EVALUATION OF TWO COMPUTER PROGRAMS FOR USE IN HIGH SCHOOL CHEMISTRY

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ABSTRACT

Certain concepts in the final year of Ontario's high school chemistry course, SCHOA, are often difficult for students to understand. This project presents the results of a study of selected computer programs that could be used to enhance the teaching of selected difficult concepts in an attempt to make them easier to understand.

The identification of the difficult concepts was an important component of this project. They were identified by means of a student survey, teacher interviews, literature review and personal experience. The difficult concepts were identified, in order of decreasing difficulty, as: 1. Buffers, 2. Solubility, 3. Redox, 4. Independent Investigation, 5. Acid/Base Equilibrium, 6. Reaction Mechanisms, 7. Free Energy.

Two programs were selected for evaluation - The Electric Chemistry Building and Chem1 Problem Proctor and a checklist was established to examine these computer programs. The two programs address the identified difficult concepts and use a variety of teaching techniques (tutorial, drill and simulation).

Chem1 Problem Proctor consists of tutorial and drill lessons, suitable for use by students of SCHOA. The key objectives of this program are to encourage problem-solving and to promote an understanding of the principles underlying the chemistry concepts. The program accomplishes this to various degrees of success by requiring the student to make decisions, to make qualitative estimates before some of the calculations and by asking questions related to the concept but not necessarily part of the solution to

the problem.

The Electric Chemistry Building is a simulation of a building made up of three laboratories, two of which were evaluated in this project. The key objective of this program is to develop problem-solving skills by providing students with the opportunity to design and perform experiments, make observations and draw conclusions.

Based on the evaluations of Chem1 Problem Proctor and The Electric Chemistry Building in this project, both programs appear to be worthwhile for use in SCHOA. The Electric Chemistry Building is a very good simulation program which would enhance the teaching of the difficult concepts of SCHOA. Chem1 Problem Proctor is a good tutorial/drill program which should be improved with respect to its presentation of chemical notation and mathematical formulae, and the feedback to its drill questions. Once these aspects of the program are corrected, it will also be effective in enhancing the teaching of difficult concepts of SCHOA.

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Dr. Blizzard was so kind as to lend me copies of the software, "The Electric Chemistry Building", for use in this project. Additionally, I would like to thank Dr. S. K. Lower of Simon Fraser University for providing me with a copy of his program, "Chem1 Problem Proctor". The availability of these programs made this project possible.

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CHAPTER 1

INTRODUCTION

Certain concepts in OAC[1] Chemistry are often difficult for students to understand. This project presents the results of a study of the potential use of selected computer programs in high school Chemistry. The objective of the project was to investigate whether computers can enhance the teaching of selected difficult concepts in an attempt to make them easier to understand. Waddington (1984) states that, "the central problem of chemical education is how to teach a highly developed body of knowledge so that it is learned in a meaningful way". Although computers are readily available in many schools and many students have access to computers at home, it has been found that, "studies on the effectiveness of computers in realizing curriculum objectives are remarkably few in number. So it is reasonable to infer that research on ways to use computers as a supplement to existing curricula should be undertaken" (Beattie, 1987).

In this project, twenty-two OAC students at Westdale Secondary School in Hamilton, Ontario were surveyed to identify those concepts in OAC Chemistry that the students perceive to be difficult. Several teachers were consulted to further assist in the identification of the difficult concepts. The project reviewed a selected set (the criteria for the selection will be discussed) of computer chemistry software suitable for the OAC

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[1] OAC Ontario Academic Course - the final year of high school in Ontario

level, and identified, from a teaching perspective, those programs that could be effective in enhancing the teaching of the difficult concepts. The value of such a project is stressed by other researchers, such as Choi and Gennaro (1987) in their statement, "Researchers need to explore the teaching of those topics in science which might be enhanced by using computer simulations."

One of the results of this project is the identification and ranking of the difficult concepts of OAC Chemistry. Such a list should be useful to teachers of this course, assisting them in their lesson preparation. Another result is the identification of computer programs that might enhance the teaching of the difficult concepts. These programs are evaluated and recommendations are made on how teaching the concepts could be enhanced with use of the computer. Such research will be useful since "we may not yet have hit upon ways of using computers that will enhance learning" (Beattie, 1987).

This project is arranged in the following manner:

Chapter 2 provides a brief overview of the SCHOA[2] curriculum and attempts to identify the difficult concepts in SCHOA,

Chapter 3 discusses three teaching strategies used in computer software - tutorial, drill and simulation,

Chapter 4 develops an evaluation scheme which is used in this project,

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[2] SCHOA Code for the OAC in Chemistry

Chapter 5 presents the evaluation of the selected computer programs - The Electric Chemistry Building and Chem1 Problem Proctor,

Chapter 6 gives conclusions and recommendations based on the evaluations of the computer programs.

The appendices contain the student survey and its results, the evaluation checklist and the detailed evaluation of each program.

CHAPTER 2

THE OAC CHEMISTRY CURRICULUM

2.1 - INTRODUCTION

This chapter provides a brief overview of the curriculum of the OAC Chemistry course, SCHOA, prescribed by the Ministry of Education, (Ontario Ministry of Education, 1987) and attempts to identify the difficult concepts in SCHOA. The difficult concepts were identified using a student survey, teacher interviews and personal teaching experience. Each method is described, and the difficult concepts identified by each are discussed and compared. The chapter concludes with a discussion on how the identified difficult concepts were used in this project.

2.2 - OVERVIEW OF SCHOA

SCHOA provides students with the opportunity to further expand the content and processes introduced in the prerequisite course, SCH3A[1]. Students enrolled in SCHOA may concurrently take courses at the grades 11, 12, or OAC levels, provided that they have successfully completed SCH3A.

SCHOA pursues an in-depth treatment of the way in which matter changes and interacts. The OAC in Chemistry is intended to prepare students for further studies in

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[1] SCH3A Code for the Grade 11 course in Chemistry

science at the post-secondary level and therefore places significant emphasis on mathematical problem-solving (Ontario Ministry of Education, 1987).

The SCHOA course is divided into ten major topics, as shown in Table 2.1. Most of these topics contain several different concepts. SCHOA begins with a brief review of the relevant concepts of SCH3A. The first new topic is chemical energy (topic #3), which is an introduction to chemical thermodynamics. This is followed by an introduction to reaction rates, which leads directly to the major topic of chemical equilibrium. The concepts of equilibrium law and of equilibrium systems in general, in acids, in bases, and in solutions are discussed. In redox and electrochemistry, students study how electricity can be produced by chemical reactions and the effect of electricity on chemical reactions. The final topic in the course is an introduction to organic chemistry - the nomenclature and properties of selected organic compounds, and a few of their chemical reactions.

Since 1987, SCHOA has included an independent investigation as a required component of the course (Ontario Ministry of Education, 1987). Although students are expected to work on their investigations on their own time, the inclusion of such investigation affects the entire course. The result is that there is pressure on both the teacher and the students to meet certain deadlines, and it eliminates the possibility of pursuing optional topics as a class.

TABLE 2.1 Outline of SCHOA Curriculum

1. Review of SCH3A
   - -Nomenclature
   - -Moles/Stoichiometry
   - -Bonding/Shapes

2. Atomic Structure
   - -Atomic theory
   - -Properties of elements
   - -Metallic bonding

3. Chemical Energy
   - -Heats of reaction (ΔH)
   - -Hess' Law
   - -Bond energy
   - -Entropy (ΔS)
   - -Spontaneity (ΔG)

4. Reaction Rates
   - -Activation energy, activated complex
   - -Rate law expressions
   - -Reaction mechanisms
   - -Factors affecting rates

5. Chemical Equilibrium
   - -Characteristics of equilibrium
   - -Le Chatelier's principle
   - -Equilibrium and rate
   - -Equilibrium law expression
   - -Equilibrium law constant, K_{eq}
   - -K_{eq} calculations

6. Solubility Equilibrium
   - -Solubility rules
   - -Solubility product, K_{sp}
   - -Common ion effect
   - -Predicting precipitation

TABLE 2.1 (continued)

7. Acid/Base Equilibrium
    - -Bronsted-Lowry definition
    - -Strength of acids and bases
    - -Conjugate acid/base
    - -Predicting reactions
    - -pH
    - -K_a, K_b, K_w
    - -Hydrolysis
    - -Titration
    - -Buffers
    - -Lewis definition

8. Electrochemistry/Redox
    - -Oxidation numbers, balancing equations
    - -Half-cell method for balancing equations
    - -Electrochemical cells
    - -Nernst equation
    - -K_{eq} for redox
    - -Electrolytic cells
    - -ΔG for redox

9. Organic Chemistry
    - -Alkanes, -enes, -ynes
    - -Alcohols
    - -Aldehydes, ketones
    - -Carboxylic acids
    - -Esters

10. Independent Investigation

2.3 - IDENTIFICATION OF DIFFICULT CONCEPTS OF SCHOA: STUDENT SURVEY

Certain concepts in OAC Chemistry are often difficult for students to understand. In order to identify these difficult concepts, a survey of students was conducted. The survey format was chosen because it would provide specific information and it would be easy to administer (Hopkins, 1988). Identification of the difficult concepts in SCHOA was considered to be specific information, as defined by Hopkins. It was important that the survey be easy to administer since interruption of the SCHOA classes had to be kept to a minimum. The survey questions are presented in Appendix A.1.

2.3.1 - Set-up of the Student Survey

The survey asked students to indicate the difficulty they experienced in learning and understanding the concepts of the course. It divided the course content into ten topics and listed the major concepts associated with each topic, in the order in which they are studied, similar to Table 2.1.

The surveys were completed anonymously to encourage students to be honest in their responses. The students indicated the level of difficulty with each concept by circling a number from one to five (one was labelled as 'not difficult' and five as 'difficult'). Such a rating scale was used to make the survey as simple as possible for the students, and thus increase the number of students responding. A range of five was chosen to indicate the degree of difficulty the students experienced since this range offers some flexibility but does not imply undue precision in their responses.

The survey was completed during the last formal class of the semester, at which time most of the students should have reviewed the course material in preparation for the upcoming examination. The survey was presented by the author to two classes taught by other teachers so that the students would not think that the survey was part of their own evaluation (which is a concern of students at examination time). Unfortunately, attendance for the final class was reduced and this resulted in a small sample size (twenty-two of a possible thirty-two students). However, those students who completed the survey did so with care and many provided written comments.

2.3.2 - Analysis of the Student Survey

Of three common measures of statistical analysis, (mean, median, mode) it was felt that the mean value would differentiate the degree of difficulty of the concepts most effectively. The mean allowed the concepts to be ranked according to their difficulty because it resulted in fractional values which permitted more distinct subdivisions between the concepts.

The data obtained through the student survey and results of analysis of that data are presented in Appendices A.3 and A.4. The range of the mean values of difficulty of the concepts was 2.0 to 3.7. The range from 2.0 to 2.5 was considered to be easy, from 2.6 to 3.1 as moderate, and from 3.2 to 3.7 as difficult. In two cases (solubility and redox) students rated several concepts within the same topic as difficult and therefore the entire topic was identified as difficult. Table 2.2 presents the difficult concepts in order of decreasing difficulty. Table 2.3 summarizes the number of concepts in each category of difficulty.

TABLE 2.2 Difficult Concepts in SCHOA

Concept		Difficulty	Standard Deviation
Buffers		3.7	0.9
Solubility	- Common Ion - Precipitation	3.6	0.8
Redox	- K_{eq} - Electrolytic cells - ΔG - Electrochemical cells - Nernst equation - Balancing equations	3.4	1.0
Independent Investigation		3.4	1.2
Acid/Base Equilibrium	- Hydrolysis - Titration	3.3	0.9
Reaction mechanisms		3.2	0.7
Free energy, ΔG		3.2	1.2

TABLE 2.3 Summary of the Mean Values of Difficulty of the Concepts in SCHOA

Difficulty	Number of Concepts	% of Total
2.0 - 2.5 (easy)	17	36%
2.6 - 3.1 (moderate)	16	34%
3.2 - 3.7 (difficult)	14	30%

As shown in Table 2.3, according to this student survey slightly more than one third of the concepts are considered easy, one third are considered moderately easy/difficult and less than one third are considered difficult. Of the seven concepts identified as being difficult for the students, two (buffers and free energy) are optional and occur at the end of topics that are considered moderately easy/difficult. These difficult concepts are introduced to the students for the sake of the applications they offer.

Two of the remaining difficult concepts (hydrolysis and titration, and reaction mechanisms) are scheduled towards the end of topics that are moderately easy/difficult. At the SCHOA level, these difficult concepts are introduced but they form only a minor part of their topics.

Students reported the independent investigation to be difficult for several reasons: inexperience in devising/conducting/writing a scientific research report, time constraints, and a heavy workload. They also found it difficult to select a topic, collect and organise data and present results. Due to the individual nature of the independent investigation, this difficult concept was not considered suitable for inclusion in this project.

Solubility and redox are the final two items to be discussed. Both of these are topics as opposed to single concepts, and fortunately not every concept within them was considered difficult. Solubility is taught first, usually at the end of the first term of a semester, and redox is studied in the second term of the semester. The two topics are separated by a discussion of acid/base equilibrium. It is fortunate that both of these difficult topics include laboratory activities and demonstrations which help the students learn the concepts involved.

2.4 - IDENTIFICATION OF DIFFICULT CONCEPTS OF SCHOA: TEACHER APPRAISAL

The students' performance on tests indicate difficulty with the same concepts as those identified in the survey. This is reflected in the results of the teacher interviews and the literature reviewed. Therefore, although the number of students surveyed was small, the results of that survey are supported by the teachers' responses and by literature references.

2.4.1 - Teacher Interviews

A total of five teachers, teaching at four different schools, were asked to identify those concepts of SCHOA they consider to be difficult for their students to learn and/or understand. Each teacher was asked to respond individually.

The list of difficult concepts prepared by the teachers was very similar to the students' list, with a few exceptions. The teachers identified solubility equilibrium as being the most difficult for their students. Next, in decreasing order of difficulty, were redox, reaction mechanisms, rate law, and buffers. The students' list rated the first three of these concepts in the same order, but they put buffers at the top of their list. This discrepancy may be explained by the relative lack of importance placed on this concept by the course outline. The concept of buffers is not included in the Ministry of Education guidelines, and although many teachers (including those interviewed) teach it, they view it as an optional topic. The students are unaware of this.

