THE DESIGN AND IMPLEMENTATION OF MICROCOMPUTER-BASED LABORATORY INSTRUMENTATION IN THE BRITISH COLUMBIA HIGH SCHOOL CHEMISTRY CURRICULUM

By

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Abstract

This thesis is concerned with the design, development and implementation of Microcomputer-Based Laboratory experiments appropriate for Chemistry 11 and 12 in British Columbia. Computer apparatus, software and instructional materials were designed and constructed with feedback and assistance from students and teachers. These materials were then used in the classroom laboratory to collect and prepare real-time graphs of pH, spectrophotometric and temperature data for modified versions of laboratories 2a, 16b, 19b, and 20h taken from the Canadianized Heath Chemistry laboratory program.

Results of student academic performance are presented, along with samples of the interactions used during iterative materials design. The appropriateness of MBL incorporation is discussed at length, and suggested courses of action presented to B.C. Chemistry educators interested in acquiring MBL technology.
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I would also like to thank my wife and daughters for their impatient reminders that I should finish this project and get on with my life.
Chapter 1: The Problem

"I'm convinced that one could develop a marvelous method of participatory education by giving the child the apparatus to do experiments and thus discover a lot of things by himself."

-- Piaget (in Tinker, 1984)

1.1 Statement of the Problem

This study is concerned with the implementation and evaluation of Microcomputer Based Laboratory (MBL) procedures into grade 11 and 12 high school Chemistry laboratory practise. The study is intended to guide high school Chemistry teachers in the adoption and classroom use of this type of instrumentation. It may also be of interest to school administrators interested in acquiring Microcomputer-Based Laboratory technology, and to researchers and designers of such materials.

The general problem addressed by this study is to determine the circumstances under which the use of Microcomputer Based Laboratory (MBL) instrumentation is appropriate to the grade 11 and 12 B.C. Chemistry curriculum.

Implementation during this study was addressed by developing and providing experimental materials and procedures to participating students and teachers. Curricular materials, computer hardware and software were all produced specifically for this study and these materials underwent considerable revision while being used in working school classroom laboratories.

Evaluation procedures used in the study to examine the effectiveness of instrumentation consist largely of participant observation, comment and suggestion. All participants, including students, teachers and university researchers provided written and oral comment, and their suggestions were evaluated and sometimes implemented in working grade 11 and 12 Chemistry classes and laboratories. Student laboratory reports, quiz results and review test results were also used to a lesser extent to evaluate MBL activities. Implementation and evaluation were used in an iterative
manner throughout the study in an effort to maximize the quality of student experience and teacher comfort while adhering to the B.C. Chemistry curriculum.

1.2 The Appropriateness of MBL Technology

The introduction of computer technology into the school laboratory raises various classes of questions of appropriateness. For the purposes of this study they have been roughly grouped into three broad categories (with some overlap):

i. Implementation appropriateness, which refers to the logistical, administrative, organizational and managerial characteristics of the use of MBL technology;

ii. Pedagogical appropriateness, which refers to those issues concerning the incorporation of MBL technology specifically into the subject domain of the high school Chemistry laboratory; and

iii. Cognitive appropriateness, which refers to those issues arising from an examination of how MBL technology is able to bring about changes in student learning.

These questions and issues are discussed in detail in Chapter 2.

1.3 Definitions

Microcomputer-Based Laboratory (MBL) - is a form of laboratory practise incorporating computerized instrumentation for the purpose of data acquisition through sensors and analysis via real-time graphical presentation (Bross, 1986). Note that the term deliberately excludes science simulations which do not acquire real-world data in the laboratory (MacKenzie, 1988).

Sensor - a device used to convert a physical characteristic under measurement into a varying electrical quantity which can be interpreted and displayed by a computer.
pH Electrode - a sensor used to determine the concentration of hydronium $[\text{H}_3\text{O}^+]$ ions present in a solution. The ration of the logarithm of this concentration compared with that of pure water is defined as pH.

Thermistor - a common sensor (THERMally sensitive resISTOR) used to determine the temperature of a substance by variations in the resistance of a semiconductor (Macklen, 1979).

Spectrophotometer - an optoelectronic instrument used to determine the transmittance and absorbance of chemical solutions at various wavelengths of light. This transmittance (or absorbance) can be used to determine solute concentrations via a relationship known as Beers' Law. The small test tubes used to hold spectrophotometer samples are known as cuvettes.

Laboratory Interface - a collection of hardware and software used to connect a sensor to a computer so that signals from a sensor may be interpreted by the computer. Sensors require interfaces to amplify or convert their signals to a digital form appropriate for computer interpretation. The hardware interface used throughout the MBL Project was known as the DART box (Hickman, 1988). The Macintosh software interface varied somewhat between experiments and was developed in a language known as ZBASIC 5.0 (Gariepy, 1988).

Calibration - a laboratory practise involving the use of known measurements to standardize the response of an instrument or sensor. Eg - to calibrate a pH electrode, two buffered solutions of known pH are used to define two points upon a linear scale; the computer will map voltage output by the probe onto a range of pH values using the slope and offset determined by the original two known (calibration) points.
1.4 Scope

The scope of the MBL Project was limited to a series of Chemistry experiments chosen from the grade 11 and 12 British Columbia Chemistry (British Columbia Ministry of Education, 1987) curriculum. The B.C. curriculum is largely determined by the two prescribed texts - a text and lab handbook (Herron et al, 1987; DiSpezio et al, 1987), and by the first three authorized texts - a teacher's annotated text, an annotated laboratory guide and a resource guide (Herron et al, 1987; DiSpezio et al, 1987). All of these materials are from the Canadianized Heath Chemistry program of materials.

Experiments examined during the MBL project included two grade 11 laboratories:

- Lab 2A: Cooling and Heating Curves of a Pure Substance; and
- Lab 16B: Preparation of a Standard Solution Using a Spectrophotometer.

and two grade 12 laboratories:

- Lab 19B: The Quantitative Relationship involving Concentrations of Reactants and Products at Equilibrium; and
- Lab 20H: Obtaining Titration Curves Using a pH meter.

The student laboratory activities sections of the listed experiments were rewritten to make use of MBL instrumentation, and software and hardware were created to allow students to collect data from these experiments via the Macintosh computer and to prepare output plots of their data. The original pedagogical intent of these experiments as described in the B.C. Chemistry Curriculum Guide was left unchanged, although some procedures had to be modified. Extracurricular information concerning MBL technology (specific techniques or instruction) was provided where circumstances warranted.
Additionally, a third grade 11 experiment (Lab 16A - Polar and Nonpolar Solutes and Solvents) was examined without making an attempt to incorporate MBL technology. This experiment served as a check on some of the data collection methods used during the study.

1.5 A Rationale for the Problem

With the recent increase in access to microcomputer hardware by high school students (Becker, 1984), and corresponding strides in school computer utilization has come a demand to integrate computers into science classrooms. High school science teachers are usually amongst the instructional staff considered technically most able and least resistant to the incorporation of technological change in their day-to-day activities. Many high school science teachers are supportive of the incorporation of computer technology into their instruction to some degree (Amend et al, 1989). These teachers are also generally aware of current research practise in their subject domains, which widely incorporates computerized data gathering and processing. Some technically inclined teachers have even designed and or constructed their own MBL interfaces either from scratch or from kits. Various high school science teachers' professional organizations including the National Association of Science Teachers (NSTA), the American Association of Physics Teachers (AAPT) and related institutions such as the Technical Education Research Centres (TERC) have used professional development seminars to train teachers in the construction and utilization of this technology (Slootmaker, 1985; Layman, DeJong and Nelson, 1985).

High school science students are becoming increasingly technically and computer literate. Presently, many students have elementary computer skills including familiarity with computer operating systems and wordprocessing before entering the school science laboratory (Becker, 1986a). In addition, students perceive science research as performed by professional scientists to be highly computer dependant. The use of computer technology by students during instruction has been described as 'intrinsically motivating' (Swan & Mitrani, 1991; Dalton, 1991), and students have been observed to be positively motivated by MBL technology during instruction (Linn & Songer, 1989).
Producers and creators of computerized instructional design materials have long been aware of the laboratory capabilities of the personal computer and of inexpensive interface technologies, but due to very low levels of actual implementation, MBL technology is still referred to as '...one of science education's best-kept secrets' (Tinker, 1984b). A large number and variety of suppliers of school science equipment have developed or have purchased rights to MBL-style packages, and as a result there are now in excess of three dozen school laboratory instrumentation packages being marketed. These packages vary widely in quality and cost; together they cover all levels of science instruction, most school science laboratory phenomena and all common personal computers. Most of these packages consist of software and interface hardware for a specific computer, the required sensors and lesson guides or curricular materials (IBM, 1989; Vernier, 1990). There is little or no standardization amongst these products, and few or none are compatible with more than one computer. There has been little large-scale adoption of this technology by high school Chemistry teachers to date.

1.6 The Evolution of the Project Methodology

During the course of the MBL Project study, several research methodologies were tried and discarded before an Action Research design was selected. The rationale behind the selection of the methodology provides some insights upon the problem of technical innovation and evaluation in the classroom.

1.6.1 The Quantitative Study Design

The original design envisaged the collection and statistical analysis of student prelaboratory quiz and complete laboratory report marks for both MBL-modified and standard methodological treatments of laboratories chosen from the curriculum. Two or more classes of students would participate, one of which would make use of MBL techniques for a chosen experiment (the treatment) while the other used standard curricular materials (a control). At a later date, the classes would reverse methodological treatments for a second experiment. Each class group would be examined for evidence of anomalies in the laboratory report marks assigned between the different
methodological treatments. Any large discrepancies between group abilities (due to the fact that student assignment to each class was not random) would be examined and corrected for using prelaboratory quiz marks. This design (Table 1) is a slight variation of the well-documented Quasi-Experimental Design for Nonequivalent Control Groups using Counterbalancing (Campbell & Stanley, 1963).

**TABLE 1 - CounterBalanced Quasi-Experimental Design (after Campbell & Stanley, 1963)**

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<td>PLQ₂ X₂ LR₂</td>
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<tr>
<td>Class 2</td>
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<tr>
<td>PLQ₁ X₁ LR₁</td>
<td>PLQ₂ S₂ LR₂</td>
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PLQ = PreLaboratory Quiz, LR = Written Laboratory Report, S = standard laboratory procedure, X = instrumented version of a standard laboratory procedure.

During the technical redesign (to incorporate MBL technology) of the first selected laboratory experiment procedure it became apparent that the incorporation of technological enhancement did not constitute a clearly defined event capable of meaningful evaluation as a treatment. The development of the materials used was not a discrete process, but one which required several iterations of in-class experience with student and teacher input to achieve a workable result. (This situation is analogous to difficulties encountered during professional computer software development when preparing applications for marketing, the program software moves through several iterations of design and redesign known as versions.)

It was also unlikely that two separate experiments from the curriculum could be considered either to be of equivalent difficulty or to be equally easy to implement via laboratory technology, introducing uncontrolled variation between student MBL experiences (the treatment). Even the non-MBL (control) Chemistry experiments were subject to large fluctuations in presentation and difficulty.
During exploratory student use of MBL, it also became apparent that the standard B.C. Chemistry curriculum was itself a major (and often unreasonable) constraint upon the implementation of the technology. The movement of observation records and data tables onto a Macintosh screen was not effective use of the technology, and more appropriate experimental activities (most of which were beyond the original scope of the experiments) became both obvious and possible. Exclamations such as Can we do this? and Now we can do extra runs [...with changed experimental parameters] were noted during these explorations. It became apparent that an appropriate use of technology in the lab was not merely to complete the textbook activities at greater speed. The movement to a different technology in the laboratory had greater implications than a new presentation media; the instructional event had been completely changed. The technology itself changed the curriculum, and both teachers and students expected better application of this technology. To neglect these suggestions seemed contrary to the spirit of a pragmatic investigation.

Similar reservations with this quantitative design were expressed in communication with other MBL investigators.

As far as your [the authors' Quasi-Experimental] design is concerned, I am very skeptical of such "controlled" experiments because usually they require unreasonable compromises in the use of technology. As a result, the technology is not really tested and the results are less interesting than they might be. ...we recommend a design where alternative uses of MBL (based on some theoretical principles) are contrasted. Then the best use of technology is possible and the experimental treatment investigates an educational principle. (M.C. Linn, personal communication via the Internet, 2 August 1989).

Therefore, the original methodology for quantitative study was discarded in search of a more worthwhile and pragmatic approach.

1.6.2 The Case Study Design

The approach considered next was a Case Study involving the categorization of qualitative data by some relevant criteria, followed by a statistical analysis of occurrence. This technique has the advantage of permitting an in-depth study of a situation involving many uncontrollable or partially-controllable variables, or one where the boundaries between the phenomenon and the context are not
clearly evident (Yin, 1984). Case studies use a well-defined set of procedures and instruments (known as a protocol) to amass a large amount of data (the data base) from many different sources. Construct validity is demonstrated through the degree of convergence amongst the observations from the data base, and reliability by the number of recurrences.

An example of a case study design identifying the situational characteristics inherent in student use of MBL technology would be as follows: the researcher would develop a protocol describing details of the MBL characteristics under examination including student activity supposedly attributable to these characteristics. Students would participate in an experiment modified for MBL and would be observed and videotaped during this experiment. At the conclusion of the experiment, students would complete a brief survey describing their impressions of the experience. The researcher would examine the data base for examples of activities and comments attributable to the characteristics under study and would examine them by their frequency of occurrence and their quality. Note that a Case Study would examine student use of MBL technology in terms of '...the natural experience acquired in ordinary personal involvement' (Stake, 1978).

The Case Study design also proved inadequate to the requirements of this study. Case study procedure is generally accepted to presuppose little or no situational control of events; it makes extensive use of passive, noninterventionist, observation-reporting techniques (Yin, 1984). The MBL Project is dominantly interventionist in nature, and the series of successive interventions (the design and redesign of MBL materials) was largely controllable by the study participants. While the data-gathering and analytical capabilities of the protocol were clearly desirable and appropriate for this study, the passivity inherent in case study techniques was not. Therefore, a strict Case Study design was not undertaken, although many of the tools available to that research style were employed.
1.6.3 Methodology Decisions

Due to the discarding of earlier designs, an appropriate research design for the MBL Project was not determined until well after investigation had commenced, and the final decision was again a pragmatic one. The chosen design had to include most of the data collected to date (and guide data collection through to the project conclusion), and to recognize the highly interactive, participatory nature of its collection. An Action Research design fits these criteria and it was chosen as the final research methodology for this study. The AR design is discussed in Chapter 2.
Chapter 2: A Review of Related Literature

"It is unworthy of excellent men to lose hours like slaves in the labor of calculation."

-- Liebniz (in MacKenzie, 1988)

This review describes relevant literature concerning implementation, pedagogy, cognition and the methodology of this study. A guide to the relationships between these topics is given in Figure 1. Each of these major areas and linkages will be discussed in this chapter.

Figure 1: A Guide to the Literature Review
2.1 Implementation Issues

This discussion of implementation issues contains a brief analogy, then lists some specific concerns focusing on instructional design. Finally, some of the issues raised by published MBL research are examined.

2.1.1 An Implementation Analogy (Burkman, 1987)

In 1873, companies planning to market the newly-developed typewriter faced a dilemma: the placement of type bars led to jamming when the keys were struck too rapidly (ibid). To counter this phenomenon, Christopher Sholes performed extensive trials and determined a key placement of extreme user inefficiency - the QWERTY keyboard arrangement. This layout was designed for the sole and specific purpose of ensuring that a typist would constantly have long reaches during common letter sequences.

After typewriter technology had surpassed mechanical difficulties around 1932, August Dvorak redesigned the keyboard layout, minimizing awkward finger movements. This arrangement proved easy to learn, led to fewer errors and allowed a far greater typing speed than the older layout. This layout is known by his name - Dvorak.

When Dvorak tried to introduce the keyboard into general use, he was totally rebuffed. To this date, the Dvorak keyboard, with all its innate technical superiority and efficiency, has been adopted by few typists worldwide. Typewriter users, sellers, manufacturers and instructors did not perceive this technical innovation as advantageous. This result has been observed with other technical innovations. Clearly, in some types of implementations issues, matters such as changeover costs, short-term discomfort, disruption and communication weigh more than does efficiency. The key to adopting an innovation is to understand the perception of the intended user.
The adoption of MBL technology in the classroom is a similar situation -- before any such adoption, students, teachers and school administrators must perceive the technical innovations in MBL to be advantageous in terms of two criteria:

i. the amount of effort required to implement and use the technology; and

ii. the effect of MBL use upon their interpersonal relationships.

2.1.2 General Implementation Concerns

General considerations facing the adoption of MBL technology by school students and teachers include the following (Burkman, 1987):

1 The nature of teacher-student interactions. 'Most experienced instructors have preferred relatively constant personal interaction with learners and have preferred to deal with learners as a group rather than one at a time' (Burkman, 1987). MBL can be perceived to usurp this relationship, and to reduce the amount of teacher-student personal interaction.

2 The potential for student motivation. MBL activities are widely perceived to be computer-centred, replacing the teacher as the source of student motivation. Teachers have tended to reject materials-based teaching methods (Burkman, 1987).

3 The degree of teacher management and logistics required. MBL technology involves the use of unfamiliar tools and methods and can require large amounts of facility scheduling, equipment loan and movement, assembly, and storage management. 'Many experienced instructors do not like to manage things, do not feel they have time for much classroom management, and are not especially good managers' (Burkman, 1987).
4 The perceived cost of implementing and maintaining MBL technology can be the key factor in adopting the technology. These costs have historically restricted the availability of MBL technology to private and public research laboratories, reducing or eliminating teacher exposure to the technology and promoting the impression of data acquisition as financially untenable for school use (Burkman, 1987).

5 MBLs and computer-based instructional materials can be perceived as both difficult to understand and inflexible. Teachers have concerns regarding the quality, language and format of instructional materials in general and specifically computer-based materials. Instructional procedures must not rely upon a long chain of correctly performed complex events by many users to be viable (Burkman, 1987).

Relationships

The pedagogical basis upon which science is taught is currently changing from a teacher-oriented presentational style to a participatory style involving the negotiation of meaning (constructivism) wherein teachers must surrender a large degree of situational control. MBL technology and methods can provide a route to this style of interaction by encouraging student control centred upon the experimental relationships under study rather than instructor and textbook direction (Linn, 1988).

Additionally, MBL technology has been seen to enhance the qualities of on-task interstudent communications:

..students' propensity to monitor and compare their results to others', which was made possible by the fact that results were displayed graphically on the computer screen. Students compared results with one another constantly and thus were alerted to disparities. The sharing of data also encouraged cooperative remediation of problems, with students forming into consulting groups of increasing size according to the difficulty of the problem at hand. (Stein, 1987)
Student Motivation

It is difficult to overstate the extremely high levels of student motivation associated with MBL technology. Almost without exception, MBL researchers and designers have noted great student interest and participation. The use of technology seems extremely attractive and attention-grabbing, and comments include teacher enjoyment of MBL activity despite 'technical difficulties' (Stein, 1987), as well as increases in student scientific attitude as measured via instruments such as the Scientific Attitude Inventory (Powers & Salamon, 1988).

The students exhibited a keen interest in the experiments; the participating teachers were impressed with the ease of scientific mastery of the technology and the richness of the learning that ensued. Students were attracted to the equipment, quickly and naturally learning to control it through play and exploration. (Tinker, 1984b)

...there are other less lofty but still pedagogically sound reasons for involving students in interfacing experiments. ...interfacing can be fun, new, exciting, practical, relevant, inexpensive and challenging for both instructors and students. (Powers, 1986)

Teacher Management and Logistics

Teachers are faced with greater managerial tasks in the use of technological innovation in the laboratory, but have nonetheless become strong supporters of MBL after experience and training (Amend et al, 1989). The chief managerial difficulty in the case of MBLs is one of laboratory access to computers, which usually necessitates the movement of computers. Recent surveys (Becker, 1984b) show that over a third of US schools owning computers were moving them from site to site within the school for various activities, and some schools have dispersed computers in several locations, including the science laboratory.
While microcomputers are not located in the majority of science labs, much of the equipment is mounted in such a way as to facilitate this movement into the lab, usually via computer carts (Becker, 1984). Greater constraints in the laboratory are available floor space, power requirements and the necessity to keep expensive equipment safe from laboratory mishap. The setup of six or eight MBL stations in a crowded chemistry lab can present considerable difficulty. In the case of one of the sites of the MBL Project, a new school is presently under design and modifications in the plans for the Chemistry laboratory have resulted from project experiences addressing the need for computer space and power (L. Gibbs, personal communication, May 1990).

Cost

There is no consensus on how to measure the actual cost of instruction, nor upon which resources are expended in such a way as to be included in such costing (Burkman, 1987). However, the major costs in MBL implementation are instructional training and preparation, and hardware purchase. The problem of hardware cost has rapidly been diminishing -- the use of MBL technology was not even an issue in school labs several years ago due to a lack of computer access, while currently most secondary schools have access to adequate microcomputer resources for MBL purposes (Becker, 1986b).

Additionally, MBL technology has the ability to replace a large variety of expensive, discrete instrumentation with a single set of apparatus. Interfaces can be constructed to replace and often outperform data recorders, oscilloscopes, volumeters, ohmmeters, ammeters, electrometers, wattmeters, joulemeters, counters, timers, motion detectors and velocity measuring apparatus, pH meters and so forth (Bitter & Camuse, 1988), often allowing measurements otherwise prohibitively expensive or impossible to be made.

Finally, MBL interfaces have recently become available on a large scale at a price comparable to other common school computer peripherals such as printers (IBM, 1989; Vernier, 1990). Material costs do not present an insurmountable barrier any longer.
Complexity

Any activity incorporating computers is inherently more complex than one without, due to the prior knowledge required of the user. Users of computers must have some degree of familiarity with the hardware, software and the operating system to be used. Large scale surveys (Becker, 1984a) suggests that these skills are already to be found in a growing number of High School students, and these skills were not anticipated to be a major problem with this study. However, computerized measurement equipment and techniques are almost universally unfamiliar to the teachers and students making use of them, and materials and activities must be designed to account for this unfamiliarity.

Certainly initial experiences with prototype systems reveal that excellent teachers with no formal background require considerable time and preparation to conduct MBL lessons effectively. The equipment itself seems fairly trouble-free after setup, but if technical difficulties arise, they monopolize teacher attention, even to the detriment of the lesson (Stein, 1987; Linn & Songer, 1989). Spare apparatus might alleviate some of these problems; certainly well-developed, tested, robust hardware and software are required.

MBL materials must also be flexible and adequately supported so as to allow users to make fairly substantial innovations to their own use of the technology. These innovative applications of instructional material (departures from supplier-suggested activities) are usually perceived as higher orders of use by the user. Teachers usually feel that even minor adaptations of technological innovation to their own intents is highly desirable (Burkman, 1987).

2.2 Pedagogical Issues

To address some of the pedagogical issues inherent in the adoption of MBL technology, typical science laboratory procedures are examined and juxtaposed with MBL techniques. A discussion of past and present science pedagogical theory follows, along with a brief examination of the forces currently influencing change in laboratory science instruction.
2.2.1 School Laboratory Procedure

Typical high school science laboratories attempt to approximate research methodologies using processes similar to that in Figure 2. In the research lab, the researcher chooses an experimental problem and designs the experiment; in the school lab these activities are usually prescribed by the curriculum or text due to time constraints -- students usually do not participate in experimental design.

Students follow the given directions in the lab procedure, acquire data, perform calculations to treat the raw data appropriately and then complete some form of analysis, usually including graphical procedures. Then a generalization of some form is extracted (usually including an explanatory theory in active research) and results are documented for a report.

![Scientific Laboratory Process Diagram](Figure 2: Scientific Laboratory Process (Amend et al, 1989))
2.2.2 MBL Laboratory Procedure

MBL procedures most notably affect those steps in the laboratory experiment sequence involved in data acquisition and analysis. MBL procedures are an adaptation from research use of the same technology for similar tasks:

In this day and age very few real experiments are conducted without employing the latest technology -- sophisticated measurement instruments supplying large amounts of accurate data to a computer for storage, analysis and display. (MacKenzie, 1988)

MBL laboratories typically involve the use of sensors or probes to directly collect data in an electrical form and to display it in both numerical and graphical form as it is collected. This real-time display greatly abbreviates analysis and allows for immediate observation and control of experimental variables (Amend et al, 1989).

Students set up their apparatus and sensors, set scaling and display options on the microcomputer and then calibrate their sensors using known standards. Data are then collected using a series of real-time 'runs', with continuous observation of the computer screen and the physical process. After a run is complete, data collected are saved to disk and/or printed, results are discussed and compared with others and decisions regarding experimental repetition or variable control are made. Usually, some variable is modified and the experiment repeated, with results juxtaposed and examined. When complete, the experiment is written up into a report as before (ibid).

Laboratory Advantages to MBL Procedures

The advantages for science students inherent in the use of MBL technology in the laboratory are twofold (Amend et al, 1989):

1. MBLs allow students to do the steps in the experimental process faster, more thoroughly and more accurately, and

2. MBLs involve the student in more of the scientific process.

The computer becomes a tool which allows repeatability -- the reliable and untiringly accurate collection of data -- in volumes not otherwise possible due to time and attention constraints. Events...
become more easily quantified, and those events which happen too quickly to examine otherwise may be analyzed. Additionally, experiments involving a number of simultaneous measurements may be easily performed (ibid).

The data collected can be displayed instantaneously, and in any numerically processed form desired. This rapid processing and analysis allow the testing of user suggestions and conjectures not otherwise possible due to time constraints. The amount of data throughput is greatly increased -- the data are meaningfully examined while being collected, encouraging investigation by discovery. More time than before can be spent examining relationships, postulating relationships, controlling experimental variables and redesigning the experiment. MBL technology has the ability to free the user from the drudgery of quantification and graphical analysis and allow active investigation (Amend et al, 1989).

Scientific Measurement and Instrumental Effects

MBL technology also introduces students to scientific measurement. This includes errors of measurement, graphical interpretation, instrumental effects (calibration, accuracy, repeatability, error of quantification, resolution, scaling) and control of extraneous variables. These topics are not typically treated in the school laboratory because of the nature of 'precooked' experiments, the lack of available precision and time. They are nonetheless valuable laboratory science skills (Linn, 1989).

Instrumental effects refer to the inherent distortions in data due to the collection process. When using MBL, data can be made unreliable by five major instrumental causes: inappropriate graph scaling (in software), inappropriate setup, poor probe calibration (and resulting inaccuracy), inadequate probe resolution (where the equipment cannot discriminate fine enough gradations in the phenomena) and experimental variation (due to random error or invalid procedures). Students can be trained to recognize and correct these problems (Nachmias & Linn, 1987) and such training should be an integral part of MBL laboratory instruction.
2.2.3 Changes in Science Pedagogy

Recently science education has been turning from the content-based curriculum established by the revolutions of the 1950s and 1960s (Duschl, 1985) with voluminous transmission of information and attendant laboratory exercises stressing the replication of proven concepts to a more process-oriented curriculum stressing skills of analysis, questioning, synthesis and problem solution via laboratory experience.

As an example, the National Science Teachers Association (NSTA, 1983) has identified the following concerns regarding science education:

1. The textbook is the curriculum.
2. The goals of individual classes are not related to previous or subsequent classes.
3. The lecture is the main form of instruction with laboratories used for verification.
4. Science is evaluated in the traditional method.
5. Science is removed from the world outside of the classroom.

Several investigators suggest that the adoption of MBL techniques provides a response to several of these concerns:

Teachers and students will be active participants in the science process. Teachers will utilize methods of moving away from the text towards laboratory experiences which may be more directly related to the world of the student outside of the classroom. As a result, teachers will lecture less, and students will be involved in the active seeking of information. This will necessarily cause a change in the classroom evaluation procedures utilized (Woerner, 1987).

Tinker has also decried the science laboratory in its present form,

...[science labs invoke] unpleasant memories of boredom or fear in most high school survivors. The lab is a place where normal common sense is suspended in favour of that ineffable 'scientific method' which seems to consist of lots of numbers, lab books and funny equipment. For many, the whole process resembles having to cook a meal for someone with terrible taste, cleaning up afterwards, and then doing penance with pages and pages of arithmetic (Tinker, 1984).
while suggesting solutions provided by MBL:

...use the computer as a laboratory instrument. Make it into a tool that allows students to quantify the world around them. Give students a fantastically powerful tool that no science teacher could have dreamed of having in class only a few years ago -- an instrument that can measure ... ...give students these tools and you will see a (pardon the expression) revolution in science education -- a true embodiment of Piagets' notion that children learn best by discovering and creating the world for themselves (Tinker, 1984a).

2.2.4 The Incorporation of Technology into Curricula

The aforementioned 'crisis' of ineffectiveness in [US] science education is recognized as a major concern and technological innovation is being heralded as at least a partial solution. Prescriptive plans to integrate technology into the science curriculum have mentioned possible improvements as due to the following facts (Linn, 1988):

1. Scientists are using these tools - students might also be helped by them.

2. Technology has already invaded schools - over 1.4 million computers at schools [in the US].

3. The information explosion has changed student needs and access to information handling skills should be made available in schools.

4. Technology has transformed the workplace and students will require more extensive learning skills (they will change jobs and retrain more often), and technological skills.

5. Educators make use of technological tools for managerial tasks such as secretarial tasks and record-keeping.

6. The experience of scientists using technology to solve complex problems can be used to instruct technological problem-solving skills to students.

Linn goes on to suggest that the implementation of technology for instruction purposes moves through three major stages of acceptance:

1. Technology in the service of established goals; followed by

2. Adapting science education to technological innovation; and finally

3. The integration of technology and learning.
This would suggest that MBL adoption will catalyze significant changes in science curricula by making apparent present procedural shortcomings in instructional delivery, then by changing the curriculum content to surmount these limitations and finally by supporting reforms in the curricular paradigms of science pedagogy. Such reforms are already apparent in the constructivist movement in science pedagogy, which embraces many of the characteristics of free investigation and student empowerment ascribed to technological innovation (ibid).

2.3 Cognitive Issues

This section addresses issues raised by an examination of MBL characteristics and human learning theory. Different investigators have identified a long list of cognitively desirable instructional characteristics of MBL. These include (Tinker, 1984a):

1. **Environmental Simplicity.** Both in functional and conceptual terms, MBL reduces distractions and lower-level student chores during the laboratory.

2. **Fast Feedback.** The immediacy of feedback allows students to 'self-regulate their learning' and to readily select information so as to construct appropriate mental structures.

3. **More Direct Experience.** MBL allows 'normal' science through the ready quantification of complex phenomena not ordinarily accessible to analysis. Larger quantities of data and greater data throughput are also available than would be otherwise possible.

4. **Student Control and Interest.** Motivating students is one of the key prerequisites of learning and of any school science endeavour, and MBL is an attractive, empowering technology encouraging dynamic student control in the laboratory (Tinker, 1984a).

5. **Ease of Data Transformation.** MBL allows rapid transformation of data from numerical format into a much more meaningful graphical form. Given a graphical representation, many high-order analysis processes are readily carried out.

**Environmental Simplicity**

One unexpected characteristic of MBL activities is a simplified experimental environment, due to fewer repetitive chores such as data collection and graphing. More of the student's concentration can be spent upon the phenomena and relationships, reducing cognitive overhead. Cognitive overhead refers to the constraints of human short term memory (Gagne & Glaser, 1987) which
make learning difficult when experiencing an extended series of discontinuous events. Human learning performs best with a sharply limited series of contiguous events. This means that timely interpretation of experimental data is required for learning, and that next-day discussion of graphically analyzed laboratory results (common in school experiments) is far from optimal.

MBL technology may also provide a situational simplification in reducing all data collection, storage and transformation to a single device. Different experiments may make use of a common, modular design, repeating similar procedures with similar equipment for calibration, data collection and analysis over a wide variety of experiments (Tinker, 1984a).

Fast Feedback

The immediacy of feedback during MBL activity is an empowering characteristic of the technology. Data that is immediately available in a comprehensible form may make more time available for the Piagetian processes of 'accommodation' and 'self-regulation'. These terms describe the development of cognitive structures that resolve apparently aberrant phenomena, and more opportunity for these regulatory processes may be experienced with more iterations in laboratory experience. The importance of high quality situational feedback is recognized by almost all learning theories.

There is an oft-perceived disadvantage to fast feedback in the science laboratory -- that students do not perform as many detailed numerical data manipulations and calculations when using computers. There are appropriate laboratory situations for extensive student calculation for pedagogical purposes, but after the required mathematical manipulations are mastered by the student, repetition can become drudgery. An analogy can be made to the use of calculators in lower-level mathematics courses; while several hundred repeated low level calculations might be appropriate in an elementary mathematics class, high school students are widely permitted and encouraged to use a calculator for arithmetic operations.

Direct Experience

Gagne and Glaser (1987) describe the ability of the mind to accept data from several sensory channels of different limitation. They refer to the visual channel as having the greatest bandwidth,
that is the greatest transmissive ability of information in a single chunk. Such chunks are then theorized to be processed in a sharply limited short term memory and go on to be learned.

