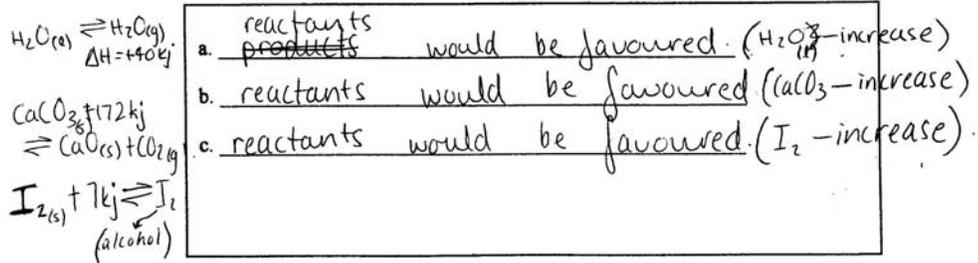


List ways in which the analogy is NOT like the target:

MELTING ICECREAM

NOT A CLOSED SYSTEM
 NOT AN EQUILIBRIUM
 NOT REVERSIBLE.
 NOT A CHEMICAL REACTION.

Answers to the questions:



If we heat it the concentration of N_2O_4 will decrease and the product concentration of $2NO_2$ will increase.

Example 2

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Catalysts: ?

↓ ~~chemical~~
substance

3. Catalysts:

What is a catalyst? a thing that speeds up a reaction without affecting or becoming involved in the products formed.

- lowers activation energy.

What Effect does a catalyst have on the equilibrium reaction?

It doesn't have any effect as it affects both sides of the equilibrium the same.

How is the analogy unlike the target?

- one direction whereas equilibrium has 2
- not closed
- catalyst would be bulldozer not car
causes not follows the lower reaction energy
- not reacting anything

mediator - brings 2 parties together so talk/sort out their differences.

Example 3

Appendix F

Paper presented at the National Association for Research in Science Teaching conference St Louis, MO, March 2001 and at Australasian Science Education Research Association conference, Sydney, August 2001.

The design, development and implementation of multimedia analogies for the teaching of chemical equilibrium

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Objectives

In this paper, we review the development process of a multimedia presentation designed to assist the teaching of chemical equilibrium using analogies. The objective of this paper is to report on the process of designing animated analogies and the subsequent employment of these analogies in a teaching program for grades 11 and 12 students. This paper describes a case study in the effective use of technology in the classroom based on established research in the field of analogical thinking.

Significance

There are two significant aspects addressed by the research. In the field of the use of analogies in education, this is a practical proposal to implement theoretical ideas. The constructivist school of ideas is driven by the key concept that students construct their own meanings based on past experience and the way in which teachers present information (Hsiao, 1997; Treagust, Duit & Fraser, 1996). Analogies take the familiar, real world example and use it to link the students' experiences to novel concepts. By suitably challenging individuals to modify existing ideas, the goal is to teach new concepts with a sufficient level of mastery. This program provides evidence to the body of research data on the effectiveness or otherwise of the use of analogies in teaching chemistry.

In the emerging field of multimedia education, there is a pressing need for the development of effective learning programs. In tying the use of analogies to multimedia, the goal is to produce a template for further development of positive learning experiences delivered from computers. The deployment of such programs over an Intranet or the Internet is a rapidly developing field and suitable applications are required in all fields of study (Pea, 1996).

From a broader theoretical perspective, a key aspect of the software under development is the use of small collaborative groups during the instruction cycle. Computer supported collaborative learning (CSCL) is a field of study which is a derivative of the social constructivist ideas proposed by Vygotsky (Miller, 1995). The software is designed to borrow from this school of thought and incorporate features of constructivism. CSCL is based on the premise that computer-supported systems can facilitate group processes and group dynamics in ways that are not achievable or as readily achievable with normal face to face learning experiences (Koschmann et al., 1996; O'Malley, 1995). One of the key ideas in the discussion of multimedia analogies is the formulation of ideas about the nature of the analogies themselves (Treagust, Harrison & Venville, 1998). A collaborative process within small groups best achieves this as it allows students to come to consensus about the analogies and relate them to the concepts being taught. This is a key feature in the design of the software.