The teachers' list did not contain the independent investigation because they did not consider this as a concept of SCHOA. However they all felt that it was difficult for their students to prepare this investigation, mainly due to time constraints. The teachers' list also did not contain the concept of free energy. This concept is also not included in the Ministry of Education guidelines and a few of the teachers did not teach it.

Overall, there appears to be a general agreement between teachers and students on the identification of the difficult concepts in SCHOA.

2.4.2 - Literature Support

A review of the literature supports the results of the student survey and the teacher interviews discussed in the preceding sections. One group of researchers found that even, "given an ideal teaching situation, it is still possible that a significant proportion of pupils will still experience difficulty with aspects of the concept of chemical equilibrium because of the inherent abstract nature of the topic" (Johnstone, MacDonald and Webb, 1981).

Another concept "considered difficult to teach and difficult to understand" (The Unesco Press, 1981) is oxidation and reduction. One researcher (Herron, 1972) feels that students become confused with the ideas of gaining or losing electrons, and proposes as a solution to emphasize the use of oxidation numbers.

The concept of thermodynamics is described as "not a very popular subject among students of chemistry and is often found difficult" (Wright, 1974). The author states that one of the reasons why students find thermodynamics so difficult is its mathematical nature. Another reason is the concept of entropy which is a "stumbling-block" (Wright, 1974) for many students. However, a second researcher suggests that it is possible to teach entropy successfully in high school through statistical mechanics (disorder) or classical thermodynamics (heat engine) (Morwick, 1975).

The concepts identified as difficult through this literature review were chemical equilibrium, reaction mechanisms, redox, thermodynamics and entropy. These results are in agreement with the concepts identified by students and teachers, since solubility is included in chemical equilibrium, and free energy is included in thermodynamics and related to entropy. It is reassuring to find consensus among all three sources.

2.4.3 - Personal Experience

After having surveyed students, interviewed teachers and reviewed the literature, it seems important to also draw from personal experience. This personal experience spans ten years, two provinces (Ontario and Alberta) and one state (California).

My personal experience is in agreement with the concepts already identified as being difficult. My ranking of the difficult concepts coincides closely with that of the teachers who identified the topic of equilibrium as most difficult. Solubility concepts of common ion and precipitation seem to be the most difficult for students, followed by equilibrium constant calculations. I have found that students also experience difficulty with the concepts of rate law and reaction mechanism, and redox. If buffers are taught, they can be found to be difficult.

Since the identification of the difficult concepts was essential to this project, it was desirable to collect information from as many sources as possible. The separate identifications by students, teachers, literature, and through personal experience all provide very similar conclusions on what are perceived to be the difficult concepts in SCHOA.

2.5 - SUMMARY

The purpose of this project is to investigate whether the use of computers can enhance the teaching of selected difficult concepts of SCHOA. The identification of the difficult concepts has been an important component of this project.

This chapter began with a brief overview of SCHOA, the OAC course in chemistry. The purpose of this chapter was to explain the methods by which the difficult concepts of SCHOA were identified, and to discuss the subsequent results.

The difficult concepts were identified by means of a student survey, teacher interviews, literature review and personal experience. The establishment of the student survey was detailed and the results of each method were discussed. After reviewing the results from all four sources, a ranking of difficult concepts was established, shown below in order of decreasing difficulty:

1. Buffers
2. Solubility
3. Redox
4. Independent investigation

5. Acid/Base Equilibrium

6. Reaction mechanisms

7. Free energy

The difficult concepts above are all suitable for computer applications. These concepts are suitable for tutorial, drill, and laboratory simulation types of computer programs. This project investigates computer programs that may enhance the teaching of all of these difficult concepts, with the exception of the independent investigation. The independent investigation will be omitted because of its individual nature.

CHAPTER 3

TEACHING STRATEGIES USED IN CHEMISTRY COMPUTER SOFTWARE

3.1 - INTRODUCTION

The teaching strategies used in computer software can be categorized into four major groups: tutorial, drill, simulation or game. The computer software examined in this project applied the first three teaching strategies. Games suitable to the difficult concepts identified in Chapter 2 were not found. In this chapter each teaching strategy will be defined and its general structure will be outlined. There will be brief discussions of the advantages and disadvantages of each teaching strategy.

3.2 - TUTORIAL

Tutorials are "computer programs that teach by carrying on a dialogue with the student" (Alessi and Trollip, 1985). Tutorial programs can be used to teach a new concept, to review a concept or to provide remediation. A tutorial program presents information and asks the student questions to which the student responds. The tutorial then judges the student's response and decides whether to present new information or to give some form of remediation. The flowchart in Figure 3.1 (Alessi and Trollip, 1985) summarizes the structure of a tutorial program.

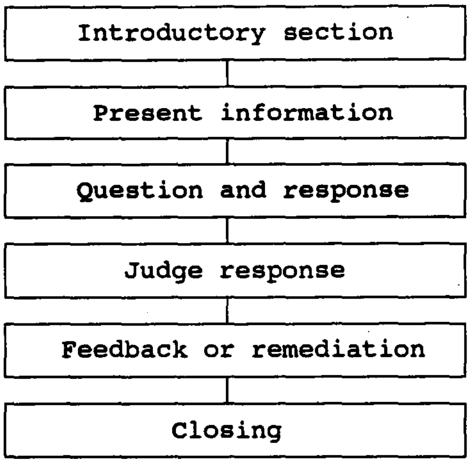

Figure 3.1 - Structure of a Tutorial Program

Tutorials offer several advantages: (1) they can motivate students by asking questions that arouse their curiosity, and therefore their interest to learn (MacLachlan, 1986), (2) they can be available to and accessible by the students, in school or at home, (3) students can follow a tutorial without direct supervision or guidance from the teacher (Disney and Disney, 1983), and (4) tutorials can help students improve their reasoning and problem-solving skills (Tamir, 1985/86).

Tutorials also have disadvantages: (1) they are often written to meet the needs of students of a specific ability (Disney and Disney, 1983), and therefore may not offer alternate options for students of lesser or greater ability, (2) they also do not allow for any creativity on the part of the student, since they lead the student through a set sequence of questions.

3.3 - DRILL

Drills are computer programs that provide practice and reinforcement for material that has already been taught (Alessi and Trollip, 1985; Kahn, 1985). Drills are not intended to teach new concepts. A drill presents a selection of questions or problems, and continues to do so until the student is able to successfully answer or solve them. The use of drills is supported by many teachers and researchers, for example, "A well planned drill, presented on an individual basis with immediate feedback reinforcing correct responses and correcting mistakes is a powerful instructional device" (Tamir, 1985/86). The flowchart in Figure 3.2 summarizes the structure of a drill (Alessi and Trollip, 1985).

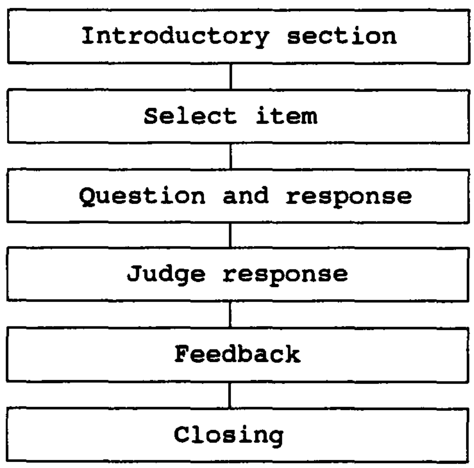

Figure 3.2 - Structure of a Drill Program

Drills offer several advantages: (1) they can motivate students if they use variety in the questions and problems, competition and graphics (Alessi and Trollip, 1985), and (2) they provide immediate feedback to each response, an aspect which may be difficult for the teacher to provide, especially in larger classes (Tamir, 1985/86).

Disadvantages to drills are that they often provide numerical grades or scores of the student's performance. This can motivate some students, but can deter others (Gillis, 1986). Drills often use a multiple-choice format (Tamir, 1985/86), that makes the drill easy and quick to use, but it may encourage guessing rather than review and problem-solving.

3.4 - SIMULATION

Simulations are computer programs that teach about a phenomenon by imitating it. There are two types of simulations applicable to chemistry: physical and procedural. Physical simulations teach the student how to use a piece of physical equipment. Procedural simulations teach the student how to carry out a sequence of steps (a procedure). Sometimes there is little or no distinction between a physical and procedural simulation.

A simulation presents a scenario which requires some action by the student. The scenario is updated based on the student's action, and new input is required. The flowchart in Figure 3.3 summarizes the structure of a simulation (Alessi and Trollip, 1985).

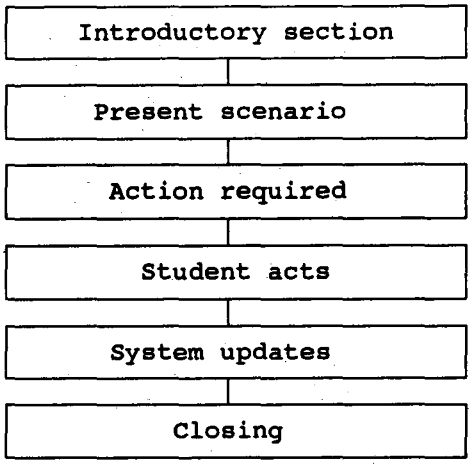

Figure 3.3 - Structure of a Simulation Program

Simulations offer several advantages. They can motivate students to learn (Alessi and Trollip, 1985). They are safe, convenient, controllable, less expensive, less time-consuming, always repeatable and always available (Alessi and Trollip, 1985; Tamir, 1985/86; Snir, 1988). Simulations permit students to perform experiments and to study variables which might otherwise be too dangerous, expensive or time-consuming (Tamir, 1985/86; Snir, 1988; Disney and Disney, 1983). They can also provide the student with an opportunity to consolidate what has been learned (Collis, 1988).

Although simulations have many more advantages than disadvantages, a few disadvantages must be noted. Simulations may lead to the neglect of laboratory work. Many researchers believe that simulations should not be substituted for actual laboratory activities, but that they can be a powerful supplement (Alessi and Trollip, 1985; Tamir, 1985/86; Disney and Disney, 1983; Snir, 1988; Helgeson, 1988; Kahn, 1985). Simulations often have no relationship to other course components (Bork, 1981), but this problem can be avoided by selecting appropriate simulations. Unlike tutorials or even drills, "considerable instruction must have taken place before a simulation is likely to have educational value" (Collis, 1988).

3.5 - SUMMARY

The teaching strategies used in the chemistry software to be evaluated in this project have been introduced. The three strategies are quite different from one another and serve different purposes. A tutorial can be used to teach new material, reinforce previously learned material or to provide remediation. A drill can be used for practice and remediation of previously learned material. A simulation can be used to reinforce previously learned material, but is best suited to extend and to explore beyond that material. Depending on the student's needs, software using the most suitable teaching strategy can be chosen.

CHAPTER 4

EVALUATION SCHEME FOR COMPUTER PROGRAMS

4.1 - INTRODUCTION

In order for the evaluation of the computer programs to be as effective and as consistent as possible, several aspects of the evaluation scheme were considered during its development:

- the purpose of the evaluation
- the intended users of the evaluation
- the necessity of the evaluation.

Once these aspects had been taken into account, they determined what information needed to be collected during the course of the evaluation (Owston, 1987).

One purpose of the evaluation was for familiarization and understanding of the programs. A second purpose was to determine whether the software programs could be used to facilitate learning in SCHOA.

The intended use of the evaluation was to ascertain the effectiveness of the various software programs to address the difficult concepts of SCHOA. The intended users of the evaluation would be teachers of this chemistry course. The evaluation was deemed to be necessary in order to identify software programs that would facilitate learning/teaching of difficult concepts of SCHOA (Criswell and Sweezey, 1984).

4.2 - DEVELOPMENT OF THE EVALUATION CHECKLIST

An evaluation checklist was established to examine the software programs. A checklist format was selected to ensure that all relevant features of the software would be considered in a complete and standard manner (Alessi and Trollip, 1985).

The following is based primarily on the checklist found in "Computer-Based Instruction, Methods and Development", by Alessi and Trollip (1985). That checklist was modified by incorporating criteria from other sources to suit the programs being evaluated. These sources were: Gillis (1986), The Council of Ministers of Education (1985), Chambers and Sprecher (1983), Owston (1987), Wallace and Rose (1984), Bitter and Wighton (1987), Moore and Moore (1986), Roy (1983).

The checklist was divided into seven parts:

1. Description
2. Administrative Issues
3. Subject Matter
4. Language and Grammar
5. Surface Features
6. Instruction and Motivation
7. Documentation

The complete checklist is given in Appendix B.

4.2.1 - Description

The first part of the checklist serves as an introduction and overview of the program being evaluated. The description of the program indicates the type of computer application, its instructional intent, and the intended users. Based on this description, a teacher may choose to read the rest of the evaluation. Prior computer experience of the user is often assumed by programs and this is quite a realistic assumption. Unfortunately, lack of computer experience can hinder the user and result in frustration.

4.2.2 - Administrative Issues

The second part considers the administrative issues. These are important to the teacher who may be considering purchasing the software package. A version of the program that is compatible with the computers available for SCHOA students must be available. Most educational institutions operate on restrictive budgets and therefore, the cost of the package is a factor to consider.

4.2.3 - Subject Matter

The next part of the checklist examines the subject matter within the program. It is important that the objectives of the program be clearly defined, giving direction to the user. The information provided by the program should be relevant, accurate and complete (but not exhaustive). The emphasis of the program should be appropriate to its goals and the sequence followed should be logical. The content sequence should be appropriate to the intended users and the size of the incremental steps should also be appropriate for the same intended users. In order to provide challenge to the user there should be a choice of multiple levels of ability and variable levels of difficulty. The questions should be random enough so that the program does not become repetitive. If the program assumes prior knowledge, this should be made apparent from the start, either within the manual or in the instructions on the screen.

Educational software should involve a high degree of user interaction - making decisions and developing strategies. The program should encourage experimentation and risk-taking. There should be opportunities for users to work together and learn from each other, as well as from the program. Since stating the objectives clearly is important, it is equally important that those objectives are attainable.