MBL provides an enormous throughput of information in this readily learnable visual form, allowing the complexities of laboratory situations to be analyzed by students in the laboratory. MBL increases access to phenomena, allowing new experiments that are otherwise too technically or conceptually difficult (Linn & Songer 1989).

Student Control

MBLs represent a novel situation making use of familiar media (television and computers), encouraging student control, ownership and involvement. MBL technology is attractive, dynamic and interesting. Again, the majority of learning theories indicate that student interest is of considerable import (Tinker, 1989a).

Student control is a situational characteristic inherent in MBL practise and in the instructional philosophy known as constructivism. Thornton describes student control in a constructivist MBL curriculum:

In such a setting students can directly manipulate physical objects. Such experiential learning provides a specific and concrete basis on which students may develop and/or alter their more general understandings of the physical world. The curriculum is heavily based on research and uses a guided discovery approach that pays attention to student alternative understandings, supports peer learning, makes use of student predictions, and provides opportunities for students to construct knowledge for themselves (Thornton, in press).

In the MBL laboratory, the locus of experimental control shifts to the student and away from the teacher and the curriculum. MBL gives the student a tool that encourages '...even badly prepared students to become active participants in a scientific process which invites them to ask and answer their own questions' (ibid). Students are encouraged through an increased ability to control the experimental environment and develop an understanding of a specific phenomenon before attempting to progress to more abstract concepts.
Data Transformation and Graphs

This is possibly the single most studied cognitive characteristic of MBL technology because student graphical interpretation abilities are quantifiable. There is wealth of information readily available for analysis even in simple graphs, while in contrast, tabular numeric data are of much more limited use to experimenters and students. The effects of MBL graphical data presentation upon student learning have been closely examined and found to be very encouraging (Brasell, 1987; Nachmias & Linn, 1987; Stein, 1987). Gagne and Glaser describe the process of appropriately encoding data so as to emphasize important features as essential to learning (Gagne & Glaser, 1987).

Graphical interpretation and evaluation have been extensively studied by many MBL investigators. These studies conclude that the real-time graphing features of MBL are effective in improving student graphic interpretation performance (Brasell, 1987; Nachmias & Linn, 1987; Stein, 1987). Graphs permit the ready display of key information in relationships -- a graph presents a starting point, endpoints, slopes, cusps, asymptotes and so forth, all containing interpretable information. Information must be drawn from the graphs through active student interpretation.

The majority of graphs examined by students during the instructional process are presented in textbooks and therefore graphs are rarely disputed -- they are largely accepted upon faith. Student-produced graphs, however, are typically evaluated in terms of inaccurate data, poor labelling and messiness rather than by comparison with experimental phenomena. Graphs produced with MBL are typically evaluated by comparison with subject knowledge or by instrumental effects (Nachmias & Linn, 1987). The interpretation of MBL graphs by students can be said to increase the level of critical appraisal in two ways -- both in terms of the subject matter itself and in terms of the data collection and presentation methods.

The formal abstraction of meaning from data via visual transformations has also been addressed by Novak and Gowin. Pictoral representations of information represent simple dissociations of
student thought from the experimental context, which can be carried on into the mapping of concepts and relationships themselves (Novak, 1984).

2.4 Action Research Design Issues

Action Research (AR) has been described as an informal, qualitative, formative, subjective, interpretive, reflective and experiential model of enquiry in which all individuals involved in the study are knowing and contributing participants (Hopkins, 1985). Action Research has the primary intent of providing a framework for qualitative investigations by teachers and researchers in complex working classroom situations.

Some of the most widely accepted definitions of Action Research include the following:

[Action Research] ...aims to contribute both to the practical concerns of people in an immediate problematic situation and to the goals of social science by joint collaboration within a mutually acceptable ethical framework.
- Rapoport (cited in Hopkins, 1985)

Action Research is a form of self-reflective enquiry undertaken by participants in social (including educational) situations in order to improve the rationality and justice of (a) their own social or educational practices, (b) their understanding of these practices, and (c) the situations in which the practices are carried out. It is most rationally empowering when undertaken by participants collaboratively...sometimes in cooperation with outsiders.
- Kemmis (cited in Hopkins, 1985)

[Action Research] ...is the systematic study of attempts to improve educational practise by groups of participants by means of their own practical actions and by means of their own reflection upon the effects of those actions.
- Ebbutt (cited by Hopkins, 1985)

In short, AR is characterized by those constraints and strengths given a research methodology intended to be a workable technique for working classroom teachers.

Characteristic AR Designs

The essentials of Action Research design are considered by Elliott (cited by Hopkins, 1985) as per the following characteristic cycle:

- initially an exploratory stance is adopted, where an understanding of a problem is developed and plans are made for some form of interventionary strategy. *(The Reconnaissance & General Plan)*

- then the intervention is carried out. *(The Action in AR)*
- during and around the time of the intervention, pertinent observations are collected in various forms. *(Monitoring the Implementation)*

- the data are examined for trends and characteristics, and a new strategy developed for implementation. *(The Revised Plan or Maintaining the Action)*

- the new interventional strategies are carried out, and the cyclic process repeats, continuing until a sufficient understanding of (or implementable solution for) the problem is achieved.

The Iterative Approach

The protocol is iterative or cyclical in nature and is intended to foster deeper understanding of a given situation, starting with conceptualizing and particularizing the problem and moving through several interventions and evaluations. A representation of an AR protocol by Kemmis (cited in Hopkins, 1985) is provided in Figure 3.

![Figure 3: Action Research Protocol after Kemmis (cited in Hopkins, 1985)
Figure 3 clearly displays the iterative nature of AR along with the major steps of planning, action, observation and reflection before revising the plan. This may be thought of as similar in nature to the numerical computing technique known as successive approximation - the idea is to close in upon a final goal or outcome by repeated iterations.

Later protocols reflect changes in the goal as determined via experience during the reflections of earlier iterations of AR. For instance, Figure 4 reflects the evolution of the general idea or main topic of interest throughout the process.

Figure 4: Action Research after Elliott (cited in Hopkins, 1985)
Elliott's model emphasizes constant evolution and redefinition of the original goal through a series of reconnaissances recurring every cycle. The reconnaissance necessarily includes some degree of analysis. This design permits much greater flexibility, and seeks to '...recapture some of the 'messiness' which the Kemmis version tends to gloss' [over] (Hopkins, 1985). Ebbutt (cited in Hopkins, 1985) further illustrates the evolution of the overall plan through a spiral analogy, as described in Figure 5:

Figure 5: Action Research Protocol after Ebbutt 4: (cited in Hopkins, 1985)

The Role of Communication

Another distinguishing characteristic of Action Research is the degree of empowerment given to all participants. Involvement is of a knowing nature, with no hidden controls or preemption of direction by the researcher. All participants negotiate meaning from the data and contribute to the selection of interventionary strategies, including the university researchers, the teachers and the students.
Elliott considers the need for communication between all participants to be of paramount importance:

Since action research looks at a problem from the point of view of those involved it can only be validated in unconstrained dialogue with them (Elliott, 1978).

and;

Since action research involves unconstrained dialogue between ‘researcher’ (whether he be an outsider or teacher/researcher) and the participants, there must be free information flow between them (ibid).

The Role of Reflection

Perhaps the key component involved in AR is the notion of praxis. AR is intended to be the '...reflective counterpart of practical diagnosis...' (Elliott, 1978). Schon describes the use of reflection to generate models from a body of previous knowledge -- these models are used to frame a problem; then experiments are performed to bring about outcomes which are subjected to further analysis. This model (called reflection-in-action) frames means and ends interdependently and recognizes that there is little or no separation of research from practise, little or no separation of knowing and doing (Schön, 1983). Schön's model of reflection-in-action compliments the iterative and investigative natures of Action Research.

The Methodological Decision

The marked quality and amount of student and instructor communication resulting from the first use of MBL technology in the classroom led to the redesign of this study. What commenced as a quantitative analysis of student performance became a qualitative examination of a wide variety of factors and issues concerning technological innovation and implementation in a working classroom. The quality of participant communication, combined with the necessity of a qualitative, iterative approach involving situational diagnosis and reflection resulted in the adoption of an Action Research methodology.
Chapter 3: The Research Setting, Curriculum and Instruments

"Technology is not about tools, it deals with how man works."

-- Druker (in Dale, 1984)

This chapter discusses the environment of the MBL Project study. As the actual study procedures were derived from student feedback, those activities will be discussed in the context of their results in chapter four. Here an attempt is made to describe the setting, curriculum and data collection instruments for the study. Particular emphasis is placed upon a description of the standard B.C. laboratory curriculum, later modified for the study.

3.1 The Locations

The MBL Project operated at three physical sites: The Computers in Education Research Group (CERG) offices in the Scarfe Building at the University of British Columbia, the Chemistry classroom and laboratory of a senior secondary school in Richmond and the Chemistry classroom and laboratory of a secondary school in Surrey, British Columbia.

The CERG office at the UBC Faculty of Education had previously designed and developed hardware intended for eventual use as a laboratory interface (Hickman, 1988) and interface development continued here throughout the project. Hardware design, evaluation and construction as well as software development and refinement occurred in the CERG offices, and are detailed in Appendices C and D.

The Richmond senior secondary school is a grade 11 and 12 high school located in a municipality of greater Vancouver serving slightly less than a thousand students and administered as part of the Richmond School District No 38. The project coordinator for the MBL Project was the teacher responsible for the majority of Chemistry instruction at that school. A second Chemistry teacher from the same school participated in the study. Major funding to the MBL Project from the British Columbia Ministry of Education was administered by the Vice-Principal of that school. MBL Project funding and administrative organization are further detailed in Appendix B.
The Surrey secondary school is a combined school teaching grades 8-12 also located in greater
Vancouver, administered by the Surrey School District No 36. The Chemistry instructor at North
Surrey also participated as a cooperating teacher in the project.

3.1.1 Schools

The two schools participating in this study are quite different. The Richmond school is a fairly
specialized high school drawing very academic students from a suburban region. Many of these
students, intent upon taking advantage of this academic reputation, specifically attend that school via
cross-boundary school transfers. The school regularly enters most of the available academic
science and mathematics competitions including the International Chemistry Olympiad. A high
proportion of graduates from this school pursue a university degree after graduation, and student
performance in the Chemistry 12 provincial exam is above the provincial average. The school has
been aggressively acquiring computer technology for the last decade and has a large Macintosh
computer laboratory as well as a number of computers scattered throughout the buildings, including
the science laboratories and classrooms.

Chemistry is a popular offering in the Richmond school, and it is not unusual for three or four
classes of twenty to twenty-five students to be taking Chemistry 11 simultaneously, with a slightly
lesser number enrolled in Chemistry 12. Due to this large population, significant technical and
laboratory resources are available. Classroom floor and table space is sharply limited, but other
Chemistry laboratory resources include a dedicated Apple //e computer with a commercially
available MBL-- Human Relations Media's Experiments in Chemistry (Malone, Naiman & Tinker,
1985) and a liquid crystal overhead projection device, as well as two Spec 20D spectrophoto-
meters. Typical laboratory resources such as pH meters, glassware and chemicals are abundant.
The science department has several Macintosh computers, printers and a MODEM, and employs a
full-time laboratory technician to assist teachers and maintain the facilities.

The Surrey school is more rurally set (it lies upon the boundary between a suburb and rural
farmlands), with about 1100 students with lesser financial resources distributed over a far wider
range of course offerings by grade (junior and senior high) and subject. There are fewer computing resources than at Richmond, although improvements such as a new Macintosh lab are underway, and there are fewer Chemistry laboratory resources as well. Students come from a larger geographical area and have less selection amongst schools. Surrey students on average commute farther to school, which restricts in-school study, makeup time and extended classroom opportunities. However, the Chemistry laboratory (also used to instruct junior high Science) is more spacious and makes better use of floor and counter space than in Richmond, having separate desk and laboratory bench facilities. The science department has two Apple //GS computers and a Macintosh for instructor use, as well as a HRM interface, a Spec 20D, pH meters and other standard Chemistry facilities, equipment and instruments. Many Surrey graduates pursue further formal education after graduation, and student performance in the Chemistry 12 provincial exam is at the provincial average.

3.1.2 Teachers and Researchers

The teachers involved with this study were all experienced instructors with an interest in Chemistry laboratory instrumentation. The principal teachers from each site acquired MBL resources (the HRM package for the Apple //) for their schools previous to this study and the Richmond instructor had been making extensive use of that equipment for classroom demonstration. Both of these gentlemen have served on the Provincial Chemistry 11 and 12 Curriculum Revision Committee (British Columbia Ministry of Education, 1987), and have approximately 20 years each of instructional experience in Chemistry 11 and 12. The Richmond instructor (who holds a masters' degree in Science Education) has been active in promoting the use of MBL to other B.C. Chemistry teachers. The Surrey instructor is currently enrolled in a Masters' program. All teachers volunteered their own participation and that of their students in the MBL Project.
The UBC Department of Mathematics and Science Education administers the CERG offices and resources, which include several Macintosh computers, a wide variety of software and peripherals and a modest library of technical references. Office and Chemistry laboratory space was also made available at CERG. Funding and access to UBC Department of Electrical Engineering and Stores was also arranged through CERG. CERG previously designed and constructed the original Macintosh interface hardware with funding under an Apple Canada Education Foundation grant.

3.1.3 Students

The students participating in the study represented a wide spectrum of high school student background and ability. Several students placed highly in concurrent university scholarship competitions. One student was a mature adult immigrant upgrading his high school chemistry certification for admission to a local technical institute. Other students were enrolled in Chemistry 11 as part of programming for special-needs students. A number of students spoke English as their second language (ESL). Many students had technical interests and had access to computers out of school in addition to regular in-class school access. Many of the students worked part-time in addition to their high school studies.

3.2 The B.C. High School Chemistry Curriculum

Chemistry 11 and 12 as offered in British Columbia (British Columbia Ministry of Education, 1987) have four major program goals:

A: The Chemistry curriculum should provide opportunities for students to develop scientific attitudes, and to develop positive attitudes towards chemical science.

B: The Chemistry curriculum should provide opportunities for students to acquire the skills and to understand the processes of chemical science.

C: The Chemistry curriculum should provide opportunities for students to develop an understanding of the basic concepts and principles of chemical science.

D: The Chemistry curriculum should provide opportunities for students to develop critical and abstract thinking abilities.
The curriculum is defined through a series of intended learning outcome statements which are specified in terms of pages in the prescribed textbook and laboratory activities from the prescribed laboratory manual. The curriculum guide further specifies that approximately twenty-five percent of available class time in Chemistry 11 and 12 is to be devoted to student experiment or teacher demonstration in a laboratory setting.

Chemistry 11 is organized with 80 hours of core topics, and 20 hours available for optional material. Chemistry 12 contains five major units with no provision for option. Student exit performance in Chemistry 12 is evaluated via a two hour provincial examination (unlike Chemistry 11).

The Chemistry 11 and 12 curriculum guide suggests a number of appropriate computer support materials, and these six commercially available packages include two MBLs: Human Resource Media's Experiments in Chemistry (Malone, Naiman, & Tinker, 1985) and Science Toolkit (Broderbund, 1985), the remainder of the software being more traditional CAI products emphasizing drill and practise.

3.3 The Grade 11 B.C. High School Chemistry Curriculum

The Grade 11 B.C. Chemistry curriculum is based upon a core of eleven topics with attendant laboratory activities scheduled as follows:
Table 2: Grade 11 B.C. Chemistry Curriculum Topics

<table>
<thead>
<tr>
<th>Topic</th>
<th>Title</th>
<th>Time</th>
<th>Laboratory Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Lab Safety</td>
<td>4 hours</td>
<td>1a</td>
</tr>
<tr>
<td>II</td>
<td>Introduction to Chemistry</td>
<td>7 hours</td>
<td>1b, 2b, 2d</td>
</tr>
<tr>
<td>III</td>
<td>Properties of Substances</td>
<td>5 hours</td>
<td>1c, 2a-2c, 3a-d, 4a, 7a</td>
</tr>
<tr>
<td>IV</td>
<td>Introduction to Inorganic Naming</td>
<td>4 hours</td>
<td>nil</td>
</tr>
<tr>
<td>V</td>
<td>The Mole Concept</td>
<td>5 hours</td>
<td>4b, 4c, 4d, 7b</td>
</tr>
<tr>
<td>VI</td>
<td>Chemical Reactions</td>
<td>12 hours</td>
<td>4a, 5a-d, 6a-e, 7b, 7c, 17b</td>
</tr>
<tr>
<td>VII</td>
<td>Atomic Structure</td>
<td>5 hours</td>
<td>8a, 10a</td>
</tr>
<tr>
<td>VIII</td>
<td>Introduction to the Periodic Table</td>
<td>4 hours</td>
<td>5d, 11a, 13a</td>
</tr>
<tr>
<td>IX</td>
<td>Introduction to Bonding</td>
<td>3 hours</td>
<td>12a, 12b</td>
</tr>
<tr>
<td>X</td>
<td>Solution Chemistry</td>
<td>15 hours</td>
<td>12a, 13b, 16a-d, 20c</td>
</tr>
<tr>
<td>XI</td>
<td>Organic Chemistry</td>
<td>11 hours</td>
<td>12b, 23a-c, 24a</td>
</tr>
</tbody>
</table>

An additional ten untimed optional topics (with laboratory activities) include: Nuclear Chemistry (9a), Consumer Chemistry (20c), Analytical Chemistry (2d, 16e, 21b-c, 22b-c), Environmental Chemistry (20i), Pulp and Paper (nil), Food and Food Additives (nil), Local Industrial Chemistry (14a), Metallurgy (21f), Petrochemicals and Polymer Chemistry (nil) and Biochemistry (nil).

3.3.1 Experiment #2a - Cooling and Heating Curves of a Pure Substance

This experiment involves the investigation of the temperature of fusion of paradichlorobenzene (PDB or mothballs), a chemical with a melting point of 53.1°C (Weast, 1980). Students record the cooling behavior of liquid PDB through its freezing point, and the heating behavior of solid PDB through its melting point. Students observe that both freezing and melting temperatures are the same and create graphs that indicate that all of the PDB must freeze before the temperature can fall below 53°C when cooling, or that all of the PDB must melt before the temperature can rise above 53°C when heating.

Curricular Intent

This experiment is intended to supplement classroom activities addressing the grade 11 B.C. Chemistry curricula topic III: Properties of Substances (British Columbia Ministry of Education, 1987) partially detailed in Table 3. Learning outcomes particularly pertinent to laboratory 2a have been italicized.
Table 3: Intended Learning Outcomes for Properties of Substances

<table>
<thead>
<tr>
<th>Topics</th>
<th>Intended Learning Outcomes</th>
</tr>
</thead>
</table>
| A. Phases of Matter and Phase Changes | 1. Classify a substance as either a solid, liquid or gas;  
2. Define the terms boiling point, freezing point, melting point;  
3. Identify gases as being compressible and elastic (springy). |
| B. Categories of Matter | 1. Describe a substance as having a set of unique and identifiable properties;  
2. Classify a given material as either homogeneous or heterogeneous  
3. Classify a given material as an element, compound or mixture, using the properties of the material. |
| C. Atoms and Molecules (and Introduction to Ions) | 1. Relate the observable properties and characteristics of elements, compounds and mixtures to the concept of atoms and molecules;  
2. Describe the simple molecular motions and molecular arrangements for solids, liquids and gases and the changes in molecular motions and arrangements that occur during phase changes;  
3. Relate the heat changes that occur during phase changes to changes in molecular motions and arrangements;  
4. Cite evidence for the existence of ions. |
| D. Measurement in Chemistry | 1. Demonstrate skills in measuring mass, volume (liquid) and temperature;  
2. Describe the imprecise nature of all measurements;  
3. Record uncertainties with measurements as a +/- quantity; |

[D has been truncated and E omitted for brevity]

Experimental Procedure

Experiment 2a – Cooling and Heating curves of a Pure Substance is detailed as follows (DiSpezio et al, 1987):

PreLaboratory Quiz:

1. How can melting and freezing points be used by chemists?  
   [For identifying pure substances]  
2. What substances will be studied in this experiment?  
   [Paradichlorobenzene]  
3. What is the reason for using two thermometers in this experiment?  
   [One is used to report the temperature of the PDB; the other to monitor the temperature of the water bath]  
4. Before starting either the heating or the cooling process, what should you and your partner decide?  
   [Who will observe and who will record]
Objectives:

1. To investigate the cooling process for liquid paradichlorobenzene;
2. To investigate the heating process for solid paradichlorobenzene; and
3. To determine and compare the melting and freezing temperatures of paradichlorobenzene.

Procedure: Part I -- The Cooling Process

Students work in pairs, one partner as observer and one as data recorder. The students put 300 mL of cold tap water into a 400 mL beaker, which is placed on a laboratory ring stand. Then a large test tube containing solidified paradichlorobenzene is heated over a bunsen burner flame until molten. A thermometer is placed in the liquid PDB and it is heated to a temperature of 70-75 C. Then the tube is clamped so that the end of the tube containing liquid PDB is immersed in the cold water. The recorder will take temperature readings every 30 seconds for about 10 minutes as the PDB cools, while the observer records time of initial and complete solidification.

Procedure: Part II -- The Heating Process

Partners exchange observing and recording duties. The test tube containing frozen PDB with the embedded thermometer is raised clear of the water and swung to one side, and a second thermometer is placed in the beaker. The bunsen burner is then used to heat the water to approximately 75C, then moved to one side. The test tube is re-immersed and clamped in position, and temperatures are recorded every 30 seconds as the PDB warms and melts. The burner is used to maintain the water temperature above 60C and the PDB is stirred gently as required. The initial and complete melting times and temperatures are recorded. Then the test tube is stoppered and returned to the teacher, and the thermometers and other apparatus are cleaned and put away.
Data Analysis: Graphing

Data analysis continues as a home assignment, where students graph their numeric data, creating both a heating and a cooling curve upon the same graph. The points at which melting and solidification began and ended are also indicated. A graph of this nature is indicated in Figure 6.

ANALYSIS OF DATA (GRAPHING)

Figure 2A-1T Cooling and heating curves for paradichlorobenzene.

Figure 6: Heating and Cooling Curves for Paradichlorobenzene (DiSpezio et al, 1987)
Then the following questions (DiSpezio et al, 1987) are answered:

1. What property of PDB may convince you that it is an ingredient in mothballs?
   [the characteristic odour]
2. From your cooling curve, determine the freezing point of PDB. [near 53°C]
3. From your heating curve, determine the melting point of PDB. [near 53°C]
4. Compare your melting and freezing points with those of two other lab groups, and describe any similarities or differences.
   [all the data should be quite similar]
5. What can you conclude about the melting points and freezing points of a pure substance? [they are the same.]

Follow-Up Questions:

1. How would you explain the plateaus in your heating and cooling curves?
   [incomplete melting or freezing -- the potential energy rather than the kinetic energy of the molecules is being altered]
2. Suppose that more PDB had been used in Part I. What would be the appearance of the new cooling curve? [slower temperature drop -- gentler slope; much broader plateau at the same freezing point; then slower drop again]

Procedural Commentary

Part I of the procedure usually consumes a single class period of about an hour. Part II of the procedure also consumes a single class period of about an hour, then students complete their graphs and analysis as homework. Analysis (graphing) usually occurs off-site, and after the ability to control experimental variables and correct procedural errors has passed. Follow-up questions from the laboratory manual are treated in class at a later date.

The various graph differences experienced by students are partially due to contamination of the PDB, as the same samples are reused for some time, and to the thermometer contacting the glass walls of the test tube rather than being completely surrounded by the PDB, which will give an apparently warmer melting temperature and an apparently cooler freezing temperature.

3.3.2 Experiment #16b - Preparation of Standard Solutions and Use of a Spectrophotometer to Measure the Concentration of an Unknown Solution

This experiment involves the use of a Spec 20D spectrophotometer and several solutions of a known ionic concentration to prepare a straight line graph expressing Beer's Law (light absorbance...
at a characteristic wavelength versus concentration) for solutions of Co\textsuperscript{2+}. This graph can then be used to determine an unknown concentration of Co\textsuperscript{2+} by finding the absorbance of the unknown solution using the Spec 20D and reading the corresponding concentration.

Curricular Intent

This experiment is intended to supplement classroom activities addressing the grade 11 B.C. Chemistry curricula topic X: Solution Chemistry (British Columbia Ministry of Education, 1987) detailed in Table 4. Learning outcomes particularly pertinent to laboratory 16b have been italicized.

Table 4: Intended Learning Outcomes for Solution Chemistry

<table>
<thead>
<tr>
<th>Topics</th>
<th>Intended Learning Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>F. Molarity of Aqueous Solutions</td>
<td>1. Describe Molarity (mol/L or M) as the preferred way to specify concentration in Chemistry;</td>
</tr>
<tr>
<td></td>
<td>2. Describe the necessary steps to prepare a solution of given concentration;</td>
</tr>
<tr>
<td></td>
<td>3. Calculate the molarity of a solution when given the number of moles of solute dissolved in a given volume solution (mL or L);</td>
</tr>
<tr>
<td></td>
<td>4. Calculate the concentration of a solution given the volume of the solution and the mass of the solute;</td>
</tr>
<tr>
<td></td>
<td>5. Calculate the volume of a solution of known concentration which would contain a particular mass of solute;</td>
</tr>
<tr>
<td></td>
<td>6. Produce a given volume of working solution from a standard stock solution;</td>
</tr>
<tr>
<td></td>
<td>7. Calculate the resulting concentration when a given volume of a solution of known concentration is diluted with water to a given volume;</td>
</tr>
<tr>
<td></td>
<td>8. Calculate the concentration of ions resulting when two solutions of known concentration and volume are mixed, assuming no reaction.</td>
</tr>
</tbody>
</table>

Experimental Procedure

Introduction:

The introduction to the laboratory gives a brief introduction to the theory and operation of the Spec 20 spectrophotometer (see Figure 7), which simply passes a light through a solution, and measures the amount of light absorbed by the solution at a certain frequency by reflecting transmitted light.
from a diffraction grating and detecting it via a photocell shrouded by a narrow slit. The Spec 20 must be allowed to warm up in advance (to stabilize bulb and amplifier characteristics), then the wavelength is selected and the amplifier background level is set to zero using the left-hand dial (with no cuvette in the sample compartment, a shutter blocks light from striking the photocell). Next, a cuvette containing sample of distilled water is set in the sample compartment and the right-hand amplifier gain is set to a transmittance of 100% (light passing through the distilled water provides a reference signal that becomes 100% transmittance or 0 absorbance). Then the Spec 20 may be used to read percentage absorbance for any sample at the calibrated wavelength by simply placing a cuvette containing the desired sample in the compartment and closing the lid, then waiting for the reading to settle. If the Spec 20 is to be used at another wavelength, it must be recalibrated from scratch. Students are given a handout in advance of this laboratory to familiarize them with the Spec 20D, and this laboratory is their first use of the device.

**The Spec 20D Spectrophotometer**

![Diagram of the Spec 20D Spectrophotometer](image)

Figure 7: The Spec 20D Spectrophotometer
PreLaboratory Quiz (DiSpezio et al, 1987):

1. What does a spectrophotometer measure?
   [the amount of light of a particular frequency passing through a solution]
2. What does increasing the concentration of a solution do to the amount of light transmitted?
   [decreases the amount of light transmitted]
3. What is meant by a standard solution?
   [A solution with a concentration that is known accurately]
4. Why is it essential that the cuvettes or test tubes placed in the spectrophotometer be clean?
   [If dirty, the transmittance of the light will be interfered with by the impurities]

Objectives:

1. To prepare a standard solution of known concentration of cobalt (II) nitrate.
2. To prepare various dilutions of the standard solution.
3. To measure the percentage transmittance, or absorbance, or both, of the solutions using a spectrophotometer, and to construct a calibration graph from the data.
4. To obtain the concentration of an unknown solution using the calibration graph.

Procedure: Part I -- Preparation of a Standard Co(NO₃)₂ Solution

Students calculate the mass of Co(NO₃)₂·6H₂O needed to make 100 mL of a 0.160 M solution, then measure out this amount into a small beaker and dissolve it. Then this solution is poured into a 100 mL volumetric flask and the volume of solution is made up to 100.0 mL using distilled water washings from small beaker. This solution is stoppered, and is the standard.

Procedure: Part II -- Preparation of Dilute Solutions of Co(NO₃)₂

Five small test tubes or cuvettes are obtained, and are labelled A through E. Into A, 5 to 10 mL of the 0.160 M stock solution are poured (enough to fill the cuvette and allow a stopper or a parafilm covering to prevent evaporation). Then, 12.0 mL of the stock solution are watered to 16.0 mL in a graduated cylinder, and cuvette B is filled from this. Next 8.0 mL of stock are watered to 16.0 mL, and cuvette C is filled. Finally, 4.0 mL and 2.0 mL of stock are both watered to 16.0 mL for cuvettes D and E. The molarities for the five cuvettes are calculated and then entered into a data table.
Procedure: Part III -- Measuring the Concentration with a Spectrophotometer

Use of the Spec 20 is reviewed, then the spectrophotometer is warmed up and calibrated (readings for the Co\textsuperscript{2+} ion are taken at a wavelength of 510 nm -- a reddish-brown colour). Then each cuvette is placed into the sample compartment, and the percent absorbance and transmittance are recorded in the same data table describing the concentration of each sample. Then an absorbance and transmittance is recorded for the instructor-provided unknown sample. All Spec 20 readings are repeated and double-checked. Finally, all reagents are disposed of and the apparatus is put away.

Questions and Calibrations (DiSpezio et al, 1987):

1. Calculate the molarity of the Co\textsuperscript{2+} ion in each of solutions 1 - 5. The new molarity is given by the molarity of the stock solution multiplied by the dilution factor (ratio of original volume to final volume). [A = 0.160 \( M \), B = 0.120 \( M \), C = 0.080 \( M \), D = 0.040 \( M \), E = 0.020 \( M \)]

2. Plot a graph of your results, using metric graph paper. Put concentration on the X-axis, using a scale of 1 cm = 0.01\( M \), and absorbance on the Y-Axis, using a scale of 1 cm = 0.05 A. (If you recorded your results as percent transmittance, use 1 cm = 5\% transmittance.) [see Figure 8 and Figure 9]

![Graph](Figure 8: [CO\textsuperscript{2+}] vs Absorbance (DiSpezio et al, 1987))
3. Determine the concentration of your unknown solution by reading from your graph the concentration that is equivalent to the absorbance or percent transmittance you recorded. Be sure to state in your report which unknown you used if more than one was available. [a simple lookup to determine concentration -- see the dotted lines in Figures 8 and 9]

4. Why does a volumetric flask have the shape it does? [for greatest precision in fluid level measurement and minimum thermal expansion and contraction, it has a very high and thin neck]

5. Looking at your results, and the shape of your graph, do you think your results could have been improved by the use of graduated pipets instead of graduated cylinders? [careful technique will yield an excellent line; the pipets are not required.]

6. What is the advantage of reading the absorbance rather than the percent transmittance on the spectrophotometer? [this question is usually waived; the advantage is the linear rather than logarithmic plot.]

7. Why is it a good idea to wash out the cuvettes with the solution you are using before refilling it to read in the spectrophotometer? [to ensure that the sample is not diluted by water from cleaning the cuvette still present in the cuvette.]

Figure 9: [Co2+] vs Transmittance (DiSpezio et al, 1987)

Graph 1  [Co2+] vs. % Transmittance
Follow-Up Question:
1. In order to analyze the waste water containing Co$^{2+}$ from a manufacturing process, 1.0 L of water was evaporated to 10 mL, then placed in a spectrophotometer cuvette. The absorbance was found to be 0.20 (63% transmittance). Using your calibration curve, calculate the number of milligrams of Co$^{2+}$ in 1.0 L of waste water. [22 mg/L]

Procedural Commentary

Students usually complete Part I and II in a single laboratory session of about an hour, and calculate the molarities as homework for the next class, when the solutions will be measured with the spectrophotometer. To prevent water evaporation and changing concentrations, the five cuvettes and the remaining stock solution are sealed from the air using rubber stoppers or laboratory parafilm while left overnight. Part III consumes another classroom laboratory session, although some students do commence plotting their graphs before leaving the classroom.

Students plotting absorbance will obtain a near-straight line graph by using a ruler and estimating the best line fit by eye; students usually do not plot transmittance (this activity is waived). Both plots are representations of Beer's Law, the theory of which is not taught. Again, the majority of data analysis occurs outside the lab.

3.4 The Grade 12 B.C. Chemistry Curriculum

The Grade 12 B.C. Chemistry curriculum is based upon a core of five topics with attendant laboratory activities scheduled as follows:

<table>
<thead>
<tr>
<th>Topic</th>
<th>Title</th>
<th>Time</th>
<th>Laboratory Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Reaction Kinetics</td>
<td>10-15 hours</td>
<td>18a-c</td>
</tr>
<tr>
<td>II</td>
<td>Equilibrium</td>
<td>15-20 hours</td>
<td>19a-b</td>
</tr>
<tr>
<td>III</td>
<td>Solubility of Ionic Substances</td>
<td>15-20 hours</td>
<td>16c-e, 19c-d, 22a</td>
</tr>
<tr>
<td>IV</td>
<td>Acids, Bases and Salts</td>
<td>35-40 hours</td>
<td>20a-i</td>
</tr>
<tr>
<td>V</td>
<td>Oxidation - Reduction</td>
<td>20-25 hours</td>
<td>21a-f, 22b, 23d</td>
</tr>
</tbody>
</table>
3.4.1 Experiment #19b - The Quantitative Relationship Involving Concentrations of Reactants and Products at Equilibrium

This experiment is another spectrophotometry experiment, examining the reactants in the following reaction:

\[ \text{Fe}^{3+}(\text{aq}) + \text{SCN}^- \leftrightarrow \text{FeSCN}^{2+}(\text{aq}) \]  

(1)

where the \( \text{FeSCN}^{2+} \) ion is a deep blood-red ion absorbing light strongly at a wavelength of 590 nm. Here the concentrations of the reactants are known, and that of the product is measured via the Spec 20D, then the Equilibrium Constant for the reaction may be determined (LeChatelier's Principle).