Theoretical Underpinnings

There is an increasing body of research into methods of incorporating the ideas of the constructivist school into instructional programs. The key features, as summarised by Jonassen (1994), are to:

- ◆ Provide multiple representations of reality, thereby avoiding oversimplification of instruction by representing the natural complexity of the real world.
- ◆ Focus on knowledge construction, not reproduction.
- ◆ Present authentic tasks (contextualising rather than abstracting information).
- ◆ Provide real-world, case-based learning environments, rather than pre-determined instructional sequences.
- ◆ Foster reflective practice.
- ◆ Enable context- and content-dependent knowledge construction.
- ◆ Support collaborative construction of knowledge through social negotiation, not competition among learners for recognition.

There are a number of aspects of computer-based instruction and the use of multimedia that can be moulded to fit these major constructivist ideas in practical learning situations.

The use of analogies in the teaching of chemistry in the classroom has been extensively researched and the findings have been less than encouraging. Most teachers use some form of analogical reasoning but their presentation of such analogies is often unstructured and this can lead to possible misconceptions by students. The model for teaching with analogies provides a definite framework to incorporate constructivist ideas and promote collaboration (Treagust et al., 1998).

Chemical equilibrium has proved to be an area in which students consistently find difficulties with the underlying concepts. Tyson, Treagust and Bucat (1999), having considered prior research, decided to investigate students and their teachers in an attempt to understand the difficulties involved in teaching chemical equilibrium. They found that the specific nature of the content was a significant factor because it is abstract with a high degree of linkage to other content areas of chemistry. To arrive at a

correct conclusion, in many examples, students' thinking has to be highly sophisticated, as the interpretation required of terminology and concepts is very specific. Tyson et al. provide three approaches to the teaching of equilibrium effects – use of Le Châtelier's principle, the Equilibrium Law and reaction kinetics. All three teaching approaches can be used independently to predict changes in an equilibrium system but there are limits to their useability in the classroom. Le Châtelier's principle may lead to the correct answer in specific instances but at the same time it may provide an incorrect scientific interpretation as to the cause. The Equilibrium Law will yield a correct answer but may take too much

time and effort in cases where Le Châtelier's principle also yields the correct answer. Reaction kinetics may be just too abstract for some students to follow in many examples.

In a survey of teachers, Tyson et al. found 87% preferred to teach Le Châtelier's principle ahead of more accurate, numerical methods. There appears to be a clear need for alternative presentation methods of Le Châtelier's principle that can provide students with a more useful pathway to understanding.

Design and Procedures

The study sought to find the most appropriate methods and technology to present analogies for chemical equilibrium in a structured, effective manner. The underlying methodology is that of a case study (Merriam, 1988; Yin, 1984). Having reviewed the literature, it became apparent that analogies in texts and in the classroom were either verbal, written or pictorial. (Thiele & Treagust 1994;1995) and hence animations were chosen to try a more effective means for cueing retrieval of concepts. The production of suitable software followed the iterative process typical of a system design and development. The initial stage involved the feasibility of creating multimedia analogies followed by research into areas of need. The most effective use for analogies in the instructional cycle is as a link between familiar concepts and abstract ideas. Chemical equilibrium and Le Châtelier's principle provided a rich field for design but producing effective animations was an untried field. The platform preferred was HTML as all Australian schools had ready access to a browser as part of their operating systems and most schools had permanent Internet connections. The animations were designed initially and incorporated into a defined sequence that was intended to promote collaborative, interpretive activities. Related worksheets also were designed to provide structured activities throughout the process of interacting with the software. The first prototype analogies were created and tested in the classroom and their effectiveness evaluated. The analogies were then either modified or replaced with a more suitable example that was tested with subsequent groups of students. The students also needed education in the use and function of analogies in the learning process. The software incorporated screens giving a definition of an analogy and guidelines for their use. In addition, several key facts about equilibrium were provided to help students recall previously studied material.