4.2.4 - Language and Grammar

The fourth part of the checklist looks at various aspects of language and grammar. An educational program should be free of grammatical, spelling and syntax errors. Errors in language and grammar can give rise to questions concerning the technical accuracy of the program. The reading level of the material should be appropriate for the users of the program. The absence of bias is desirable since its presence can limit the usefulness of a program. An example of a pertinent cultural bias is the use of the metric system, which must be considered when reviewing programs produced in the United States. Technical terms, abbreviations and jargon should be defined and relevant. Since the checklist was designed to evaluate chemistry programs, the correct and clear use of chemical formulae is an important aspect.

4.2.5 - Surface Features

The next part of the checklist examines the surface features, or those features that relate to the physical aspects of the program. An educational program should be simple to start up. The information within the instructions should be presented in appropriate amounts so that the program does not appear to be difficult or threatening.

In educational software it is important for the user to be able to control the direction of the program. Ability to control the rate at which information is being presented is important, especially to the novice user. The user should be able to control the sequence of the information, reviewing or bypassing information as desired. Where applicable, the user should be able to move from one mode of the program to another and return to the point of departure.

Since the amount of time available to use a program will vary it is important that a program can be interrupted. The interruption may be accidental or planned, but the program should be able to be resumed later on. This feature also eliminates users feeling pressured to reach a certain point in the program before they can leave. In educational software, there should be some indication that users have completed the lesson. Users also need to know their degree of success with the lesson. In some programs score-keeping is appropriate.

The surface features of animation, graphics, colour, audio-visual effects and display are all related to the 'fantasy' and 'curiosity' aspects of a program. They should create images that will improve the memory and understanding of the material being presented (fantasy). These features should also appeal visually to the user and attract their interest (curiosity). The user will most likely be motivated to continue the program if these features are present. It is important to question whether they are relevant to the content and are important to the learning process. Sound effects should have the capability of being turned off or down, since it can be annoying and embarrassing to the user and to others working nearby. Both overwriting and scrolling can be frustrating to the user, and user control of these functions is desirable.

4.2.6 - Instruction and Motivation

The next section of the evaluation checklist examines the instructional and motivational aspects of the program. The menus should clearly show how to make a choice and how to change that choice. The questions should make it clear how to respond and how to avoid a response if the answer is not known. The program should be somewhat lenient in its judgement of responses, and provide a cue as to whether the format of the answer needs to be modified (ie., if a formula is required rather than a name, or vice versa), or if a unit is missing or incorrect. It is less frustrating especially for the novice computer user, if the program is not overly sensitive to unexpected input. In addition to cues for incorrect format, it is helpful if the program provides a hint after a few incorrect responses. These hints should guide students and allow them to reach the solution on their own. There should be help available 'on-screen' and it should be easy to obtain. If the cues, hints and help have not led the student to a correct response, it should be provided before frustration sets in. The feedback provided should be appropriate to the program and the intended user, and be accurate. It should be supportive, corrective and immediate. Feedback should reward the correct rather than the incorrect responses, therefore negative feedback should not be more interesting than the positive.

4.2.7 - Documentation

The final section of the evaluation checklist looks at the documentation provided by the package. The presence of 'off-line' materials will enhance the use of the program by teachers who have not had much computer experience. The manual should contain directions that are correct and simple to follow. It is often helpful if the manual also contains an overview of the program, outlines the prerequisite skills, suggests classroom strategies and activities. The manual should contain a good index that makes information easy to find. The manual should be easy to read, and the amount that must be read before using the program should not be excessive. Since the program will hopefully be used by several teachers and many students, the manual should be durable enough to withstand such use. The documentation may include a student workbook with worksheets and other forms.

4.3 - SUMMARY

An evaluation checklist was developed to assist in the evaluation of the computer programs in this project. The criteria in this checklist have been discussed and the reasons for their inclusion have been outlined. The checklist was presented in the format that was used during the evaluation.

CHAPTER 5

EVALUATION OF SELECTED COMPUTER PROGRAMS TO TEACH DIFFICULT CONCEPTS IN OAC CHEMISTRY

5.1 - INTRODUCTION

During the investigations for this project, two computer programs were evaluated using the evaluation scheme established in Chapter 4. Initially, the method for the selection of these programs is presented. The programs are then discussed separately since they are very different in nature (tutorial/drill and simulation). The evaluation of each program has been divided into two sections, for general and specific evaluations. The general evaluation pertains to the aspects common to all of the lessons in the program, and a separate section is for those aspects pertaining to a specific lesson within the program.

5.2 - SELECTION OF THE COMPUTER PROGRAMS TO BE EVALUATED

Selection of the computer programs to be evaluated in this project was made from among several possible programs (Appendix C.1). The first criterion in the selection process was that the lessons within the program should "fit well into the curriculum" (Waugh, 1986) and include the difficult concepts identified in Chapter 2. The second was that they should use the teaching strategies discussed in Chapter 3.

The computer programs needed to be available in a format suitable for school and home use. Programs that were IBM-compatible seemed to be the most appropriate choice. It was also required that the programs be accompanied by written support materials, for both the teacher and the students.

The other criteria considered in the selection process were availability, cost, and country of origin of the program. Since the purchase of a program may lead to the purchase of additional programs, they should be readily available. Educational institutions are restricted in their budgets, therefore the cost of the program is a major factor in its possible purchase. Canadian educational institutions favour materials which originate in Canada, and in some instances (for example, textbooks) the materials must be Canadian.

Using these criteria, two programs were selected: Chem 1 Problem Proctor (a tutorial), and The Electric Chemistry Building (a simulation).

5.3 - EVALUATION OF CHEM 1 PROBLEM PROCTOR (GENERAL)

Once the evaluation of the six lessons of Chem 1 Problem Proctor was completed, it was found that many of the results were common to all of the lessons. This section presents these common aspects of the evaluation.

5.3.1 - Description

Chem 1 Problem Proctor (C1PP) is a set of twenty tutorial and drill lessons designed for use by students in a first-year course in General Chemistry at the college or university level. The lessons are also suitable for the chemistry courses taught at the high school level in Ontario, especially SCHOA. Students can use the programs successfully with little previous computer experience. Six C1PP lessons were evaluated in this project, and were found to be very suitable in all cases.

5.3.2 - Administrative Issues

Chem 1 Problem Proctor will run on an IBM PC or compatible. It requires a hard disk drive, a floppy disk drive, and 256K of memory. The requirement of a hard disk drive may make the programs impossible for some students to use at home. The programs are available in both 3.5-in and 5.25-in diskettes. The author of C1PP is Canadian, but the programs are distributed by Falcon Software, Inc. of Wentworth, New Hampshire. The use of a US distributor may hinder the adoption of these programs in Ontario.

5.3.3 - Subject Matter

Chem 1 Problem Proctor is accompanied by a brief Instructor's Guide which describes the "problems-oriented approach" (Lower, June 1988) (Appendix C.2 outlines this approach) and objectives of the program. The key objectives of this program are to encourage problem-solving and to promote the understanding of the principles underlying the chemistry concepts. The program accomplishes this to various degrees of success by requiring the student to make decisions, to make qualitative estimates before some of the calculations and by asking questions related to the concept but not necessarily part of the solution to the problem.

Each problem begins with a brief introduction which indicates the problem to be solved, and the concepts covered in that problem. This provides a good focus for the student, and is an excellent feature of this program. The information provided is relevant, but many inaccuracies were discovered in four of the six lessons evaluated (# 9, 16, 19, 20). The emphasis is appropriate to the problems and for university level students, but some of the problems are beyond SCHOA with respect to content and mathematics. The sequence of questions and problems is well-organised, generally increasing in difficulty, and appropriate to SCHOA. Within each lesson there are questions and problems of various levels of difficulty and challenge.

The program does not necessarily require previous knowledge of the chemistry concepts involved in the problems, but the lessons would be most effective if the students have been introduced to these concepts and have had some practice in using them. Some of the lessons in C1PP provide excellent examples of applications of the chemistry concepts. A few lessons offer ideal opportunities for applications but no examples are given.

C1PP encourages the student to make decisions/choices and to develop strategies in problem-solving. This program does not encourage exploration, and is generally better-suited to students working independently rather than cooperatively. The tutorial/drill nature of the program may lead to one partner giving the answers while the other partner only watches. If the students work independently, then each one must master the problems.

5.3.4 - Language and Grammar

Chem1 Problem Proctor is a tutorial/drill program and therefore contains more reading material than does a simulation. The reading level is appropriate and there is no evidence of any bias. The technical terms are appropriate to the subject, some are defined and of those that are not, most should be familiar to a student who has been introduced to the concepts (there is one exception, ie., "EMF" in lesson #19). Errors were discovered in the naming of such elements as O_2 as dioxygen and H_2 as dihydrogen. This may cause some confusion especially in those students who are still struggling with nomenclature.

The six lessons of C1PP that were evaluated have a common drawback in their inconsistent use of upper and lower case letters, subscripts and superscripts. This makes some of the problems so confusing that students would likely give up in frustration before completing the problem. The acceptance of upper case or lower case letters in chemical formulae is unpredictable throughout the program. Once the student has established this, then she will hopefully try lower case if upper case letters are not accepted when entered, and vice versa. The teacher could warn students of this idiosyncrasy of the program, but it is nonetheless a very frustrating feature.

The use of subscripts and superscripts is a much more serious drawback. The program evaluated does not use subscripts or superscripts (apparently the program has since been updated to allow subscripts and superscripts). The lack of subscripts makes recognition of chemical formulae confusing in some cases. The lack of superscripts is more serious in these lessons, because several problems use mathematical formulae.

While the mathematics may be quite simple, the formulae are difficult to decipher without superscripts (most of these formulae involve the square root). In some problems, this would likely be a stumbling block for most students.

Several of the concepts in the lessons use mathematical formulae, therefore two features of numerical responses (units and significant figures) were important to consider. The use of units following a numerical response is generally not required within the lessons. This is most unfortunate, especially from the point of view of a teacher who emphasizes the inclusion of units. The use of significant figures is consistent with classroom practice, with only one exception in lesson #15 (discussed separately).

5.3.5 - Surface Features

Chem 1 Problem Proctor is simple to start-up, but the insertion of the lesson disk must be done before that lesson number is requested and this is not made clear in the instructions. The user can control the rate at which information is presented, but the sequence and the amount is determined by the program. This should not present much of an inconvenience, since the user can spend as long with any screen as she wishes. A problem can be interrupted at any point but cannot be resumed at that point later on; the problem has to be repeated from the beginning.

Completion of a problem is indicated, but not with reliability. It was found that problems that were completed were not labelled as such, and that problems that were only read and then escaped from were labelled as being completed (and with a score of 100%!). If the lesson is interrupted and resumed at a later time there is no record kept of the problems completed during the previous session. Success is indicated by a score, but as has just been suggested, this score is not always accurate. These aspects of the program are adequate, as long as the teacher is not interested in recording the students' progress or scores. Since the program is designed as a tutorial/drill, score-keeping is not necessarily desirable.

The method of input is with the keyboard, therefore some typing skills would be helpful. The display is text, with some variation in colour to add interest. Two of the lessons include problems that have some graphics - diagrams and graphs. These graphics are used appropriately but could be improved in both cases to make them more effective.

When the program poses a question, the previous question and its answer appear above the new question. This can cause confusion since students tend to read from the top down, and the first question they encounter is the one they have just answered. Once the student catches on to this method there should not be trouble because this practice is consistent throughout the program.

5.3.6 - Instruction and Motivation

The menu for this program has clear instructions on how to choose a problem, how to get help, how to quit and how to return to the main menu later on. A very good feature of this menu is the ability to preview the problems before making a selection. The student can more easily choose a problem that will provide the practice she seeks.

Once a problem has been selected, the questions within that problem make it very clear when and how to respond. It is possible to correct a response and to bypass a question. It is not possible to go back and review previous questions, which would be helpful at some points in the lessons. If a student wishes to bypass an entire problem, each question within the problem has to be bypassed individually. (Escaping from one question automatically brings up the next question within the same problem.)

Chem1 Problem Proctor is relatively lenient in its acceptance of responses. The program is inconsistent in its acceptance of chemical formulae, sometimes requiring upper case letters and requiring lower case letters at other times. This problem can be tolerated but it does not reinforce correct nomenclature.

This program does not seem to tolerate unexpected input. However, if the question expects a numerical answer and gets a word or letter, there is a polite response asking for a numerical answer. The same is true if a number is entered when a word is expected, or if units are forgotten when they are required (this does not occur often). In judging numerical responses, the program requires that the response is fairly close to the correct answer. This is a good feature since it forces the student to calculate the answer, not simply to guess.

In the tutorial problems, hints are generally provided after two to four (depending on the lesson) unsuccessful attempts at a question, and immediately after the first unsuccessful attempt at a subsequent question. It would be preferable to allow the student a second chance at a response, especially if the first attempt is incorrect only due to a typing error. Some of the lessons (#18 and 20, in particular) do not provide hints. There are no hints provided for any multiple choice questions, which occur mainly in the drill problems. This is unfortunate since it encourages the student to guess on multiple choice questions.

After four incorrect responses to the same question, the program automatically switches to the 'help' sequence which is an excellent step-by-step determination of the answer. The 'help' consists of a series of questions which show the student how to solve the problem. The questions asked in the 'help' are the same questions that the student needs to ask herself in order to solve the problem. A disappointing aspect of the program is that if a student has had four incorrect responses and activated the 'help', the 'help' is given after the first incorrect response to a subsequent question. It would be better to allow at least two attempts at an answer, as has been mentioned above. The student can access help at any point in the questions of a tutorial problem, and the help provided in most tutorial problems is very good. This is not the case for multiple choice questions or where a numerical response is required. When a student requests help for a multiple choice question, the student is told to guess. If a student is conscientious enough not to guess at the answer in the first place, it would be very frustrating to be told to guess. If a numerical response is incorrect, the student is only told whether her response is too large or too small (and not always accurately). It is possible that if units were required, the program could recognise where the student had made her error and provide some real help.

Chem1 Problem Proctor is a tutorial/drill program and the hints and help provided in the two parts of the program are vastly different. As outlined above, the hints and help provided in the tutorials are very good and follow good teaching technique. In the drill parts of the program there are no hints given, and the only response to an incorrect entry is to 'pick another answer'. (The questions within the drill are multiple-choice.) If the student asks for help, the reply is "You don't need help for a multiple-choice question; at worst, just guess!" These responses can be very disheartening to the student trying to understand how to find the correct answer.