Curricular Intent

This experiment is intended to supplement classroom activities addressing the grade 12 B.C. Chemistry curricula topic II: Equilibrium (British Columbia Ministry of Education, 1987) partially detailed in Table 5. Learning outcomes particularly pertinent to laboratory 19b have been italicized.

Table 5: Intended Learning Outcomes for Equilibrium

<table>
<thead>
<tr>
<th>Topics</th>
<th>Intended Learning Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. Le Chatelier's Principle</td>
<td>1. Formulate a statement of Le Chatelier's Principle given sufficient data on the shifting of equilibrium;</td>
</tr>
<tr>
<td></td>
<td>2. Apply Le Chatelier's Principle in the rationalization of the shifting of equilibrium caused by changes in temperature, concentrations, or partial pressures, or volume;</td>
</tr>
<tr>
<td></td>
<td>3. Predict the shift of an equilibrium due to an imposed change, using Le Chatelier's Principle;</td>
</tr>
<tr>
<td>F. Mathematical Relationships Among Product and Reactant Concentrations at Equilibrium.</td>
<td>1. Demonstrate an ability to gather and interpret data on the concentration of reactants and products of a system at equilibrium;</td>
</tr>
<tr>
<td></td>
<td>2. Hypothesize a relationship among equilibrium concentrations of reactants and products;</td>
</tr>
<tr>
<td></td>
<td>3. Generalize this hypothesis to other equilibrium systems.</td>
</tr>
</tbody>
</table>
G. Equilibrium Constant Expressions

1. Write the expression for the equilibrium constant when given the equation of the reaction for an equilibrium system;

2. Write the expression for the equilibrium constant for a reaction which includes solids and liquids.

[Topics H - K omitted for brevity]

Experimental Procedure

PreLaboratory Quiz (DiSpezio et al, 1987):

Before commencing the experiment, students are given a short quiz consisting of the following questions:

1. On the basis of Le Chatelier's principle, what result do you expect to see if a lower $[\text{Fe}^{3+}]$ is used in this experiment, while $[\text{SCN}^-]$ is kept constant? $[\text{FeSCN}^-]$ should decrease as the equilibrium shifts left to compensate for lower $[\text{Fe}^{3+}]$. Colour intensity decreases.

2. Why must absorbance be measured in this experiment, rather than % transmittance? [because the concentration must be calculated, since no calibration curve can be drawn]

3. Explain why the original $[\text{Fe}^{3+}]$ and $[\text{SCN}^-]$ must be halved in each case to get initial concentration of each ion in the reaction mixture. [because equal volumes of each are being mixed together, the final volume is twice the initial volume, resulting in a dilution factor of one half]

4. Why can you assume that in test tube A essentially all of the SCN$^-$ will be in the form of FeSCN$^{2+}$? [because there is a large excess (100:1) of $\text{Fe}^{3+}$ in relation to SCN$^-$, pushing the equilibrium virtually all the way to the right]

Objectives:

1. To prepare various dilutions of $\text{Fe}^{3+}$ ion and react them with SCN$^-$ ion;
2. To measure the concentration of FeSCN$^{2+}$ ion produced by means of a spectrophotometer;
3. To use a spectrophotometer to discover a constant mathematical relationship among the concentrations of reactants and products at equilibrium.

Procedure: Part I -- Reaction of SCN$^-$ with various dilutions of $\text{Fe}^{3+}$.

Students obtain approximately 30 mL of 0.0020 $M$ KSCN and 20 mL of 0.200 $M$ Fe(NO$_3$)$_3$ in two beakers, and then produce five dilutions of the Fe(NO$_3$)$_3$ solution as follows: test tube A is to contain 5.0 mL of undiluted solution, then 10.0 mL of the remaining solution are watered to 25.0 mL, and 5.0 mL are drawn off and placed in test tube B. 10.0 mL of the remainder of this first dilution are further watered to 25.0 mL, and 5.0 mL are drawn off for test tube C. Then 10.0 mL of
the remainder of the second dilution are watered again to 25.0 mL, and 5.0 mL are drawn off for D and the procedure is repeated again for E. Then to each of the five test tubes is added 5.0 mL of the 0.0020 M KSCN. Finally, each of these solutions is placed in a cuvette for spectrophotometric measurement.

Procedure: Part II -- Measuring the Concentration of FeSCN$^{2+}$ with a Spectrophotometer

Procedures for the operation of the Spec 20D are reviewed, then each of the five cuvettes is placed in the spectrophotometer and the absorbances of the FeSCN$^{2+}$ are recorded in a data table along with the calculated initial concentrations of Fe$^{3+}$ and SCN$^{-}$. A data table similar to table 6 is produced:

Table 6: Data and Observations for Experiment 19b

<table>
<thead>
<tr>
<th>Test Tube</th>
<th>Initial [Fe$^{3+}$]</th>
<th>Initial [SCN$^{-}$]</th>
<th>Absorbance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.100 M</td>
<td>0.0010 M</td>
<td>0.55</td>
</tr>
<tr>
<td>B</td>
<td>0.040 M</td>
<td>0.0010 M</td>
<td>0.50</td>
</tr>
<tr>
<td>C</td>
<td>0.016 M</td>
<td>0.0010 M</td>
<td>0.44</td>
</tr>
<tr>
<td>D</td>
<td>0.006 M</td>
<td>0.0010 M</td>
<td>0.32</td>
</tr>
<tr>
<td>E</td>
<td>0.003 M</td>
<td>0.0010 M</td>
<td>0.18</td>
</tr>
</tbody>
</table>

Calculations:

1. & 2. Students calculate the initial [Fe$^{3+}$] and [SCN$^{-}$], then use the fact that there is such an excess of Fe$^{3+}$ ions (approximately 100X the SCN$^{-}$ population) in test tube A that all of the SCN$^{-}$ ions are used in this particular reaction. Therefore, the concentration of the products of this reaction in test tube A -- the [FeSCN$^{2+}$] is equal to the concentration of the initial SCN$^{-}$ ion -- 0.0010 M. This known concentration of reaction products is assumed to be entirely responsible for the absorbance of that sample at 590 nm, and Equation 2 can be used to calculate the [FeSCN$^{2+}$] (the reaction products) in each of the four test tubes B - E.
\[ [\text{FeSCN}^2+] \text{ (test tube X)} = [\text{FeSCN}^2+] \text{ (test tube A)} \times \frac{\text{Absorbance (test tube X)}}{\text{Absorbance (test tube A)}} \] (2)

3. The \([\text{FeSCN}^2+]\) is determined for each test tube B - E and then the equilibrium \([\text{Fe}^{3+}]\) and \([\text{SCN}^-]\) are calculated by subtracting the \([\text{FeSCN}^2+]\) from the initial concentrations of each of the reaction products. This is possible due to the reaction mole ratio of 1:1:1.

4. Students are asked to calculate the values of the following expressions in search of a constant mathematical relationship between equilibrium concentrations:

   \[ \frac{[\text{FeSCN}^2+][\text{Fe}^{3+}]}{[\text{SCN}^-]} \quad \frac{[\text{FeSCN}^2+]}{[\text{Fe}^{3+}][\text{SCN}^-]} \quad \frac{[\text{Fe}^{3+}][\text{SCN}^-]}{[\text{FeSCN}^2+] + [\text{SCN}^-]} \quad \frac{[\text{FeSCN}^2+]}{[\text{Fe}^{3+}][\text{SCN}^-]} \]

   [notice that formula b is LeChatelier's Principle]

5. Finally the student selects the equation that yields the least overall change between maximum and minimum values for the four test tubes.

Follow-Up Questions (DiSpezio et al, 1987):

1. The most constant expression in question 5 is called the equilibrium constant expression \((K_{eq})\). Describe the form of the equilibrium of the equilibrium constant expression \((K_{eq})\) in terms of equilibrium concentrations of products and reactants. How are these concentrations related? [the relationship is the numeric form of LeChatelier's Principle, or ]

   \[ K_{eq} = \frac{[\text{products at equilibrium}]}{[\text{reactants at equilibrium}]} \] (3)

2. Referring to the fact that equilibrium products have an equilibrium constant expression, explain why changing the concentration of a reactant or product causes an equilibrium shift in the direction predicted by LeChatelier's Principle. [changing any single term will force the other terms to change in such a manner as to maintain a constant \(K_{eq}\). This change will follow LC's P]

Procedural Commentary

This laboratory typically requires two class periods to complete -- students spend the majority of the first day preparing their solutions and dilutions, then they take and record spectrophotometer
data the second day. Calculations are performed later, and it is not unusual for students to make large dilution errors and not find them until well after the experiment has been performed.

3.4.2 Experiment #20h - Titration Curves

Titrations form an integral part of all high school Chemistry curricula. With widespread availability of pH electrodes and meters, it has become fairly common to examine the pH level of a titrate while titrating. These curves tell much about the physical process, and visual interpretation of titration curves is included in the provincial examination.

Curricular Intent

This experiment is intended to supplement classroom activities addressing the grade 12 B.C. Chemistry curriculum topic IV: Acids, Bases and Salts (British Columbia Ministry of Education, 1987) partially detailed in Table 7. Learning outcomes particularly pertinent to laboratory 20h have been italicized.

Table 7: Intended Learning Outcomes for Acids, Bases and Salts

<table>
<thead>
<tr>
<th>Topics</th>
<th>Intended Learning Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>J. Neutralizations of Acids and Bases</td>
<td>1. Demonstrate an ability to design a neutralization experiment involving the following:</td>
</tr>
<tr>
<td></td>
<td>- primary standards</td>
</tr>
<tr>
<td></td>
<td>- standardized solutions</td>
</tr>
<tr>
<td></td>
<td>- titration curves</td>
</tr>
<tr>
<td></td>
<td>- suitable indicators;</td>
</tr>
<tr>
<td></td>
<td>2. Calculate from titration data at the stochiometric point the concentration of an acid or base;</td>
</tr>
<tr>
<td></td>
<td>3. Calculate the volume of an acid or base of known molarity needed to neutralize a known volume of a known molarity base or acid;</td>
</tr>
<tr>
<td></td>
<td>4. Write a complete ionic and net ionic equation representing the neutralization of a strong or weak acid by a strong base in solution;</td>
</tr>
<tr>
<td></td>
<td>5. Calculate the pH of a solution formed when a strong acid is mixed with a strong base;</td>
</tr>
<tr>
<td></td>
<td>6. Contrast the equivalence point of a strong acid-strong base titration with the equivalence point of a titration involving a weak acid or weak base.</td>
</tr>
</tbody>
</table>

[Topics K - L omitted for brevity]
Experimental Procedure

PreLaboratory Quiz (DiSpezio, 1989):

Before commencing the experiment, students are given a short quiz consisting of the following questions:

1. What is the equivalence point for an acid-base titration? [The point in the titration where the number of moles of $\text{H}_3\text{O}^+$ added equals the number of moles of $\text{OH}^-$ in the solution or vice versa]
2. What is a titration curve? [A plot of pH versus volume of acid or base added during an acid-base titration]
3. What quantity is a pH meter actually reading? [The voltage developed when the glass electrode is inserted]
4. The pH meter must be set for a particular temperature, because the pH of normal water decreases as the temperature increases. Explain the reason for this. [The reaction $2\text{H}_2\text{O} \leftrightarrow \text{H}_3\text{O}^+ + \text{OH}^-$ is endothermic. Therefore, as the temperature increases, the equilibrium shifts right, producing more $\text{H}_3\text{O}^+$ (and $\text{OH}^-$) and thus lowering the pH (and pOH)]

Objectives:

1. To calculate the pH at various stages of the titration of a strong base against a strong acid and plot the results on a graph;
2. To measure experimentally the pH at various stages of the titration of a strong base against a strong acid and plot the results on a graph;
3. To measure experimentally the pH at various stages of the titration of a strong base against a weak acid, plot the results on a graph, and compare the shape to that obtained in Part II.

Procedure: Part I -- Calculated Titration Curve

Students perform a large number of calculations before commencing this laboratory -- a complete titration curve is calculated for the titration of 25.00 mL of 0.100 M HCl with a burette of 0.100 M NaOH. The pH in the titrated solution after the following amounts of titrant are added is calculated and plotted: 0.00, 5.00, 10.00, 15.00, 20.00, 22.00, 24.00 24.50, 24.80, 24.90, 24.95, 25.00, 25.01, 25.05, 25.10, 25.20, 25.50, 26.00, 28.00, 30.00, 40.00 and 50.00 mL. Then the pH calculated at each point is plotted against the volume of NaOH added.

Procedure: Part II -- Experimentally Obtained Titration Curve for NaOH against HCl

Students set up and calibrate their pH meter according to instructions, then pipet 25.00 mL of 0.100 M HCl into a 250 mL beaker, and add three drops of phenolphthalein indicator. Then a buret is
rinsed with the NaOH solution to be used (0.100 M NaOH), filled with the NaOH solution and set into the buret clamp and stand. The glass electrode of the pH probe is then mounted so it is immersed in the beaker, and then the solution in the beaker is titrated with the amounts of NaOH previously calculated in Part I and the exact volumes and pHs are recorded, along with the volume at indicator colour change. This titration is usually repeated for accuracy.

Procedure: Part III -- Experimentally Obtained Titration Curve for NaOH against CH₃COOH

Students then repeat the procedure in Part II, replacing the 0.100 M HCl with 0.100 M CH₃COOH. A data table similar to Table 8 is completed.

Table 8: Data Table for 20h

<table>
<thead>
<tr>
<th>Part I</th>
<th>Part II</th>
<th>Part III</th>
</tr>
</thead>
<tbody>
<tr>
<td>(25.00 mL 0.100 M HCl)</td>
<td>(25.00 mL 0.100 M HCl)</td>
<td>(25.00 mL CH₂COOH)</td>
</tr>
<tr>
<td>Calculated Values</td>
<td>Experimental Values</td>
<td>Experimental Values</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volume of NaOH (mL)</th>
<th>pH</th>
<th>Volume of NaOH (mL)</th>
<th>pH</th>
<th>Volume of NaOH (mL)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td></td>
<td>5.00</td>
<td></td>
<td>10.00</td>
<td></td>
</tr>
<tr>
<td>15.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[Table extends to 50.00 mL and is truncated for brevity]

Questions and Calculations (DiSpezio et al, 1987):

1. Plot a graph of pH versus the volume of NaOH solution added for each set of results from Parts II and II. [see Figures 10 and 11]
2. State three differences in appearance between the graph in Part II (strong acid) and that in Part II (weak acid). [differences include the following: The weak acid curve starts at a higher pH, and rises more steadily in the buffer region (halfway to the equivalence point). The weak acid curve also has a shorter vertical section and a higher equivalence point (the mid-point of the vertical section is greater than pH 7.0).]
3. In Part I, for the addition of 0.02 mL (less than half a drop), by how much did the pH change between 24.99 mL and 25.01 mL? [4.6 pH units -- pH 9.30 to pH 4.70]

4. In Parts II and II, what was the largest pH change you observed when only one drop was added? [about 4 pH units for Part II and 2 pH units for Part III]

5. The equivalence point in an acid-base titration is found at the middle of the most vertical portion on a titration curve. Find the value of the pH at this point for the graphs in Parts II and III. [approx pH 7.00 for Part II, pH 8.87 for Part III]

6. Explain the reason for the difference between the equivalence points for strong and weak acids, as shown by your answer to question 5. [Sodium acetate solution produced at the equivalence point will undergo hydrolysis, becoming basic as OH⁻ is produced]

Follow-Up Questions (ibid):

1. Describe the shape of the titration curve if 0.100 M HCl were run from a buret into 25.00 mL of 0.100 M NaOH. [It would start at pH 13.00, lower gradually until close to the equivalence point, then drop rapidly through pH 7.00 with the addition of one drop. It would then level off rapidly, eventually reaching about pH 1.50 when twice as much acid has been added]

2. Use the table of indicators in Appendix 4 to select all the indicators which would be acceptable for use in your titration of a strong acid with a strong base. [suitable indicators include methyl red, litmus, bromethyl blue, phenol red and phenolphthalein]

3. Why is phenolphthalein the best indicator for titrating a strong base with a weak acid? [because it changes colour in the region pH 8.2 to 10.6, where the equivalence point for a SB/WA titration will lie]

4. From your graph for Part II, read the pH at the point where half the acetic acid has been neutralized. (This corresponds to the point where half the volume of NaOH required for neutralization has been added.) Calculate the [H₃O⁺] that corresponds to this pH. How does this concentration compare to the Kₐ for acetic acid? Explain this result by referring to the Kₐ expression for acetic acid.

[the pH at 12.50 mL is 4.74 [H₃O⁺] is 1.8 x 10⁻⁵ at that point, or equal to Kₐ for acetic acid. When half of the acid has been neutralized, [CH₃COO⁻] = [CH₃COOH]. These terms cancel out of the Kₐ expression, leaving Kₐ = [H₃O⁺] ]

Conclusion:
Describe the general shapes of the graphs obtained in Parts I, II and III.

Procedural Commentary

The graph calculated in Part I is a multi-hour homework assignment, and the resulting plot may require extensive correction due to error. The following two titrations usually take two laboratory periods, and are both repeated for accuracy.
3.5 Data Collection Methods

This study used a wide variety of techniques to collect data during the MBL versions of laboratories 2a, 16b, 19b and 20h. The next section will introduce each of these methods. Chapter 4 will deal with details and interpretations of the observations themselves.

Written Observations

The first method employed was recorded observations made by the author, as no alternative was then available. He observed the equipment and software present for the lab, the many technical difficulties encountered during the class laboratory, the number of students present and their comments upon the experiment, student preparedness, common procedural errors made by students and made notes for future improvements to the experiment.

These notes were not employed as much in later sessions; in order to discuss the activities and assist students it became necessary to make fewer and much briefer notes -- hence the need for a generalized form to be completed by students with their laboratory comments (the laboratory questionnaire). The written observations collected during classroom sessions are found in Appendix F.

Laboratory Reports

Each student taking Chemistry 11 and 12 must produce written laboratory reports to their instructor for a fixed proportion of their grade. These reports were collected and photocopied for several laboratories in both their original unmarked state and later with the teachers grades and comments. These laboratory reports were then scrutinized for evidence of various activities and processes reflecting the appropriateness of MBL technology. This was done using a list of characteristics and a database program to code information from each report in such a way as to allow room for significant comments and general qualitative statistics on the prevalence of the characteristics sought. Approximately 65 complete laboratory reports were collected and examined.
The Laboratory Questionnaire

As extensive observer notes proved ineffective in gathering generalized commentary from students regarding their perceptions of their laboratories, a Laboratory Questionnaire was designed. Students completing MBL (and some routine curricular experiments as well) were asked to fill out an open-ended questionnaire asking them which activities during their laboratory seemed easy to do and understand, and which activities did not. Students were actively involved in the implementation of the MBL materials into their laboratories, and were asked to evaluate the equipment and procedures, and to suggest improvements for the curriculum, hardware and software.

Approximately 165 Laboratory Questionnaires were collected and analyzed via a database and list of characteristics. Many students provided thought-provoking commentary upon these questionnaires. A copy of the questionnaire can be found in Appendix G.

Still Photography

Extensive use was made of still photography during the study to document student behavior and laboratory apparatus setup and operation. Over 95 colour slides and 40 black and white still photos were taken of students at both locations using the MBL materials produced during the study, and these illustrate student behavior such as attentiveness, changes in social groupings, tinkering and experimenting. Photos showing the design and construction of MBL hardware were also taken for presentation use. Copies of these photographic materials are obtainable at CERG or from the author.

VideoTape

A partially-successful attempt was made to document student laboratory activity using a fixed videocamera, and about two hours of videotape were recorded, but detailed analysis of the tape proved beyond available time resources. A cursory examination of the tape provided more validation for certain behaviors (such as attentiveness, grouping and tinkering) noted via other means. Use of videotape was discouraged by instructor discomfort as well.
The pH Review Test

The most extensively-developed MBL experiment during the study was 20h -- Titration Curves. Other research studies (Thornton, in press; Stein, 1987; Linn & Songer, 1989) used achievement tests to measure changes in student learning in either the specific subject domain taught or in general graphical interpretation abilities. An attempt was made during this study to develop a similar instrument using the Chem 12 provincial exam as a guide, and the instrument was used by students as a review for their final exams. This pH Review Test made use of a titration curve diagram with a series of multiple-choice questions requiring the interpretation of data from the curve and the use of numerical data from the diagram in calculations.

The pH Review Test was developed with extensive instructor feedback and administered to approximately 50 grade 12 students. Test results were inconclusive except as a guide for further instrument refinement and therefore are only briefly discussed in Appendix H.

Interviews

End of study exit interviews were held with both a selection of students and the participating instructors. Students were selected for interview by the nontrivial content of their written commentary upon the Laboratory Questionnaire forms and were interviewed for approximately 10 to 15 minutes each by the author. Teachers were interviewed after class hours for a slightly longer period of time. Interview questions were intended to verify observations extrapolated from previously collected questionnaire, observation and report data.

Approximately 130 minutes of interview tape were recorded and transcribed for analysis. Analysis is detailed in Chapter 4, and complete transcripts appear in Appendix E.
Other Feedback

Other data were collected from the instructors in the form of written or verbal commentary. Teachers prepared notes concerning laboratory methods and equipment as they ran through laboratory procedures and tested trial versions of equipment and procedures, providing detailed comment. Much of this comment was shared by Electronic Mail (EMAIL) between the three sites, and is available from the author or CERG.

3.6 Scheduling

This study examined the integration of technology into the regular Chemistry 11 and 12 curricula, and time restrictions due to the standard curricular schedule were always present. Hardware, software and curricular procedures had to be constructed and tested for each of the four MBL laboratories, and the apparatus had to be assembled at each of the two sites at fixed times, sometimes at one site within a short time of the other. The curricular schedule for Chemistry 11 and 12 at the schools determined the sequence of the majority of activities of this study.

The study activity went through two stages: a series of activities prior to classroom intervention during which hardware and software design and construction activities were dominant; then a second series of activities accompanied by a growing technical presence in the classroom laboratory. A chronology of project activity is detailed in Appendix A.

Prestudy Activities

Provincial government funding for the study was granted in January of 1988 (Appendix A) and immediate steps were taken to start hardware development --- ordering of components and tools, etching of printed circuit boards etc., with the intention of producing ten sets of hardware. The original hardware design for the CERG Digital-Analog Receiver/Transmitter (DART) Board was modified, and construction of two sets was accelerated so as to examine the effects of these modifications. The modifications proved satisfactory (save some casing difficulties which caused a reworking of subsequent cases), and construction of the remaining interfaces commenced.
However, extensive difficulties and delays in acquiring parts and finding adequate assembly time were encountered, due to a severe underestimation of the effort involved.

During the construction of the hardware, the researchers and teachers familiarized themselves with current academic literature (much from ongoing research) and newly developed commercial MBL products. Software design commenced, and the specific laboratories chosen for employment of MBL technology. It was initially hoped that the project could examine MBL employment in the accompanying laboratories of all three major high school science disciplines (Chemistry, Physics and Biology), but time restrictions constrained activities to the area of greatest instructor expertise -- Chemistry.

Due to slow progress while constructing hardware and obtaining permission for extensive intervention from both UBC and School Board authorities, the first experiment chosen was 19B, which used the Spec 20D spectrophotometer as a sensor. This experiment requires no interface hardware beyond a simple cable (the Spec 20D provides an RS232 digital interface suitable for connection to a wide variety of computers) and would not be hampered by possible delays in hardware development. The software and activities were designed to be as close as possible to the standard laboratory activities (e.g. -- students filled out a data table on the Mac screen identical to the data table in their lab manual) to minimize the degree of curricular intervention, and the researchers would passively observe. This policy of minimal intervention was adopted for the first experiment as a result of the quasi-experimental design methodology, and was not continued to such an extreme in later activities, after an action research design was adopted.

3.7 Summary

This chapter has described the curricular intent and student procedures involved in the four Chemistry experiments chosen for MBL implementation. The standard (non-MBL) activities for these laboratories have also been presented, and these descriptions will serve as the basis for discussing the MBL implementation and evaluation in chapter 4.
Data collection techniques were briefly presented in this chapter, showing the largely qualitative nature and great variety of data sources to be used in the evaluation of the MBL interventions. This variety of sources is required for reasons of validity. When collecting qualitative data, observations from different sources that concur (or converge) promote greater confidence in the conclusions drawn.

Finally, the practical (and overwhelming) demands of regular school scheduling of events and MBL materials development were discussed. At the outset of this study it seemed that these scheduling constraints determined the majority of activity. The development of MBL materials from scratch presented a recurring Project commitment of such import that the study methodology was redesigned to incorporate this iterative materials development and subsequent evaluation.
Chapter 4: MBL Implementation

“That which we learn to do we learn by doing.”
-- Aristotle (in Laws, 1990)

Introduction

This chapter examines the activities of the MBL Project interventions into the four Chemistry experiments described in Chapter 3. The activities are described using Kemmis' action research protocol discussed in Chapter 1. Due to scheduling constraints imposed by hardware and software development time, the four chosen experiments do not follow their curricular presentation order here, but a chronological one (see Appendix A).

4.1 Experiment #19b - The First Cycle of Action Research

The first experiment modified for MBL use was 19b -- *The Quantitative Relationship Involving Concentrations of Reactants and Products at Equilibrium*, one of the technologically least demanding experiments to modify to MBL. No sophisticated hardware interface was required, as the Spec 20D spectrophotometer has an RS232C computer port (hence the 'D' designation for a Digital interface) and can be connected to a Macintosh computer via a simple cable. Software was prepared that allowed the control of and the capture and graphing of data from the Spec 20D. The experimental design used for this intervention was still the quantitative quasi-experimental design described in Chapter 2.

4.1.1 The Plan -- The Introduction of Instrumentation to the Chemistry Laboratory

The goals of the first experiment were highly exploratory, and the investigators had three main objectives:

i. to evaluate the usefulness of prelaboratory quiz and laboratory report marks as a measure of MBL appropriateness;

ii. to evaluate the basic design of suitable software for the project; and
iii. to determine the scope of the logistical and managerial requirements of MBL chemistry labs.

Curriculum

Experiment 19b activities consist of a series of dilutions to prepare five solutions with varying concentrations of reactants Fe$^{3+}$ and SCN$^-$ resulting in the product FeSCN$^{2+}$ at various different equilibria. Students calculate the initial concentrations of the reactants, and then use the Spec 20D to measure the light absorbance due to the concentration of the coloured reaction products. This information is placed into a data table (Table 6) and then is used to calculate the concentrations of the products of each of the five dilutions (Equation 2). Finally, the specific numerical relationship between the concentration of products and reactants at equilibrium (Le Chatliers' Principle) is inferred through a large series of trial calculations using the data collected and calculated during the experiment.

For the MBL implementation of this experiment, the laboratory theory and solution preparation were left unchanged from the standard procedure, but the collection of data from the Spec 20D was modified to allow students to control the calibration procedures from the Macintosh as well as the subsequent collection of data. The data were entered again in tabular form identical to Table 6 (which appeared on the Mac screen), and the program calculated and supplied values for the product concentration from the student-calculated reactant concentration. Finally, the program graphed the relationship between the calculated product concentration and the absorbance of the solution from the spectrophotometer. This linear relationship was seen by the students in a previous experiment introducing the spectrophotometer (16b), and is actually known as Beers' Law, a fact never made explicit. The MBL procedure for 19b finally had the student print out the Beers' Law graph and data table for the experiment.

Hardware and Software

This experiment did not require the DART board hardware interface -- the only hardware required was four cables carrying RS232C signals from a manufacturer-supplied black plastic box attached
to the underside of the Spec 20D. This box had a prominent red button on it and was intended for connection to a null MODEM cable through a standard DB25S connector. The author constructed four cables with a DB-25P connector leading from this box and connecting to the mini-DIN 8 connector on the Macintosh serial port. Cable details are shown in Appendix C.

The software written for the Spec 20D/Macintosh interconnection was a ZBASIC 5.0 stand alone application using standard Macintosh human interface techniques, such as windows, buttons, edit fields and mouse selection. When the application icon was launched by double-clicking at the desktop, the program (known as Experiment 19b - Spec 20D) displayed a line diagram reviewing the main controls and parts of the Spec 20D for the students. Below the diagram were three Macintosh buttons giving students the choice of calibrating the Spec 20, collecting absorbance data and quitting the application. Students selected these routines by clicking on the appropriate button with the mouse pointer (Figure 12).

Figure 12: Main Menu for Experiment 19b
To calibrate the Spec 20D requires the manipulation of the three knobs upon the instrument, which are not possible to control from the Macintosh (two control variable resistors, the third drives a worm screw which rotates a diffraction grating). The calibration routine selected from the main menu listed the instructions required for calibration in a point form, while continuously updating displayed values for Wavelength and Transmittance as sent to the computer from the Spec 20D via the cable. This display is shown in Figure 13.

**SPEC 20D Calibration Routine**

1. Ensure that the SPEC 20D has been turned on; that the MAC modem port is connected to the interface box, and that the box is connected to the SPEC 20D bottom interface port.

2. Adjust the SPEC 20D to your desired Analytical Wavelength with the large dial on top. Note the wavelength is displayed below.

3. With the Sample Compartment empty and cover closed, adjust the Amplifier Control Knob (front left) until the Transmittance reads zero. Note the %T value displayed below.

4. Place a Reference Blank (water only) into the Sample Compartment, close the cover and adjust the Light Control Knob (front right) until the Transmittance reads 100%.

5. You are now ready to collect data.

   Wavelength in Nanometers: 590  (Set to 590 NM for FeSCN++)

   Percent Transmittance (Adjust to 0 & 100): 33.4  
   (No Sample - Left Knob, then with Blank - Right Knob)

Figure 13: Calibration Menu for Experiment 19b

The data collection routine for the program created a duplicate of the experiment data table detailed in the students' lab manual (Table 6), as well as displaying and printing a calibration plot of light absorbance versus reaction product concentration. Students entered their calculated values for initial reactant concentrations into this data table as the light absorbance of each of the five samples was read by the Spec 20D, and the software calculated final product concentrations. When the student completed all of the data entry (Figures 14 and 15), the program sorted the data, performed
a least-squares fit of a line to the data and graphed the data points and the best fit line. Above the graph, the Y-intercept and slope of the line was displayed to the student as well.

The program finally allowed students to print their data graph (Figure 16) and the accompanying table, along with time and data information. The program calculates the concentration from student-calculated values without checking these values, and the concentrations of the FeSCN$^{2+}$ product ion are also calculated assuming the student input was valid. This means that final data always were perfectly linear given consistent errors, although the slope would be incorrect. 19b does not ordinarily require a plot of [FeSCN$^{2+}$] for this and other reasons.

Figure 14: Partial Data Entry for Experiment 19b
4.1.2 Action

Three classes of Grade 12 students from the Richmond school participated, for a total of 64 students. The quasi-experimental design required at least one of the three classes to make use of standard laboratory procedures to complete the experiment, and at least one class to use MBL techniques for the same experiment. Of the three consecutive Chemistry classes, the first two (known as blocks A and B) each completed the experiment using MBL techniques. The final class of the morning (block C) completed the experiment without the computer.

Prelaboratory quizzes were written by all students and were collected and marked by the instructor. Written observations of student laboratory behavior were recorded by the author, and the complete laboratory reports from this experiment were collected after instructor marking. The software and cables for the experiment were afterwards loaned to another instructor, who used the materials to run a similar unobserved and uncontrolled activity at Surrey with one class of students. His comments regarding general implementation and software design are therefore also included.
### Data Collection and Calculations

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Initial Concentrations</th>
<th>Equilibrium Concentrations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[Fe+++]</td>
<td>[SCN-]</td>
</tr>
<tr>
<td>1 Control</td>
<td>0.10000</td>
<td>0.00100</td>
</tr>
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<td>0.00100</td>
</tr>
<tr>
<td>5</td>
<td>0.00260</td>
<td>0.00100</td>
</tr>
</tbody>
</table>

Figure 15: Completed Data Entry for Experiment 19b - Spec 20D

### Setting

The same Chemistry classroom at Richmond was used for all three experiments. This room is quite cramped due to the large number of fairly small tables (both fixed and movable) used as both desk seating for lectures and laboratory counter top area. Access to outlets and sink space is limited by a need to thread through this maze of tables, and is even more difficult when chairs and other students are present blocking paths. There is a narrow counter top running the length of the room on one side, and another counter top at the front of the room. Both of these counter tops are usually used for laboratory and teaching materials storage.