Examples of analogies incorporated into the multimedia design included one for exothermic reactions. In this analogy, the forward reaction is represented by a man going for a walk on a cool day. An equilibrium is established between the heat produced by the mild exercise and the outside environment. Heat is applied to the system by having the man walk into increasingly warmer environments. The heat eventually causes the man to give up his walk and return home. This is intended to show that heat applied to the system favours a shift towards the reactants. Endothermic reactions are represented by a melting ice cream. More heat applied causes more melting (or shifts the reaction towards the products). A pressure analogy shows fish in a tank evenly distributed. Pressure is applied in the form of a cat that pounces on the tank making loud cat noises! The fish subsequently crowd together under a rock. The shift here is towards a more condensed state.

Initial and subsequent testing with three different groups of students led to modifications and refinement. Students were audio-taped throughout the lesson sequence and, following transcription, their discussions and questions were interpreted in relation to the stated aims of the project. Later groups were also evaluated via a survey form.

Discussion

Whilst the design and development of the analogies was the main thrust of the research, the implementation phase showed that these analogies must be integrated smoothly into a lesson sequence. It is not possible to use an analogy in isolation and must be presented in context. Analogies and metaphors are often generated spontaneously in the classroom in an attempt to better explain a difficult concept. It became clear in the testing phase that planning the use of the analogies within a structured lesson plan was required to maximize their effect. The lessons needed to be designed around the software to orient the students to the required knowledge and, after using the program, link the new knowledge to further concepts. A series of practical experiences were used to introduce the concept of a reversible reaction. This was followed by a demonstration of the $\text{NO}_2/\text{N}_2\text{O}_4$ equilibrium undergoing changes due to temperature and some revision notes on equilibrium reactions. Students were informed during the instructional sequence as to the nature of analogies and their purpose in the learning process. As the lessons progressed, the conversations of the students showed a critical approach to the use of analogies and an awareness of the function of each analogy as it related to the concept being considered. One of the most important design aspects of the analogies was the analysis of how well the analogy mapped to the target. The students needed careful instruction as to how to achieve this in the first analogy studied. The subsequent analogies showed that students were keen to participate and as a group tended to dominate the discussion. The following excerpt from taped lessons was concerned with the melting ice cream analogy for an endothermic reaction. The students were debating whether the analogy accurately portrayed a reversible reaction. Some argued that re-freezing ice cream shows the analogy is modelling a reversible reaction. Others argued that you cannot remake the ice cream in

the cone to its original shape. One student tries to modify the analogy:
(Note T = Teacher S1,S2 etc denote different students)

S3 If you did it in a container with the exact same shape then it would freeze back to the original

He follows this up with his own analogy:

S6 Let's get back to the melting of ice cream

S3 It should be like water and ice cubes

S6 I don't think this case is reversible

T So do we have consensus on whether it is reversible. What sort of change is it?

S3 Well, it's a change of state

T So we are dealing with physical rather than chemical change. Do we agree that it is probably not reversible?

S1 Because it is not a chemical reaction? Yes
(general agreement because you can't retrieve the original in its own form)

This exchange illustrated a desire on the part of the students to make the analogy work. In effect, they were constructing a better analogy (water and ice cubes) to fit the target. The spontaneous generation of a different, albeit very similar, analogy demonstrated a metacognitive process that became increasingly evident as the lessons proceeded. It became more obvious throughout this process that most of the group had become immersed in the discussion and were actively engaged in sense-making about analogies. They openly questioned the way that they were thinking about the analogy, spontaneously designed new analogies and questioned the need for analogies in the learning process.

The following exchange provided some useful insights into the effectiveness of the analogies used.

T The whole idea of the analogy is to give you something to hang your hat on. You're no longer looking at a chemical equation on paper that is just dry. So when you're thinking about an endothermic reaction it gives you a picture in your mind. Make it a little easier to understand.

S3 The only problem with that is inventing an analogy for each individual thing, for endothermic, exothermic, addition of pressure and so on.

T Right. For endothermic/exothermic you could choose either the ice cream or the chips as one is the reverse of the other. So if you like the ice cream better than the chips, you could use that one.