The feedback provided in the tutorial problems is immediate and corrective, if the entry is incorrect. The feedback received is either a "Correct!", followed by the answer or a "Wrong!", followed by a hint. The program supplies a series of hints before giving the answer, which enhances the teaching aspects of this program. As the student progresses through a question, the feedback is encouraging and displays good teaching technique. Many of the messages are prefaced with "Please" which also adds to the encouragement. Some problems provide a summary or review of the results within the problem, and this is a very helpful feature. One major drawback of the feedback is its inaccuracy in some of the problems, and these cases will be discussed individually.

5.3.7 - Documentation

Chem1 Problem Proctor is accompanied by a student problem book which contains all of the problems in the program. This problem book has the appearance of any other collection of problems. One benefit of providing such a book would be if students wanted to practice the problems at home or without the help of the tutorial. It would be one way for the student to ascertain if she understands the problem.

The instructor's guide explains the 'problems-oriented approach' followed in the program and the objectives of the program. It gives an overview of the program and suggests how the program can be integrated into a chemistry course. The instructor's guide is mainly philosophical and since the program is simple to use, printed directions are not really necessary. However, for the teacher or student who is hesitant about computers, a written manual can be very helpful.

5.4 - EVALUATION OF CHEM 1 PROBLEM PROCTOR (SPECIFIC)

The previous section presented those aspects of the evaluation of Chem 1 Problem Proctor that were common to all of the lessons evaluated in this project. These lessons were selected for evaluation because they teach the difficult concepts identified in Chapter 2. This section presents those aspects of the evaluation that relate to specific lessons.

5.4.1 - C1PP #16: Solubility Equilibria

Chem1 Problem Proctor #16 (Solubility Equilibria) is a set of eight problems. The first three problems are calculations using K_{sp} and pH, that are so straightforward they could be classified as a drill. The remaining five problems are more lengthy calculations and are tutorial in nature. The problems within this lesson provide the student with the opportunity to apply most of the concepts of solubility equilibria.

This lesson on solubility equilibria would be best if it followed the study of the concepts of that topic. The first problem calculates the K_{sp} given the solubility, while the second calculates the solubility given the K_{sp}. The second problem also finds the solubility of the substance in a solution containing a common ion, in addition to finding the solubility in pure water. The third problem calculates the pH required for precipitation to occur, and relates the result to 'real-life'. All three of these problems are brief, well organized and a very good review of the basics of solubility equilibria. The student will likely develop confidence with which to approach the more difficult problems that follow.

The fourth, fifth, and sixth problems apply the concepts of common ions - one to precipitation, another to solubility. The sixth problem demonstrates an application of these concepts by examining the solubility of limestone in water containing dissolved carbon dioxide. The problem first finds the K_{eq} for the reaction by summing three intermediate steps, and then calculates the solubility of the limestone. The concepts of common ions are difficult for SCHOA students and these problems offer a good review of common ion calculations.

The seventh problem examines the precipitation of a substance by controlling the pH. This would lend itself perfectly to a practical application, but there is no mention of any application. The problem is also confusing at certain points. The last problem finds the solubility of a substance in the presence of a complexing agent. Again, this would lend itself to a practical application, but instead the problem is very mathematical (more than is necessary).

Chem1 Problem Proctor is generally relatively lenient in its acceptance of responses. Exceptions to this occur in the acceptance of chemical formulae (upper case and lower case letters) and the absence of subscripts and superscripts. These problems occur throughout Chem1 Problem Proctor. In this lesson there were instances when the program did not accept an answer the first time, but if the same answer was entered a second time it was accepted. This would be frustrating for the students. The program also accepted the answer 'x^2' as if it were '2x', and this is a significant flaw since the student may not understand where she made the error (or may not even realize that an error was made).

The instruction provided in all of the problems on solubility equilibria is very good and several of the problems give a 'real-life' application. The hints and help are also very good, consistent with the other lessons in Chem1 Problem Proctor. The only exception occurs in the first problem where the help gives the answer and then responds with "OK, perfect!" when the answer is entered. This response is inappropriate since the answer was given, and it would have been better to give a hint.

The feedback is provided immediately and is generally very good. Most of the feedback is corrective, encouraging and accurate. In the fourth problem there is a big jump in the feedback. The student is asked to calculate the concentration of silver ions in the presence of chloride ions, and the feedback goes on to calculate the concentration in the presence of chromate ions and the amount of precipitates formed. This feedback will take the student by surprise, and it would be much better if the student were allowed to follow through with the calculations herself. In the sixth problem an incorrect chemical equation is presented initially, but it is corrected on the following screen. This will probably not cause too much confusion. In the seventh problem mention is made of a third reaction which never actually appears on the screen and it is not clear where this reaction is used. In the last problem (which is overly mathematical) the message at the bottom of a screen filled with mathematical equations is that "...it is apparent that ...", which is not apparent at all. However, despite problems with some of the feedback, this lesson on solubility equilibria is very good.

5.4.2 - C1PP #9: Oxidation-Reduction

Chem1 Problem Proctor #9 (Oxidation-Reduction) is a set of three tutorial/drill problems. The first problem is a tutorial in determining oxidation numbers. The second problem is a drill in identifying the oxidizing and reducing agents. The third problem is a tutorial in balancing redox equations. These are three skills which a student in OAC Chemistry must develop during the study of oxidation-reduction.

The information provided in Chem1 Problem Proctor #9 is relevant, but many inaccuracies were discovered especially in the problem on balancing equations. Selection of the questions within a problem is random in the first two cases.

5.4.3 - C1PP #19: Electrochemistry

Chem1 Problem Proctor #19 (Electrochemistry) is a set of eight tutorial problems. Several of these problems are practical applications of the concepts of electrochemistry. For example, one problem determines the mass of copper deposited when a solution of copper(II) sulfate is electrolysed for one hour. Other problems use a fuel cell or an electrochemical cell as their application. It is very important for students to be able to apply their knowledge, and this lesson provides an opportunity for students to apply the concepts of electrochemistry to practical problems.

The information provided was relevant, but many inconsistencies were found which could be quite confusing to students. Since the eight problems within this lesson are different one from the other in style and quality, they will be discussed individually.

The first problem (electroplating of copper) follows a very good sequence of questions leading the student through the steps required for its solution. At the end of the problem, a review of the steps is given. The second problem (fuel cell) provides a diagram of a fuel cell and an excellent explanation of fuel cells. The calculations that are part of this problem rely on the student having completed the first problem. A good summary of the steps followed is given at the end and provides a review of the first two problems.

The third problem (electrolysis) assumes prior knowledge of the use of reduction potentials to predict reactions, which is a reasonable assumption. There are several inconsistencies which may be confusing, especially to the weaker students. For instance, the problem is working with nickel sulfate and a subsequent question asks about sodium sulfate. Another question states that the solution has a gold electrode but once work has begun on the question the electrode is inert. These inconsistencies detract from the effectiveness of this third problem, and it does not seem to be of the same quality as the first two problems.

The remaining five problems all involve calculations of the Gibb's Energy and use of the Nernst equation. These concepts are not required in SCHOA, but are occasionally included. The fourth problem (prediction of redox reactions) asks the student to predict the spontaneity of four redox reactions. Different questions are asked about each reaction which adds interest and makes each question appear new. The seventh problem (equilibrium compositions) provides a good application of equilibrium in a redox reaction, and illustrates why a fuel cell 'dies'. Both of these problems are worthwhile, and although they contain the Nernst equation the problems are instructional even if this equation is ignored.

The emphasis of the problems within this lesson are appropriate to the level for which they are intended, but those problems that emphasize the Nernst equation are not really appropriate for SCHOA. As has been indicated, some problems can be done by overlooking this equation and still be very useful. The sequence of questions and prompts is very appropriate, and some of the problems demonstrate good teaching technique.

5.4.4 - C1PP #15: Acid-Base Mixtures

Chem1 Problem Proctor #15 (Acid-Base Mixtures) is a set of eight tutorial problems. The first four are excellent buffer problems and the remaining four problems deal with acid equilibrium and K_a. Within the buffer problems there are examples of the action of a buffer solution, the carbonate system in blood, the preparation of a buffer solution and the nature of an acid-base indicator (Lower, July 1988). These problems provide the student with an opportunity to apply her knowledge of buffers. The acid problems are adequate, but they encourage the student to use a very tedious (and questionable) method in her solution of quadratic equations. Since the topic identified as difficult by SCHOA students was buffers, it would be recommended to use only the first four problems of this lesson.

This lesson would be most effectively used after the students have studied buffers and indicators. The first problem calculates the initial pH of an acetic acid buffer solution, and then calculates the pH upon addition of strong base or strong acid. The fourth problem begins with the preparation of a cyanide buffer solution, and then calculates the pH after addition of strong base or strong acid. The results are displayed in a table at the end of this problem, providing a very good summary. The second problem discusses the carbonate buffer system in blood, an excellent example of the importance of buffers. The third problem determines the pH range of an acid-base indicator, which would be extremely appropriate after a titration experiment.

5.4.5 - C1PP #20: Chemical Kinetics

Chem1 Problem Proctor #20 (Chemical Kinetics) is a set of six tutorial problems. The first problem determines the rate law and rate constant, given experimental data. The second problem calculates the reaction order by inspection and graphically. The third and fourth problems involve the concept of half-time, which is beyond the SCHOA curriculum. The fifth problem determines if a proposed mechanism is consistent with the rate law, and the sixth problem looks at the effect of temperature and a catalyst on the rates of a reaction.

The information provided is relevant, but an SCHOA student would require additional information in order to solve many of the problems within this lesson. The emphasis of most of the lesson is not appropriate at the SCHOA level, although it would be at the college level (for which it was designed). The sequence followed by most of the problems is appropriate, but the mathematics would be difficult to follow for an SCHOA student. The problems within this lesson are of the same level of difficulty (quite difficult), and would be appropriate only for those students who understand the concepts of chemical kinetics and wish to challenge themselves. This is very disappointing since many students have trouble understanding rates of reaction and reaction mechanisms, and this lesson does not provide them with any assistance.

The first problem asks the student to determine a rate law and rate constant given a set of experimental data. This is a very good problem, and provides good instruction. This is the most useful problem for SCHOA, and is worthwhile trying even if the rest of the lesson is not used. The second problem requires the student to look at a set of experimental data and to estimate the reaction order. This is a good exercise in estimating, a process often overlooked by most students. The problem then continues to explain how to solve this same question graphically, which is accurate but an SCHOA student may not be able to understand the mathematics. The third and fourth problems both involve mathematics that are likely beyond the SCHOA level, but could be attempted by students looking for a challenge. The fifth problem has the potential to be useful but it contains a major flaw - the program will not accept the correct answers at a certain point and the problem can only be escaped from. The last problem examines the effect of temperature and a catalyst on the activation energies and the rates of the forward and reverse reactions. This problem gives only one example of an exothermic reaction; a second example with an endothermic reaction would be helpful.

This lesson requires previous knowledge of chemical kinetics and is most suitable to students who understand these concepts very well, with the exception of the first and last problems. Problem Proctor encourages the student to make decisions/choices and to develop strategies in problem-solving. This program does not encourage exploration but different from the first two lessons evaluated, this lesson would probably be most effective if the students worked cooperatively. In this way the partners can help each other and learn from each other (and share any frustrations with the problems).

5.4.6 - C1PP #18: Thermodynamics of Equilibrium

Chem1 Problem Proctor #18 (Thermodynamics of Equilibrium) is a set of seven tutorial and drill problems dealing with the second law, free energy and equilibrium. The first two problems are both good examples on the concept of entropy. The next three problems are applications of thermodynamic properties such as enthalpy, entropy and free energy. The sixth problem demonstrates how the equilibrium constant for the synthesis of sucrose can be determined by adding the intermediate steps. The last problem is not appropriate to SCHOA, in content or in the mathematics involved.

This lesson would be most effective after students have been exposed to the thermodynamics properties used in the problems. These problems could serve as a very good review of entropy and free energy, and most of the problems demonstrate how the thermodynamic properties are related to each other.

The first problem is a drill asking the student to estimate the entropy change associated with six different chemical reactions. The six examples provide a good overview of the possible combinations of reactants and products, and how these can used to predict the entropy change. This problem begins with an introduction on entropy and randomness, and states that it is important for chemistry students to develop 'chemical intuition', which is very true.

The second problem shows how the entropy changes of the system, surroundings and universe are related, and shows how temperature effects these values. The third problem determines the equilibrium composition of system. The fourth problem calculates the temperature at which the system is at equilibrium. The fifth problem derives five properties of bromine from thermodynamic data. The sixth problem calculates the equilibrium constant for the synthesis of sucrose by using the thermodynamic data of its intermediate steps. All of the problems in this lesson are applications of thermodynamics and would be a very good review/reinforcer of these concepts.

5.5 - EVALUATION OF THE ELECTRIC CHEMISTRY BUILDING (GENERAL)

Once the evaluation of the two phases of The Electric Chemistry Building was completed, it was found that many of the results were common to both phases. This section presents these common aspects of the evaluation.

5.5.1 - Description

The Electric Chemistry Building (ECB) is a simulation of a building made up of three chemistry laboratories - a physical laboratory, an inorganic laboratory and an organic laboratory. Each laboratory contains different chemicals and equipment, the ones that are required to carry out the experiments within that laboratory. The program would be suitable for use at the high school level (both SCH3A and SCHOA), and at the university level. The student does not require previous experience on the computer, since the simulations can be performed using only the arrow keys and the return key. This project examined two of the laboratories, since they dealt with topics that had been identified as difficult. The physical laboratory has the facility to study redox reactions and the inorganic laboratory has the facility to study solubility equilibrium. A computer simulation was appropriate in both of these applications, but as will be discussed later, should not replace the laboratory activities associated with these topics.

5.5.2 - Administrative Issues

The Electric Chemistry Building will run on an IBM PC or compatible. The program requires two disk drives (either a combination of hard and floppy drive or two floppy drives) and 256K of memory. The requirement for two disk drives may make it impossible for some students to work at home. The program is available in 5.25-in and 3.5-in diskettes. The authors of the program are Canadian and the source is Snowbird Software,Inc. in Hamilton, Ontario. Since the authors and the source are Canadian, The Electric Chemistry Building should be acceptable to schools in Ontario.