### Site Preparation

Two additional spectrophotometers were borrowed from neighboring schools to increase the number of laboratory stations available to students and to allow for additional access time to the instruments, bringing the total available to four. All four machines were connected to Macintosh...
Plus computers, and the computers and Spec 20Ds were set up along the wall on the narrow counter top. Between each pair of stations an Imagewriter printer was placed for obtaining data tables and graphs. An unsuccessful attempt was made to make use of a third printer, but this printer was intended for network use (it used different connector cables and network software drivers) and the effort was abandoned due to time constraints. All of the equipment was set up and tested before the students arrived for class.

![Completed Graph for Experiment 19b](image)

Figure 16: Completed Graph for Experiment 19b

The PreLaboratory Quiz

The students of all three classes began their experiment by writing the prelaboratory quiz for 19b. This quiz has the intent of assuring adequate student preparation before starting the lab, and the quiz mark represents about 1% of the final assigned mark for the course. The teacher issued paper for the quiz, then displayed the four questions on an overhead projector transparency, and the students wrote answers on their paper. Students were then presented with the correct answers and a
brief explanation using the overhead again, and the quiz papers were collected by the teacher for later marking. Of all students completing the experiment in the three blocks, only one student did not complete the quiz due to her late arrival.

The questions in the quiz and their accepted answers were described in detail in Chapter 3.

Student Activities

After completing their quizzes, students from the first two blocks (A and B) observed a demonstration of the revised experimental procedure using the MBL software and the Spec 20D. After completing the demonstration, the teacher fielded questions, then had the students commence laboratory activity. The students dressed in protective clothing appropriate for the lab and prepared the required dilutions from the stock solutions given working in self-selected groups of three to five students. After preparing their dilutions, the groups of students started the MBL software and calibrated the Spec 20D. Then they placed their five test tubes of solution into the instrument one by one while entering their calculated concentration values for the reactants into the computer. Finally, the resulting graphs and data tables (Figures 15 and 16) were printed out on an Imagewriter for inclusion with the final lab reports. These activities consumed all of the available class time.

The final class (block C) completed the laboratory with the four Spec 20Ds only -- the Macintoshes, printers and cabling had been removed from the classroom during a recess. Students proceeded as before in blocks A and B, but had no MBL demonstration, and recorded their data in their notebooks before leaving. Again, students did not have time to commence the laboratory report in the classroom.

4.1.3 Observations

A number of different forms of data were collected, including the prelaboratory quizzes, a brief set of observers' notes, and still photographs. Several weeks later, the completed laboratory reports for the entire chapter including 19b were collected by the instructor and marked. The reports for 19b were recorded and handed on to the MBL Project for further evaluation. Another instructor
obtained a copy of the software and an interface cable from Richmond and attempted to run the same experiment at Surrey with his students without any demonstration or assistance. His list of comments and observations is included in this analysis as well.

Observer's Notes and Impressions

The complete observers' notes are found in Appendix G. These notes describe the enthusiasm of all students when using the Spec 20D, and the particularly high enthusiasm of students from the two MBL using blocks. Students expressed their enthusiasm for the MBL experimental technique in a series of unsolicited comments such as '...now this is the way to do a lab...' and queries about how long the program took to prepare, would they have more experiments of a similar nature (referring to the computer) and so forth. Students rushed somewhat through their dilutions in their haste to tinker with the electronic apparatus, and several groups were so hasty that they made errors diluting the stock chemicals. These errors were discovered by the MBL users after plotting their graphs by comparison with other groups, and these students repeated their dilutions correctly. The final block (non MBL users) took longest to complete their dilutions, and the group that erred did not discover the error during class time. A great deal of enthusiasm was shown for the final laboratory printouts -- students wanted these printouts as records of their data, for inclusion in their reports and even extra copies to show to peers not taking Chemistry. At least one student made several additional copies for his own purposes.

All of the blocks seemed poorly prepared for their laboratories in general, with block B perhaps the best prepared of the three. Many of the students had not read the laboratory procedure beforehand, and some had not completed the calculations of initial reactant concentration required. Block C (the non MBL group) seemed particularly ill-prepared, but this may have been due to their noticeably greater questioning activity. The students also seemed to brighten up considerably as the morning progressed, with block A the least and block C the most alert groups.

Many students had difficulties with the software, especially having to re-do samples or struggling with calibration procedures, but none of the students had problems using the mouse and buttons.
Almost all had printer difficulties; the printers were quite slow, the computer remained frozen while data was printed, students had difficulties setting different grades of print quality etc. Most students operating the computers tinkered with the software, and several snarled themselves up by impatiently repeating requests (particularly for printing) while the computer was slowly handling print requests, obtaining undesired reactions from the computer as the computer event queue was handled request by request. Getting the highly-prized hardcopies of results proved to be a major unanticipated bottleneck. Some students eventually had to settle for photocopies of their group results rather than an original hardcopy due to this bottleneck and time constraints. Students were very intent upon the precision of their results, repeating measurements and went to some pains to obtain measurements accurate to the final digit displayed on the Spec 20D.

Instructor Assessment

The instructor commented on student unpreparedness several times (particularly with block C), but indicated that this was commonplace. He seemed quite excited and highly-motivated by the MBL procedures. Moving computers into the lab and setting up computer hardware was an unpleasant inconvenience for all concerned, (particularly for the instructor who ran the computer laboratory) but the Chemistry instructor obviously enjoyed demonstrating the apparatus to the students and his enthusiasm seemed to motivate them. He also noted several procedural shortcomings involving printer problems and data entry corrections during the experiment, although these were not recorded in writing at the time.

PreLaboratory Quiz Marks

The prelaboratory quizzes were marked out of a total score of four points, each question having an assigned a mark of 0.0, 0.5 or 1.0 marks each. Of sixty-four total students, sixty-three wrote the quiz. The first two blocks were marked by the instructor, and the third block quizzes were exchanged and marked by students from the same class, then collected and were re-marked by the instructor. Resulting marks analyzed by block were as shown in Table 9.
Table 9: Prelaboratory Quiz Marks for 19b by Block

<table>
<thead>
<tr>
<th></th>
<th>All Blocks</th>
<th>Block A (MBL) n=19</th>
<th>Block B (MBL) n=23</th>
<th>Block C (non MBL) n=22</th>
<th>Block A+B (total MBL) n=42</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Mark</td>
<td>1.841</td>
<td>1.842</td>
<td>1.273</td>
<td>2.409</td>
<td>1.537</td>
</tr>
<tr>
<td>Standard Dev</td>
<td>1.208</td>
<td>0.851</td>
<td>1.152</td>
<td>1.297</td>
<td>1.051</td>
</tr>
<tr>
<td>Completion</td>
<td>98.4%</td>
<td>100%</td>
<td>95.7%</td>
<td>100%</td>
<td>97.6%</td>
</tr>
<tr>
<td>Min Mark</td>
<td>0.0</td>
<td>0.5</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Max Mark</td>
<td>4.0</td>
<td>3.5</td>
<td>3.5</td>
<td>4.0</td>
<td>3.5</td>
</tr>
</tbody>
</table>

The large values for the standard deviation of the above marks indicate a great discrepancy between student marks within blocks, probably due to little preparation for the quiz on the part of many students. This may be attributed to the fact that students are aware that their quiz results form a very minor portion of their permanently assigned mark. Due to the large standard deviations and a low number of samples, statistically significant differences between blocks are not apparent, but trends indicate that student performance likely improved with the time of day; causing a slight rise in block C performance. Trends further indicate that block A was an average class, B performed slightly below average and C better than average.
Table 10: Prelaboratory Quiz Marks for 19b by Gender

<table>
<thead>
<tr>
<th></th>
<th>All Students</th>
<th>Block A (MBL)</th>
<th>Block B (MBL)</th>
<th>Block C (non-MBL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M n=29 F n=35</td>
<td>M n=12 F n=7</td>
<td>M n=8 F n=15</td>
<td>M n=9 F n=13</td>
</tr>
<tr>
<td>Mean Mark</td>
<td>1.862</td>
<td>1.583</td>
<td>1.375</td>
<td>2.667</td>
</tr>
<tr>
<td>Standard Dev</td>
<td>1.117</td>
<td>0.900</td>
<td>1.157</td>
<td>1.000</td>
</tr>
<tr>
<td>Completion</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Minimum Mark</td>
<td>0.0</td>
<td>0.5</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Maximum Mark</td>
<td>4.0</td>
<td>3.5</td>
<td>3.5</td>
<td>4.0</td>
</tr>
</tbody>
</table>

The examination of these marks by gender (Table 10) also reveals no statistically significant differences between blocks due to a large standard deviation and low sample sizes. However, trends confirm the average, poorer and better performances of blocks A, B and C respectively.

Laboratory Report Marks

The laboratory reports were due in to the teacher several weeks later (all of the course laboratory reports were due in simultaneously near the end of the term), and the most notable observation is the low return rate -- about 66% overall. Many students simply did not turn in the lab, preferring to take a zero mark for this activity, while several others turned in their reports quite late. For this reason, many of the sets of student marks examined in Tables 11 and 12 are incomplete.

Table 11: Lab Report Marks for 19b by Block

<table>
<thead>
<tr>
<th></th>
<th>All Blocks n=42 (64)</th>
<th>Block A n=17 (19)</th>
<th>Block B n=12 (23)</th>
<th>Block C n=13 (22)</th>
<th>Block A+B n=29 (42)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Mark</td>
<td>8.012</td>
<td>7.647</td>
<td>8.208</td>
<td>8.308</td>
<td>7.879</td>
</tr>
<tr>
<td>Standard Dev</td>
<td>0.997</td>
<td>1.101</td>
<td>1.054</td>
<td>0.663</td>
<td>1.099</td>
</tr>
<tr>
<td>Completion</td>
<td>65.6%</td>
<td>89.5%</td>
<td>52.2%</td>
<td>61.9%</td>
<td>69.1%</td>
</tr>
<tr>
<td>Min Mark</td>
<td>4.0</td>
<td>4.0</td>
<td>6.5</td>
<td>7.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Max Mark</td>
<td>10.0</td>
<td>9.0</td>
<td>10.0</td>
<td>9.5</td>
<td>10.0</td>
</tr>
</tbody>
</table>
Again, no statistically significant results can be seen in marks for those students who completed their laboratory reports. Trends indicate that block A has slightly lower marks than B and C, which are nearly identical. Completion rates are higher for block A than either B or C, although all leave something to be desired. The marks themselves show little variation, with the majority of marks falling within a range from 7.0 to 9.0 out of a possible ten. This might represent a tendency of the instructor to 'reward' students somewhat for laboratory report completion.

Table 12: Completed Only Laboratory Marks for 19b by Gender

<table>
<thead>
<tr>
<th></th>
<th>All Students</th>
<th>Block A (MBL)</th>
<th>Block B (MBL)</th>
<th>Block C (non-MBL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M (29) MBL</td>
<td>F (35)</td>
<td>M (12)</td>
<td>F (7)</td>
<td>M (8)</td>
</tr>
<tr>
<td>n=17</td>
<td>n=25</td>
<td>n=10</td>
<td>n=7</td>
<td>n=3</td>
</tr>
<tr>
<td>F (1)</td>
<td></td>
<td>F (7)</td>
<td></td>
<td>F (15)</td>
</tr>
<tr>
<td>n=3</td>
<td>n=7</td>
<td>n=9</td>
<td>n=9</td>
<td>n=4</td>
</tr>
<tr>
<td>Mean Mark</td>
<td>7.912</td>
<td>7.450</td>
<td>7.929</td>
<td>8.500</td>
</tr>
<tr>
<td>Standard Dev</td>
<td>1.162</td>
<td>1.322</td>
<td>0.673</td>
<td>0.500</td>
</tr>
<tr>
<td>Completion</td>
<td>58.6%</td>
<td>83.3%</td>
<td>100%</td>
<td>37.5%</td>
</tr>
<tr>
<td>Min Mark</td>
<td>4.0</td>
<td>4.0</td>
<td>7.0</td>
<td>8.0</td>
</tr>
<tr>
<td>Max Mark</td>
<td>9.0</td>
<td>9.0</td>
<td>10.0</td>
<td>9.0</td>
</tr>
</tbody>
</table>

An examination of completed marks by gender (Table 12) reveals that the expected higher scores for females did not materialize -- females generally slightly outperformed males in their lab reports. Female students also have a higher completion rate than their male counterparts. This might be expected from research that indicates female students do better on activities involving task completion (Ragsdale, 1988). A single anomalously low mark (4.0 for a male in block A) is due to a partially-completed laboratory report consisting of the printout from the MBL program only.
Laboratory Report Quality

The overall impression of student Laboratory Reports produced is one of monotony -- student responses are quite mundane, usually consisting of a word for word copy of laboratory objectives from the manual, referring to the manual again for procedure and apparatus, listing the data tables, then performing the large number of numeric substitutions required to answer the questions. Many of the reports were obviously completed well after the event, and qualitative, non-numerical observations (such as the colour changes when preparing solutions) are notably absent.

While most of the reports from students using the Macintosh had computer printouts attached to them and had obviously copied the numeric data table from the printouts into their report data tables, only four of the very few students who made qualitative commentaries referred to the computer at all. These students (all from block A) mentioned the computer as a possible source of experimental error, citing '...uncertainty in the computer...' or '...uncertainty in the computer's program...' None of the students further labelled or made any indicating marks at all upon the computer printout itself. The overall return rate of reports was quite low, with a large percentage turned in either late or not at all.

Correlations and Response rates

In fact, the return rates were so low as to warrant further investigation in themselves. The instructor revealed that the return rate was low but that this was not atypical of response rates for 19b as it is possibly the most theoretically abstruse and demanding laboratory activity of that semester in grade 12 Chemistry. Due to this anomalous degree of difficulty, it was not possible to statistically examine the influences of MBL techniques on laboratory report completion rate, but it is likely that the presence of a complete, attractively presented set of experimental data contributed to the slightly higher overall laboratory report completion rate for those students who used MBL.
Table 13: Various Correlations for 19b

Correlation Matrix for Variables: X₁ ... X₄

<table>
<thead>
<tr>
<th></th>
<th>PLQ tot</th>
<th>Lab Rep</th>
<th>Sex</th>
<th>MBL?</th>
</tr>
</thead>
<tbody>
<tr>
<td>PLQ tot</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lab Rep</td>
<td>.224</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sex</td>
<td>.305</td>
<td>.107</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>MBL?</td>
<td>-.398</td>
<td>-.188</td>
<td>-.148</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: 23 cases deleted with missing values.

An examination of correlations (Table 13) between Prelaboratory Quiz and Laboratory Report Marks, MBL presence and Gender reveals no strong correlations.

Off-site Commentary

Another grade 12 Chemistry instructor borrowed a copy of the software and the interface cable from the MBL Project after experiment 19b had been run at Richmond and attempted to make use of the MBL techniques in his classroom at the Surrey school without any written instructions or demonstration. His comments are detailed in Appendix J, and consist of a great deal of encouragement, a large number of procedural and software modifications, a list of printer difficulties, some comments regarding the manufacturer-supplied Spec 20D interface cable and some observations regarding curricular extension for the experimental procedure. An interesting discrepancy between instructors was the desire to have different labels for the Y-axis of the graphs - one preferred Optical Density, the other Absorbance. Ideally, MBL software should be able to such accommodate instructor customization.

The software and procedural criticisms related to the need for greater clarity and flexibility in the program design, especially a need for data storage and editing and error recovery. The hardware connection instructions were inadequate, and this was exacerbated by the fact that the software made no allowances if the connections were not made properly -- the Macintosh would crash and restart if the Spec 20D was not connected and responding to the program. The manufacturer-supplied box
with the red button was distracting, and if the button upon it was depressed, noise was recorded by the computer. Printer support was inadequate and the printer was very slow.

The experiment itself supplied a graph not ordinarily used in the experiment, and the offsite instructor suggested a series of activities appropriate with the graph, as well as extending the software so that laboratory calculations could be performed similar to a spreadsheet.

Still Photography

A number of still black and white photographs of classroom setup and student activities illustrated the lack of available floor and counter space in the Richmond Chemistry classroom. The majority of the photographs display students using the Macintosh and Spec 20D together, but also show students performing dilutions and the instructors' equipment demonstration. The photographs suggest that the computer became the focal point of activity -- of 38 students photographed while collecting data via MBL, 29 students (76%) are either using or viewing the apparatus, predominantly the computer. The majority of students were unaware of the photographer at the time. Students were quite attentive to the Macintosh display during the laboratory, and took turns as computer operator and Spec 20D operator, although a few students appeared uncomfortable with the computer, preferring to let their peers use the device. One of the photographs shows students from one group comparing results with another group by examining other computer displays as well as their own. These data are also obtainable from field notes.

4.1.4 Reflections

After examining the data, a series of recommendations for further action was drawn up. Looking at the original evaluative goals, decisions were arrived at to discard the original research design and to modify materials and procedures.

Research Design

First, it became apparent that the employment of MBL technology was not a discrete event capable of quantitative evaluation by the quasi-experimental design (note that the effectiveness or presence...
of a single trait ascribed to MBL is quantifiable). The success of the technology was obviously highly dependant upon a number of uncontrolled variables involving the exact hardware, software and curricular implementation used. It was also desirable to attempt to improve the implementation of all of these variables in an iterating fashion, which was outside the scope of a fixed quantitative design.

Laboratory report marks were mainly a function of completion and report contents did not reflect qualitative in-laboratory activity or methodology. The prelaboratory quizzes were also poor or useless as indicators of student ability due to their lack of immediacy. To investigate student response to new technology in their laboratories, a new instrument would be required. The low return rates suggested that it should be brief and completed and collected immediately without a need for advance preparation -- akin to the prelaboratory quizzes. The preponderance of rote responses also suggested that the instrument be open-ended and non-specific to avoid student provision of stock replies and to encourage qualitative observation and comment.

Hardware

Hardware difficulties for this experiment had to address the manufacturer-provided box with the red button, as well as cabling directions for setup. New cables were constructed that eliminated the need for the manufacturers' box entirely and ran continuously from the six-pin Jones connector on the Spec 20D to the mini-DIN-8 on the Macintosh. The need for cabling directions was bypassed through software extension -- the software was modified so that if the computer could not communicate with the Spec 20D for any reason, a message would appear notifying the user and detailing remedial action.

Additionally, printer availability had to be addressed -- better printer access had to be arranged and printout times speeded greatly. Computer to printer connections had to be improved to avoid a need to plug printers into one computer after another through the use of some printer sharing device, network or technique.
Software

Software had to be extensively modified to provide for data editing, permanent disk storage and more intuitive control. A routine to prevent crashes if the Spec was not connected or shut off had to be included. Printer speed had to be increased through rewriting the software to continually keep the Imagewriter buffer filled and doubling transmission speed. Scientific notation and significant digits had to be incorporated in the displays.

Curriculum

MBL presence obviously pressed the curriculum hard. Merely filling out an experiment data table on the computer was a trivial use of the technology, and the more appropriate use of presenting graphical information for interpretation went well beyond the curricular goals for the usual laboratory activity. Students and teachers alike pressed for further activity and investigation for which there was no curricular provision. Non-curricular topics such as the logarithmic relationship inherent in spectrophotometry, Beers' Law, fitting equations to experimental data and the original unexamined assumptions of linear relationships in the procedures for 19b became of far greater import and interest than repeatedly plugging data into equations which were possible candidates for expressing LeChatliers' Principle.

The teachers involved both suggested and prepared extension activities (find unknowns, etc) for the laboratory, and even went as far as to rewrite the entire experimental procedure. Considerable teacher enthusiasm was expressed despite the considerable logistical difficulties encountered.
Cycle 1: Experiment 19B

4. Reflections:
The proposed design does not adequately recognize the quality of MBL interactions, nor does it allow for a continuous improvement in materials and techniques. The marks collected are not an accurate reflection of student laboratory activities. The materials prepared are adequate with several improvements, but their use encourages extending the curriculum well beyond its present scope. Logistical difficulties are severe, but teachers still seemed very enthusiastic.

3. Evaluation:
Collect student PreLaboratory Quizzes, completed Laboratory Reports, observer and instructor notes and still photographs of student laboratory activities.

1. Investigate:
1. Are prelaboratory quizzes and Laboratory Reports suitable for assessing MBL appropriateness?
2. Are the MBL materials prepared for this experiment adequate and how can they be improved?
3. Are the logistical and managerial requirements of MBL unreasonable for working Chemistry teachers?

2. Implementation:
Develop and employ MBL materials for a standard curricular experiment. Use these materials with some students, and the regular curriculum with others for comparison.

Figure 17: Action Research Cycle 1 Summary
4.2 Experiment #2a - The Second Cycle of Action Research

The second experiment involved a much more graphically oriented activity -- *Cooling and Heating Curves of A Pure Substance*, which involved the determination of the melting and freezing points of Paradichlorobenzene (PDB) by examining the rate of temperature change through phase transitions. This experiment is widely carried out in high school and middle school level science. A fairly sophisticated hardware package consisting of a computer-controlled analog to digital converter (the DART board) and associated signal conditioning hardware (the preamplifier pod for the thermometer probe) had to be partially designed and wholly constructed from scratch for this activity. Details of this process appear in Appendix C. Software originally used in 19b was extensively rewritten and extended in scope, directed by observations from the previous research cycle and teacher commentary. Details of this process appear in Appendix D.

Trial versions of both the hardware and software interface were completed barely in time to do this experiment with the students as a portion of their regularly scheduled curriculum. Participating students had recently completed this activity using traditional methods and actually repeated this experiment with the MBL apparatus a few days later.

4.2.1 The Plan -- Methodological Juxtaposition and Student Aided Design

The goals of this second experiment included:

i. to test the open-ended MBL Project Laboratory Questionnaire as an instrument for collecting student qualitative observation and comment upon their laboratory experiences;

ii. to obtain knowledgeable student direction for further materials development, taking advantage of student familiarity with both the MBL and traditional laboratory method for 2a; and

iii. to further refine MBL techniques used by the MBL Project, particularly software interface design and curricular treatment of specific activities such as calibration.
Curriculum

This laboratory involves student collection of a fairly large amount of temperature data at regular timed intervals. This information displays characteristic cooling and heating behavior for the chosen substance (PDB) which shows the freezing and melting temperatures for that substance as a plateau upon a graph of temperature versus time (Figure 6 in Chapter 3).

Hardware and Software

This experiment was the first utilizing the DART board analog to digital converter, a thermistor temperature probe of the type used to control cooking temperatures within a microwave oven, and a signal preamplifier used to convert the logarithmically changing temperature sensor resistance to a 0-5 VDC voltage interpretable by the DART board (see Appendix C). The two DART boards used in the course of this investigation were design prototypes which were subsequently modified for various reasons including their susceptibility to spurious noise which caused them to hang and require a reset power up. While these shortcomings were known at the time, it was hoped the apparatus would be adequate for a student evaluation.

The selection of thermometer probes also left something to be desired. The particular probes used were chosen due to the use of a similar probe in a commercial MBL (HRM Experiments in Chemistry) and their inexpensive cost. The author had enjoyed a fair degree of past success experimenting with a variety of linear semiconductor sensors, but was not previously familiar with the operation of negative temperature coefficient thermistors. A closer examination of seven randomly-chosen thermistors (of the twenty-five obtained) revealed that the logarithmic nature (Macklen, 1979) of their electrical response presented difficulties when operated below room temperature. Figure 18 shows the nonlinear response, as well as the large error difference between an idealized logarithmic response and these sensors below room temperature.

Some degree of correction was possible by actively linearizing the thermistor output (Thomkpins and Webster, 1988) with a two-stage operational amplifier circuit in the preamplifier pod, but this
still involved some tradeoff between the resolution possible and the operating temperature range. These difficulties are due to the original specifications for the thermistor probe; microwave ovens do not require temperature sensitivity greater than five degrees (nor any accuracy below room temperature), but do require a large operating range. It was finally decided that the probes were still adequate over the limited range of temperatures required for 2a, but extensive experimentation would be required when working outside of this range.

\[
y = 152.69 + -77.459\cdot\text{LOG}(x) \quad R^2 = 0.993
\]

Figure 18: Average Thermistor Response and Logarithmic Fit

The software interface for experiment 2a made use of the same overall structure as was used in 19b. The initial window of the application displayed a line drawing of the apparatus (an attempt to use digitized video camera images of the materials proved an interesting failure) with identifying labels intending to assist students assembling the equipment (Figure 19). The diagram did not indicate that any difficulty would be encountered positioning the preamplifier pod, and rather optimistically shows the pod readily supported by the ring stand. The diagram also does not allude to another difficulty in physical setup -- it is difficult to support the probe in such a manner so that the
stainless steel length of the probe is entirely immersed in PDB and does not contact the wall of the
test tube. In practise, these are difficult to achieve and neglecting either will contribute to
experimental error.

This screen also noted the existence of another substance often used for comparison to PDB in a
similar laboratory exercise, sodium thiosulphate penthydrate. Again, the choices of calibration, data
collection and terminating the program were displayed as buttons below the diagram.

![Diagram of Thermal Behaviour of a Pure Substance](image.png)

Figure 19: Main Menu for Experiment 2a

The calibration procedure differed markedly from the software used in 19b -- the calibration had to
allow the computer to measure a probe voltage (shown as a DART Value between 0 and 255 on the
screen) and to associate a known temperature with that value. After repeating this procedure twice
to define hot and cold values, the computer can logarithmically interpolate any probe voltage and
associate a calculated temperature value with that voltage.
Students therefore calibrated the temperature probe by pressing the Set Cold button, then placing the probe into a water bath at room temperature and allowing the displayed DART value on the computer screen to stabilize. The actual temperature of the bath was read from a laboratory thermometer as precisely as possible and entered into the computer (Figure 20). When the return key was pressed, the computer recorded and displayed the cold calibration values. The procedure was repeated with a bath of hot (boiling or recently-boiled) water and after the second return was pressed, the two point calibration was completed, and the computer could interpret the thermistor probe voltage as an accurate temperature.

The accuracy of all subsequent measurements was a function of the calibration accuracies, therefore the instructor encouraged students to calibrate carefully, and this was stressed throughout the presentation.

Figure 20: Calibration Menu for Experiment 2a
The Get Data button allowed the use of a set of data collection and handling routines displayed in Figure 21. The computer screen displayed a graph scaled appropriately for the amount of PDB used in this activity, and if calibration had been completed, the cold and hot calibration information was displayed at the top of the screen. A flashing bar (updated every second) indicating the current time and temperature of the probe was displayed between the calibration information if a DART box was connected to the computer. If not, the software displayed an alert asking if the user wanted to retrieve previously collected data for use or to check the hardware connections.

If the Start button was selected, all of the other buttons except Stop were turned off and the computer plotted the temperature from every third sample (every 3 seconds) on the screen until a total of 16 minutes elapsed or the Stop button was selected. This allowed students to observe the physical changes closely during the cooling and heating processes while being cued to look for solidification or melting by the graphical computer display. The Save button allowed students to store data onto disk into a file both retrievable by this software and importable into a spreadsheet for analysis. The Print button allowed students to dump a copy of the graph and the complete data table of times and temperatures at 3 second intervals to the printer. The software used modified printout code which insured that less time was required to prepare and transmit data to the printer, reducing printout time required by about 30%.
The two remaining buttons allowed students to Load data from diskette into the computer for examination and printout (or to re-acquire the calibration settings from that session) or to Quit the data collection routines and return to the main menu.

4.2.2 Action

Three classes of Grade 11 students from Richmond participated, blocks C (27 students) and D (22 students) were taught by one chemistry instructor and both used and commented upon the MBL materials prepared for Experiment 2a about a week after they had completed the activity with traditional materials. The third class, block E (30 students) was taught by the original instructor and did not have the opportunity to use the MBL materials due to time constraints, this class commented upon the traditional materials only.
Setting

Again, the same Chemistry classroom laboratory at Richmond was used for all three classes. The quarters were slightly less cramped upon this occasion due to a lesser amount of hardware being used during the course of these classes, but other apparatus (for experiment 16b) was erected along the wall counter top.

Site Preparation

Again, computer hardware and printers were borrowed from the school computer laboratory and brought into the laboratory, to the (somewhat lesser upon this occasion) discomfort of the school computer instructors. The computers were left upon their wheeled cart/desks and the DART boards were placed beside the computers on the carts as well. A long lead to the preamplifier pod ran from the cart to the desktop experimental area, where the materials for 2a were erected. This physical separation provided some degree of protection for the computer hardware from liquid spills and other laboratory accidents.

Two stations were erected back to back roughly in the center of the classroom where most students could see where they were, and also see when the apparatus was free.

The MBL Project Laboratory Questionnaire

The laboratory questionnaire was developed as a result of the observations and concerns which arose in the previous MBL activity, experiment 19b. The questionnaire was designed to be extremely open-ended and brief, and to be completed as part of the laboratory activity for immediate collection. It contained a total of eight questions asking for a brief description of the sequence and purpose of the experimental activities, as well as inquiries concerning those parts of the activity which were clear and easily understood and which were not straightforward, and what activities could be improved, retained or discarded in a procedural redesign of the experiment. The entire questionnaire text can be found in Appendix G, and detailed results are discussed later in this section.
Student Activities

Students were all given a copy of the laboratory questionnaire at the start of the class, and those participating in the MBL materials evaluation were told that they would be helping evaluate a new set of experimental apparatus for experiment 2a. Students were then given a brief demonstration of the apparatus, including the calibration procedure. They were told participation would be voluntary, and only two groups could participate at a time, but that all would have an opportunity to test the apparatus in turn. Most then commenced homework and laboratory report preparation at their seats while self-selected groups of students explored the apparatus. Those exploring the apparatus partially repeated experiment 2a, and completed their questionnaires. Groups took turns examining the materials. While participation was voluntary, the majority of students had the opportunity to operate the apparatus. At the end of the class, the completed questionnaires were collected from those students who chose to participate in the activity.

Block D students had a seemingly slight departure from this itinerary; block C students had expressed some minor confusion over calibration, and the author used the chalkboard for a brief (unplanned) five minute presentation upon the evolution of the Celsius and Fahrenheit scales, along with the implications for calibration. This presentation described scales as physically defined hot and cold points with linear interpolation and extrapolation from those two points. (Fahrenheit used the human body temperature as 100 degrees on his scale and a bucket of sea water with salt added to depress the freezing point as low as possible for 0 degrees. Neither point was sufficiently accurate or meaningful to continue to perpetuate the scale as a scientific one today. Celsius based his scale on the freezing and boiling points of pure water, which has stood the demands of science somewhat better, although the definition of the the freezing point as lower end has been replaced with the triple point.) This presentation was to have a notable effect upon returned questionnaires.

The third group (block E) performed the activity without MBL apparatus two weeks earlier, and the author was not present during this laboratory. Students completed the questionnaires after data
collection in class, but before commencing the laboratory report and attendant graphing of their
data.

4.2.3 Observations

Prelaboratory quizzes and completed laboratory reports were not collected, but the newly-
constructed MBL Project Laboratory Questionnaire was used extensively. Some observers' notes
and instructors' commentary were also collected along with a number of colour slide photographs.

Observer's Notes and Impressions

The authors' notes taken during this activity were very brief due to a far greater interaction with the
students. The equipment required some tending, and one of the DART boards hung up part way
through the first class and required a significant amount of prodding by the author to get it
restarted. The software source code was actually compiled on site before each run, rather than
previously compiled into a stand alone version. While this allowed some additional flexibility,
whenever students quit the application entirely, they were returned to the ZBASIC 5.0 development
environment rather than to a desktop icon. This made for some confusion on the part of the
students whenever they tinkered their way out of the application, which had to be restarted by the
author. As well, the author held some lengthy discussions regarding the MBL materials and
particularly concerning calibrations with single students or groups of students.

The notes do indicate that some students were very interested in the MBL apparatus, while others
were less so. The teacher also indicated that several of the most interested individuals were not
strong academic achievers, while several strong academic achievers seemed uninterested. This had
also been noted in Experiment 19b.

Instructor Commentary

The instructor for blocks C and D seemed very pleased with the overall tone and direction of the
activity. This instructor was not familiar at all with MBL technology and methods. While several
students did not achieve a great deal during the course of the two MBL laboratory classes, he
commented approvingly about the experience as fulfilling a student need to see how 'real science' took place and the real difficulties encountered trying to do experiments that were not 'precooked.' He seemed almost perversely pleased with the DART board difficulties, and also commented on the need for students to learn 'modern' laboratory technology. He expressed pleasure with student participation in the development of curricular materials with a university-based researcher. Overall, he described the activities of the day as being a valuable experience for both himself and his students.

Questionnaire Responses

Of the three classes that participated, a total of 54 of a possible 79 laboratory questionnaires were turned in for a return rate of 68%. While the return rate was low, the number and quality of responses were not. A total of 403 encodeable qualitative responses were taken from these forms, and they are described in detail in Appendix G. Table 14 describes a brief statistical breakdown of these responses by type, occurrence and class. A high proportion of the encodeable replies were trivial or noninformative in nature (students either did not reply or indicated that all was fine or nothing required improvement). Note that no differentiation has been pursued for gender.