S1 The ice cream is better than the chips because it is in some way reversible (even if its not completely)

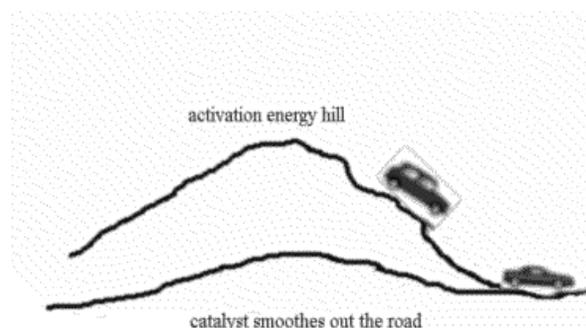
T What you've got to have is an analogy that you like. It's got to work for you. We've got to map an abstract concept to a concrete idea in your brain. So if you can find something to hang your idea on, it should make it easier for you to solve, not harder.

It was clear that some of the students believed that the use of analogies should be governed by two factors – frequency and appropriateness. It was realised that it is a difficult process to develop analogies and that in some cases they might not work. Also using one analogy to describe two complementary processes is a way to reduce cognitive load.

Interpretation of the taped lessons initially showed an improved awareness by students as to the use and function of analogies in the learning process of chemical equilibrium. There was a distinct collaborative process observed during the lessons that led to fruitful conclusions about the nature of the chemical equilibrium process. It was observed that the proportion of student talk to teacher talk increased dramatically as subsequent analogies were presented. After using the software students were asked to evaluate the techniques employed.

- T So what did you think of that approach?
 S5 Good, a lot different
 S1 It was interesting
 S3 I learnt the difference, how it made you think what it wasn't, as well. Because the bad things were pointed out,
 S1 Sort of more obvious
 S3 Yeah, like it made it more obvious what it is rather than what it isn't.
 T Well once you can eliminate all of the extraneous bits, you can focus on what we are trying to learn which is what the equilibrium reaction does when its doing what its supposed to be doing.

Students displayed positive responses towards the software and compared it favourably with other presentations such as video or textbook analogies. Some students displayed metacognitive skills, as their personal observations led them towards a better understanding of their own thought processes. The students readily engaged in the collaborative process, as they were actively involved with the presentation of the software. The following excerpt is a discussion about catalysis represented by two different cars taking two different routes on a journey.



- T What things are wrong with the analogy?

- S6 There's two different cars
 T Right, the cars are different
 S6 They should be the same
 S1 Their colour (Author's note: one was red the other blue)
 S6 because the cars are just going on different roads. Should be the same.
 S5 The cars are not a very good representation of a chemical reaction.
 T OK, why not?
 S5 With the ice cream you could see that it was doing something, with the chips on fire you could see it was doing something, with cars
 S1 Perhaps they should change colour or something
 T Yeah, they should change on the way through
 S1 Yeah
 S3 Yes that would show a reaction happening

The ability of several of the group to see obvious problems in the mapping and then suggest changes to improve it demonstrated an involvement beyond the traditional learning process.

The animations proved to be a persistent concept for several students as they were able to recall the analogies several months later. The testing of the students to observe their problem solving ability showed a good level of achievement and understanding at a basic level. A surprising finding was the interest displayed by the students in creating their own analogies after they had seen the ones displayed in the multimedia program. As an example, one student thought that the crowd at a boxing match was a better analogy for a catalyst than the idea presented of two cars going different routes on a journey.

The study has shown that there is potential for chemistry teachers to incorporate multimedia analogies in their teaching sequence of abstract and difficult concepts. The active promotion of collaborative procedures using the software as a stimulus also shows promise. The ability to ground students' interpretations in familiar situations and promote further discussion provides a solid argument for the continued use of such methods in the classroom.

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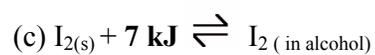
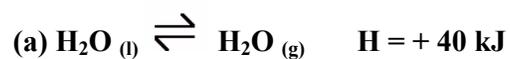
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Appendix G

Exam questions

Test your knowledge

1. For each of the following reactions, state whether the reactants or the products would be favoured by lowering the temperature of an equilibrium mixture



Answers :

In each case the reactants are favoured. Cooling an endothermic reaction at equilibrium will cause the reaction to compensate by shifting to the side that will produce more heat (the reactants or left side)

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