5.5.3 - Subject Matter

The teacher's notes accompanying The Electric Chemistry Building give both a set of general and a set of detailed objectives. The general objectives applicable to redox reactions and to solubility equilibrium are to help students: a) learn to solve problems concerning the chemical reactions through the design of systematic investigations and by careful observations, b) become familiar with the function of common pieces of apparatus and the kinds of questions each piece can answer, and c) develop enthusiasm for exploring the world of chemistry (Snowbird Software, 1988/89).

The detailed objectives for redox reactions and solubility equilibrium are divided into attitude, skills and knowledge, consistent with the objectives in the Ministry of Education guidelines for SCHOA. These objectives provide a good indication of the possible applications of this program.

The ECB laboratory is a simulation of a chemistry laboratory and is therefore not concerned with presenting information, but rather permits the student to discover things for herself. The emphasis of the program is on experimentation leading to an improved understanding of the chemistry concepts. The simulation encourages the student to explore by providing chemicals unavailable in a high school laboratory and by providing a very 'safe' environment. Use of the simulation would be most appropriate by students who have experienced a 'real' experiment within the topic explored, and are therefore familiar with the equipment required and how to set up an experiment.

The degree of user interaction possible with this simulation is very great. The student can choose to use equipment and chemicals in many combinations, restricted only by what equipment and chemicals are available. Depending on the concept the student is investigating, the program allows the student to develop strategies, encourages creativity and exploration. The program is suitable for a student to work independently or in cooperation with other students.

5.5.4 - Language and Grammar

This simulation uses many technical terms and formulae, but only those that are necessary to the program. All of the terms and formulae used should be familiar to students who have been introduced to the concepts used in the simulation. The terms and formulae are used appropriately and should help the student develop the chemistry concepts.

5.5.5 - Surface Features

The program is simple to start-up, once it has been installed on the hard disk by the teacher and this installation is also simple. The instructions are clear and appropriate to the room occupied by the student. Most of the aspects of user control deal with the information presented, and are therefore not applicable to this program which does not present a lot of information. The aspect of user mobility through the program is applicable and the student has freedom to move through the 'building' at any time.

An experiment can be interrupted, saved, and resumed later on. Accidental interruption would be difficult since the exit from the 'building' is clearly an exit. However, if the student forgets to save her work or if the computer is accidentally turned off, the work will be lost. The student can monitor the contents of the reaction vessel(s) at any point during the experiment and completion of the experiment is indicated. The student can save any portion of her work on a floppy disk or the hard disk.

The method of input for this program is with a keyboard, using primarily the arrow keys to 'move' through the building and to highlight choices, and the enter key to pick up equipment, etc and to make choices. Students with limited computer experience should find this program easy to use.

Animation and graphics are especially important in a simulation, but they should be relevant and the level of detail should not distract the student. In the Electric Chemistry Building the experiments are the emphasis of the program. The animation in this program is consistent with the emphasis on experiments - the laboratory equipment looks realistic, and the chemicals are in containers which indicate if they are solid, liquid or gas. Events occurring during reactions are simulated (ie., bubbles for a gas formed in solution, solid precipitate deposited at the bottom of the flask, an electrode that decreases/increases in mass). There is a high level of detail in the apparatus and reactions which enables the program to truly simulate the experiments. The level of detail in the representation of the 'experimenter' and the rooms is much simpler, and does not distract the student. Colour is used in the simulation, most importantly to indicate if the chemical is acid, base or neutral. The displays are not cluttered; in fact, if the student picks up too much equipment and tries to deposit it on the laboratory bench, the program gives the message that the equipment selected "won't work" and to "try again". There are no audio effects in this simulation. Audio effects can often be annoying, but in a laboratory simulation it would be nice if there were some sound produced when the reaction on the screen normally produces sound (eg., explodes).

5.5.6 - Instruction and Motivation

Throughout this program, the menus make it very clear when and how to make choices. It is clear how to get help, how to return to a menu, how to return to a previous screen, or how to move on in the simulation. This simulation asks few questions, and they are clear. Help is available in every room of the building, and is easily accessible, since the same key is used throughout and there is a message at the bottom of many screens reminding the student how to get help. When help is requested, the help that is received depends on the room from which it was requested. This is very good because the student is only offered help within the room he experienced difficulty rather than being overwhelmed by the amount of help that is available throughout the program. The student can choose which aspect of the room she would like assistance with, and the help that is provided is clear, complete and easy to follow. The student can access help as often as necessary to accomplish the task with which she had difficulty.

The format of feedback provided in this simulation varies according to the cue. While a reaction is taking place the feedback is primarily visual, showing the student if a gas is being produced, a precipitate is being is produced, etc. There is also verbal feedback in the form of half reactions and a balanced redox equation. There is numeric feedback in that the voltage produced is shown for an electrochemical cell and the student can look at the contents of the reaction vessels at any point in the experiment. (This aspect of the simulation is wonderful from an instructional viewpoint, but not very realistic.) Little corrective feedback is appropriate to this program, but in situations where it is necessary such feedback is provided.

5.5.7 - Documentation

Teacher's notes are provided with each phase of The Electric Building. These notes give clear and complete directions on how to run the program. Directions for sample laboratory experiments are listed. A summary of the operations possible in each room is given for handy reference. There are also some detailed experiments provided that a teacher could give to her students. The notes make suggestions for at least eighteen other possible applications of the program. These notes also contain a complete list of objectives - in general for The Electric Building, and specifically for each topic covered in the physical laboratory. The manual is clearly written and gives the procedures in steps that should be easy to follow by people with and without computer experience. Quite a bit of the information given in the teacher's notes is also given in the on-screen help, but for a person with limited computer experience having instructions written on paper is less intimidating than having everything on the computer.

5.6 - EVALUATION OF THE ELECTRIC CHEMISTRY BUILDING (SPECIFIC)

The previous section presented those aspects of the evaluation of The Electric Chemistry Building that were common to the two phases evaluated in this project. This section presents those aspects of the evaluation that are specific to one phase only.

5.6.1 - ECB - Physical

The physical laboratory within The Electric Chemistry Building contains the equipment required to study various aspects of redox reactions. There is the equipment to set up an electrochemical cell, a redox titration and an electrolysis. These allow the student to investigate redox reactions and to review material learned in class.

5.6.2 - ECB - Inorganic

The inorganic laboratory within The Electric Building contains the equipment to study various aspects of solubility equilibria, as well as many other types of reactions. The equipment consists of a flask which can be heated or cooled. The student can investigate the solubility of many compounds, predict the result of mixing pairs of solutions and then test her predictions (Snowbird Software, 1987). This will allow the student to discover some of the concepts of solubility for herself.

5.7 - SUMMARY

The evaluations of the two computer programs investigated in this project were presented in this chapter. The results of these evaluations form the major component of the project.

This chapter discussed the method for selecting the computer programs to be evaluated and the subsequent evaluation of those programs. The results of the evaluation were presented in detail, but these results are not sufficient to arrive at a conclusion whether these programs can enhance the teaching of selected difficult concepts in

SCHOA. Recommendations regarding the computer programs evaluated will be presented in the next chapter, and these recommendations combined with the evaluations will permit conclusions to be formulated.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 - INTRODUCTION

This project investigates whether the use of computers can enhance the teaching of selected difficult concepts of SCHOA in an attempt to make them easier to understand. Arons (1984) states that "Much of the weak performance in science courses stems from failure to grasp concepts and lines of reasoning at crucial early points." Use of computers may help students to understand the difficult concepts and therefore improve the students' performance in SCHOA.

Conclusions and recommendations regarding the use of computers in SCHOA are made in this chapter. While making these conclusions and recommendations it would be prudent to remember that, "we must not assume that education is automatically improved by using computers" (Bork, 1985). The conclusions and recommendations are based on the results of the evaluation of the programs, Chem1 Problem Proctor and Electric Chemistry Building. It is assumed that these programs would be used as a complement to the regular classroom instruction, not as a replacement. Many researchers have reported gains in student achievement when computers are used in conjunction with traditional classroom instruction (Shaw and Okey, 1985).

Students and teachers of SCHOA were consulted in the identification of the difficult concepts of SCHOA. Within the scope of this project, it was impossible to involve students and teachers of SCHOA in the evaluation of the computer programs. Therefore the following conclusions and recommendations are based solely on my evaluation of the programs. They should be reviewed once students have been involved in the evaluation since, "success of a program is in the minds of students, not in the mind of the teacher" (Fugler, 1989).

6.2 - C1PP, TUTORIALS AND DRILLS

Chem1 Problem Proctor (C1PP) is a set of twenty tutorial and drill lessons. The conclusions and recommendations in this section are for C1PP specifically, and for tutorials and drills in general.

6.2.1 - Conclusions

#1 : Tutorials and drills can be used for review, reinforcement or remediation.

Tutorials and drills using a computer is one way of providing students with review, reinforcement or remediation. The presence of these three aspects of learning is important in any course, and is especially important in SCHOA where the concepts build upon one another. Use of computer tutorials and drills offers students a different style of teaching concepts that have already been presented by their teacher.

C1PP tutorials use a question and answer teaching style, leading students from one idea to the next. These tutorials are likely to be most effective in reinforcement or remediation where the student is prepared to spend the time necessary to work through the tutorial. C1PP drills use a multiple choice style which enables the drills to be done quickly. This drill format is good for review where the student can easily determine whether the concept has been understood, but it may not be as effective for reinforcement or remediation which require more thought.

#2 : Tutorials and drills can be used to provide one-to-one dialogue.

"Many students can grasp concepts only if they receive help in the form of a one-to-one dialogue. Computer tutorials provide this" (Arons, 1984). Students benefit from individual instruction where they must think through the questions and find the answers on their own, but it is very difficult for a teacher to provide each student with individual instruction. In a large class it is easy for some students to rely on others to answer the questions posed by the teacher, but those students will not understand the concept as well as if they had answered the questions themselves. Computer tutorials require students to think for themselves.

Computer tutorials and drills can provide instruction anywhere and anytime, unlike a classroom teacher (Lagowski, 1989). As long as students have access to a computer, they can work with the programs at school or at home, whenever they like. This is a significant advantage since many students have part-time jobs or other extra-curricular commitments which prohibit them from seeking help from teachers after school. However this may be an unfair advantage for those students who have ready access to a computer.

C1PP tutorials provide a very good one-to-one dialogue, leading the student from one idea to the next. The questions posed by the tutorial require the student to think about the concepts involved and help the student make decisions. The questions follow a logical progression which should help the student understand the steps in solving the problem. C1PP is an easy program to use, therefore students would be able to use it at home and in the absence of their teacher.

#3 : Tutorials can be used to develop problem-solving skills.

Many tutorial programs, including C1PP, use a question and answer format. These questions lead the student through the steps required in solving the problem. By following the steps of the tutorial, the student should be developing problem-solving skills which can be applied to other problems, not just those on the program.

"The process of acquiring problem-solving skills is facilitated by active reinforced practice" (Rivers and Vockell, 1987). C1PP tutorial lessons provide 'active reinforced practice'; 'active' because the student must think about the question and find an answer, 'reinforced' because the feedback is generally good and supportive, 'practice' due to the tutorial nature of the program. Therefore, C1PP assists in the development of problem-solving skills.

#4 : Drills can be used to diagnose conceptual problems.

"Computer drills can be used to diagnose conceptual problems that the student may be having" (Trollip and Alessi, 1988). This facility would be of tremendous value to both students and teachers. C1PP does not provide any diagnosis, and this is one feature that should be considered for addition to future versions of the program.

6.2.2 - Recommendations

#1 : C1PP provides good applications, but more applications would be helpful.

The curriculum guidelines from the Ministry of Education emphasize practical applications of the concepts learned within science courses. Practical applications should add relevance and help the student to understand concepts by applying what has been learned. C1PP provides some good applications within its tutorial problems, especially in lessons #15, 16, 18, and 19. Although the applications in C1PP are good, several opportunities for applications are overlooked and it would be recommended to include them. For example, there are two precipitation problems in C1PP that would be improved if they included a practical application.

#2 : C1PP should improve the feedback on its multiple choice questions.

C1PP provides generally very good feedback in its tutorial problems, but the feedback provided in its drill questions (multiple-choice format) is very poor. If a student requests help during a drill question, the student is told "You don't need help for a multiple-choice question; at worst, just guess!". Since the student was conscientious enough not to guess, it is very frustrating to be told to guess. It would be more effective if the drill provided a hint so that the student could attempt to solve the problem and not just guess at the answer.

#3 : C1PP should improve its use of subscripts, superscripts, upper and lower case letters, and correct errors in the program.

Chemistry programs require the facility for subscripts, superscripts, upper and lower case letters. Without this facility, balanced chemical equations and mathematical equations become unnecessarily difficult (Disney and Disney, 1983). C1PP does not have the facility for subscripts or superscripts, which makes chemical formulae and mathematical equations difficult to recognise and use. This problem has apparently been corrected in a later version of the program.

The use of upper and lower case letters is unpredictable and therefore can be frustrating for students. In some answers upper case letters are required, in others lower case letters are required. However it is never clear which type of letters are acceptable, and the student may be told that an answer is incorrect only because the wrong letters were used. An additional frustration to this problem is that the student must often give a chemical formula incorrectly (ie., all in lower case) in order to be able to answer the question. This is certainly not reinforcing correct chemical nomenclature, which is most unfortunate.

Many errors and inconsistencies were discovered throughout the lessons in C1PP, as detailed in Chapter 5. Some of these errors and inconsistencies can be compensated by the teacher, but may be a stumbling block for those students working outside the classroom. A few of the errors make the problem impossible to solve even with the help of a teacher. All of these errors and inconsistencies should be eliminated from the program.

#4 : C1PP should either improve its method of scoring or eliminate scoring.

Students often dislike having their work on a computer scored by the computer. "Students dislike being graded by the computer because there is no chance for partial credit or negotiation" (Reed and Judkins, 1986). Especially at the OAC level students are very concerned about their grades and may feel uncomfortable using a computer program that is scoring their work.

C1PP tutorials and drills provide a numerical score at the completion of each problem. This score is not always accurate as was discussed in Chapter 5, section 5.3.5. For example, if a student does nothing but read the question and escape from the problem, she receives a perfect score. Even if the teacher instructs her students to ignore the scoring, its presence may hinder exploration and deter some students from making full use of the program. It was felt that C1PP would improve its effectiveness if scoring was eliminated.

6.3 - ECB AND SIMULATIONS

The Electric Chemistry Building is a simulation of a chemistry laboratory. Therefore the conclusions and recommendations in this section will be for ECB specifically and simulations in general.