Table 14: Laboratory Questionnaire Returns and Replies for Experiment 2a

<table>
<thead>
<tr>
<th>Group (treatment) (n)</th>
<th>Questionnaire returns</th>
<th>Encoded Replies</th>
<th>Trivial Replies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block C (MBL) (27)</td>
<td>18 66.7%</td>
<td>137 7.61</td>
<td>32 23.4%</td>
</tr>
<tr>
<td>Block D (MBL) (22)</td>
<td>21 95.5%</td>
<td>157 7.48</td>
<td>38 24.2%</td>
</tr>
<tr>
<td>Block E (n/MBL) (30)</td>
<td>15 50.0%</td>
<td>109 7.27</td>
<td>38 35.0%</td>
</tr>
<tr>
<td>Totals (both) (79)</td>
<td>54 68.4%</td>
<td>403 7.46</td>
<td>108 26.8%</td>
</tr>
</tbody>
</table>
The majority of the replies were grouped into fairly broad, obvious categories and assigned a positive, neutral or negative tone within those categories. Some of the comments overlapped categories and were counted twice (once in each). Again, the object is not statistical analysis, but a desire to categorize the topics and extent of student interest through their comments and observations of their laboratory experiences.

The responses were categorized (Table 15) by the following topics:

- **Apparatus Setup** includes references to difficulties assembling physical materials and equipment as well as starting the computer and software,
- **Observations and Data Collection** includes comments directed towards acquiring and recording experimental information,
- **Lab Instructions** includes responses describing student reactions to their laboratory directions,
- **Overall Method** includes responses concerning the experimental procedure, and
- **Calibration** includes responses describing difficulties setting measurement accuracy with the apparatus.

<table>
<thead>
<tr>
<th>Topic (n)</th>
<th>Block C</th>
<th>Block D</th>
<th>Block E (non MBL)</th>
<th>Block C+D (MBL totals)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+ 0 -</td>
<td>+ 0 -</td>
<td>+ 0 -</td>
<td>+ 0 -</td>
</tr>
<tr>
<td>Apparatus Setup</td>
<td>2 5 6 1</td>
<td>4 1 2</td>
<td>3 5 5</td>
<td></td>
</tr>
<tr>
<td>Observations &amp; Data</td>
<td>- - 2</td>
<td>- - 15</td>
<td>- - 2</td>
<td></td>
</tr>
<tr>
<td>Lab Instructions</td>
<td>8 - 8</td>
<td>1 2 16</td>
<td>16 - 1</td>
<td></td>
</tr>
<tr>
<td>Graphs &amp; Analysis</td>
<td>- - 4</td>
<td>- -</td>
<td>- -</td>
<td></td>
</tr>
<tr>
<td>Overall Method</td>
<td>7 1 4</td>
<td>4 4 11</td>
<td>11 1 -</td>
<td></td>
</tr>
<tr>
<td>Calibration</td>
<td>2 7 4</td>
<td>3 2 11</td>
<td>5 9 15</td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>19 13 12</td>
<td>16 2 16</td>
<td>4 20 10</td>
<td>35 15 23</td>
</tr>
</tbody>
</table>

Some examples of student comment classification for the above table follow:
mentioning clarity for 'use of the thermometer probe', 'program' or 'the experiment' was classified as positive commentary regarding laboratory instructions, a desire to change calibration to 'a better, more sure fire method', or to 'make an automatic calibration' was classified as negative calibration comments, asking 'What is calibration?' was classified as a neutral comment upon calibration, calling the whole experiment 'clear and conscise' [sic] was classified as a positive comment upon laboratory instructions; and 'Although it makes a graph simpler to plot, a student does not get a chance to learn how to plot a graph' was classified as negative to both graphs and analysis and overall method.

Aside from the above classifications assigned a 'quality of tone', there were some additional comments worthy of commentary. These include comments from the MBL using students involving a need for probe, preamplifier pod and printer hardware improvements and the presence of sophisticated comments concerning experimental design (Overall Scope). These are tabulated in Table 16.

Table 16: Other Questionnaire Responses by Occurrence

<table>
<thead>
<tr>
<th></th>
<th>Block C (MBL)</th>
<th>Block D (MBL)</th>
<th>Block E (non MBL)</th>
<th>Block C + D (MBL totals)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Scope</td>
<td>12</td>
<td>15</td>
<td>9</td>
<td>27</td>
</tr>
<tr>
<td>Probe/Pod Improvements</td>
<td>5</td>
<td>5</td>
<td>n/a</td>
<td>10</td>
</tr>
<tr>
<td>Printer Improvements</td>
<td>3</td>
<td>4</td>
<td>n/a</td>
<td>7</td>
</tr>
</tbody>
</table>

Again, all of the classifiable student comments are described in Appendix G, but some examples include the following:

general observations regarding the suitability of the technique for instruction or the modifications of techniques, methods and technology to compare or improve accuracy were classified as comments upon overall scope, and comments, suggestions or complaints concerning specific items of hardware were classified as hardware improvements.

Finally, the replies of the MBL using students displayed a marked variation of topics suggested as the purpose for experiment 2a. These replies were classified into three groups: those students with
well-defined standard purposes describing characterization of PDB as the goal, more technical responses stating the purpose was an evaluation of the characteristics of PDB using MBL technology, and a third very pro-technology group claiming the experiment was intended to 'prove' or 'demonstrate the superiority of' MBL techniques. These are enumerated in Table 17.

Table 17: Experimental Purpose Responses by Occurrence

<table>
<thead>
<tr>
<th></th>
<th>PDB</th>
<th>PDB and/or MBL</th>
<th>'Prove' MBL Better</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group C (MBL)</td>
<td>6</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>Group D (MBL)</td>
<td>4</td>
<td>12</td>
<td>5</td>
</tr>
</tbody>
</table>

Finally, two of the laboratory questionnaires elicited diagrams from the students, one explaining how a temperature probe could be fitted with a device to eliminate the possibility of contact with the walls of the test tube (Figure 22) and the second a humorous artistic impression of the apparatus after the author spent twenty minutes reviving a dead DART board (Figure 23).

9a. If you had the opportunity to entirely redesign the experiment, what improvements would you make? The box that the probe is connected to should be placed better and that the probe should have a centering thing on it.

9b. Which parts would you retain?

Figure 22: Student Suggested Temperature Probe Centering Device
Figure 23: Student Illustration of MBL Apparatus

Photographs

Approximately one dozen colour slides of students using the trial apparatus were taken, revealing that students showed a great deal of interest in the apparatus. One notable photograph reveals a graph made by student-directed tinkering showing the cooling curve of PDB. The students had experimented to find the exact point of the plateau in the cooling curve and the graph shows they had allowed the PDB to entirely freeze, waited for a minute and then heated the PDB up and remelted it. This showed the consistency of the plateau as a hysteresis-free temperature characteristic of PDB. The melting and freezing points were identical. This activity would be quite difficult and unlikely to be reproduced in the absence of MBL apparatus.
4.2.4 Reflections

A number of results were disclosed by the second research cycle. These suggested followup action for the project methodology, hardware and software.

Methodology

The laboratory questionnaire did result in significant student comment upon laboratory procedures and methods in a meaningful way for further design and evaluations of MBL methods. Although the questionnaire could have been further developed to improve completion rate and reduce the number of trivial or unencodeable responses, the questionnaire encouraged students to participate in the action research methodology used for the MBL Project, and the results were adequate for evaluation purposes -- so it was retained as it was. Students made sophisticated comments and suggestions regarding the experiment scope, design and methodology and enjoyed their participatory status. The instructors also recognized and commented positively upon the role of student participation and attitudes in the research methodology. It was also decided that both the instructors and students would be given a greater opportunity to participate through videotaping experiments.

Curriculum

The curricular activities were inadequate to meet the student and teacher expectations that arose in the presence of MBL. Students making use of the MBL materials tinkered with the experiment in ways that were not readily repeatable without the technology. A large number of students managed to repeat the majority of the data collection and graphing of experiment 2a within a single class period using shared apparatus, and it was felt that students would have considerable scope for tinkering and additional experimentation given more sets of MBL apparatus. Some in-laboratory discussion of scientific measurement theory raised a large number of worthwhile questions regarding calibration, an activity typically unchallenged by students (ie -- the calibration of the Spec 20D in Experiment 19b). This topic alone drew more comments than any other, leaving students
split between satisfaction and dissatisfaction, but nonetheless interested in laboratory measurement techniques.

Students responded more analytically to the content of this activity than in the previous cycle, probably due to the wealth of information encoded into the computer-generated graph. Rather than a simple straight line to be translated into meaningful concentrations, this graph displayed inflections, plateaus, intercepts and slopes -- all of which held interpretable information. Since the student could readily observe physical processes (as per coded commentary) and speculate during the creation of the graph, it is likely that their comments regarding improved graphing can be interpreted as a greater ability to construct meaning from the graphs without distraction. This in turn suggests that MBL technology is best utilized in an environment combining observation with the simultaneous creation of complex graphical representations of processes under study, rather than processes that can be expressed through simple, linear graphs.

The use of MBL was observed to have an effect upon the participation and motivation of nonacademically inclined students -- both the observer and instructors noted that some students who usually were disinclined to participate in the laboratory activities seemed to enjoy tinkering with and manipulating the equipment. This participatory status was reinforced by the requests for student commentary and laboratory procedure evaluation. An interesting contrast appeared when one of the brightest students claimed that technology was not 'entirely beneficial to science students', because it made plotting graphs too simple.

The students obviously relished the opportunity to effect changes upon the laboratory materials and procedures as did the instructor, offering an enormous variety of comments, suggestions and even drawings. Students took positions ranging from that of a devils' advocate attempting to dispel the myth of MBL to evangelistic desires to prove the technology to be better, faster, neater etc.

Hardware and Software

Hardware changes necessary included increased resistance to noisy on-board signals and a recasing to eliminate an excessive number of distracting toggle switches (see Appendix C), and the
construction of a complete set of ten DART boards for classroom use. The temperature probe preamplifier pod required reworking to optimize resolution and accuracy for the PDB experiment through a sacrifice of available temperature ranges, or by designing a set of alternative pods for different temperature ranges or constructing a resettable multipurpose pod along with rescaleable software. Some technique for suspending the pod (a clip of some nature) would allow easier pod placement, as the probe leads were too short but not readily reworkable as they were solidly molded for liquid resistance. Again, some form of printer enhancement had to be addressed, possibly by print spooling, which would send output intended for the printer to disk and then on to the printer as printer memory became available, freeing the computer in the meantime to collect more data for another group.

Software changes would have to include the use of compiled software only, as well as the adoption of print spooling to hasten printing. The software proved quite satisfactory to a majority of students, (particularly the overall design and instruction) but the calibration routine would have to be improved, as well as better error handling and data editing.

It was also apparent that some discussion of instrument calibration and scientific measurement was appropriate as part of the prelaboratory demonstration, probably making use of the historic allegories of the Celsius and Fahrenheit temperature scales.
4. Reflections:
The Laboratory Questionnaire does not supply data suitable for statistical analysis, but provides data suitable for assessing and refining MBL materials and techniques. Students both are capable of and enjoy participating in the materials design in an active, knowing way. The materials prepared for this activity seem very appropriate with many suggested changes, ie - the topics of calibration and scientific measurement. MBL may represent a means for non-academically inclined students to excel in laboratory activity.

3. Evaluations:
Collect Laboratory Questionnaires, observer and instructor notes and still photographs of student laboratory activities.

1. Investigate:
1. Is the Laboratory Questionnaire suitable for assessing MBL appropriateness?
2. Can students make useful, knowing contribution to MBL materials design for this study?
3. Are the MBL materials prepared for this activity appropriate and how can they be refined?

2. Implementation:
Develop and employ MBL materials for experiment 2A. Have students complete 2A as usual, then have them use the MBL materials and compare the two experiences. Use the qualitative Laboratory Questionnaire to collect student comments.

Figure 24: Action Research Cycle 2 Summary
4.3 Experiment #16b - The Third Cycle of Action Research

The third experiment modified for MBL was Preparation of Standard Solutions and Use of a Spectrophotometer to Measure the Concentration of an Unknown Solution, the grade 11 experiment that is the curricular precursor to 19b in the grade 12 curriculum. This experiment introduces students to the use of the Spec 20D spectrophotometer. Students use the Spec 20D spectrophotometer to create a Beers' Law Curve for known concentrations of a coloured ion (aka the calibration curve, students do not refer to Beers' Law per se), then this curve is interpolated to find the concentration of a teacher-supplied unknown sample.

4.3.1 The Plan -- A Generalized MBL Tool

The materials and techniques previously developed for the first AR cycle (Experiment 19b) were considerably refined with the intent of creating a more general-purpose tool. The extensive teacher and observer commentary from the first cycle was used to refine the Spec 20D software.

The goals of this third AR cycle included the following objectives:

i. to evaluate the appropriateness of the MBL materials prepared for Experiment 16b, through collection of student commentary unavailable from Cycle 1;

ii. to juxtapose student commentary upon MBL activities involving complex graphical phenomena (such as Cycle 2) with activities involving simpler graphs (this activity), and

iii. to examine the appropriateness of a general-purpose MBL spectrophotometer tool for student laboratory use.

Curriculum

The standard laboratory curriculum was employed without changes for the dilution preparations from the standard solutions. This procedure is broken into three parts; during the first part, students make a standard solution of 0.160M cobalt (II) nitrate hexahydrate, Co(NO₃)₂·6H₂O using a volumetric flask and a precision balance. During the second part, students prepare five dilutions of the standard. During the third students measure their light absorbances with a spectrophotometer. Finally, students plot absorbance against concentration, obtaining a straight-line graph, and use this graph along with the spectrophotometer to determine the concentration of a teacher-supplied sample of Co(NO₃)₂·6H₂O in solution. Details of this procedure can be found in section 3.3.2.2 of chapter 3.
Changes in the MBL procedure occurred at the spectrophotometer, which was connected to the computer by a cable similar to that used in experiment 19b. Students used the computer calibration routine to calibrate the spectrophotometer, then entered the five samples one at a time along with the calculated sample concentrations. Upon entering the five samples, students instructed the computer to plot the line (again, a least-squares fit routine was employed) and either saved their graph to disk or printed it out. The final sample was then measured and related to the graph without the software, using the spectrophotometer alone.

Hardware and Software

The hardware and software were developed versions of the materials used in experiment 19b (cycle 1). The cable was reworked to eliminate the manufacturer-supplied plastic box with the red button, and simply ran directly from the Spec 20D to the Macintosh computer.

Software from 19b and from 2a was modified to allow the collection of Spec 20D data as before. The calibration routine from 19b remained unchanged, and the data collection routine now more closely resembled that of 2a, including a Save button for data which wrote the recorded wavelength, absorbance, transmittance, time and student-entered concentration to a tab-delimited textfile capable of being read by most spreadsheet programs. A Load button permitted students to retrieve their data at will. A continuously-updating value for the absorbance and transmittance of the sample compartment (as well as the current time) was displayed at the top of the screen similar to the temperature display, with the intent of encouraging students to wait for the values to settle before recording and graphing them. The X axis was rescaled for the much greater (three orders of magnitude) concentration of the \([\text{Co}^{2+}]\) ion under measure. A commercial print spooler known as SuperLaserSpool (SuperMac Software, 1988) was installed into the computers' operating system that allowed students to cue up hardcopies and to continue collecting data while the printer was running.

The major intent in the redesign of the software was to create as flexible a tool as possible so as to allow teachers to use this software to measure any concentration of any ion. With this intent, references to \(\text{Co}^{2+}\) were specifically avoided (see Figure 25). With further modifications (most notably the addition of a rescaling feature) the software hopefully could be used for almost any spectrophotometer activity.
4.3.2 Action

The three classes of grade 11 students from Richmond school discussed in the second cycle participated in this activity. Blocks C (27 students) and D (22 students) were taught by one instructor and completed the activities without using MBL apparatus; block E (30 students) completed the experiment with MBL apparatus and was taught by a second instructor. All blocks had completed laboratory questionnaires for the second cycle and for several other activities (notably experiment 16A) and were quite familiar with the form. All students completed part III (the spectrophotometric measurements) for this laboratory in a single class period. Students had no previous experience with the Spec 20D spectrophotometer at all.

Setting & Site Preparation

The same classroom laboratory was used as in the first and second cycles. Spectrophotometers from other schools were not borrowed for this activity; hence only two spectrophotometers were set up along the wall counter top. For block E, each Spec 20D had a computer and a printer available without any need to share printers.
Student Activities

Students were prepared quite differently for this activity by their different instructors, without interference from the author. The instructor from blocks C and D calibrated the spectrophotometer for the students at the start of the class and then advised the students not to move the instrument settings. To 'encourage' them to complete the laboratory questionnaires, the students were told the form would be reviewed by the instructor and graded. This was contrary to the original study intent. The instructor for block E encouraged students to calibrate their own spectrophotometers; specifically instructed students to 'evaluate the MBL program'; and did not coerce students for laboratory questionnaires. All students completed this experiment over two days, and most had completed preparation of their standard solutions (Part I) the previous day. A few had also completed the dilutions as well (Part II), but none had made use of the Spec 20D before the class in question.

4.3.3 Observations

Prelaboratory quizzes (completed the previous day) were not collected, although laboratory questionnaires, observers' comments, photographs and the completed laboratory reports for block E were collected for analysis. Additionally, the computer data for the final class (Block E) were all recorded on disk and preserved for later examination.

Observers' Notes

The author made several notes regarding unexpected student difficulties making use of the software. It was thought that the software was sufficiently developed to permit easy and intuitive student use, but student problems with off-scale points, excessive header flicker, selection of print quality through the print routine, and control of the spooler via the finder were all documented. The program also did not refresh well, nor was there any ready correction for irregular or mistaken data entries.

Laboratory Questionnaires

Overall, the three classes returned 58 laboratory questionnaires of a total possible of 79 for an overall rate of 73%. Two of these questionnaires were not encoded for analysis because these students (and others who did not complete a questionnaire at all) did not complete the laboratory upon the assigned date when MBL materials and the author were present in the classroom. Due to instructor pressure, general questionnaire response quality for blocks C and D was much higher than for block E.
Of the 19 questionnaires coded from the three blocks, only those submitted by block E referred to the computer at all in the first two questions concerning procedure and purpose. Of block E students, 20% referred to the computer or MBL materials in the procedure and 42% referred to the computer or MBL materials in the purpose; the remainder of block E students all paraphrased the laboratory manual descriptions for the activity or gave trivial replies. All students in blocks C and D paraphrased the laboratory manual for these two questions.

Comments and replies for the remaining questions were grouped into six categories and then rated as supportive (+), neutral (0) or critical (-). The six categories were: preparation of the standard solution (Part I), the dilutions (Part II), the use of the spectrophotometer, the transfer of dilutions to cuvettes, calibration of the spectrophotometer and the use of the computer (all from Part III). This information is then divided by the total count classified in the table (a normalization of sorts) to show the percentage occurrence in Table 18.

Table 18: Questionnaire Responses Percentage by Topic

<table>
<thead>
<tr>
<th>Topic (n)</th>
<th>Block C (MBL)</th>
<th>Block D (MBL)</th>
<th>Block E (MBL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+ 0 - Tot</td>
<td>+ 0 - Tot</td>
<td>+ 0 - Tot</td>
</tr>
<tr>
<td>Prep S Soln</td>
<td>5.6% 4.2% 7.0% 17%</td>
<td>11% 0.0% 2.1% 13%</td>
<td>9.1% 0.0% 0.0% 9.1%</td>
</tr>
<tr>
<td>Dilutions</td>
<td>20% 8.5% 8.5% 37%</td>
<td>8.5% 11% 11% 31%</td>
<td>6.1% 0.0% 3% 9.1%</td>
</tr>
<tr>
<td>Spec 20D</td>
<td>11% 5.6% 5.6% 22%</td>
<td>30% 6.4% 8.5% 45%</td>
<td>12% 6.1% 6.1% 24%</td>
</tr>
<tr>
<td>Cuvettes</td>
<td>0.0% 2.8% 16% 19%</td>
<td>2.1% 2.1% 2.1% 6.3%</td>
<td>0.0% 0.0% 0.0% 0.0%</td>
</tr>
<tr>
<td>Calibration</td>
<td>1.4% 4.2% 0.0% 5.6%</td>
<td>0.0% 6.4% 0.0% 6.4%</td>
<td>3.0% 0.0% 3.0% 6%</td>
</tr>
<tr>
<td>Computer</td>
<td>na na na</td>
<td>na na na</td>
<td>6.1% 21% 9.1% 36%</td>
</tr>
<tr>
<td>Totals</td>
<td>71 replies is 100%</td>
<td>47 replies is 100%</td>
<td>33 replies is 100%</td>
</tr>
</tbody>
</table>

Of particular note is the consistently high occurrence of comment upon the use of the spectrophotometer, most of it favorable in nature. Students find the device interesting and largely enjoy using it. The two most common complaints regarding the use of the spectrophotometer were either not having more information upon how it worked or not having the opportunity to calibrate the instrument.
Student comments regarding the Spec 20D included the following:

'...and get the students to calibrate the spectrophotometers (how are the students going to learn if they don't try it?)'
'Also I would want to calibrate the spectrophotometer myself'
'Perhaps students could calibrate spectrophotometer themselves.'
'Have the students set up the spectrophotometer, turn it on, find the appropriate wavelength, set transmittance and absorbance. Discover how to exactly go from knowing the absorbance to knowing the concentration.'

The dilution process also was considered worthy of note as the complex process presented some challenge to students (most students enjoyed it as well). An interesting effect of the presence of MBL instrumentation is that fewer students comment upon the dilutions, as their attention is centered upon Part II of the experiment. This effect was noted during the first cycle as well.

Student comments regarding the dilutions included:

'Part II however was a little more complicated and required more thinking to understand.'
'The preparation of dilute solution of Co NO₃ was quite clear and easily understood.'
'Part II was a little difficult to understand.'
'I think that we should calibrate our own spectrophotometer, make more dilutions and make stronger solutions.'

A notable number of students from the non-MBL blocks complained that the procedure had students prepare too much solution for the Spec 20D cuvettes, resulting in some wastage and a need for further manipulations of the solution. This complaint did not arise with the MBL group.

The MBL group commented stridently upon the computer apparatus. Many students found that the computer was complex or unclear, but wanted to retain it nonetheless. Like the case of the spectrophotometer, students again wanted more information about and access to the technology Some such comments included:

[Which parts would you retain?] 'The part with the computers & printer.', 'using the computer to record and print data & graph', 'To use the computer to do data.'
[...what improvements would you make?] 'the process of using the computer -- just make it more easily understood', 'I would have more computers and spectrophotometers.', 'I would have a longer period to do it', 'know how to print graphs on computer more efficiently', 'using the computer to draw a graph gives you extra knowledge', and 'have more knowledge of computer use'.

A few students expressed the opinion that the introduction of the computer made the activity overly complex:

'...retain all of it except the part of where we had to use the computer because it was just extra work...', 'I would retain all parts except the computer part', and 'don't use a computer'.
But some students from the non-computer using block expressed an interest in greater access to the computer:

'Have all spectrophotometers hooked up to a computer', 'I would try using to [sic] computer for making the graph.'

Overall, the responses encoded above indicate that students enjoy and want to maximize their exposure to instruments and technology, with some exceptions where the process becomes overly complex.

An additional coding treated the comments proposing amendments to the experiment, which were classified as changing to other chemicals (either more samples or less toxic ones were usually suggested), changing the procedure to have more time, graph transmittance as well as absorbance, change the number of dilutions or the procedure of diluting, use different labware, use a spectrophotometer that did not require calibration, modify computer software or correct hardware (printer difficulties). These responses are detailed in Table 19.

Table 19: Other Questionnaire Responses by Occurrence

<table>
<thead>
<tr>
<th></th>
<th>Block C (no MBL)</th>
<th>Block D (no MBL)</th>
<th>Block E (MBL)</th>
<th>Block C + D</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Chemicals</td>
<td>4</td>
<td>6</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>Procedural</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>Modifications</td>
<td>na</td>
<td>na</td>
<td>5</td>
<td>na</td>
</tr>
<tr>
<td>Software</td>
<td>na</td>
<td>na</td>
<td>7</td>
<td>na</td>
</tr>
<tr>
<td>Modifications</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Modified Spec 20D</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Other Labware</td>
<td>9.9%</td>
<td>2.2%</td>
<td>38%</td>
<td>-</td>
</tr>
</tbody>
</table>

The notable student quotes corresponding to the above observations include:

[new chemicals] '...perhaps a few more dilutions of Co (NO₃)₂', '...make 3 different dilutions of 2 different chemicals', 'using a different compound...'
[new procedures] '...use smaller test tubes', 'make the dilutions in the smaller test tubes', 'I would use percent transmittance too', '...use the spectrophotometer to calculate transmittance rather than absorbance', 'make more time slots out for use of the computer...', 'I would have a longer period of time to do it.'
[software modifications] 'In the computer program, allow the user more menu options and print speeds when calibrating and printing results. Also, warn the user about the spectrophotometer readings (ie - not to enter molarity before the calibration is complete)', '...more spectrophotometers with printers to speed up that part...'
[printing modifications] '...tell us how to print!', 'graph the transmittance also',
[Spec 20D] '...a spectrophotometer that had press numbers rather than a dial as the dial was not easy to use.', 'make the adjustment knobs easier to control...', '...get less
9a. If you had the opportunity to improve improvements would you make? 

\[ \text{mark ml on test tube} \]

9b. Which parts would you retain? 

\[ \text{everything else} \]

Figure 26: Suggested Labware Modifications

Laboratory Report Quality

Of a possible thirty students in block E, twenty-four completed a laboratory report for experiment 16b. This is the same rate of response as for the laboratory questionnaire returns. These reports include very few if any qualitative descriptions of the experimental procedural; as in the first cycle the reports consist of references to the laboratory manual, responses to laboratory questions, a data table (almost always copied from an MBL printout) and a graph or graphs.

The reports were categorized by the quality and type of graph included with the report in Table 20:

Table 20: Student Submitted Graphs for 16b

<table>
<thead>
<tr>
<th>Number of Students</th>
<th>Type of Graph(s) Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 students (33%)</td>
<td>MBL printout only with annotations (Figure 27)</td>
</tr>
<tr>
<td>3 students (13%)</td>
<td>MBL printout only, no annotations</td>
</tr>
<tr>
<td>6 students (25%)</td>
<td>MBL printout, no annotations plus manual absorbance plot</td>
</tr>
<tr>
<td>1 student (4.2%)</td>
<td>MBL printout, no annotations plus manual plots (two)</td>
</tr>
<tr>
<td>2 students (8.3%)</td>
<td>no MBL printout, manual plot (Figure 28)</td>
</tr>
<tr>
<td>4 students (17%)</td>
<td>no MBL printout, generated plot with CAD program (Figure 29)</td>
</tr>
</tbody>
</table>

Total students with MBL printout only: 46%.
Figure 27: MBL Printout with Annotations

These laboratory reports represent a wide range of student acceptance of the computer-generated graph as a portion of their laboratory report. Almost all feel that a computer-generated graph is an important part of their report (17% feel this strongly enough to have generated their own graph on a separate software package in the school IBM Computer-Aided Design (CAD) laboratory after losing their original printout), but a number of students feel a need to replicate the plot and offer an alternative copy (29%). Obviously the majority of students feel comfortable enough to turn in the MBL printout as their only plot (46%), but some (13%) do not clearly annotate such information as to the name of the ion under study or where the unknown sample would lie upon the graph.

Photographs

A dozen colour slide photographs were taken during this activity, they show student interest captured by the laboratory equipment, but nothing remarkable.
4.3.4 Reflections

This cycle was intended to evaluate the appropriateness of the MBL materials prepared for experiment 16b. The materials seem adequate, with much scope for improvement. The software still needs polishing, and printing is still not satisfactory. Students want more information about and access to the technology used during this activity, and this is not possible due to the very casual treatment of spectrophotometry and its principles in the curriculum.
A comparison of complex and simpler graphs (cycles 2 and 3) reveals that students are less willing to be inconvenienced by complex software and hardware to obtain a simple linear calibration graph in comparison to a more complex graph with a higher level of information content. Given such an easily produced graph, a large number of students will not hesitate to manually repeat the graphing procedure, but the majority of students have a little difficulty accepting and assuming ownership of the computer-generated report.

The software used for this experiment communicated with the Spec 20D; most if not all of the functionality of the software could be preserved by an independent computer with software that merely did a least-squares fit and plotted a line along with the data points input at the keyboard. A spectrophotometer link may not be justified in this case due to unwarranted complexity.

Finally, the question of a general-purpose MBL spectrophotometer tool must be addressed. This is an achievable goal; such software would have to be far more robust and offer additional options such as a flip back and forth between plots of transmittance (with an exponential fit) and absorbance, the ability to remove and insert additional data points, a cue to the student to label the printout graphs appropriately and variable X and Y axis scaling. This would be a truly universal spectrophotometer tool, and the something like it is currently available in commercial laboratory plotting and charting software such as Igor, Cricketgraph, KaleidaGraph, DeltaGraph and so forth. These capabilities would all be additions to the curriculum. Perhaps a permanent laboratory computer with such a package would be even more useful.
Cycle 3: Experiment 16B

4. Reflections:
Students enjoy using and want to maximize their access to technology in the laboratory, including the computer. These materials are less appropriate for student use than those from the second cycle due to lesser graphical complexity, and many students regraphed their data manually. A commercial laboratory software package may suffice for this activity. General purpose tools for the Spec 20D are very appropriate because they allow great flexibility, and readily permit activities that extend beyond the curriculum.

3. Evaluation:
Collect student Laboratory Questionnaires, completed Laboratory Reports, observer notes, disk copies of student graphs and still photographs of student laboratory activities.

1. Investigate:
1. Are the MBL materials prepared for this experiment adequate and how can they be improved?
2. Does MBL appropriateness vary with higher levels of graphical information content?
3. Are more generalized MBL procedures more appropriate for Spec 20D experiments than specific procedures duplicating the standard curricular activities?

2. Implementation:
Develop and employ generalized MBL materials for a standard curricular experiment. Use these materials with some students, and the regular curriculum with others. Compare and contrast the two groups and results between this and the previous (the second) cycle.

Figure 30: Action Research Cycle 3 Summary
4.4 Experiment #20h - The Fourth Cycle of Action Research

The fourth experiment chosen and modified for MBL use was 20h -- *Titrations Curves*. This experiment most resembles 2a, and required a working DART board for each group of students. Six DART boards were prepared in time for student use, along with the required pH probe preamplifiers. The software written for 2a was again modified and extended for use in this cycle. Details of these processes can be found in Appendices C and D. The curricular treatment, hardware and software were considered to be fairly well developed at this point through earlier experiences, and therefore were used with grade 12 students at two separate school sites.

The examination of student laboratory reports from the previous cycle revealed some interesting variation in student acceptance of computer-produced graphs and data tables. This cycle was intended to shed some light upon this matter by observing student reactions after presenting each student with several different examples of very complex graphs and tables.

As well, an attempt was made to develop an instrument similar to that used by Linn et al (Linn & Songer, 1989) designed to measure the effects of MBL employment upon student graphical interpretation skills. This instrument was designed from a combination of Linn's Critical Evaluation of Graphs (CEG) instrument (Nachmias and Linn, 1987), provincial final exams in Chemistry (Ministry of Education, 1988) and teacher expertise and commentary. The instrument was not available previous to the laboratory experiment, but was piloted by students using the MBL apparatus a few weeks later as a partial review for the course.

4.4.1 The Plan -- Advanced MBL and Skills Assessment

The goals of the fourth cycle included the following objectives:

i. to evaluate the appropriateness of the MBL materials prepared for Experiment 20h;

ii. to examine student presentation of computer-produced graphs and data tables in student laboratory reports; and

iii. to develop an instrument designed to measure student graphical interpretation skills using the subject domain of titration curves.
Curriculum

Experiment 20h is organized into three sections which all require the production of a separate titration curve plotting titrate pH against titrant volume. The first of these three graphs is calculated and plotted by hand before commencing laboratory activity and consists of a theoretical 20 point titration of a strong base (NaOH) against a strong acid (HCl -- this procedure is also known as an SBSA titration). Part II has students record pH during a laboratory repetition of this experiment, then plot the resulting graph. Part III repeats the procedure using a sample of dilute acetic acid (CH₃COOH), which is a strong base weak acid (SBWA) titration with a markedly different titration curve from that of Part II.

The MBL implementation of this experiment remained unchanged for Part I (the student calculated graph), but during the prelaboratory session students using MBL held a brief discussion regarding calibration and the pH scale, followed with a demonstration of MBL materials use. They then calibrated and collected data using their own MBL apparatus, saved their data to disk and printed the graph for the titrations from Parts II and III.
Hardware and Software

This experiment required each group of students to have their own computer, DART box, pH electrode and preamplifier pod, titration apparatus and software. The author constructed six sets of apparatus, details of which are presented in Appendices C & D. No difficulties were encountered providing signal processing for the pH probes used.

Software for the activity was modified from experiment 2a. New apparatus setup and calibration pictures and procedures were developed (Figures 31 and 32) which required students to use high and low pH buffer solutions to define a scale rather than two temperature baths.