6.3.1 - Conclusions

#1 : Simulations can be used to discover new information.

Simulations provide a completely safe laboratory environment, therefore students can perform many experiments and hence discover new information. Since the simulation performs experiments quickly, students can repeat the same experiment several times, changing the variables as they wish. "Students are able to test many more hypotheses within a designated time, able to run an experiment several times and learn from repeated experiments" (Vockell, 1987).

The feature of a completely safe laboratory allows students freedom to experiment, although it does not represent reality. ECB is a laboratory simulation that attempts to represent reality, while being completely safe. For example, ECB depicts if a gas or a precipitate is produced, and if a colour change or an explosion occurs. Use of a simulation is one of the few opportunities students may receive in high school where they can create and perform their own experiments, and, as stated by Gerhold (1985), "Simulations allow students to make mistakes and find their own way". The benefits of using a simulation outweigh its lack of realism, however, and as will be discussed in a later recommendation, students should experience both simulations and laboratory experiments.

#2 : Simulations can be used for further exploration of concepts.

Simulations can be used not only for the discovery of new information as discussed in Recommendation #1, but they can also be used for further exploration of previously-learned concepts. "Simulations give students more flexibility in how they explore the simulated environment" (Fugler, 1989).

Students can extend a laboratory experiment by repeating the experiment using a simulation and changing the variables in different ways, or by creating their own data (Rivers and Vockell, 1987). Students can repeat the same experiment as performed in the laboratory and then explore the effect on the experiment when they make changes to the variables or procedure. ECB has an excellent feature allowing students to examine the contents of the reaction vessel. With this information students can easily modify the variables or experimental conditions, and make further explorations.

#3 : Simulations can be used to provide students with experiences that may be otherwise difficult or impossible to obtain.

Many researchers (for example, Bork, 1981; Kahn, 1985) believe that computer-simulated laboratories allow students to perform experiments that may otherwise be impossible in a high school laboratory. Such experiments may be impossible due to potential hazards, cost, and limited time (Smith, 1984).

As the list of hazardous chemicals that are prohibited from high school use continues to grow, teachers are searching for experiments that are interesting, relevant and use non-hazardous chemicals. In cases where an appropriate laboratory experiment has not been developed, a simulation allows students to perform the experiment. Since ECB closely resembles a laboratory, students gain some laboratory skills (knowing what materials are required, collecting the equipment and chemicals, and controlling variables) as well as benefit by participating actively in the experiment.

#4 : Simulations can be used for review.

"Simulations provide students with the opportunity for active reinforced practice" (Rivers and Vockell, 1987). Students can apply concepts learned in the classroom through the use of a simulation. They can use the simulation to repeat problems solved in class and to try solving other similar problems. Simulations provide active practice since the student can be creative in the problems explored and the student is involved in decision-making.

"Simulations provide an opportunity to consolidate learning" (Collis, 1988). An important aspect of learning a new concept is to understand its relationship to other concepts and how they are interdependent. Simulations often require the student to apply several concepts in one problem or experiment, and therefore those concepts are no longer viewed as being independent.

Computer simulations such as ECB allow students to review laboratory experiments done earlier in the semester. This would be beneficial, especially in preparation for a test or exam. ECB could also be used to review material other than experiments, and since this simulation uses a different teaching style than a classroom teacher it would provide an effective review, requiring students to look at the same material from a different perspective.

Computer simulations could be an effective way to review concepts learned in the prerequisite course, SCH3A. Students of SCHOA are required to review the concept of solubility and to remember the solubility of compounds as developed in SCH3A. An experiment could be set up using ECB so that students would develop the solubility table by testing various combinations of compounds and water. Reviewing the solubility table in this manner would enable students to remember the table much more easily since their review was active rather than passive.

The Electric Chemistry Building contains a library as one of its rooms. The library has information on the elements and compounds in the chemical storerooms of the building. This feature would be a quick way for students to review the properties of those elements and compounds.

#5 : Simulations can be used to develop problem-solving skills.

Computer simulations can be used to develop problem-solving skills since they require students to make many decisions. "Successful simulations involve students in decisions about strategy, choice of materials, and organization" (Lagowski, 1989). ECB is an example of a successful simulation, requiring students to develop their own strategy, obtain the materials, prepare the necessary solutions, set up and perform the experiment, and draw their own conclusions. Computer simulations also allow students to work more efficiently, therefore allowing them to solve more problems and increase their problem-solving skills (Rivers and Vockell, 1987).

6.3.2 - Recommendations

#1 : Simulations should not replace laboratory experiments, but rather they should enhance each other.

Computer simulations should be used when their advantages will be felt, not just as a substitute for experiments (Kahn, 1985). Both simulations and experiments have their advantages and there are situations where one is more suitable than the other, but many researchers (including this author) believe that simulations should not replace laboratory experiments.

Practical laboratory experiments are a necessary part of any chemistry course, providing students with opportunities to physically set up and perform the experiments. Students need to have 'hands-on' experience and to master certain laboratory techniques and procedures, especially if they wish to pursue chemistry beyond high school (which is a reasonable assumption to make of students in SCHOA).

Although laboratory experiments should not be eliminated, "simulations can augment and extend laboratory experiences" (Lagowski, 1989). Simulations can be used for experimenting with chemicals and equipment that are inaccessible due to restrictions of time, cost or safety. Simulations can also be used after a laboratory experiment to provide additional practice for students (Arons, 1984). Since simulations use a different teaching style than classroom teachers, "students having trouble mastering certain science concepts might benefit from instruction using both computer simulations and laboratory experiments" (Shaw and Okey, 1985).

As part of the requirements of a course taken during this author's graduate work, a study was conducted to examine the effectiveness of instruction using a computer simulation and a laboratory experiment, separately and in combination. The simulation used in this study was ECB, and it was found that the combination of a simulation and a practical laboratory experiment provided the most effective instruction.

#2 : ECB should add more chemicals to its storerooms, provide more equipment, and allow more flexibility with the equipment.

Computer simulations permit students to experiment with chemicals and other materials that are otherwise impossible to obtain in a high school laboratory. Therefore it is necessary for a simulation to provide a wide range of chemicals and materials. Although ECB contains many hazardous chemicals, there are some chemicals that are missing whose inclusion would increase the number of possible experiments that students could perform.

ECB contains quite a variety of laboratory equipment, but more laboratory equipment would increase the number of possible experiments. In ECB, chemicals can be transferred from the inorganic to the physical storeroom, thereby increasing the number of chemicals available. Equipment cannot be transferred, but if it could be, that would be one way in which to increase the number of possible experiments.

Students select the equipment they require for their experiment within ECB, but the program does not allow students to pick up inappropriate combinations of materials. It is recommended that there be more flexibility in the selection of equipment. This would require students to make more decisions, to plan their strategy carefully and to revise their plans if they have selected materials that are incompatible with the experiment. This flexibility would also more closely simulate a practical laboratory.

6.4 - CONCLUSIONS ON COMPUTER USE IN SCHOA

The conclusions in this section are on computer use in general in SCHOA.

#1 : Computers can be used to provide motivation.

"Motivation has been identified as a critical component in learning" (Swenson and Anderson, 1983). Reinforcement is essential to motivation, and computer programs (tutorial, drill, simulation and game) have the ability to provide reinforcement in the form of feedback that is immediate, appropriate and relevant. The feedback should occur immediately after a response, be appropriate to the students, the question and the response, and be relevant to the students' knowledge.

Use of computers provides the students with alternative teaching methods (Smith and Jones, 1989), and computer programs can "provide a new perspective on the topic that will help students understand the material better" (Trollip and Alessi, 1988). There has been much discussion on the benefits of providing students with alternative teaching styles. Many teachers believe that different students learn in different ways, and that by using alternative teaching styles they will be able to provide an appropriate style for most of their students. Students will be motivated to learn when the material is presented in the style they best understand and computers help teachers in providing various styles.

It has been found that students enjoy using computers, and since the students enjoy it, they will spend more time using computers. Therefore if the students are using instructional computer programs, they will be spending more time learning (Bork, 1985). Enjoyment is a significant factor in motivation, and if students spend more time learning their success will also be a factor in their motivation.

#2 : Computers can be used to promote cooperative learning.

Computers have been present in the educational system for many years, but it is still unusual to find a school that can provide every student in a class with their own computer. Students will often work at the computer with a partner, which can have certain advantages but it may not always be desirable (as in the tutorials and drills of C1PP).

An advantage of students working together at one computer is that they learn from one another. "Extremely valuable learning occurs because of the student-student interaction" (Bork, 1985). "Having more than one student working together promotes productive discussion" (Kahn, 1985). Students working cooperatively will discuss strategies and successful or unsuccessful approaches. They will learn not only from the computer program, but also from each other.

#3 : Computers can be used to encourage exploration and creative thinking.

Computers provide a safe, yet unsupervised environment in which students can explore concepts learned in class. Since there are no safety hazards associated with computers, "students feel free to experiment and try things" (Trollip and Alessi, 1988). Students can become motivated to explore concepts beyond what was presented in class and will benefit as a result. Students can work on the computer without any teacher supervision and they may "feel more comfortable making mistakes" (Trollip and Alessi, 1988). If students feel free to make 'mistakes', they will also likely feel free to explore and to be creative. This should increase the students' motivation and may interest some students to pursue chemistry.

#4 : Computers can be used for active learning.

"Computers are an interactive medium, allowing constant interaction" (Bork, 1985). Computers not only allow constant interaction, they require the students to learn actively. Since students are active in the learning process, they will be more successful at learning. "Computers demand intellectual participation rather than passivity" (Arons, 1984). Students cannot work with a computer without becoming actively involved. This active learning should encourage students to feel more responsibility for their learning and to be more satisfied with their success.

#5 : Computers can be used with great flexibility.

Computers are very flexible - they can be used anytime, anywhere (Lagowski, 1989), as often as is necessary, by one student or by many students. "Computers will repeat any operation as many times as required; they don't get bored, tired or prone to error after repeating the same operation many times" (Kahn, 1985). This feature of computers is advantageous when a student is working with tutorials, drills or simulations that involve repetition. Students can repeat a problem or an experiment as often as they like.

Computers will allow students to work at their own speed, and spend as much time as they like on a problem, question or experiment (Bork, 1985; Smith and Jones, 1989). The absence of time constraints should allow students to relax and concentrate on the concepts they are learning. This should motivate students to learn and increase their enjoyment in learning.

6.5 - SUMMARY

This project has investigated the use of computers to enhance the teaching of selected difficult concepts of SCHOA in an attempt to make them easier to understand. Two programs were evaluated - the tutorial/drill program Chem1 Problem Proctor and the simulation program The Electric Chemistry Building. This chapter presented conclusions and recommendations, based on the evaluation of these programs in Chapter 5. Conclusions and recommendations were given regarding C1PP and ECB separately due to the different nature of these programs (tutorial/drill vs simulation). Conclusions were also given regarding the use of computers in general in SCHOA.

Based on the conclusions and recommendations presented in sections 6.2 and 6.3, both programs, C1PP and ECB, appear to be worthwhile for use in SCHOA. ECB could be used very effectively in its present form, although it could be improved as mentioned in Recommendation #2 of section 6.3.2. The problems with C1PP outlined in Recommendations #1, 2, 3, and 4 of section 6.2.2 should be corrected before this program can be truly effective. If C1PP also includes the diagnostic feature as in Conclusion #4 (section 6.2.1), C1PP would be a very effective tutorial/drill program and beneficial to students of SCHOA.

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APPENDICES

APPENDIX A.1

SCHOA Student Survey

Indicate the difficulty you experienced in learning/understanding each of the following topics by circling the appropriate number.

Topic	Difficulty Not difficult				Difficult
1. Review of SCH3A					
-Nomenclature	1	2	3	4	5
-Moles/Stoichiometry	1	2	3	4	5
-Bonding/Shapes	1	2	3	4	5
2. Atomic Structure					
-Atomic theory	1	2	3	4	5
-Properties of elements	1	2	3	4	5
-Metallic bonding	1	2	3	4	5
3. Chemical Energy					
-Heats of reaction (ΔH)	1	2	3	4	5
-Hess' Law	1	2	3	4	5
-Bond energy	1	2	3	4	5
-Entropy (ΔS)	1	2	3	4	5
-Spontaneity (ΔG)	1	2	3	4	5
4. Reaction Rates					
-Activation energy, activated complex	1	2	3	4	5
-Rate law expressions	1	2	3	4	5
-Reaction mechanisms	1	2	3	4	5
-Factors affecting rates	1	2	3	4	5
5. Chemical Equilibrium					
-Characteristics of equilibrium	1	2	3	4	5
-Le Chatelier's principle	1	2	3	4	5
-Equilibrium and rate	1	2	3	4	5
-Equilibrium law expression	1	2	3	4	5
-Equilibrium law constant, K_{eq}	1	2	3	4	5
-K_{eq} calculations	1	2	3	4	5

Topic	Difficulty				
	Not difficult				Difficult
6. Solubility Equilibrium					
-Solubility rules	1	2	3	4	5
-Solubility product, K_{sp}	1	2	3	4	5
-Common Ion effect	1	2	3	4	5
-Predicting precipitation	1	2	3	4	5
7. Acid/Base Equilibrium					
-Bronsted-Lowry definition	1	2	3	4	5
-Strength of acids and bases	1	2	3	4	5
-Conjugate acid/base	1	2	3	4	5
-Predicting reactions	1	2	3	4	5
-pH	1	2	3	4	5
-K_a, K_b, K_w	1	2	3	4	5
-Hydrolysis	1	2	3	4	5
-Titration	1	2	3	4	5
-Buffers	1	2	3	4	5
-Lewis definition	1	2	3	4	5
8. Electrochemistry/Redox					
-Oxidation numbers, balancing equations	1	2	3	4	5
-Half-cell method for balancing equations	1	2	3	4	5
-Electrochemical cells	1	2	3	4	5
-Nernst equation	1	2	3	4	5
-K_{eq} for redox	1	2	3	4	5
-Electrolytic cells	1	2	3	4	5
-ΔG for redox	1	2	3	4	5
9. Organic Chemistry					
-Alkanes,-enes, -ynes	1	2	3	4	5
-Alcohols	1	2	3	4	5
-Aldehydes,ketones	1	2	3	4	5
-Carboxylic acids	1	2	3	4	5
-Esters	1	2	3	4	5
10.Independent Investigation	1	2	3	4	5

APPENDIX A.2

Procedure for Analysis of Survey Results

The first step in the analysis of the results of the student survey was to tabulate the number of students selecting each of the five levels of difficulty within a concept. The next step was to calculate the mean difficulty of each concept. These results are shown in Appendix A.3. The final step was to rank the concepts according to their degree of difficulty, shown in Appendix A.4.

Once the mean difficulty of each concept was calculated, those concepts with a mean difficulty greater than 3.1 were considered in the identification of the difficult concepts. In two cases, several concepts within the same topic were considered difficult and the topic was identified as being difficult.

APPENDIX A.3

Results of Student Survey

Topics	Mean Difficulty	Standard Deviation
1. Review of SCH3A		
-Nomenclature	1.9	0.9
-Moles/Stoichiometry	1.6	0.6
-Bonding/Shapes	2.5	1.1
2. Atomic Structure		
-Atomic theory	1.9	0.9
-Properties of elements	2.5	1.1
-Metallic bonding	2.2	1.0
3. Chemical Energy		
-Heats of reaction (ΔH)	2.5	0.8
-Hess' Law	2.5	0.8
-Bond energy	2.4	0.6
-Entropy (ΔS)	2.8	1.1
-Spontaneity (ΔG)	3.1	1.2
4. Reaction Rates		
-Activation energy, activated complex	2.0	1.0
-Rate law expressions	2.7	1.2
-Reaction mechanisms	3.2	0.7
-Factors affecting rates	2.7	0.9
5. Chemical Equilibrium		
-Characteristics of equilibrium	2.5	0.8
-Le Chatelier's principle	2.5	1.0
-Equilibrium and rate	3.1	0.8
-Equilibrium law expression	2.6	1.0
-Equilibrium law constant, K_{eq}	2.5	0.9
-K_{eq} calculations	2.8	0.6

Topics	Mean Difficulty	Standard Deviation
6. Solubility Equilibrium		
-Solubility rules	2.8	1.1
-Solubility product, K_{sp}	2.9	1.0
-Common Ion effect	3.6	0.6
-Predicting precipitation	3.6	0.9
7. Acid/Base Equilibrium		
-Bronsted-Lowry definition	2.3	0.8
-Strength of acids and bases	2.8	1.0
-Conjugate acid/base	2.7	0.9
-Predicting reactions	3.0	1.0
-pH	2.0	0.9
-K_a, K_b, K_w	2.7	1.0
-Hydrolysis	3.3	0.9
-Titration	3.2	1.0
-Buffers	3.7	0.9
-Lewis definition	3.0	1.0
8. Electrochemistry/Redox		
-Oxidation numbers, balancing equations	2.8	1.4
-Half-cell method for balancing equations	3.1	1.2
-Electrochemical cells	3.1	1.2
-Nernst equation	3.1	0.8
-K_{eq} for redox	3.4	0.5
-Electrolytic cells	3.4	1.3
-ΔG for redox	3.4	1.3
9. Organic Chemistry		
-Alkanes, -enes, -ynes	2.4	0.8
-Alcohols	2.5	0.8
-Aldehydes, ketones	2.8	0.8
-Carboxylic acids	2.8	0.9
-Esters	2.9	1.0
10. Independent Investigation	3.4	1.3

APPENDIX A.4

Ranking of All Concepts in Decreasing Order of Difficulty

Difficult Concepts of SCHOA

Concept		Difficulty
Buffers		3.7
Solubility	-Common Ion - Precipitation	3.6
Redox	- K_{eq} - Electrolytic cells - ΔG - Electrochemical cells - Nernst equation - Balancing equations	3.4
Independent Investigation		3.4
Acid/Base Equilibrium	- Hydrolysis - Titration	3.3
Reaction mechanisms		3.2
Free energy, ΔG		3.2
Solubility Equilibrium	- Solubility rules - K_{sp}	2.8
K_{eq} Calculations		2.8
Reaction Rates	- Rate Law expressions - Factors affecting rates	2.7

Concept	Difficulty
Acid/Base Equilibrium - Strength of acids/bases - Conjugate acid/base - K_a, K_b, K_w	2.7
Organic Chemistry	2.7
Chemical Equilibrium - Characteristics of equilibrium - Le Chatelier's principle - Equilibrium Law expression - K_{eq}	2.5
Chemical Energy - Heats of reaction - Hess' Law - Bond energy - Entropy	2.5
Bronsted-Lowry definition of acids and bases	2.3
Atomic structure	2.2
Activation energy, activated complex	2.2
pH	2.0
Review of SCH3A	2.0

APPENDIX B

The Evaluation Checklist

The following is the itemized checklist used for the evaluation of computer programs in this project.

Part 1 - Description
- Program name
- Version used in evaluation
- Type of computer application (tutorial, drill, simulation)
- Instructional intent
- Intended users
- Brief description of the program

Part 2 - Administrative Issues
- Microcomputer compatibility
- Operating System requirements
- Memory requirements
- Disk format
- Source
- Cost

Part 3 - Subject Matter
- Instructional objectives - clearly stated
- appropriate to intended users
- appropriate to content
- attained
- Information - relevant
  - accurate
  - complete
- Emphasis - appropriate
- Sequence - appropriate to intended users
  - appropriate incremental steps
  - effectively organised (progressing from easy to difficult, concrete to abstract)
- Multiple levels of ability
- Variable levels of difficulty
- Randomness
- Assumption of prior (chemistry) knowledge

- User interaction
  - making decisions/choices
  - developing strategies
  - encourages creativity
  - encourages cooperation
  - encourages exploration

Part 4 - Language and Grammar

- Reading level - appropriate
- Absence of bias - race, sex, cultural
- Technical terms
  - relevant
  - defined
- Abbreviations, jargon
  - relevant
  - defined
- Formulae
- Spelling
- Grammar, vocabulary

Part 5 - Surface Features

- Ease of start-up
- Instructions
  - clear
  - appropriate
- Amount of information presented
- User control
  - rate of presentation
  - sequence of information
  - amount of information
  - mobility through program
- Interruption of lesson
  - possible
  - accidental
  - resumed later on
- Completion of lesson - indicated
- Success - indicated
- Student records
  - score-keeping
  - accessible by teacher
  - accessible by student
- Method of input (keyboard, mouse)
- Animation
  - relevant
  - level of detail
- Graphics
  - relevant
  - level of detail
- Colour
- Displays - clear and uncluttered
- Audio - can be switched on/off/down
- Overwriting
- Scrolling

Part 6 -Instruction and Motivation

- Menus- clear when to make choice
  - clear how to make choice
  - clear how to change choice
  - clear how to get help
  - clear how to return to menu
  - clear how to bypass
- Questions - clear when to respond
  - clear how to respond
  - clear how to change response
  - clear how to bypass question
- Response - leniency in acceptance of responses
  - tolerance to unexpected input
- Hints - provided after _ incorrect responses
  - suitable
- Help - available
  - accessible
- Correct answer given after _ incorrect responses
- Feedback - format
  - appropriate
  - accurate
  - supportive
  - corrective
  - immediate
  - nonviolent
  - reward correct rather than incorrect responses

Part 7 - Documentation

- Manual- correct directions
  - complete directions
  - index
  - readable
  - durable
- Forms, scoresheets - provided
- Other resources - available
  - appropriate

APPENDIX C.1

Programs Considered for Evaluation

1. Chem1 Problem Proctor
   S. K. Lower
   Simon Fraser University
   Burnaby, BC

2. The Electric Chemistry Building
   Snowbird Software
   Hamilton, Ontario

3. Chempro Courseware
   J. S. Martin and E. V. Blackburn
   University of Alberta
   Edmonton, Alberta

4. Introduction to General Chemistry
   S. G. Smith, R. Chabay, and E. Kean
   University of Illinois
   Urbana, Illinois

5. Project Seraphim
   J. W. Moore
   University of Madison-Wisconsin
   Madison, Wisconsin

APPENDIX C.2

Outline of the 'Problems-Oriented Approach'

Chem1 Problem Proctor is a set of lessons, where each lesson is based on the type of problems that would usually be assigned as homework (Lower, June 1988). "Lessons based on the same kinds of problems that students are required to do in the course are the ones that are most appreciated and used by the students" (Lower, June 1988).

The 'problems-oriented approach' does more than present the solution to the problem. It uses the interactive nature of the computer to lead the student through the problem step-by-step, involving the student in decision-making at every step. This approach introduces the student to the reasoning that goes into the solution of the problem and develops her problem-solving skills. The 'problems-oriented approach' discourages students from simply memorizing a formula and encourages them to understand the solution by forcing students to make so many decisions.

APPENDIX D

Summary of the Evaluation of the Programs

The Electric Chemistry Building - Physical

Description: The Electric Chemistry Building-Physical is a laboratory simulation which contains the equipment required for redox reactions (electrochemical cell, electrolysis, titration), acid-base titration and gas experiments.

Administrative Issues: This program requires an IBM PC or compatible, two disk drives and 256 K memory. It is available in 5.25" and 3.5" diskettes. Its authors and distributor are Canadian.

Subject Matter: The teacher's notes provide both general and specific objectives. "The general objectives are to help students: a) learn to solve problems through the design of systematic investigations and by careful observations, b) describe some chemical and physical properties of common chemicals, and c) develop enthusiasm for chemistry" (Snowbird, 1988/89). This program is a simulation, therefore it does not simply present information but, rather, permits its discovery. The simulation is experimental; some experience in the laboratory would be helpful. Knowledge of redox is required. There is a high degree of user interaction. The program can be used for independent or cooperative work. It encourages exploration.

Language & Grammar: This program uses only those technical terms and formulae that are necessary, and they are used appropriately.

Surface Features: The program is simple to start up once it has been installed on the hard disk. The instructions are clear and appropriate. There is freedom to move throughout the building. An experiment can be interrupted, saved and resumed later on. Accidental interruption is difficult. The contents of the reaction vessel can be monitored throughout the experiment. Input is with a keyboard, using the arrow keys. There is good animation, colour is used well and there is no audio.

Instruction & Motivation: The menus are clear. There are few questions. Help is very available, and easily accessible. The help is appropriate to the room from which it is requested. There is visual feedback during the experiments. The equations for the reactions are given, as is the voltage produced/required. Little corrective feedback is provided

Documentation:
Teacher's notes accompanying the program are very good - providing clear directions, sample experiments, suggested experiments and lists of objectives.

The Electric Chemistry Building - Inorganic

Description: The Electric Chemistry Building - Inorganic is a laboratory simulation containing the equipment required for solubility equilibrium experiments and other inorganic experiments.

Administrative Issues: This program requires an IBM PC or compatible, two disk drives and 256 K memory. It is available in 5.25" and 3.5" diskettes. Its authors and distributor are Canadian.

Subject Matter: The teacher's notes provide both general and specific objectives. "The general objectives are to help students: a) learn to solve problems through the design of systematic investigations and by careful observations, b) describe some chemical and physical properties of common chemicals, and c) develop enthusiasm for chemistry" (Snowbird, 1987). This program is a simulation, therefore it does not simply present information but, rather, permits its discovery. The simulation is experimental; some experience in the laboratory would be helpful. Knowledge of redox is required. There is a high degree of user interaction. The program can be used for independent or cooperative work. It encourages exploration.

Language & Grammar: This program uses only those technical terms and formulae that are necessary, and they are used appropriately.

Surface Features: The program is simple to start up once it has been installed on the hard disk. The instructions are clear and appropriate. There is freedom to move throughout the building. An experiment can be interrupted, saved and resumed later on. Accidental interruption is difficult. The contents of the reaction vessel can be monitored throughout the experiment. Input is with a keyboard, using the arrow keys. There is good animation, colour is used well and there is no audio.

Instruction &
Motivation: The menus are clear. There are few questions. Help is very available, and easily accessible. The help is appropriate to the room from which it is requested. There is visual feedback during the experiments. The equations for the reactions are given, as is the voltage produced/required. Little corrective feedback is provided.

Documentation:
Teacher's notes accompanying the program are very good - providing clear directions, sample experiments, suggested experiments and lists of objectives.

Chem1 Problem Proctor - #16 Solubility Equilibria

Description: Chem1 Problem Proctor #16 consists of eight problems on solubility. There are three drill problems on solubility constant, K_{sp}, and pH. There are five tutorial problems based on solubility calculations.

Administrative
Issues: This program requires an IBM PC or compatible, with a hard and floppy disk drive, and 256 K memory. It is available in 5.25" and 3.5" diskettes. Its author is Canadian and distributor is in the United States.

Subject
Matter: C1PP is accompanied by a brief guide outlining the 'problems-oriented approach' followed by the program. The guide gives two key objectives: "that the student will acquire a feeling for the kind of reasoning that goes into the solution of a problem, and will become more confident about problem-solving" (Lower, June 1988), and outlines how these objectives are accomplished. Each problem begins with a brief introduction. Each problem provides opportunity to apply knowledge. The emphasis is quite mathematical, but this is appropriate to the topic. There are variable levels of difficulty. The sequence is good. This program would be most effective following the study of solubility and K_{sp}. The drill problems should develop the student's confidence. There are three problems on common ions - one is an application problem of the solubility of limestone in water with dissolved carbon dioxide. Two problems examine solubility and pH, and a complexing agent; both of these lend themselves to applications which are not mentioned.

Language &
Grammar: The reading level and technical terms are appropriate. Acceptance of upper or lower case in formulae is unpredictable (this is common throughout C1PP). The lack of superscripts make square roots difficult to recognize. One problem uses unusual units.

Surface
Features: The program is simple to start up except that the lesson disk must be inserted before the lesson number is selected, and this is not made clear in the instructions. The user controls the rate, but not the sequence or the amount of information presented. A problem can be interrupted but not resumed. Completion of a problem is indicated but its accuracy is not reliable. Problems that are only read and escaped from are labelled as being 'done'. No record is kept of which problems were completed in a previous session. Some problems give a percentage score but this is unreliable. Input is with a keyboard. The program consists of text with some colour.

Instruction &
Motivation: The menus are clear and problems can be previewed before being selected. The questions in the problems make it clear how to respond. Answers can be corrected. Questions can be bypassed, but the next question in the same problem is presently automatically. It is impossible to refer back to a previous question. The program is relatively lenient in its acceptance of answers, but it is inconsistent in its acceptance of formulae, sometimes accepting only upper case and at other times only lower case (eg., 'hcn'). Sometimes an answer is not accepted upon first entry but is the second time. The program considers 'x^2' and '2x' as equivalent, which is a problem. The instruction, hints, and feedback are good except in one problem where the it is inappropriate. One problem has a big 'jump'. Another problem shows an incorrect chemical equation initially which is corrected on a subsequent screen. One problem refers to a reaction whose role is unclear. The last problem is too mathematical.