The software than allowed students to collect pH data with control buttons identical to those used in the second cycle, with appropriately-modified labels and scales. A new button labelled Scale was intended to allow students to vary the titrant volumes and the pH ranges used (Figure 32), but this remained unimplemented, an oversight that proved unfortunate during student activity.
4.4.2 Action

One class of grade 12 students from Richmond and two from Surrey participated in this cycle, for a total of 56 students. The 28 students from Richmond were most accessible to the author and the bulk of the laboratory questionnaire and laboratory report data were collected from them, but some additional data were also gathered from the Surrey students, particularly regarding the graphical skills assessment instrument. The Surrey students performed the experiment about two weeks later than Richmond, due to a different semestering system at each school and scheduling manipulations.

The single class from Richmond all completed Parts II and III in a single laboratory session using five stations set up in various sections of the classroom laboratory at Richmond described earlier. Two weeks later at Surrey six stations were initially erected, but one DART board malfunctioned and only five were actually used during student data collection.

Laboratory questionnaires were again collected from students at both sites (one of the Surrey classes did not complete the questionnaire), along with photographs and disk copies of student graphs. Both sites also completed the graphical skills assessment. The completed laboratory
Setting & Site Preparation

The same classroom at Richmond described in earlier cycles was again used, with five complete stations (three printers) set up. The classroom at Surrey used by both classes of students was a significantly different setting, with much more available laboratory countertop space apart from regular desk space, which considerably alleviated the usual difficulties encountered setting up, moving about amongst and operating the MBL apparatus. Surrey counter space is also organized into three large islands, and the physical arrangement greatly encouraged student interaction and comparison of computer-produced graphs. Six stations and four printers were set up at Surrey, but only five stations were actually used due to hardware problems.

The prerequisite number of computers and printers at both sites were obtained by removing them from the school computer laboratories, which required a fair amount of coordination with the computer instructors and a good deal of labour in transporting the machines. Surrey computers are now secured with cable locks to discourage theft, which would make reproducing MBL events even more difficult. Moving this much hardware led participating instructors to speculate about the feasibility of MBL implementation at that time.

Student Activities

Students were again differently prepared for this activity by the two different instructors, this being the first time the author participated in laboratory activity at Surrey. The instructor at Surrey gave a lengthy prelaboratory demonstration and discussion which somewhat reduced the amount of time available to students, while the Richmond instructor’s demonstration had greater brevity. Students at both sites also participated in a brief discussion and presentation discussing calibration and the definition of scalar measurement. All students completed this activity in two days, having prepared the theoretical titration curve on the first day and the MBL activities on the second. Students worked in self-selected groups of between 3 and 5 students.

One noteworthy difficulty encountered was in titrant volume scaling. The X-axis of the graph upon the computer monitor should reflect the volume capacity of the buret used for the titration, and the titration equivalence point must fall wholly upon the screen. During software design discussions, there was some confusion between the author and the instructor, which led to students attempting a titration where the equivalence point occurred exactly upon the right margin of the graph on the computer screen. This led to a great deal of confusion in the first titration graph (Figure 34), which was avoided in the following titrations by halving the amount of titrants used. Had there been adequate time to implement the forementioned Scale feature to cover the commonest buret sizes
available, this would have been easily remedied without confusion. This confusion was evaded at Surrey by checking the sample and buret sizes to be used, and manually re-scaling the software source code and doing a separate compile for Surrey.

A second source of confusion was encountered (this time in Surrey) due to poor preparation of the pH electrodes. A bottle containing several electrodes in a storage solution had spilled, allowing the sensing surfaces of these to dry off completely. This resulted in erratic probe response for two probes which was evidenced by difficulties in calibration and settling and response difficulties. To rectify this problem spare probes were brought in. Details concerning probe function and care are given in Appendix C.

![Figure 34: 20h Offscale Titration](image)

4.4.3 Observations

Laboratory questionnaires, photographs, laboratory reports and videotape recordings were taken from the Richmond site. At Surrey, videotape and laboratory reports were not recorded, and only the first group completed laboratory questionnaires. Students at both sites later participated in a follow-up activity, the piloting of graphical skills assessment test, used as a review of laboratory content.
Laboratory Questionnaires

One class each from Richmond and Surrey completed laboratory questionnaires, for a total of 22 and 17 forms respectively. Richmond students made 154 codable comments (7 per student) with 30 trivial replies (11%). Surrey students made 121 codable replies (7.1 per student) with 44 trivials (36%), probably due to time constraints and participant unfamiliarity with both MBL and the project questionnaire.

An analysis of the comments describing the laboratory procedure revealed that at Richmond, 68% of students described the use of the computer as part of the procedure, and 9% of students described calibration in their procedure. From Surrey, 65% described computer use in their procedure, with 11% mentioning calibration. Comments concerning experimental purpose were split 60% : 20% from Richmond and 67% : 7% from Surrey between the experimental purpose described in the laboratory workbook and a purpose including evaluation or use of computers or MBL technology.

Comments and replies for the remaining questions were grouped into categories and then rated as supportive (+), neutral (0) or critical (-). The categories were: procedural directions, software calibration, data entry, scaling, resolution, saving and loading data, editing or correcting mistaken data, plotting several graphs on the same screen, hardware pH probe and printer, labware magnetic stirrer and buret manipulation. This information is then divided by the total count classified in the table (a normalization of sorts) to show the percentage occurrence in Table 21.
### Table 21: Questionnaire Responses Percent by Topic

<table>
<thead>
<tr>
<th>Topic (n)</th>
<th>+</th>
<th>0</th>
<th>-</th>
<th>Tot</th>
<th>+</th>
<th>0</th>
<th>-</th>
<th>Tot</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Typical</td>
<td>Richmond</td>
<td>Surrey</td>
<td>Tot</td>
<td>Typical</td>
<td>Richmond</td>
<td>Surrey</td>
<td>Tot</td>
</tr>
<tr>
<td>Directions</td>
<td></td>
<td>5.7%</td>
<td>0.0%</td>
<td>1.9%</td>
<td>7.5%</td>
<td>20%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>SW: Calibration</td>
<td></td>
<td>7.5%</td>
<td>1.9%</td>
<td>0.0%</td>
<td>9.4%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>10%</td>
</tr>
<tr>
<td>SW: Data Entry</td>
<td></td>
<td>26%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>26%</td>
<td>20%</td>
<td>5%</td>
<td>0.0%</td>
</tr>
<tr>
<td>SW: Scaling</td>
<td></td>
<td>0.0%</td>
<td>0.0%</td>
<td>15%</td>
<td>15%</td>
<td>10%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>SW: Resolution</td>
<td></td>
<td>1.9%</td>
<td>0.0%</td>
<td>3.8%</td>
<td>5.7%</td>
<td>0.0%</td>
<td>5%</td>
<td>20%</td>
</tr>
<tr>
<td>SW: Saving/Loading</td>
<td></td>
<td>0.0%</td>
<td>1.9%</td>
<td>0.0%</td>
<td>1.9%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>SW: Error Correction</td>
<td></td>
<td>0.0%</td>
<td>0.0%</td>
<td>3.8%</td>
<td>3.8%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>SW: Multiple Plots</td>
<td></td>
<td>0.0%</td>
<td>0.0%</td>
<td>3.8%</td>
<td>3.8%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>HW: pH Probe</td>
<td></td>
<td>1.9%</td>
<td>0.0%</td>
<td>3.8%</td>
<td>5.7%</td>
<td>0.0%</td>
<td>5%</td>
<td>5%</td>
</tr>
<tr>
<td>HW: Printer</td>
<td></td>
<td>5.7%</td>
<td>1.9%</td>
<td>3.8%</td>
<td>11%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>LW: Magnetic Stirrer</td>
<td></td>
<td>0.0%</td>
<td>3.8%</td>
<td>0.0%</td>
<td>3.8%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>LW: Buret</td>
<td></td>
<td>0.0%</td>
<td>1.9%</td>
<td>3.8%</td>
<td>5.7%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Totals: 53 replies is 100% 20 replies is 100%

Sample quotes from the most prevalent categories include the following:

**[Directions]** [What parts of the experiment seemed clear and easily understood?]

'All parts, since a demonstration was given before the experiment.' 'especially because it was demonstrated to the class once...', 'The setup of equipment, the preparation and operation of the computer should've been given out on a hand-out beforehand.' 'easy once I knew what was going on...', 'better pre-lab instructions...', 'Better explanation in use of computer, pre-lab instructions.', and 'They all seemed clear and easily understood once you understood what you were doing.'

**[Calibration]** [What parts of the experiment seemed clear and easily understood?]

'Calibrating, etc...', 'calibrating pH electrodes', 'calibrating', 'I'd have the probes already calibrated.' and '...the process of calibrating the pH indicator and sensor, '...how the measuring device worked...'

**[Data Entry & Error Correction]** [What parts of the experiment seemed clear and easily understood?]

'using the computer', 'use of computers to graph out the chart.', 'When I was doing the titration with the computer', 'If you make one mistake, there is no 'UNDO' command...', 'clear and understood was plotting the graph with the computer...', '...put in the ability to erase some data entries...', 'the plotting of the points on the computer, the actual titrating of the acid by the NaOH...', 'the procedures -- they are easy to understand and follow.'
[Scaling] 'change scale of computer graph', 'prompt the user for their choice of volume scale (e.g., 0 to 25 mL or 0 to 50 mL etc)', '..should be pre-set beforehand between the person mixing the solutions and the programmer...', '..make the graph adjustable', '..have the ability to alter the values of the graph...', 'entering data into the computer

[Resolution] 'have the computer plot pH values to nearest one-hundredth...', 'I would improve the resolution of the graphs.', 'try to stabilize the pH on the computer to create a better accuracy level' [this can also be ascribed to probe use or calibration], 'The pH level jumped back and forth (reading at top of screen) and so our graph readings were not very accurate.', 'find a way to make the titration more accurate', 'why the numbers measuring the pH were continual [sic] changing in a standard solution.'

[Printer] 'speed up the printing process (either by xeroxing multiple copies or connect it to a laser printer).', [retain] 'data table printing'

[Others] '..devise a method of getting 1/2 drop or less from the buret...', 'find the buret that can drop 0.01 ml...', '..a lower level so the buret can be seen easier...', 'I would use the electric swirler instead of using manpower...', '..have a stronger glass electrode so you don’t have to worry about the magnet...', '..make a stronger glass electrode...', 'more computers...', 'plot 2 graphs on one sheet of paper instead of two...', '..less clutterings of equipment...

Additional coded comments including outright statements by students to retain the computer or MBL apparatus, to do more titrations, use weak bases or other substances and have smaller groups or more time or more computers are listed in Table 22 by frequency.

Table 22: Other Questionnaire Responses by Occurrence

<table>
<thead>
<tr>
<th></th>
<th>Richmond</th>
<th>Surrey</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retain Computer</td>
<td>13</td>
<td>7</td>
<td>20</td>
</tr>
<tr>
<td>Extend Experiment Scope</td>
<td>9</td>
<td>8</td>
<td>17</td>
</tr>
<tr>
<td>Smaller Groups -- Time</td>
<td>-</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

The notable student quotes corresponding to the above observations include:

[Computer Retention] 'Data Table printing.', 'accuracy', 'The implement of the Computer', 'I would retain the computer program for plotting the graphs.', [retain] 'use of the printer to show graph immediately afterward', [retain] '...use of computer (time saving)...', [retain] 'the computer plot because it makes the job much easier.', [retain] 'the format of the output', '...computerized titration curve. It looks neat.', [retain] 'using the computer to do the graphing and take data', [retain] '...usage of the computer, because it is time saving and much more accurate (in graphing, calculations)

[Experimental Scope] 'a part involving a titration for a weak base with a weak acid, in order to compare...', '...do the titration a greater number of times & using more variety of acids.', '...plot more points..."
[Groups & Time] 'use smaller groups. 3 at most per group.', 'smaller groups.', 'give myself more set up time', '...very clear, but make it an individual experiment', 'more time', '...have people working in groups of 2 only. The third person usually just stood there.'

[Others] '...connect a meter or detector to the buret...', '...smoothing algorithms for the plotting of the graph for a smoother curve...', 'let the computer control the drops of NaOH solution'

Laboratory Report Quality

The instructor made available multiple copies of several student graphs so that all students had either original or photocopies of at least one SBSA and SBWA computer-generated plot. Twenty four reports were turned in for marking, and these reports were categorized by the quality and type of graph included with the report as follows:

<table>
<thead>
<tr>
<th>Number of Students</th>
<th>Type of Graph(s) Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 students (25%)</td>
<td>Didn't include Part I (hand-drawn from calculations)</td>
</tr>
<tr>
<td>3 students (13%)</td>
<td>Did not include MBL printouts for both Parts II &amp; III</td>
</tr>
<tr>
<td>15 students (63%)</td>
<td>Met the minimum required number of plots (1 each)</td>
</tr>
<tr>
<td>3 students (13%)</td>
<td>Replotted computer plots by hand</td>
</tr>
<tr>
<td>5 students (21%)</td>
<td>Annotated MBL plots</td>
</tr>
<tr>
<td>4 students (17%)</td>
<td>MBL-generated 'junk' (ie Figure 34 -- Offscale)</td>
</tr>
<tr>
<td>5 students (21%)</td>
<td>Referred to MBL printout for data tables</td>
</tr>
</tbody>
</table>

Examples of student-produced graphs by calculations are given in Figures 35 and 36. No student turned in a report without an MBL-generated plot.

These reports indicated a very high level of acceptance of MBL-generated plots by students, only 13% of students felt a need to reproduce these graphs by hand. This is half the number of students who neglected to do any hand-drawn graphs (for Part I) at all. About 21% of students annotated their graphs, and 17% handed in garbage plots generated by mis-scaled or botched titrations, while recognizing this fact in annotations.

Still Photographs

Approximately a dozen colour slide photographs were made of the activities at Surrey and Richmond during experiment 20h, and they show no unusual activity other than as described in earlier cycles.
Videotape Recordings

Approximately an hour of videotape was taken of the experiment and activities at Richmond, mostly depicting the backs of students clustered about computers and apparatus. There was considerable indication of student movement between stations comparing results from one screen to another, and it was evident that all students had the opportunity to complete both required titrations, a mis-scaled titration and other experiments. However, the videotape was not retained or analyzed due to instructor discomfort (particularly after the scaling mishap). Videotape was not shot at Surrey due to logistical difficulties transporting equipment to that site.
Eleven graphs were saved to disk by Richmond students and seventeen by Surrey students, probably representing a majority of graphs made. The files are usually the names or pseudonyms of individual students or a collage of group names (this identification was encouraged by the software prompted default save name -- *Freddy Kreugers' Graph*). These graphs document several interesting events and student strategies for titrations, of which the most interesting is displayed in Figure 37 -- the step strategy. Several students completed their titrations in two parts; first they quickly ran through the buret of titrate (and the x-axis complete range) in very coarse but easily manageable steps to roughly determine the equivalence point, then the procedure was repeated a second time exercising much finer buret control. Such a strategy can considerably reduce the amount of time needed to complete a titration curve, as the major effort in data collection is precise buret control and titrate meniscus reading. For an example of excessive student control, compare the step strategy in Figure 37 with the painstaking curve involving considerable time and effort displayed in Figure 36 (containing 46 data points).
Other interesting phenomena saved to disk included titrations with incorrect samples where the curve barely leaves the lower portion of the sigmoid, curves depicting considerable probe 'jumpiness' where a smooth curve must be interpolated by eye, partial curves and curves taken with scaling over and under-runs.

The Graphical Skills Assessment Instrument

This instrument consisted of a three page multiple choice test depicting three titration curves with appropriate scales; two SBSA curves, and a WASB curve. A total of ten questions associated with the diagrams were asked requiring the student to read numerical values from the graphs, identify and interpret critical sections of each graph and to translate freely between ion concentration and pH or pOH units. All of these tasks were taken from a previously used grade 12 provincial final exam and are similar in nature to those used by Linn to examine childrens' identifications and interpretations of MBL-generated graphs in the domain of thermodynamics. The test was piloted with this cycle, and the test, an analysis and commentary are included in Appendix H. Much more development is required (to increase reliability and validity) before a comparative examination of MBL and non-MBL treated students can be made with this instrument.
4.4.4 Reflections

This cycle, like all previous cycles, was intended to evaluate the appropriateness of the prepared MBL materials. The activity appears highly appropriate due to the complex graphical nature and extensive data collection required of experiment 20h. There is still scope for improvement, but if chemistry teachers are considering the adoption of MBL technology for their laboratories, then this is definitely the activity to start with. Students showed great enthusiasm and interest in the MBL materials and activities, and their support survived the actual implementation well.

Students strongly indicated an interest in extending their exposure to this particular apparatus and these experiments. Students commented very positively on data entry and graph generation during the experimental procedure, which indicates they are taking advantage of the opportunity to construct meaning and relationships between ongoing physical processes and abstracted graphical relationships which they may not have done during the standard curricular exercises.

Students commented upon laboratory shortcomings, particularly scaling, resolution and printing difficulties, but the first can be remedied with software manipulation and the second with better probe care and handling. Only the third is likely to remain a real difficulty, and it can be greatly alleviated by storing data on a class or disk for later printout at leisure and through teacher distribution of photocopied results as occurred at Richmond. A final shortcoming, lack of an ability to edit and modify data table entries during a titration can also be addressed through software revision.

The apparent student reticence to accept computer-generated graphs noted in the third cycle was probably due to an unavailability of computer output at the time the laboratory report was produced and to the simplicity with which a manual plot could be produced rather than for any intrinsic reasons. When the instructor ensures that students are each provided with computer-generated output, the majority of students are quite willing to claim ownership of the results. In fact, students are all too likely to turn in nonsensical information with their laboratory report merely on the grounds that it was produced by a computer. An extension of the curriculum (as requested by many students) that increases student exposure to MBL and includes the interpretation and annotation of scientific graphs would likely be the solution in this case.

Finally, the design of an instrument intended for the assessment of student graphical skills requires several iterations of redesign and employment to increase reliability and validity, as well as to particularize the exact curricular content and interpretation skills of interest. With modification, the instrument under development could be used in a fifth cycle as a comparison of MBL and non-MBL curricular treatments of titration curves and acid-base titrations.
Cycle 4: Experiment 20H

4. Reflections:
MBL materials in general and these in particular are highly appropriate for this activity, more so than any other cycle. Minor improvements in probe care, software (scaling, data editing) and printing are still required but the materials are essentially adequate at present. The student manual repetition of computer-generated output seen earlier was not significantly repeated this cycle, probably due to the instructor distribution of adequate copies of all data. An instrument designed for the interpretation of graphical skills can be developed but will require iterative modification for reliability, with this iteration serving as a pilot evaluation.

3. Evaluation:
Collect student Laboratory Questionnaires, completed Laboratory Reports, observer notes, disk copies of student graphs and still photographs of student laboratory activities.

Figure 38: Action Research Cycle 4 Summary
4.5 Final Interviews

At the end of the fourth cycle and immediately before the end of the school year, a series of interviews was held to obtain and explore study participant experiences. Both students and instructors were interviewed on the question of MBL appropriateness. The students were then further questioned on their past laboratory questionnaire comments, and instructors further questioned upon the research and development methodology. Complete interview transcripts appear in Appendix E, with extracts and commentary below.

4.5.1 Final Student Interviews

Student interviews were held at Richmond only upon two consecutive days in mid June -- one month after their last MBL activity. A total of 17 students were interviewed -- four students from each of the three grade 11 chemistry classes and five from the grade 12 class. All students were selected for interview by their ability to express themselves upon their written laboratory questionnaires.

Unfortunately, a technical problem resulted in the loss of the grade 12 interviews (the automatic gain control upon the recorder microphone locked upon a chemical storage closet exhaust fan, overriding the interviews with noise). These students had completed the most developed and most recent experiment -- 20h from cycle four. Only the interviews of the twelve (nine female and three male) grade 11 students who had the opportunity to operate MBL technology in cycles two and three were transcribable from tape.

These students were interviewed according to a loose format, and the author varied questions to follow up answers where they seemed of interest. Students were first asked to recall their MBL activities by name to focus their attention on the topic and to encourage the recall of their experiences. Next, the interviewer suggested to the student that he or she would be having a computerized laboratory activity tomorrow, and students were asked what their initial reaction would be, with responses followed up. Students were queried upon their impression of the effect technology had upon their laboratory workload and the quality of their understanding of the laboratory activities, and then asked for specific gains or losses. Students were asked if additional Chemistry laboratory activities should be 'computerized', and were asked to recount how the process of calibration worked to assess the quality of their recall of the MBL activities and their assimilation of the concept. Finally, students were asked what improvements could be made in the MBL procedures presented, and several were asked to comment on the 'worthwhileness' of the innovation.
Recalling MBL Activities

The majority of students (91%) recalled the MBL activities to varying degrees, with half of those questioned on the topic of calibration (50%) recalling the activity well enough to clearly explain what the term meant later in the interview. It should be recalled (from Chapter 4) that access to the first grade 11 experiment was sharply limited due to the fact that only two sets of apparatus were available (2a -- the experiment involving Paraichlorobenzene). Typical quotes recalling the experiments include:

'We did one with paradichlorobenzene, and we did another one with the spectrophotometer. I think the paradichlorobenzene, if I remember correctly, it was a boiling point of something, and the spectrophotometer was with the graphs that we had to have printed out.'

'I don't really remember. It was quite some time back.'

'I had the opportunity of seeing it done, but I didn't do it. I didn't get to use the computer.'

'I remember doing a moth balls ones, where we would take the probes and put it in the test tube, and it would record the melting point. That's what I remember about that one. I don't remember any other one.'

'Yes, I do. Isn't that the lab where you melted stuff, and then cooled it again. I can't really remember.'

'Yes, trying to find the melting and freezing points of paradichlorobenzene and used the computer to find the temperatures and graph it up for us.'

'Basically in the lab, we measured the heating and cooling of paradichlorobenzene that using, I don't know exactly what you might call it, it's a little metal rod?'

Responses to a Suggested MBL Activity Tomorrow:

The next question suggested to students that their next laboratory activity would be an MBL activity and asked what their initial reaction (attitude) would be. Responses were generally positive or neutral rather than negative (50%:30%:16%), with most neutral responses being conditional on such factors as the activity content, or equipment preparedness rather than an expression of general dissatisfaction with MBL. Typical positive initial reactions to MBL include:

'I find it interesting because you're getting the results a lot quicker. It's not all done manually, your just punching in things and you get the results. It's all pretty technical, but it isn't like there's less direct involvement.'

'Well the first thing that I thought was that we would have to do all the computer stuff ourselves. It was really funny because I didn't know anything about computers, but then he explained that you were going to come in, so then it was okay. Actually, I thought it was good because it just seemed more scientific, it was a lot better because you wanted to find out what it could do, and it was interesting.'
A. Probably I think it would be easier, because you don't have to write up the data.

'I thought it was really interesting, and using the computers was really interesting. It really helped because it made up the graphs.'

'Well it would be very controlled. There wouldn't be a lot of errors. People do labs and they make a lot of errors. They don't time it correctly or whatever. Computers just seem a lot more efficient.'

'I don't know. I think it was an interesting experience using the computers, and once I got use to the system, I really enjoyed it a lot more than I did then because I didn't have much practice.'

'Basically, I like that idea. Mostly for the reason that ordinary chemistry labs are sort of boring. It's neat to get a computer in there and get it to graph your results for you. It's quite a bit more accurate. To have a computer, it's sort of like the computer does some of your lab for you, and does it much more accurately than you could possibly do it. It's sort of like almost a fun way to learn.'

Neutral initial reactions to MBL include:

'Well the first thing that I thought was that we would have to do all the computer stuff ourselves. It was really funny because I didn't know anything about computers, but then he explained that you were going to come in, so then it was okay. Actually, I thought it was good because it just seemed more scientific, it was a lot better because you wanted to find out what it could do, and it was interesting.'

'Okay, so what are we going to do.
[Author] So nothing special? It doesn't worry you?
Well it doesn't scare me.'

'Well it's more helpful for us.'

'Well the apparatus was set up okay. The computer part of it was pretty easy to use. I took a little while, but I got it. As far as I can remember, I don't think there was anything wrong with it.'

Finally, the negative initial reactions to MBL include:

'If it's set up, then they'll be more classroom, but if it isn't, instead of doing a lab, then it will take more time to do it. The first one, it was unprepared for. We didn't actually finish it. The spectrophotometer was hooked up and it was a lot faster. We didn't have to do the graphing.'

'I thought it was a bit more work, because it wasn't very quick to get the data, and it needed adjustments all the time.
[Author] What about the idea of using a computer to do that lab?
' I think it's a good idea.'

MBL Workload and Quality of Learning

Students generally felt that the computer decreased their workload through the elimination of record-keeping and graphing (or as one student put it 'manual labour'), but not to the detriment of
the quality of their learning. Most identified the tasks replaced by the computer as not essential to the conceptual material being studied and therefore supported the use of the computer, while a minority (25%) of the respondents claimed that using the computer to create graphs and data tables replaced tasks essential to student learning. Several students suggested that the use of MBL markedly increased the quality of their attention and the amount of cooperative learning.

Student quotes supporting the computer as a labour-saving device not detrimental to their learning include:

'I think that computers are just becoming part of our world now and that you have to accept it, and it's good because the other way we had to do the graphs and everything else, writing up notes, writing up the information, but this way it comes up automatically, and it doesn't take as much time. We actually had to go through the whole process of drawing up the graphs before. We know all the observations, and we know how to do it. Now it takes less time to get the results, and they're also more accurate because of the information in the computer.'

'Well I thought for the spectrophotometer it was a lot easier. You could see the plots, and having the computer do it all itself. You could see it better, and you could see what it was supposed to look like.'

'Yes, you just didn't have to do as much manual labour.'

'I don't think so. You can still see what's happening, you just have to watch what your doing.'

'I thought it was really interesting, and using the computers was really interesting. It really helped because it made up the graphs. [...] Well, if you [sic] the graphic skills, which they teach you how to graph first, and then to say that you can do it up on a computer, I think that's okay. But, I still think they should teach you about graphs because I don't really think that the lab isn't really for learning about graphs, right?'

'It does all the graphing for you, so that your information is set out right in front of you and that you don't have to copy down all your numbers. It's faster, probably more precise because you're not looking to human errors. [...] I think it's important that before using the computer, to learn how to do the graphing on your own, and then once you know how to do it, then its just repetitiveness for you, so you might as well let the computer do it.'

'...it's good because the other way we had to do the graphs and everything else, writing up notes, writing up the information, but this way it comes up automatically, and it doesn't take as much time. We actually had to go through the whole process of drawing up the graphs before. We know all the observations, and we know how to do it. Now it takes less time to get the results, and they're also more accurate because of the information in the computer.'

While those comments describing the computer as usurping the student role in the learning activity are:

'Well it's hard to say. It depends if the computer prints out the graph and you look at the graph, and you study it after the computer has printed it out, then yes you
learn quite a bit. But basically, for the sake of learning, it's better that you actually do the graph yourself because then you could see the trends as you plotting them out. [...] A. Yes. Like if you don't know how to graph, for example, or if you don't know what trends are supposed to be in the heating or cooling, for example, then it's better for you to do it yourself.

'Well I don't know, but for some reason I have a prejudice against computers. I think that they might do a job better, most of the time they do (and I use them myself for reports and stuff), but I just think that people seem to lose touch with what they should be doing. They should be doing the experiments themselves. I don't think computers should be used for in a lab. [...] Well I know it sounds kind of funny, but I don't think computers should be used. Well actually, they should be used, but I think you still should do the experiment yourself. It's a lot easier to understand if you do it yourself. If you tell the computer what to do, they'll just do it themselves. Computers are not as personal.'

'I don't think so. Some computers are alright, but I don't think the whole school should be computerized. It just doesn't seem like science, well computers are science, but of a different kind. I mean that it just didn't seem like chemistry anymore.'

Students describe an increase in their quality of attention, understanding or in cooperative learning:

'Well when we did it, you really concentrated a lot more. You paid a lot more attention because you didn't want to do anything wrong like the graphs and stuff.'

'You can share the information, and it's a lot quicker.'

'You get to try out new computer stuff, and the graphs are really great. The way you can play with all these apparatus is great.'

'Yes, I think so. I don't usually learn anything when I do the lab until afterwards, and then the fact that I did do a lab makes sense. While I'm doing it I don't understand.'

Overall Positive Aspects of MBL

Students were asked for comments upon the positive aspects of their MBL experiences, and commented upon both the desirability of computer experience and the accuracy, precision and 'scientific training' inherent in MBL.

'I can't see any advantages with the lab specifically, but just getting experience with the computer is something that would be an advantage.'

'Oh yes, definitely. Computers, as I said earlier, it's sort of like computers are technology, and more computers are becoming more and more involved in science; therefore, it's a good idea to introduce computers in chemistry class, in physics class, and in any class at all. Any science class, except for biology, because we don't need computers for biology, but physics and chemistry definitely. It's good to inter­mingle among computers.'

'Actually, I thought it was good because it just seemed more scientific, it was a lot better because you wanted to find out what it could do, and it was interesting.'
'Yes, I think professionally it would be a good idea because if you need to do experiments over and over again, and if you have a computer its quicker to do it with the computer, than that would speed up scientific discoveries.'

'Well it would be very controlled. There wouldn't be a lot of errors. People do labs and they make a lot of errors. They don't time it correctly or whatever. Computers just seem a lot more efficient.'

'Learning more things is better than learning just the simple things. If you learn more advanced things, then it might help you later on. You might have to go into a place and they ask you to do something, and you have all this different equipment, and if you know something about a computer program, or the apparatus, it helps to figure out how to work the apparatuses.'

Overall Negative Comments

Student comments upon the negative aspects of MBL concentrated largely upon the issue of access -- they did not feel they had adequate opportunities to use the apparatus due to both the small number of stations and large student numbers, and the low number of MBL activities. A few commented upon the additional complexity of working with computers, but many who did so seemed to have well-developed, positive opinions towards school computer use. Several noted that this application of technology was quite divergent from their typical computer-related experience (probably programming), and pleasurably so.

Student comments upon the issue of access include:

'One thing, there wasn't enough computers in the room.'

'Negative aspects, well it's all kind of confusing to me, like watching wasn't too bad because if I were to get up there, I know I wouldn't do very good. So if I just watched it was alright. If we had one computer for each table, I know that's a lot, but more computers in the room would have been better, or you could have less people in the class.'

'If it's only there for a couple of days, then it's not worth it. If we have them for the whole year and always use it, then it's worth it.'

Student comments upon the issue of technical complexity include:

'If we have a class on learning how to use computers, than it kind of takes away from the other things. Maybe we should just learn as we are doing it, like on the job training.'

'You have to know the computer, and you will have to know how to use it.'

'Yes, we had a lot of trouble with the printers. It printed out a lot of weird things so we had to spend a little bit more time trying to figure it out.'
'Well sometimes the computer wouldn't work, and a lot of people didn't know how to use the computers, so then you would have to learn how to use computers before you use it in the lab.'

'I guess just learning how to use all the equipment, and some people don't use the computers because they're afraid that they don't know how to use a computer properly and that they might screw everything up. A lot of people don't have computer skills, and that makes it hard. If you have a detailed procedure to follow, things won't be so hard.'

'It would be worth while if we all had our own disk to copy on information, and bring it up later. It certainly makes it easier, but we don't know how to use computers so it would probably be a lot more difficult to get results.'

And student comment upon their expectations of and actual experiences with computers in the Chemistry laboratory includes:

'It's interesting, and it gets us involved with computers, because I never thought that we could use computers in a chemistry lab. This was all new to me.'

A. Well the first thing that I thought was that we would have to do all the computer stuff ourselves. It was really funny because I didn't know anything about computers, but then he explained that you were going to come in, so then it was okay. Actually, I thought it was good because it just seemed more scientific, it was a lot better because you wanted to find out what it could do, and it was interesting.

A. Well it's like the last year we had a little program that we had to do, and it had typing and stuff to do. I thought it was really good.

Continued or Expanded use of MBL

When asked whether MBL should be used in more experiments, the response was overwhelmingly positive. All of the students interviewed preferred to have a larger number of MBL experiences on a regular basis, but most qualified their enthusiasm by stating that many laboratories activities were 'not appropriate' for computerization. Students did comment upon what made particular laboratory activities more appropriate than others.

'Well I guess it's something new, and something new is always interesting. I think that if I heard another class was doing it, I don't know if it would of changed my mind or anything. But if you did bring it in, it would be interesting because it's something new.'

'Some of the labs you should. Others aren't appropriate.'

'Yes, a lot of them. However, some of them should be but not all of them. The longer labs where you have to do a lot of steps with graphs, and where it has a lot of data, like data tables, should be entered on a computer because it makes it easier. There's no point in writing it down when you can just stick it into the computer.'

Basically the labs that I would computerize would be labs that required the input of a lot of data. For example, labs that would require that the computer produce
graphs for them, labs that require certain exact timings for example, that you get the computer to keep track of it.

'Yes, for example, simple reactions like an acid-base reaction or something that produces salt and water that computer isn't any good for a reaction like that because it just involves maybe one or two temperature readings, and some observations that could be written down in English, or whatever, and don't need any data. That would not be an ideal lab for a computer.'