Documentation:
Chem1 Problem Proctor is accompanied by a student problem book which contains the same problems as the program. The instructor's guide is brief, outlines the philosophy behind the program and gives an overview of the program.

Chem1 Problem Proctor - #9 Oxidation Reduction

Description: Chem1 Problem Proctor #9 consists of three tutorial/drill problems on redox (oxidation numbers, oxidizing/reducing agents, redox equations).

Administrative Issues: This program requires an IBM PC or compatible, with a hard and floppy disk drive, and 256 K memory. It is available in 5.25" and 3.5" diskettes. Its author is Canadian and distributor is in the United States.

Subject Matter: C1PP is accompanied by a brief guide outlining the 'problems-oriented approach' followed by the program. The guide gives two key objectives: "that the student will acquire a feeling for the kind of reasoning that goes into the solution of a problem, and will become more confident about problem-solving" (Lower, June 1988), and outlines how these objectives are accomplished. Each problem begins with a brief introduction. There are many inaccuracies in the problems on balancing equations. The emphasis and sequence within the problems is appropriate. There are varying levels of difficulty. Previous knowledge of redox is not necessary, but would make the program more effective. The program encourages problem-solving and decision-making, and is most suitable for independent work.

Language & Grammar: There is more reading involved in C1PP since it is a tutorial/drill, and the reading level is appropriate. Use of technical terms is appropriate. There are errors in naming elements such as O_2 ,"dioxygen" and H_2,"dihydrogen". The lack of subscripts make formulae confusing.

Surface Features: The program is simple to start up except that the lesson disk must be inserted before the lesson number is selected, and this is not made clear in the instructions. The user controls the rate, but not the sequence or the amount of information presented. A problem can be interrupted but not resumed. Completion of a problem is indicated but its accuracy is not reliable. Success is indicated by a percentage, but if a problem was only read and escaped from, the score was 100%. Input is with the keyboard. The program is text with some colour. The previous question remains on the screen when subsequent ones are presented, and this may be confusing.

Instruction &
Motivation: The menus are clear and problems can be previewed before being selected. The questions in the problems make it clear how to respond. Answers can be corrected. Questions can be bypassed, but the next question in the same problem is presently automatically. The program is relatively lenient in its acceptance of answers. If a numerical answer is required and a textual answer is given, the program asks for the number (and vice versa). In tutorial problems, hints are provided after each incorrect response and help is provided after four incorrect responses. Help consists of an excellent step-by-step series of questions to show students how to solve the problem. It is disappointing that once help has been requested it is given immediately after the first incorrect response on subsequent questions. In drill problems, no hints are provided and the student is told to guess. Feedback in tutorial problems is corrective, while in drill problems it is either 'right' or 'wrong'. Feedback is inaccurate in several problems which is frustrating.

Documentation:
Chem1 Problem Proctor is accompanied by a student problem book which contains the same problems as the program. The instructor's guide is brief, outlines the philosophy behind the program and gives an overview of the program.

<u>Chem1 Problem Proctor - #19 Electrochemistry</u>

Description: Chem1 Problem Proctor #19 consists of eight tutorial problems on electrochemistry. The problems contain several practical applications.

Administrative
Issues: This program requires an IBM PC or compatible, with a hard and floppy disk drive, and 256 K memory. It is available in 5.25" and 3.5" diskettes. Its author is Canadian and distributor is in the United States.

Subject
Matter: C1PP is accompanied by a brief guide outlining the 'problems-oriented approach' followed by the program. The guide gives two key objectives: "that the student will acquire a feeling for the kind of reasoning that goes into the solution of a problem, and will become more confident about problem-solving" (Lower, June 1988), and outlines how these objectives are accomplished. Each problem begins with a brief introduction. Some of the problems end with a review. There are many inconsistencies in the information which leads to confusion. Five of the problems involve ΔG (Gibbs' Free Energy) and the Nernst equation, but two of them are

worthwhile and the Nernst equation can be ignored. The problems follow a good sequence and teaching technique. There is no variability in ability, but there are different levels of difficulty. The program is most suitable for independent work.

Language & Grammar: There is more reading in a tutorial than a drill or simulation and the reading level is appropriate. The technical terms are appropriate but 'EMF' is used without any definition. Some formulae are difficult to understand because there are no sub or superscripts (eg., square root).

Surface Features: The program is simple to start up except that the lesson disk must be inserted before the lesson number is selected, and this is not made clear in the instructions. The user controls the rate, but not the sequence or the amount of information presented. A problem can be interrupted but not resumed. Completion of a problem is indicated but its accuracy is not reliable. Problems that are only read and escaped from are labelled as being 'done'. No record is kept of which problems were completed in a previous session. Some problems give a percentage score but this is unreliable. Input is with a keyboard. The program consists of text with some colour. One problem shows a good diagram but it could be improved.

Instruction & Motivation: The menus are clear and problems can be previewed before being selected. The questions in the problems make it clear how to respond. Answers can be corrected. Questions can be bypassed, but the next question in the same problem is presently automatically. It is impossible to refer back to a previous question. The program is relatively lenient in its acceptance of answers. However, it accepted 'h2' as hydrogen, and not 'H2'. No units are required in numerical answers. Hints are given after two incorrect responses, and then immediately on subsequent questions. Help consists of an excellent step-by-step series of questions to show students how to solve the problem. A brief note of instruction is provided following response to some questions. Feedback is very good, corrective and encouraging.

Documentation:

Chem1 Problem Proctor is accompanied by a student problem book which contains the same problems as the program. The instructor's guide is brief, outlines the philosophy behind the program and gives an overview of the program.

<u>**Chem1 Problem Proctor - #15 Acid-Base Mixtures**</u>

Description: Chem1 Problem Proctor #15 consists of eight tutorial problems on acid-base equilibrium. The four buffer problems are excellent, but the remaining problems on acid-base equilibria are tedious.

Administrative Issues: This program requires an IBM PC or compatible, with a hard and floppy disk drive, and 256 K memory. It is available in 5.25" and 3.5" diskettes. Its author is Canadian and distributor is in the United States.

Subject Matter: C1PP is accompanied by a brief guide outlining the 'problems-oriented approach' followed by the program. The guide gives two key objectives: "that the student will acquire a feeling for the kind of reasoning that goes into the solution of a problem, and will become more confident about problem-solving" (Lower, June 1988), and outlines how these objectives are accomplished. Each problem begins with a brief introduction. Each problem provides opportunity to apply knowledge. The sequence is logical and well-organised. There is only one level of difficulty, which is quite simple. This program would be most effective following a study of buffers and indicators. Two of the buffer problems consider the change after addition of strong acid and base, and provide a good summary at the end. There is an excellent problem based on the carbonate buffer system in blood. The fourth buffer problem determines the pH range of an acid-base indicator.

Language & Grammar: The reading level and technical terms are appropriate. There is an incorrect chemical equation and there is a term missing from anotherequation. Both of these errors have potential for confusion and frustration. The form of the equations is not 'proper', and the use of significant figures is unreasonable.

Surface Features: The program is simple to start up except that the lesson disk must be inserted before the lesson number is selected, and this is not made clear in the instructions. The user controls the rate, but not the sequence or the amount of information presented. A problem can be interrupted but not resumed. Completion of a problem is indicated but its accuracy is not reliable. Problems that are only read and escaped from are labelled as being 'done'. No record is kept of which problems were completed in a previous session. Some problems give a percentage score but this is unreliable. Input is with a keyboard. The program consists of text with some colour. There are some audio effects in the acid problems but they are not very appropriate.

Instruction & Motivation: The menus are clear and problems can be previewed before being selected. The questions in the problems make it clear how to respond. Answers can be corrected. Questions can be bypassed, but the next question in the same problem is presently automatically. It is impossible to refer back to a previous question. The program is relatively lenient in its acceptance of answers, but it is inconsistent in its acceptance of formulae, sometimes accepting only upper case and at other times only lower case (eg., 'hcn'). Significant figures are a problem. Hints and feedback are very good, encouraging, and allow several attempts. The only criticism of the feedback is that one problem sets out to determine the pH and ends by finding 'x' (concentration of hydronium) instead. Some problems end with a review or summary.

Documentation: Chem1 Problem Proctor is accompanied by a student problem book which contains the same problems as the program. The instructor's guide is brief, outlines the philosophy behind the program and gives an overview of the program.

<u>Chem1 Problem Proctor - #20 Chemical Kinetics</u>

Description: Chem1 Problem Proctor #20 consists of six tutorial problems on chemical kinetics (rate and rate constant, reaction order, half-time, reaction mechanism, effect of temperature and catalyst on rate).

Administrative Issues: This program requires an IBM PC or compatible, with a hard and floppy disk drive, and 256 K memory. It is available in 5.25" and 3.5" diskettes. Its author is Canadian and distributor is in the United States.

Subject Matter: C1PP is accompanied by a brief guide outlining the 'problems-oriented approach' followed by the program. The guide gives two key objectives: "that the student will acquire a feeling for the kind of reasoning that goes into the solution of a problem, and will become more confident about problem-solving" (Lower, June 1988), and outlines how these objectives are accomplished. Each problem begins with a brief introduction. The information and emphasis is relevant to the problems, but is not completely at the SCHOA level. The mathematics is difficult and the problems re challenging for SCHOA students. The first problem, which determines rate law and rate constant from experimental data, is the most worthwhil. The second problem is a good exercise in estimating. Two of the remaining problems are too mathematical and one of them has a major flaw in that it will not accept the correct response. The last problem on effect of temperature considers only an exothermic reaction and it would be better if an endothermic reaction were included. Previous knowledge is required and should be well understood, except in the first and last problems. This program would be suitable for cooperative work where students could learn from each other (and share any frustration).

Language & Grammar: The reading level in these problems is appropriate. Mathematics is the likely stumbling block. The lack of superscripts make even a simple equation appear very complicated.

Surface Features: The program is simple to start up except that the lesson disk must be inserted before the lesson number is selected, and this is not made clear in the instructions. The user controls the rate, but not the sequence or the amount of information presented. A problem can be interrupted but not resumed. Completion of a problem is indicated but its accuracy is not reliable. Problems that are only read and escaped from are labelled as being 'done'. No record is kept of which problems were completed in a previous session. Some problems give a percentage score but this is unreliable. Input is with a keyboard. The program consists of text with some colour. The problem about the effect of temperature and catalyst on rate of reaction uses a graph, but it is difficult to see the information. The response to the first question of that problem remains on the screen long after it should have disappeared.

Instruction & Motivation: The menus are clear and problems can be previewed before being selected. The questions in the problems make it clear how to respond. Answers can be corrected. Questions can be bypassed, but the next question in the same problem is presently automatically. It is impossible to refer back to a previous question. The program is relatively lenient in its acceptance of answers. Numerical responses must be fairly close to the correct answer (which cuts down on guessing). One problem has flaws when it will not accept the correct response. Units are not required. Very few hints are provided unless help is selected. Help is very good, similar to other programs in C1PP. Feedback is not helpful or encouraging. One question asks for the answer in the form of a fraction, but accepts it only in decimal form.

Documentation:

Chem1 Problem Proctor is accompanied by a student problem book which contains the same problems as the program. The instructor's guide is brief, outlines the philosophy behind the program and gives an overview of the program.

Chem1 Problem Proctor - #18 Thermodynamics of Equilibrium

Description: Chem1 Problem Proctor #18 consists of seven tutorial and drill problems on the Second Law of Thermodynamics, Free Energy (ΔG), and equilibrium. There are two problems on entropy (ΔS), three problems on enthalpy (ΔH), entropy and free energy, one problem on the equilibrium constant (K_{eq}) and one problem that is not appropriate to SCHOA.

Administrative Issues: This program requires an IBM PC or compatible, with a hard and floppy disk drive, and 256 K memory. It is available in 5.25" and 3.5" diskettes. Its author is Canadian and distributor is in the United States.

Subject Matter: C1PP is accompanied by a brief guide outlining the 'problems-oriented approach' followed by the program. The guide gives two key objectives: "that the student will acquire a feeling for the kind of reasoning that goes into the solution of a problem, and will become more confident about problem-solving" (Lower, June 1988), and outlines how these objectives are accomplished. Each problem begins with a brief introduction. Each problem provides opportunity to apply knowledge. The sequence is logical and well-organised. There is only one level of difficulty, which is quite simple. This program would be most effective after discussion of thermodynamic properties since it provides a good review of how they are related. The drill that estimates the entropy of different reactions uses a good variety of reactions. One problem shows how the entropy of the system, its surroundings and the universe are related. One problem derives physical properties from thermodynamic data. Three problems are based on equilibrium systems.

Language & Grammar: The reading level and technical terms are appropriate and accurate except that 'H+' is not accepted while 'h+' is accepted.

Surface Features: The program is simple to start up except that the lesson disk must be inserted before the lesson number is selected, and this is not made clear in the instructions. The user controls the rate, but not the sequence or the amount of information presented. A problem can be interrupted but not resumed. Completion of a problem is indicated but its accuracy is not reliable. Problems that are only read and escaped from are labelled as being 'done'. No record is kept of which problems were completed in a previous session. Some problems give a percentage score but this is unreliable. Input is with a keyboard. The program consists of text with some colour. Scrolling occurs in only one of the problems but it is frustrating.

Instruction & Motivation: The menus are clear and problems can be previewed before being selected. The questions in the problems make it clear how to respond. Answers can be corrected. Questions can be bypassed, but the next question in the same problem is presently automatically. It is impossible to refer back to a previous question. The program is relatively lenient in its acceptance of answers. Numerical responses must be fairly close to the correct answer (which cuts down on guessing). Good feedback is provided after the first response, whether it is correct or incorrect, but it is impossible to make a second attempt. No hints are given. Feedback to numerical responses consists only of whether the number is too large or too small. Help is good but not as encouraging as other C1PP programs.

Documentation:

Chem1 Problem Proctor is accompanied by a student problem book which contains the same problems as the program. The instructor's guide is brief, outlines the philosophy behind the program and gives an overview of the program.