Calibration and MBL Domain Knowledge Retention

Students provided a mixed bag of responses to the question 'What is calibration?', probably indicative of their disparate grounding in the subject. (Recall from Chapter 4 that students were overtly instructed in calibration after one group expressed considerable confusion, then the topic was specifically treated with the remainder of the students.) Calibration and computerized instrumental effects are topics not found elsewhere in the curriculum, so knowledge of the topic can be attributed only to the students' brief MBL encounters. Not all students were questioned upon the topic, only 7 of these 12. Three (25%) were able to clearly describe the process, while four (33%) could not. Those who could best recount the topic were from a class that performed the experiment later than the others, and received specific instruction in calibration. Student explanations of calibration included:

'Well I guess it's because of the temperatures. It tells the computer what the temperature is.'

'I'm not quite sure, what is it again?'

'Well, you put it into hot water and you did the temperature with the thermometer, you typed it in, and then you got cold water and you did the same thing. I think the probe we used was too long or something, because when we actually did the lab, it sort of got lost.'

'What we did was we took the temperature stick or whatever, and we tried to get it to 0 degrees and 100 degrees, so that when we did the experiments that were going to have the proper gages to what temperatures it was at.'

'It was quite a while ago. There's something about matching temperatures or something like that. I can't really remember now. But the one thing that didn't strike me about the experiment, it's been rather a bother, was having to calibrate. If there was no anyway to not have to bother calibrating, like it's already positioned, like if there was anyway to do that, that would be a lot.'
'I can't exactly remember the calibration process? I put the probe in cold water, took the temperature, and typed into the computer. I put it in hot water, took the temperature off the thermometer and typed it into the computer. Than the computer knew what was cold and what was hot, it had a scale, and it read between the two. Right. I think the logics of it are quite simple basically. Even if a person doesn't know how to do it, all you have to do for a lab is basically, if you want to get them to calibrate, just teach them the procedures of how to do it several times until they know how to do the calibration even if they don't understand how it works, because there's really know need to understand how it works, you just need to know how to do it?'

Student Suggestions for Improvement

Students were asked for possible improvements in their MBL activities, and generally replied with requests for additional access. Other comments of interest contained procedural modifications or extensions and further computer training as follows:

'Probably getting everyone to pay attention more, because we only had 2 computers, they thought they could get away without using the computer at all. I think that everyone was sitting in groups of 4 maximum, in front of the computer, and as you explained it, they could be kind of doing it at the same time, like making a list, because it's kind of difficult to have to explain it, especially when it's their first time using a computer. You would get it all explained, and then do the whole process. It's a lot easier that way. If there was something written or handed out that they could follow, it would be a lot easier too."

'Well I wasn't working at the computer, I was watching the girl who was, and she had to switch to all these different screens all the time. It just seemed all so complicated. It would be easier if it were all on one screen, or just have it set up and just press the button on the printer."

'Well I thought if you had more, than we could see maybe if you made an error on one of them so that you have a chance of getting it right. Also, I thought of graph percent transmission just to see what it looks like."

'You just have to show us how to use the computer. For those who don't know how to use it, and if it's not on their procedure, than they probably won't use it."

'If we have a class on learning how to use computers, than it kind of takes away from the other things. Maybe we should just learn as we are doing it, like on the job training."

'Like you could give out hand-outs, or instructions before hand on how to do it."

'I can't really remember what I was thinking when I wrote that down. I think more instantaneous, when you turn on the computer the program is there so you don't have to worry about finding it. Well we didn't have a task to save it for ourselves, so we didn't have our own information, it was all on your own disk so we couldn't go back to reference raw materials."

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'Basically the best way would be to tell students what is going to be done in the lab, what's going to happen, and then introduce them to the computer, and tell them how the computer works, how the computer is going to achieve various parts of the labs, and do some of this work for you (take the data observation for you, and how this works), and then introduce them to the computer and show them how to operate it. So that you get first told what the lab is, so when your introduced to the computer you can understand what the computer is doing with regards to the lab.'

4.5.2 Final Teacher Interviews

During the last days of the school year and shortly thereafter, all three teachers who participated in the MBL Project were interviewed by the author. All were asked to comment upon the use of the action research methodology, the future of MBL technology in Chemistry curricula, strengths and difficulties arising from the use of MBL, and finally for advice they would like to hand on to other Chemistry teachers considering the adoption of MBL in their own classrooms.

Action Research Methodology

Teachers' comments upon the methodology used were uniformly supportive; they felt that they had participated in a knowledgeable manner with some degree of control. They felt the author to be accountable to them, and enjoyed exerting control over the design of instructional materials. Teachers expressed concern that much educational research is short-term and independent of the working 'realities' of the classroom. Concern regarding the workload required to participate in action research also was expressed. They also felt that students appreciated the iterative design process and that the methodology involved exposing the students to 'real-world' science research.

Teacher comment upon the use of Action Research methodology included:

'The fact that also you do come back, there's a commitment, it's not just a flash in the frying pan and off you go and we don't see any results or any supportive work from you, I think it's been good that you have been with the students on 2 or 3 occasions in my class. I think that just the fact that you are a science researcher, and they you are able to actually see a real person doing this research and the fact they are able to be involved with that procedure in the process, excites a lot of students.'

'I think it’s an excellent method of that type of research. You have a global idea of what the project's all about, you have input from different sources, and once you have collected all your data, you have a firm background to refer to. I think that doing the actual research in the classroom is great opportunity. You’re right where the action is.'

'...I have been very excited to work with your project because I have learned a lot. I have come to understand better how the students work in a project like this one. So, I've been expanding my own personal goals, if you like, working with you, and being able to give feedback on the developmental software. I am quite interested in computers, and if the opportunity presents itself, I may do a little programming or possible modification of what you've done.'
That's one good part of this research is that it forced me to be involved. I gave the o.k. too. I know it's just a small involvement. That's why I liked it. It forced me to use something that was a nice idea, but I'd probably be too, well I'm not computer literate enough, to want to go ahead and do this kind of stuff on my own. Technical capabilities or mental laziness, or what prevents me. It was a great opportunity. I welcomed it and I could see it on the faces of the students, it was a good change of pace. No doubt this is the way labs are operated in industry and government research centers.

'This is what makes education much more effective. I think that more teachers are able to be involved with universities and develop new materials. The teachers who would work in this area, would be more aware of what other teachers are having to say, and be able to initiate situations that they've heard of from other teachers. Not all of my own ideas have come from myself. I've heard people making passing comments, and I thought that it was a good idea, and then maybe in some situations, I decided to pursue it myself where they wouldn't have had the time or anything.'

'In a general sense, I don't believe that all teachers would want to be involved in the nitty gritty of working in an MBL type project, and helping in the design in it.'

'Here you were doing something yourself and you were making mistakes. Now, normally we penalize students for making mistakes on something they do for the first time, and here you have been doing this many times and your still not quite getting it right, but you're adjusting and that's the real world--trial and error. We don't see that enough in science education. We pay lip service to trial and error.'

Strengths of MBL in Chemistry

Teacher comment upon the appropriateness of MBL in regards to student learning largely centered around motivation (including gender and special educational issues) and a need to emulate research laboratory experimental procedures. Several also commented upon apparent increases in student learning. Comments upon motivation and commercial research procedures follow:

'It also takes the tedium out of science education which too often is put in where students feel they're working hours on tables and graphs, consequently, the computer takes over, and the students don't have to understand how to set it up, how to plug in the data, how to interpret the data; therefore, the tediums are removed. It's efficient, impressive, it's high technology, and it gives the students a closer touch of reality than we normally do with our emphasis maybe on an old Bunsen burner tests too often.'

'First of all, increase in technology in the classroom is a great benefit. So much of what happens so far in chemistry is involving dumping one liquid into another liquid in a test tube, and where we have the technology being used that become more familiar, particularly beneficial with the girls. They very often are excluded from technology and this is one way of giving them equality with the guys.'

'...you have a motivation factor for the students. Its an innovative type of situation where the student can be excited, with the novelty of the computer in the science lab. They can effectively apply some of the techniques learned, and some of the theory that could be arrived at by a laboratory experience. I think a laboratory experience is more meaningful with a computer used as a laboratory aide.'
'It was interesting that the students had tended to be really involved in this. Many of them were students that I knew were on consentive programs. So you'd really spark the interest of the highly motivated students.'

'...we expect them to do it once, and do it real well, and they're marked on that, and then were off to another different type of assignment that require different skills. Once again, it's a one shot effort. Here you were doing something yourself and you were making mistakes. Now, normally we penalize students for making mistakes on something they do for the first time, and here you have been doing this many times and your still not quite getting it right, but you're adjusting and that's the real world--trial and error. We don't see that enough in science education. We pay lip service to trial and error.'

'It goes along with the guidelines that we need to incorporate the technology that is presently available. And at least make our students aware that there are technological changes in the computer world that could be applied in a science situation like a laboratory. I think that if nothing else with this type of approach of incorporating of the computer in the curriculum, the student will be at least exposed to what's happening in the real world. They go out of here, and they will go unto any kind of science labs, and there will be computer interface galore, everywhere they go.'

'When we had to delay a class because of other difficulties that we had, the students continuously kept asking me when they were going to do a lab. I gather from this that they were quite excited and were looking forward to being the first to be involved in using computers to do a lab.

Comments upon apparant effects in student learning include:

'Then I saw the understanding that happened because they were able to do an activity in the lab which they put a certain volume of liquid into the solution and to see the PH change dramatically on the graph when it was going along for a while. To make a reading on a buret is not as understandable as to see the flat curve on a graph, so they could see much more dramatically when something was happening. Not having to think about the process of plotting, or not having to think about how the variables were changing, but simply to observe the changing. They were able to jump into higher levels of questioning right away, and understand the process of it more quickly.'

'The students do not have to waste an enormous amount of time in doing some basic things that should have been learned before, ie: graphing, or unnecessary computations that could be done either before or after this step could be performed. They can get instantaneous feedback back out of what's happening in the lab, instead of having to interpret their own, I think that's the meaningful part of it.'
MBL Shortcomings

Teachers see MBL as a achievable challenge to their own technical abilities and to their traditional role as classroom presenters of information to passive student learners. Some instructor comments regarding the challenges MBL present to teaching styles and student-teacher roles:

'It's just a nice change from the normal routine that we can get ourselves into, and I think all teachers do. We do things that are safe, that we've done many times before very well, and I don't think there's as much learning that goes on. It's a different type of learning, and that's always exciting. You could probably excite some student that's been bored in class, or that has just gone along with the flow of the lessons, and are not really excited. You can see that. You can see strengths come out of students, and abilities come out of students that were latent throughout most of the course. You see the leadership come out too. I was impressed the way some students just took control when something when things went wrong for me, and not being an expert at computers, they were able to solve problems with other students, you've got cooperative learning there which has a real place in research, and assumed leadership roles that before the students were just content to just sit back and let the teacher be the guide. Now they're the teachers, and the teachers are the students. I think it's a humbling experience, but I think its a real life experience and I think that this computer brings us up to the 20th century.'

'Well the teachers will need to have a minimum amount of computer literacy. They have to be familiar with the basic operation of a computer. The technical, chemistry, or science aspects should be no problem at all. But if you have basic and very clear instructions on how to start an experiment with the aide of a computer, I think it should be no problem. Any teacher with a minimum amount of knowledge of computer usage, like the mouse, the keyboards, any teacher with those basic concepts of computer operation should have no problem what so ever in implementing the type of project that we have.'

'We chose some areas that were already existing in the current curriculum, and attempted to develop them so that they would function in the class room. There are more areas that have not been thought of and need to be developed, which much more work would need to be done to link these directly to the curriculum may possibly change the curriculum. More things can be done with this, and this area has not been explored in any great extent.'

Instructors also have concerns regarding access to MBL apparatus and associated laboratory management and support at present, while voicing optimism for the future of MBL in the classroom:

'It's been a little bit of a headache trying to assemble and get the computers, such as borrow, beg, steal, type of situations until we get the computers here. But once we have over come those obstacles, than everything went smoothly.'

'Well the fact that not enough students could get directly involved with the computer was the big minus. That prevented half the students of being involved, or chose not to be, they just used the standard equipment, or just stood around and watched others do it.
'Teachers tend to be overburdened with tasks, and day-to-day activities. One, to have a completed project that fits into the curriculum that they can essentially take off the shelf and put it into practice in a very easy manner, especially in the cases where some schools don’t have lab assistance with a set up like this that can be put together very easily without a lot of hassle, and that can be done and utilized simply.'

'...the negative aspect of implementing the computers is that we don’t have enough computers for all of us to use; consequently, some students may be using this tool, as some students may not be making full use of the computers because of lack of it. I think that’s one of the major obstacles is implementing a curricula using the computers, simply not having the availability of computers in science labs, and I think that’s part of the problem that we probably have to work on in the future.'

'I think funding is going to be the major limitation to this sort of thing. Its going to be slow to be brought in. I could see an MBL laboratory designed, which would be accessible to students throughout the school.'

'...having groups of 4 students at a time, I think was not so optimum. It would be better to have groups of 2 working on it. Of course, it’s not possible to have so much equipment available. In one situation, we had to wait to get the printout, so then the students had to come back at the end of the day to receive their printouts. However, some students didn’t return to pick them up. That was a negative. It would be much better if things were available immediately.'

'About the actual process of doing the lab, I don’t see any major draw backs from the students point of view. From the teachers point of view, setting up the equipment was a major problem. That was very time consuming. We had to borrow computers from the Mac lab, which in the future they’re going to be tied down with cables, it will be much more difficult than setting up for next year, so those computers won’t be available next year. Then the problem of getting enough computers from other sources is going to be a challenge. Then, all of the process of setting up the equipment so that it can be used, and checking out each one to make sure it works is very time consuming. I’m sure that process could be simplified. I guess lab set up is the biggest drawback. The rewards of having the students getting the feedback on the lab much more quickly, may offset it. A major problem with many teachers is not having lab assistants in the first place to do this type of set up. If the teacher has to do all of the set up, than this type of project might not occur in that particular school.'

'I think a number of monitors and computers, which we had 2 or 3, was a limiting factor in the success. I assumed that we would of had a higher interest if we would of had more computers.'
Teacher Suggestions and Advice

The participating teachers were specifically asked if they could pass on advice to others considering the adoption of MBL in Chemistry laboratories. They suggested that school districts should play a greater role in encouraging the adoption of new technologies in the laboratory, but that once 'bitten by the bug', MBL would be so intrinsically motivating to Chemistry instructors that these instructors would provide much impetus to the acquisition.

'I think you'd have to get them corralled into a workshop before, so you could see how it works, so you can get your hands on it, and you get bitten by the bug. At first I was bitten, and thought a computer, big deal. After a while, I got quite enthusiastic. You would have to do workshops to get the teachers involved.'

'I'd suggest that it's certainly worth the experience, because it is going to be a high interest generator for the students, and yourself you're also going to learn. It's just a nice change from the normal routine that we can get ourselves into, and I think all teachers do. We do things that are safe, that we've done many times before very well, and I don't think there's as much learning that goes on. It's a different type of learning, and that's always exciting.'

'Well in order to implement a science course using a computer as a laboratory tool, I would say that they would have to present a solid case regarding the pedagogical positive aspects of using the computer in a science lab. They have to have to a good proposal, a good project to back up the requirements or whatever. I think that if the programs are in place, if the labs are in place, all the teacher has to do is say "Hey, we have an excellent application of computers in a science situation that's applied. That all depends on how strong the proposal is. How well administration will take it. I think its a selling job. If they can show the pedagogical validity of the proposal, then there is no problem. I wouldn't be surprised if in the near future that there will be more computer applications in science.'

'Well, its nice to think about what would be ideal, but I think funding is going to be the major limitation to this sort of thing. Its going to be slow to be brought in. I could see an MBL laboratory designed, which would be accessible to students throughout the school. In our school, we are just now setting up a Mac lab. This coming year we'll be getting funding for the other half of the lab. We'll have 25 computers then in the lab with a Scanner and overhead projector device.'

'But in order to have a separate classroom put aside for laboratories, for instance, is going to take some time to set up equipment and all the other things.'

'Well I think it's inevitable. This is the direction of change, which is to have more technology. As time goes on, if more teachers have the proper support and the funding is in place to purchase this type of equipment, and providing that the teacher learns enough about the equipment to understand how to operate the computer, and to do it, then the teacher may use it. I think whenever something is easy to put into place and accessible, then the teachers will take the advantage of it, unless the teachers are not involved in technology itself.'

'Its an area that I see expanding in the future. I've learned a lot from you, Dan, from doing this and I hope you feel that we've helped each other.'
Interview Reflections

The interviews supported earlier-discussed comments regarding the marked degree of student and instructor motivation inherent in MBL technology. While both instructors and students believe that the actual implementation of MBL is difficult and costly, they feel the advantages outweigh the difficulties under appropriate circumstances. This enthusiasm was felt despite considerable difficulties arising during their own experiences during this study.

Students and instructors also carry strong (polarized) preconceptions of computer technology that are not necessarily of issue in MBL methods. Several students aggressively promoted the universal integration of computing technology, while others expressed fear and distaste for it. Actual MBL experience tended to dispel most of these strong feelings.

Teachers also felt that the use of MBL might be highly appropriate as motivation for specific populations of science students such as women and traditionally nonacademic students. They suggested that the fast feedback of graphical information and removal of more mundane laboratory procedural tasks would lead to better concentration upon the subject material and ‘...jump to higher levels’ in their understanding more quickly. Teachers also strongly felt that MBL technology would play an expanding role in future curricula despite extensive costs and difficulties.
Chapter 5: Conclusions

"We must be fearful of innovation without change."
-- Dostoyevsky (in Dale, 1984)

5.1 Findings and Constraints

This final chapter will make four major knowledge claims summarizing the data collected during this study. These claims will then be illuminated by taking examples and comments from the data which address the areas of concern described in Chapter 1 -- implementation, pedagogy, cognition and research methodology. Afterwards, extensions of those knowledge claims into future research endeavours and suggested advice to those individuals wanting to adopt MBL technology into working classrooms will be presented.

The four major claims of this discussion follow:

1. Microcomputer-Based Laboratories are intrinsically motivating;
2. Microcomputer-Based Laboratories are pedagogically appropriate for inclusion in some experimental activities taken from the current B.C. grade 11 and 12 Chemistry curriculum;
3. Action Research is an ideal research methodology to further refine and develop microcomputer-based laboratory instructional materials appropriate for B.C. High School Chemistry; and,
4. Microcomputer-Based Laboratories inherently redefine the current curriculum and the classroom roles of those who use the technology.

MBLs are Motivational

The most outstanding characteristic of MBL technology is its motivational appeal. Students expressed interest in making use of the apparatus throughout the study, and the chief complaint expressed by participants has been that access to the use of MBL equipment has been inadequate. Students have displayed interest in the empowerment and control aspects of the technology, have widely explored and tinkered with the apparatus whenever possible and have expressed considerable delight with the results of their experiences. MBL captured student interest through its innovative and highly interactive nature, and this interactive nature (reducing student tedium and attention span constraints) has been suggested by B.C. teachers and researchers (Thornton & Sokoloff, in press; Nachmias & Linn, 1987; Linn & Songer, 1989), as particularly appropriate for motivating traditionally unsuccessful science students.
MBLs are Pedagogically Appropriate

While this study shows no statistically significant improvements in student grade performance as assessed by instruments designed for the regular curriculum, it nonetheless does suggest the technology is appropriate to the B.C. Chemistry curriculum. This discrepancy is due to the fact that current curricular evaluation practices do not recognize the kinds of improvement in student achievement that are typical of MBL. The kinds of instrumental and graphical analysis skills used within MBL are not stressed within the current curriculum, nor are student control of experimental variables, tinkering, attitudes, or role changes recognized or evaluated by instruments used by the traditional curriculum. These characteristics all address recognized shortcomings in the standard curriculum (NSTA, 1983) that are addressed by the new technology. (Note that trends towards increased laboratory report completion rate are suggested by the data.)

This study did show that large-scale use of MBL technology was technically feasible and within student and instructor abilities to successfully employ with current curricular experiments. The efforts were judged to be worthwhile by the majority of participants despite the attendant difficulties. MBL subject matter was widely perceived by study participants to be timely and reflective of current Chemical research practise. MBL enriched student laboratory experience and refuted some common user preconceptions regarding computer technology.

AR is an Excellent Development Tool for MBL

Action research emerged as an excellent vehicle for the study and for further curriculum development with MBL. Praised by the participants in the study, AR gathered otherwise unavailable high-quality data and knowledgeable participation from students and teachers and fostered a positive ethos in the MBL classroom. The result of multiple iterations of AR produced a complex yet workable apparatus capable of ready use by students unfamiliar with MBL (Cycle 4). Action research developed a complex instructional product tailored to the B.C. curriculum and local classroom constraints which encouraged the appropriate focus of student attention upon the key concepts in the activities. It is doubtful that more generalized commercial MBL software could match the success of the tailored software used during this study, and any widespread adoption of MBL by B.C. Chemistry educators should include an evaluation and curricular material development conducted using action research.
MBL Redefines Chemistry Instruction

Finally, the use of MBL placed great pressures upon the traditional classroom environment and the standard curriculum. Students and teachers repeatedly requested and expected extensions, revisions and additions to be made to the present curriculum when using MBL and tinkered with new techniques and phenomena whenever possible, often under arduous conditions. The activities focussed upon interpretation of the computer graphics and relating those data to the conceptual phenomena under study, rather than the procedural manipulation of laboratory data. As well, apparent increases in the quality and quantity of student-student and student-teacher interactions promoted a more dynamic and participatory atmosphere which students enjoyed and teachers found challenging.

5.1.2 Implementation

MBL presents considerable but not overwhelming implementation challenges to most Chemistry instructors. Due to the high attendant levels of instructor and student motivation, technical training and support from professional teachers' organizations and the increasing presence of computer hardware and expertise within schools, the implementation obstacles to MBL are being continuously reduced. Many of the materials development difficulties encountered during this study would simply not be an issue with commercially obtained MBL apparatus, but some other difficulties experienced are endemic to the technology.

Cost

Good quality MBL hardware (signal processing hardware and probes) and somewhat poorer quality software and lesson guides are currently available from a variety of commercial sources (IBM, Vernier Scientific) at rates of about $500.00 US. This places a single package for laboratory demonstrations within the budgets of most high school Chemistry programs. Given the history of computer hardware pricing, it is likely these costs will drop further and that hardware quality will improve to the point where the major cost issues with MBL are the appropriate tailoring of MBL materials to the curriculum (and vice versa) and personnel training. Present costs for a laboratory package of five to seven sets of apparatus are considerable ($3500.00 US) but not out of reach of many departments and schools, and these costs are in line with current school computer capital expenditures. Such expenditures (like most other computer hardware) can often be assisted through ministerial granting programs, as was the case for this study.
Currently, personnel training costs for teachers interested in using MBL are being borne by the school districts on an individual basis as part of teachers’ regular professional development; MBL workshops are routinely held during conferences conducted by professional development organizations such as the B.C. Science Teachers Association (B.C.Sc.T.A.), the AAPT and the NSTA. Large numbers of teachers have been exposed to this technology, and a wide variety of curricular materials associated with MBL (Vernier Scientific and IBM) are now available at varying costs. There is a small but increasing population of B.C. High School Chemistry teachers with MBL and computer technical skills, and these skills are being promoted by teacher associations.

Access and Logistics

Most B.C. schools presently have access to appropriate computer hardware and can temporarily relocate some of that hardware to the Chemistry laboratory with difficulty. While it is unlikely that Chemistry teachers can relocate large amounts of hardware within the school, the relocation of hardware for demonstration purposes is no more difficult than standard practises with regard to obtaining audio-visual equipment. Many schools have obtained computers intended for permanent placement in Chemistry classrooms and laboratories, and this trend is likely to accelerate as computer technology becomes more closely integrated with science instruction.

As an illustration, two of three cooperating teachers in this study had experimented with MBL technology before, all had computers routinely accessible in their classroom and had some expertise with those computers, all had MBL hardware for classroom demonstration available to them and one was making regular use of this equipment for demonstrations. The primary constraint upon the number of stations erected during this study was the amount of reliably working MBL hardware then constructed, not any inability to obtain and relocate computer hardware within the school.

Ideally, five to seven laboratory stations (one to every two or three students) and necessary printing (and possibly networking) hardware would be set up in the laboratory for student use. The logistics of relocating and assembling this hardware is quite daunting for teachers who are not regular computer users and it is likely that this effort will not be undertaken unless teachers have training and experience with MBL apparatus and support from the computer instructors and their colleagues. Satisfaction is also unlikely without adequate time for student exposure and experimentation with several related activities; Chemistry instructors must retain the equipment in their laboratories for a reasonable length of time (approximately 2-4 days per MBL activity) to justify the administrative effort. Teachers and students both expressed discomfort with the prospect of disrupting the classroom environment for isolated activities lasting for only brief intervals of time (a single experiment). Physical space constraints (and the number of convenient electrical outlets) in the classroom laboratory also provided occasional challenges to this study.
MBL apparatus and procedures did not present complexities beyond the abilities of either staff or students during this study. Contrary to some expectations, the procedures proved straightforward enough for extensive meaningful experimentation (i.e., tinkering with the heating and cooling temperatures of PDB; the development of stepping strategies during titrations) to occur. MBL did bring in additional instrumental concepts not usually part of the curriculum (e.g., calibration), but these seemed easily within student abilities and they enriched student understandings of standard curricular topics as well (e.g., recounting temperature scale definitions, reaffirming definitions of pH).

Some MBL hardware and software did prove unnecessarily complex initially (spectrophotometry software and printing, Spec 20D original cabling), but after iterative development these issues were largely resolved. Many minor hardware and software details caused disproportionate difficulties, illuminating the need for extensive development and evaluation of any MBL system before adoption. By reducing undesirable characteristics (e.g., eliminating any unnecessary hardware and software distractions) and tailoring the apparatus to the situation and curriculum used (or designing adequate instructor control of the software for customization), MBL can be made to merge seamlessly with the curriculum.

Whenever technical difficulties did arise with the MBL apparatus, they caused quite notable discontinuities in the flow of activity. In cycle two, hardware failure brought activities to a complete halt, while in all four cycles printing difficulties and student unfamiliarity with software created a need for constant teacher supervision. In cycle four, software shortcomings (scaling difficulties) created confusion and led to procedural modifications while performing the lab (changing titration concentrations). This placed stress upon the instructors and created a demand for increased supervision well above the ordinarily high levels of supervision required in the laboratory. While most of these difficulties can be eased using fully developed robust hardware and software accompanied by instructor familiarity, MBL will never reduce working loads placed upon Chemistry instructors. MBL is inherently complex and its use introduces additional instructor difficulties and responsibilities. Because of the considerable effort required, MBL apparatus must be used only in those activities where student understandings and learning experiences can be most enriched—those involving the interpretation of relationships characterized by complex graphical data.
Extensions and Alternatives

Graphical data for two of the four activities chosen for MBL development in this study could have been equally well interpreted using standard manual data acquisition accompanied by graphing or plotting software capable of linear fitting rather than with MBL (the two spectrophotometry activities in cycles 1 and 3). These activities produce graphs of low complexity (straight lines) where accuracy rather than feature interpretation is central to the instructional concept. The use of the computer to perform graphing tasks was perceived as desirable by students (who took extra copies of computer-generated graphs for personal reasons or generated spectrophotometric plots on IBM CAD hardware independent of the Chemistry laboratory). The use of the computer as a data reduction tool for student laboratories should be further extended through the acquisition and employment of graphing software for laboratory reports independent of and as an adjunct to MBL.

Another extension of the use of MBL technology for classroom demonstration would be the use of a liquid crystal device for displaying computer output graphics with an overhead projector. These devices are becoming widely available to schools, and are used by many computer instructors. Such a device could be treated as a standard audio visual device to be periodically loaned by the Chemistry laboratory.

5.1.3 Pedagogy

MBL use inherently suggests redefinition of laboratory procedures, content of the curriculum, and interpersonal relationships within the classroom. Throughout the activities conducted during this project it was evident that the use of MBL modified instructional events in the Chemistry laboratory. Students were introduced to modern scientific measurement techniques, and used these techniques and tools to very quickly complete the usual laboratory curricular goals by escaping the time consuming tasks involved in data tabulation and graphing (Amend et al, 1989). This left them with the time and means to interpret data within the laboratory rather than as homework, and to experiment further in activities extending beyond the standard curriculum.

Increased access to physical phenomena through rapid data processing led to students repeatedly requesting and suggesting extensions to their laboratory activities such as using different concentrations of reactants in spectrophotometry, making transmission and absorption investigations, examining the freezing behaviour of additional substances, additional titrations involving new substances and concentrations and so forth. Students moved outside the curriculum as active seekers of information (Woerner, 1987). Teachers also suggested activities that extended the curriculum where MBL technology permitted additional experimentation to existing activities, and participating instructors wrote extensive comments (eg. Cycle 1) and even instructional materials to go along with possible new activities.
Curriculum

The experiments chosen from the B.C. Chemistry curriculum included two activities that already required the employment of uninterfaced laboratory technology (the spectrophotometric experiments 16b and 19b). These activities were subsequently converted to MBL techniques by cabling the spectrophotometer to the computer, controlling the Spec 20D from the Mac, and reading, graphing and performing a least-squares linear equation fit to that data (Cycles 1 and 3; Appendices C and D). This produced an attractive graph for student interpretation before students left the laboratory, but introduced considerable confusion by placing a software barrier between students and a simple measurement repeated only six times.

These experiments were also constrained by the limited number of spectrophotometers rather than the number of computers or cables. They could have been equally quickly done by using linear fitting and plotting software in three or four computers without any connection to the Spec 20D; in fact the waiting time for equipment would have been reduced by allowing more students to do more activities simultaneously. The graphs themselves are quite featureless lines which are used to determine unknown sample concentrations by simple lookup. The accuracy of the slope and intercept of the lines are important, but there is no important conceptual information coded into complex graphical features. This experiment is appropriate for technical incorporation, but not MBL -- graphing technology without acquisition is adequate and simpler.

The other two experiments appeared ideally suited for MBL intervention -- 2a and 20h (cooling curves and titration curves) both produce highly complex graphical data representation whose interpretation is vital to the concepts being learned. Both also require the collection of a large amount of tabular data (to define the relationships with adequate resolution) and the more data collected (within reason), the better the representation of the phenomenon. These relationships are not adequately dealt with during the standard laboratory treatments due to the lack of available time, and both relationships are considered vital to curricular goals (British Columbia Ministry of Education, 1987). These experiments are considered the key events within a suite of related experimental activities (2a-d, 20a-i) which would justify the presence of a complex apparatus assembly used over a period of approximately seven to ten days. In short, these activities would be ideal candidates for MBL treatments, and the latter are justified in light of the topical importance and improvements in student access to data.

Linn's model (1988) of technological incorporation into curricula was at least partially observed during this project; her first two stages (technology serving established goals followed by an adaptation of the educational events to the technical innovation) were both evident in the first and second cycles. The final stage (the integration of technology and learning) was never consistently
established during the study, although many of the activities apparent during the fourth cycle encouraged a belief in the ultimate realization of this integration.

Roles

Due to the large-scale shift of laboratory activities from data collection and graphing to data interpretation, student and teacher roles changed considerably. Students could cooperate in interpretation rather than doing it alone as homework, and readily compared results as evidenced in interview transcripts and photographs. Increased interpretational demands upon both students and instructor resulted in the realization that the teacher did not have a final goal with ultimately 'correct' results, but that further explorations and cooperation were more appropriate methods of accounting for the highly complex phenomena observed during data collection. The instructor became a source of suggested experimental avenues rather than a mandator of final goals.

Many students had considerable computing expertise and were often more familiar with computer interfaces and methods than the instructor, which placed additional demands on traditional teacher and student roles. Students appropriated some of the responsibility ('assumed a leadership role') for their own learning from the instructor during the activities, controlling and directing their own laboratory experimentation (as described in interview transcripts). Because of the willingness of students to increase their share of responsibility in their learning and the open-ended nature of MBL, it is likely that acquiring MBL technology will encourage instructors to do a smaller number of separate laboratory topics, but explore these at greater depth than is possible under the current curriculum.

5.1.4 Cognition

Other characteristics ascribed to MBL (Tinker, 1984a) such as environmental simplicity were observed during this project. In the more successful activities such as titrations, MBL apparatus did not intrude between the student and the phenomenon under examination. Students found the creation of titration curves to be quiet straightforward, and rapidly moved to a more desirable level of understanding the phenomena because of a seamless fit of the technology to the activity. After initial student exposure to MBL techniques and materials, subsequent use of the technology became more transparent to the students. Student expertise with the apparatus was shared amongst students and was cumulative amongst experiments.

Fast feedback (immediacy) was also observed during MBL activity, along with examples of on-task experimental tinkering which would not be possible without that feedback. Students concentrated upon their experimental observations and the graphical relationships of laboratory phenomenon rather than upon completion of step by step instructions for later analysis. Students were able to use this fast feedback to suggest means for extending and improving their laboratory activities to
the author in all cycles. This was in agreement with claims regarding feedback and direct experience made by Linn and Songer (1989).

An attempt was made to examine student graphical skills and to develop an instrument similar to the CEG instrument used by Linn and Songer (1989) during the final cycle of research (pH titrations), but this task was not completed due to time constraints. The instrument and some statistics describing student results and instrument weaknesses are presented in Appendix H. With additional iterations and instrument development, it would be possible to examine the roles MBL plays in the acquisition of graphing skills by students.

5.1.5 Methodology

Action research was a highly successful technique for instructional development during this study. AR provided intrinsic teacher and student motivation and the empowering atmosphere encouraged large amounts of student and teacher participation. This use of knowledgeable, empowered student participation also led to changes in student expectations and roles in the laboratory. Students were regularly engaged in critical evaluation of their own activities and of the materials used (see the extensive suggestions for modifications given in cycles 2, 3 and 4). Later reflections upon their experiences (the final interviews) provided students with an opportunity to improve the ‘rationality and justice of these [social and educational] practises’ (Kemmis, cited in Hopkins, 1985). AR proved remarkably effective in providing both the classroom teachers and the MBL developers with worthwhile and implementable strategies for improvement.

Software Design and Action Research

The iterative nature apparent in action research parallels current commercial software development methodology. Such software is developed by corporations for end-users, and is released in successive versions. While each version does undergo a rigorous pre-release test with volunteer users (called beta-testing, a semi-complete trial version of software is called a beta-release), software is continually honed and expanded as directed by user feedback and market demands. Action research allowed similar development to occur with MBL hardware and software, and this is particularly visible in Cycle two, where extensive high-quality student feedback and suggestions can be seen (probe centering devices, changing preamplifier cable lengths and so forth).
Constraints upon this Study

This study seriously underestimated the commitment required for adequate MBL hardware and software development. Although a large amount of effort was made to develop the equipment, the lack of personnel funding in particular forced repeated delays (Appendix A) and sharply limited the MBL resources available for use. While the degree of software flexibility gained by developing original MBL materials was extremely appropriate to the research, the hardware gains did not justify the effort expended (Appendix C). Future research should concentrate upon software and curricular development and avoid digitization hardware (although continued probe and sensor development would be appropriate) where possible.

Minor constraints included restrictions caused by the need to coordinate equipment loans and to transport equipment between MBL sites, meeting the development deadlines presented by the scheduling of student activities, and printing hardware availability. All of these were partially solved during study and could be completely overcome with more effort.

5.2 Discussion

This final section will address the characteristics of an idealized curriculum optimized for MBL implementation, 'ideal' MBL software and hardware, and promising research directions involving MBL.

5.2.1 Technology Curriculum

The ultimate technology-merged Chemistry curriculum would somewhat resemble the investigative, projected-oriented, partially student-directed atmosphere mainly attributed in the past to LOGO-like activities (Papert, 1980). Laboratory activities would be chosen to be open-ended, with teacher-directed requirements followed by student extensions. The use of technology for data acquisition, analysis, reporting and research would be readily available by making use of MBL, spreadsheets, scientific graphing and curvefitting software, text and equation processing and solution, on-line scientific references (eg. videodisk, CD-ROM) and electronic telecommunications to other students or scientific researchers. As optimistic as such technological claims seem, all are presently available and under trial in schools. Given the rate of personal computer introduction into schools, these related technologies may follow at a rapid pace. These technologies will revolutionalize school instruction and the implications of their integration is not more than partially understood at present.
An MBL Chemistry curriculum for the immediate future will certainly only incorporate slight deviations from the standard B.C. curriculum. The two experiments discussed in this study as very appropriate (cooling curves in grade 11 and titration curves in grade 12) provide excellent examples. Each of these activities would be done using a set of MBL stations in the laboratory over a period of 3-4 days once per term. As instructor and student confidence and expertise grew, those activities could be extended in scope (additional titrations and substances) and perhaps related phenomena would be examined. As additional activities and curricular materials appropriate for inclusion in the B.C. Chemistry curriculum were designed by teachers or produced by commercial textbook distributors, the number of MBL alternative experiments would increase. MBL curricula would parallel traditional curricula for several years due to delays obtaining sufficient apparatus for all schools (note a similar situation has been evidenced with the adoption of curricular activities requiring spectrophotometric instruments in the past).

The ultimate goal is not to convert all laboratory Chemistry activity to computer technology, but to take advantage of its strengths where appropriate.

5.2.2 Software

'Ideal' MBL Software

MBL software is inextricably intertwined with laboratory curricula and the expertise of both students and teachers. Researchers have noted both the need for the greatest degree possible of instructor control over technical innovation (Burkeman, 1987) and the need to avoid introducing extra degrees of complexity to both procedural and cognitive laboratory tasks (Stein, 1987). This is poorly reflected in commercial packages which attempt to reduce the costs of developing and providing appropriate software in favour of presenting the user with the most generalized (and lowest cost) interface possible. This may result in a nearly infinitely adaptable series of commands and menus (eg the IBM interface), which encourages distraction and inappropriate student software experimentation. When presented with a large number of software options, students will explore (tinker with) that software rather then perform more appropriate laboratory tasks centered upon the physical phenomenon under study.

The Laboratory User Interface

MBL user interface software should be easily and intuitively useful by both students and teachers. It should make use of graphics to guide apparatus setup, probe placement, calibration and other technology-specific activities interactively during the laboratory. Calibration should be intuitive and be covered by the curriculum. It should contain extensive error-checking and data editing facilities, and make data storage and retrieval easily available. Data should be stored in a form accessible to
students without the original MBL software for incorporation into other computer documents for wordprocessing and spreadsheet analysis. Where appropriate, data smoothing or curve fitting should be provided, but additional mathematical analyses should be sharply limited to the minimum required and explanations should accompany both the laboratory procedures and curriculum. The software should also encourage student annotation and other appropriate control such as labelling and changing axial ranges, which will encourage student ownership. Software should allow data display and manipulation without the hardware interface being present.

MBL software should be able to be customized by the teacher, who is uniquely sited to judge the best methods to make the interface appropriate for the particular students and activity. Teachers should be able to select items for inclusion from a wide variety of available line drawings, mathematical analyses, probe-handling and calibration routines and be able to predetermine scaling and labelling options and all program defaults quickly and easily. Then an easily-distributed stand-alone application containing these predetermined selections only should be created for student use. This would constrain the students' attention to the salient features of the experimental activity, and the instructor would always retain the ability to create applications for non-curricular experiments for advanced students, science fairs and other non-curricular investigations. It might even be desirable to incorporate the ability to control interfaces from multiple manufacturers in such a software environment.

Support Software

Additionally, science students should have access to a variety of supporting applications which would include a scientific spreadsheet capable of curve fitting, graphical analysis and plotting, a wordprocessor capable of preparing laboratory reports and handling scientific and mathematical characters and expressions, a database, an on-line full-function scientific calculator and possibly presentation software for classroom use. Such a suite of applications would be widely useful to science students and would extend beyond the scope of MBL activities and laboratory activities in general.

Many of these applications are presently available as either inexpensive shareware or from the Public Domain (PDware). Many students and school laboratories are already in possession of at least some of these applications, and many are even trained in their use as part of the present curriculum.
5.2.3 Hardware

The 'Ideal' MBL Lab

Commercially produced hardware should be used for MBL research wherever possible to enable investigators to reproduce results and share materials. Classroom teachers should not be called upon to develop any electronics expertise to use MBL hardware, and should have the same apparatus available to them as the researchers whenever possible. Like the Macintosh computer, MBL hardware should be treated like a toaster -- buy it, plug it in and go.

Hardware Specifics

Hardware should be solidly packaged in a metal housing, watertight and reliable, and should provide adequate power for a variety of sensors. It should use a three-prong plug, and opto-isolators to protect valuable computer hardware. Common signal conditioners such as pH probe amplifiers and thermistor preamplifiers should be enclosed within the main case, but provision for either third-party or user-constructed apparatus and sensors should be made as well. The interface should support a number of different analogue probes simultaneously and digital inputs and outputs as well.

All interface control should be done via software, and the interface should have an on-board CPU, RAM and ROM. It should use an RS232 serial port to communicate with a variety of computers, and should be able to sample at several kilohertz, storing signals in RAM for later downloading. At least twelve bit analog to digital conversion should be used, preferably sixteen. The interface should have a warranty and be readily available.

Probes

Sensors should be robust, use widely-available, known technology and be easily calibrated. Probes should be as thoroughly sealed and chemically inert as possible to prevent damage or decay. Probes should be streamlined for fit into test tubes or bottles, and should have adequate cable to allow their ready manipulation.
An Idealized MBL Chemistry Laboratory

The ideal high school MBL Chemistry laboratory would be networked to the rest of the school to reach both a MODEM and a high-quality printer. Six to eight stations should be provided separate from student desk space and adjacent to laboratory counter space where computers can be sited, and one or two locations should be provided for networked dot-matrix printers. All of these stations would not contain computers full-time, but should contain interfaces, power bars and network cabling so that machines can be easily transported from elsewhere for laboratory use. Several computers and a printer would reside in the classroom laboratory full time complete with the MBL and support software described earlier. If there is room to place carts adjacent to counters, then clear splash shields should be considered to protect computer hardware, if not then computer hardware should be raised above the laboratory counter surface if possible.

Computers keyboards would be covered with a clear, flexible plastic membrane to protect them from spills, and monitors would have attached pockets to store mice. The teachers would have their own networked computer with a hard drive, an overhead projector display unit and an interface at the front of the classroom to be used for demonstrations and classroom administration.

While the fictional laboratory described may seem wildly optimistic, many similar computer laboratories exist in high schools today, and computer hardware is being acquired by schools at a prodigious rate. The two sites of this study both had computers and printers dedicated to the science department, and either adjacent to or within the classroom laboratory. One site had an overhead projection system for computer screens in the chemistry classroom as well. Several of the above ideas are presently being designed into the science laboratories of the new replacement school for North Surrey by MBL Project participants.

In Chapter 2, Linn’s three-step model (1988) describing the implementation of technology into the classroom was introduced. This model describes technology as first serving established goals, then driving curricular change and finally becoming a seamless, unremarkable part of the learning environment. MBL technology is still in its infancy, and truly appropriate materials and curricula have not yet been developed or been made commercially available.
Obtaining Hardware

Instructors and administrators interested in adopting MBL technology would be recommended to commence with obtaining the support software described earlier and making it available to students in the school computer laboratory. The Chemistry instructor should adopt activities designed to involve student analysis of data and or report generation on computers available in the laboratory, perhaps conducting occasional activities in the computer laboratory. Students should be encouraged to gain familiarity with the computer's operating system and printing procedures before commencing MBL activity. There is also a wide variety of activities and materials designed to encourage computer integration into science class.

Next, the instructor should attempt to obtain a computer for their own classroom, with a printer and interface to follow. This would allow the setup of a single station in the classroom for supplementary student activity and limited demonstration. With the addition of an overhead projector display, the instructor would have a powerful set of demonstration apparatus for both laboratory activity and instruction. Finally, machines would be acquired for the stations as the opportunity presented itself.

Currently obsolete computer hardware is very cost effective and presents a readily-available entry into MBL. Teachers have equipped themselves with Apple ][ based MBL apparatus quite inexpensively (Doan and Vogel, 1990) with little difficulty.

5.2.4 Further Research

There are several avenues of research suggested by this project including the following:

Traditionally Under-Represented Science Students

Technological innovation has been theorized to motivate laboratory participation by traditionally disadvantaged science students such as female students and students who are represent ethnic or racial minorities. Although definitive research has not been carried out to date, MBL researchers have noted a sharp increase in the representation of nontraditional students as Physics majors after exposure to technologically-enhanced curricula in a first year Physics course (Laws, 1990). The great demand for technically and scientifically trained personnel in North American society may also encourage the adoption of MBL technology.
An examination of the relationship between technology, curricula and traditionally under-represented (by gender or ethnicity) science students is required. First, a quantitative study could be made to determine whether such a relationship does exist, and then qualitative research to identify those characteristics most suitable to attracting these students into science study and science-related careers.

Curricular Topics and learning in the MBL Environment

Further study of technological innovation in science curricula will concentrate upon the development of curricula suitable for widespread employment. Some of the relevant questions follow. What concepts are being addressed by traditional laboratory activities and what effect does MBL have on the development of these concepts? To what degree is simplifying the software interface environment appropriate for what levels of student expertise? Which students should have access to which tools? Where is equation-fitting appropriate? What non-traditional Chemistry curricular topics such as instrumental measurement and mathematical-graphical analysis are appropriate for what levels of school activity? Where can these topics be integrated with traditional curricular activities such as mathematics and geometry?

Laboratory Reporting

Further study of the relationship between MBL and laboratory report content and quality is required. Does MBL increase laboratory report completion rates? Does the availability of high quality tabular and graphical results encourage greater effort by science students? Many of the questions that have arisen concerning the relationship between student writing and wordprocessing can be extended to laboratory reporting.

Some suggested activities would include the extension of current laboratory reporting procedure through multiple drafting of reports and open ended laboratories where a minimum set of completion criteria is required of students and a set of suggested extension activities and or materials is provided to students. Students could be encouraged to greatly increase qualitative reporting and comment during their laboratory activities, as well as to suggest further hypotheses for experimentation as part of their reports. After a series of such reports, students could be encouraged to review, design experiments for and research one of their most likely suggestions.
Teacher Roles

Examination of the exact role played by instructor attitude and expertise in the adoption and successful integration of technology into science education is needed, both in the subject domain (i.e. Chemistry) and in the technology domain. The potential of the available technology outstrips the capacity of teacher control in the traditional sense of teacher predominance, and will present new problems in student evaluation, guidance and tutelage. There are currently demands upon science teachers to acquire and use instrumentation, but there is little understanding of how to best facilitate widespread adoption of technology into Chemistry laboratories.
Bibliography


Appendix A: Chronology of the MBL Project

Oct 1988
21/10/88  CUE Horizons Presentation: The Computer as a Lab Partner: An Introduction to Microcomputer Based Laboratories in the Science Classroom

Nov 1988
11/11/88  Contacted TERC, Cambridge MA by mail.
25/11/88  Original MBL Project Proposal made to Ed Tech Pgm, Ministry of Education by the author and cooperating teacher X.

Dec 1988
19/12/88  Received Grant Informal Notification, top 10 of 764; rec'd $8900.00
???     Ordered hardware from UBC EE stores

Jan 1989
10/1/89   MBL Project funds released to Richmond School Board
18/1/89   RSB OKs classroom observations of students - noninterventionary only
21/1/89   First contact via EMAIL with ACEF (Apple Canada Education Foundation)
27/1/89   Ordered Interface from TERC
???      Received Borlands' TurboPascal, started software experimentation

Feb 1989
17/2/89   Cooperating teacher X attended National Instruments Seminar on Laboratory Instrumentation
18/2/89   Application to President of ACEF for additional MBL Proj funding and hardware
           Interim Report made to Ministry of Education: most hardware ordering underway or complete; TurboPASCAL coding underway; MBL dB underway, wrote commercial MBL distrbs, approached ACEF for complete science lab HW setup, MODEM ordered for school. Probs: MAC serial connectors. See report for this date.
19/2/89   UBC releases PO to Active Semiconductors
26/2/89   UBC releases PO to RAE/ITT Inc
27/2/89   Work on MBL Proj DataBase Commences

Mar 89
2-13/3/90  Visited NS/NB; worked on software & Hardware at Mt A Physics Dept.
13/3/90   Spectrophotometer interface cable & MSBASIC/TurboPASCAL routines completed
14/3/90   Ordered ZBASIC 5.0 for development
14/3/90   PO'd parts from Mount Allison U Physics Dept + 25 microwave oven thermometers
20/3/90   Further component order - Active Electronics
28/3/90   Report to Dr S. Donn for CSED 580A of MBL Project activities
           Two draft papers to Dr M Westrom for CSED 546 upon MBL Design/Pedagogy

Apr 89
???      DART redesign & experimentation
???      Met ACEF: no commitment unless RSB/Schools commit $$$ and/or personnel time. No deal made.

May 89
???     Worked at VCC due to loss of CERG GAA funding from UBC
???     DART redesign & experimentation
???     DART PC etching at UBC dept of EE
June 89
30/6/89 Worked at VCC due to loss of CERG GAA funding from UBC
30/6/89 DART redesign & experimentation

July 89
30/7/89 Worked at VCC due to loss of CERG GAA funding from UBC
29/7/89 Telco to original DART designer, Victoria (DART assembly issues)
29/7/89 Telco contact with Chief Scientist, Technical Education Research Centres (TERC) in Cambridge MA; President of Vernier Scientific in Oregon (commercial MBL producers)
26/7/89 Telco contact w/ MC Linn at UC Berkeley for EMAIL address

Aug 89
1/8/89 First EMAIL contact with MC Linn @ UC Berkeley
3/8/89 Worked at VCC due to loss of CERG GAA funding from UBC

Sept 89
1/9/89 EMAIL comments from MC Linn regarding MBL Project design
3/9/89 DART assembly
3/9/89 design of MBL - Spec user interface

Oct 89
2/10/89 EXPERIMENT 19B@Richmond - Exploratory DEMO
3 classes of gr 12s - four stations, 2 printers, final class did standrd expt (no MBL)
SEE comments. Prelab quizzes and Lab reps for all students were gathered.
22/10/89 Application to RSB for interventionary research
23/10/89 Application to UBC Ethical Review Comm for interventionary research
3/10/89 Second cooperating teacher Y re-runs 19B@ Surrey - extensive list of commentary attached.

Nov 89
10/11/89 Horizons 89 Presentation: Computers in High School Science: The Microcomputer Based Laboratory Project
10/11/89 Received OK for interventionary research from RSB
21/11/89 Received OK for research from UBC Ethics Review Committee

Dec 89
31/12/89 Temp Probe Development
31/12/89 Additional Richmond Chemistry teacher Z agrees to become a cooperating teacher for the MBL Proj

Jan 90
31/1/90 Temp probe devt - attempts to frame grab image of apparatus fail
31/1/90 exchange of info - max time run for 2A temp plot
31/1/90 MBL Proj @ Richmond receives MODEM
31/1/90 Richmond teaching assignments:
    Teacher X - 1 section of Chemistry 11
    Teacher Z - 2 sections of Chemistry 11
31/1/90 Temp Probe development;
Feb 90
2/2/90 Thermo s/w - saves/recalls data; missing DART does not crash; calib routine
5/2/90 thermo s/w not ready for demo
13/2/90 original scheduled time for 2A - missed due to development probs (s/w not ready; thermo interface conditioning circuitry not sufficiently accurate) HRM product used as guide. Inaccurate version demoed to X, feedback in EMAIL regarding s/w design - mainly scaling.
15/2/90 5 DARTs running - see EMAIL
19/2/90 Mass production of DARTs started; bad parts delay
20/2/90 Ordered SONAR interface from UBC dept of EE; reconstruction of Thermo Interface (2nd hardware version); new s/w uses fields for calibration instead of asking questions.
27/2/90 EXPERIMENTS AT RICHMOND
- 3 gr 11 classes (15-20 students) examined 2A; two sets of apparatus available; students had previously run this lab. See EMAIL comments of this date. Main points - HW improvements + Calibration issue.
- 2 gr 12 classes of 19B - comparison of apparatus with previously run SPEC 20D lab (voluntary).
Final decision to scrap original study design - go with reflection in action.

Mar 90
7/3/90 Teacher Y agrees to participate in MBL Project formally, applied to Surrey School Board (SSB) for permission to conduct interventionary research... More work on thermo software - new formula used to calc temperatures.
11/3/90 Teacher Y visits UBC, debug of 19B; spooler use speeds printing; thermo interface good to 1 deg C and output is spiky
28/3/90 OK for interventionary from SSB

Apr 90
10/4/90 Nonfunctioning ICs - 4060 timer/6402 UART halt DART construction at 5
9-12/4/90 original schedule for 20H @ Surrey
12/4/90 Locate and reorder faulty ICs
13/4/90 Leave temp and pH for evaluation by X and Y
15-23/4/90 AERA in Boston; took & demoed hardware and software to MC Linn, spoke to Thornton & Tinker, joined SIG-ETC
20/4/90 X and Y debug/comment upon pH and Temp software and hardware (EMAIL)
27-28/4/90 BCScTA Catalyst 90 Conference Presentation: The MBL Project
30/4/90 Final financial exchanges with McNair
???
??
??
?? pH coding & interface construction all month

May 90
3/5/90 Note on pH probe care written; sent to Y for critique
7/5/90 2nd scheduled time for 20H@Surrey
8/5/90 Lock's comments re pH probe instructions
9/5/90 Meeting with PEMC people re MBLs (cancelled same day)
10/5/90 Expt 16B@Richmond 1st scheduled time (X reschedules)
11/5/90 Expt 16B@Richmond 2nd scheduled time (X reschedules)
14/5/90 4th scheduled time for 20H@Surrey (moved by Richmond)
14/5/90 EXPERIMENT 16B@Richmond run
14/5/90 Fix earlier 20H to Y's comments; scaling dilemma
15/5/90 3rd scheduled time for 20H@Surrey (Y reschedules)
16/5/90 Equipment setup at Surrey
17/5/90 EXPERIMENT 20H @ Surrey 2 classes
18/5/90 Patricio @ UBC working on Surveys/Lab Reps

Page 169
<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>June 90</td>
<td>1st scheduling of interviews at Richmond (X reschedules)</td>
</tr>
<tr>
<td>1/6/90</td>
<td>Author studies/preps for GREs</td>
</tr>
<tr>
<td>3-9/6/90</td>
<td>Interviews of students at Richmond</td>
</tr>
<tr>
<td>11/6/90</td>
<td>First meeting of author's thesis committee</td>
</tr>
<tr>
<td>18/6/90</td>
<td>Interview teachers X and Z at Richmond</td>
</tr>
<tr>
<td>26/6/90</td>
<td>Interview of Y in North Van</td>
</tr>
<tr>
<td>???</td>
<td>Commence Thesis writing</td>
</tr>
</tbody>
</table>
Appendix B: The MBL Project Proposal

This document contains two project descriptions -- an extremely ambitious application to the BC Ministry of Education Educational Technology Program for grant support, and a copy of the project as originally proposed to the UBC Ethical Review Committee for Human Research. Both lay groundwork for the MBL Project and reveal the original research methodology intended.

The Proposal to the Ministry of Education

Microcomputer Based Science Laboratories
(The MBL Project)

Project Description:

Microcomputer Based Laboratories (MBLs) represent a new application of information-handling technology to the school science laboratory. MBL technology promotes the rapid collection and analysis of experimental data through the use of various sensors (thermometers, photocells and pH probes) and the immediate display of this data. Students are provided with immediate graphical representations of physical relationships in the laboratory.

As peripheral costs have dropped in recent years, instrumentation and software currently considered standard equipment in working science laboratories have been modified for and made available to schools. Some of the many educational groups currently involved in the study and development of MBL technology include the National Science Foundation and the Technical Education Research Centres in the US who have developed packages for a variety of student age levels and abilities, including elementary level science, and learning disabled students.

MBL apparatus is also currently available from all large suppliers of school science laboratory equipment, but unfortunately follows no equipment standards, nor are they precise fits to existing BC curricula. Some of the current manufacturers and suppliers include CBS, HRM, DCS, Bank Street College, Carolina Biological Supply, Central Scientific Co of Canada, Boreal Scientific and Ward Scientific.

The proposed MBL Project will develop and implement the computer peripherals, software and documentation required to provide microcomputer based science experiments which will be appropriate matches for the BC Grade 11 and 12 science curricula (Chemistry, Physics and Biology). Commercial equipment and sensors will be used wherever possible, and a case study evaluation of MBL usage in these courses will be made. The project will make use of the existing expertise at both the University of British Columbia Department of Mathematics and Science Education Computers in Education Research Group (MSED CERG) and [DELETED] in Richmond, BC in the fields of high school laboratory instruction, MBL technology and the BC Curricula. The project will run over a one year span (Jan - Dec 89).

The primary personnel involved in the MBL Project will be [DELETED] chemistry teacher of seventeen years expertise, who is presently head of the [DELETED] Science Department and who has participated in the past Chem 11/12 Curriculum Review Committee. He has been using commercial variants of MBL technology in his classroom for the last three years, and has given PD workshops upon the subject. He will be assisted by Mr Daniel MacIsaac, an MA student of the UBC MSED who has taught high school Computer Science and Physics in the province of Manitoba for two years, and who is currently employed by CERG in the CERG MBL technology project. Mr MacIsaac will complete his MA thesis upon classroom applications of MBL technology during the course of the project.
Proposed Budget:

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Digital-Analog Receiver-Transmitter Boards (DART Boards)</td>
<td>$3500.00</td>
</tr>
<tr>
<td>RS232 compatible; supplied by CERG/UBC MSED.</td>
<td></td>
</tr>
<tr>
<td>10 Temperature Sensors (estd)</td>
<td>$500.00</td>
</tr>
<tr>
<td>Modified commercial microwave oven sensors.</td>
<td></td>
</tr>
<tr>
<td>10 pH Sensors</td>
<td>$1500.00</td>
</tr>
<tr>
<td>GPSM Sensor, Cat #31836 Central Scientific Co of Canada 88/89 cat.</td>
<td></td>
</tr>
<tr>
<td>10 Photocell Detectors (estd)</td>
<td>$500.00</td>
</tr>
<tr>
<td>Interruptible timing beam + light intensity measurement.</td>
<td></td>
</tr>
<tr>
<td>10 copies of TurboPASCAL (estd)</td>
<td>$1500.00</td>
</tr>
<tr>
<td>Supplied by Borland; compatible with other hardware.</td>
<td></td>
</tr>
<tr>
<td>1 Low Cost Interface and 1 Mac Interface Prototypes</td>
<td>$300.00</td>
</tr>
<tr>
<td>Supplied by TERC, Cambridge, MA</td>
<td></td>
</tr>
<tr>
<td>Modem</td>
<td>$350.00</td>
</tr>
<tr>
<td>For McNair Science Lab site.</td>
<td></td>
</tr>
<tr>
<td>Administrative Costs</td>
<td>$250.00</td>
</tr>
<tr>
<td>Photocopying, mailing, telephone, diskettes etc.</td>
<td></td>
</tr>
<tr>
<td>Various Electronic Hardware</td>
<td>$500.00</td>
</tr>
<tr>
<td>Cables, components, supplies, cases, consumable tools and equipment.</td>
<td></td>
</tr>
<tr>
<td>Program Development Costs (personnel)</td>
<td>$1000.00</td>
</tr>
</tbody>
</table>

Grand Total for MBL Project $9,900.00

Resource Allocations/Monitoring and Evaluation:

[DELETED] will directly control all day-to-day aspects of the MBL Project and will draft, revise and produce an MBL Laboratory Package consisting of lesson plans, teachers' notes and laboratory instructions regarding the use of MBL equipment in the BC senior secondary science curriculum. He will also provide a case study environment for the evaluation of these materials.

Mr Daniel Maclsaac will be responsible for all UBC/MSED/CERG liason for the MBL Project, and will order, modify and construct MBL peripherals for use with the MacIntosh PC. He will modify or write any required code under the guidance of CERG/MSED for use with the MBL Project. He will also participate in and document the final case study.

[DELETED] will provide laboratory equipment, MacIntosh computing equipment, housing and development space for the MBL project. [DELETED] will also site-test all equipment, and will provide the Case-study environment. [DELETED] science educators will assist in the evaluation of the Lab Packages as they are developed.

The Computers in Education Research Group, under the direction of Dr Marv Westrom will make available CERG computing and office facilities and partially fund Mr Maclsaac's personnel costs. CERG will also construct and provide DART Boards for the MBL project. Dr Westrom will also make available his considerable CAI expertise on an immediate consultative basis.
The UBC Department of Mathematics and Science Education will make staff resources available for consultation. In particular, Dr Stuart Donn will supervise an MA thesis concerning MBL applications in secondary science instruction to be completed by Mr Dan Maclsaac for expected graduation from UBC MSED in early 1990.

[DELETED] will provide local financial control and monitor all project funding.

[DELETED] Facilitator-Computer Science will provide immediate project timetable and technical monitoring at the District level.

[DELETED] Supervisor of Curriculum will provide project timetable and technical monitoring at the District level.

The Apple Canada Education Foundation will be approached regarding the donation of 9 Macintosh SEs, 1 Imagewriter II printer and the required Appletalk cabling and connectors to equip a HS science laboratory with ten work stations. The ACEF has been approached in the past regarding a similar proposal (MacScience) for equipment at [DELETED], which was denied due to the unavailability of matching funding and dedicated personnel. Should the ACEF not be able to provide the requested equipment, hardware presently located at the McNair site will be made available to the MBL Project as required.

The Technical Education Research Centre of Cambridge, Massachusetts will provide occasional technical consultation.

The BC Ministry of Education, through the office of the Technology Program will supply the required funding for the MBL Project.

Proposed Timeline:

31 Jan 89 All peripherals ordered; construction of DART Boards commenced.
29 Feb 89 DART Boards completed, temp sensor modifications commenced.
31 Mar 89 Temperature sensors completed, software development modifications underway. Preliminary case study observations.
30 Apr 89 Software development continues, first field tests at [DELETED] of temperature sensor.
31 May 89 Software, temperature sensor and lab package development. Early student - MBL exposure observations.
30 June 89 Software, temperature sensor and Lab Package finalized and tested. Student perceptions of MBLs studied as time permits.
31 July 89 pH and photocell sensor and software development.
31 Aug 89 pH and photocell field tests*, Lab Package development.
30 Sept 89 pH and photocell field Lab Package finalized and tested.
31 Oct 89 MBL Lab Package drafted. Major portion of case study commences.
30 Nov 89 MBL Major case study continues, Lab Package revised.
31 Dec 89 Final MBL project report completed, MBL findings published.

* some initial field testing of MBL lab packages will be done at UBC summer science symposia and local summer school programs due to summer holidays. MBL work will continue (at a reduced pace) for the full duration of the summer.
- concurrently, articles will be prepared and published in the applicable BC professional journals (The Catalyst, The Science Teacher, The CUE Journal, Chemistry in Canada etc).

- a monthly written activity report will be made to all supervising parties.

- although a formal case study will be made and evaluated no later than Oct/Nov 89, case study data will be collected during all field testing of MBLs. This information will also be reported, and most likely will form part of any final overall reporting.

- the MA thesis of Daniel MacIsaac will form part of the final MBL Project documentation.

- all documentation collected during the course of the MBL Project will be duplicated, catalogued and held upon both the McNair and CERG/UBC/MSED sites for the availability of all BC educators.

Rewrites to Main Grant Application

[1st Page] Brief Description of Project

The use of Microcomputer Based science Laboratories (MBLs) represents a new, currently growing application of information management technology in the instructional setting.

This project will develop a Lab Package of approximately twelve MBLs for use with the newly revised British Columbia chemistry, physics and biology high school science curricula. The Lab Package will consist of student and teacher laboratory instructions for the selected experiments, which will be chosen to be appropriate matches for both the curricula and the technology. A total of ten sets of MBL apparatus for the performance of these and other experiments will be constructed. A case study of the implementation of these experiments will be performed at Matthew McNair Senior Secondary School in the described courses.

[1st Page] #1 - Projects should be designed...

The information collected during the design and case study of these MBL experiments will be directly generalizable to BC high school chemistry, physics and biology courses. There has been no large scale examination of the use of MBL technology in BC high schools to date.

[1st Page] #2 - Projects should integrate...

The newly revised BC high school science curricula will be examined to find experiments which will best make use of MBL technology. This project will combine commercially available and locally developed hardware and software in an appropriate match to the selected experiments. This will be done by a teacher who has been a member of the chemistry 11/12 Curriculum Revision Committee, and who has experimented with MBL technology in the classroom for the previous three years.

[2nd Page] #4b - Control group studies...

DELETED

[2nd Page] #4e - other...

A case study analysis to explore the appropriateness of MBL technology usage in high school science will be carried out during this project, cooperatively with the Computers in Education Research Group and the UBC Department of Mathematics and Science Instruction.

[3rd Page] Describe the Evaluation/Monitoring...
Monitoring and evaluation will occur as per the attached timeline by the indicated staff at District and [DELETED] school levels, assisted by the UBC Department of Mathematics and Science Education as requested.

The Proposal to the UBC Ethical Review Committee for Human Research

Ethical review request - typists' instructions.

1. Dr J. Stuart Donn
2. Dan MacIsaac 59-50499888
3. MSED
4. 228 - 5203
5. BC Dept of Education, Education Technology Program (see enclosure).
7. The Microcomputer-Based Laboratory (MBL) Project.
8. The use of personal computers in High School Science Laboratories as measuring and recording instruments is becoming more commonplace in BC Schools. This study intends to evaluate the use MBL technology through the following questions:

   Does student use of MBL technology in High School chemistry laboratory instruction improve student laboratory performance?

   Which traits characteristic of MBL technology are seen by grade 12 chemistry students, their teachers and observers as being of value or hinderance?

9. Dr J. Stuart Donn (todays' date below)
10. Dan MacIsaac (todays' date below)
11. Dr D.F. Robitaille (todays' date below)
12. Three grade 12 classes from [DELETED] in Richmond of approximately 25 students each will participate in the study. Two instructional units of approximately one weeks' duration each will be taught. The use of standard laboratory procedures in the accompanying laboratory experiments (as defined by current teaching practise) will constitute the control. The use of the standard experiment modified to employ 10 sets of MBL apparatus constructed at UBC for the MacIntosh Computer will constitute the treatment.

Students will receive standard instruction by an experienced (>17 yrs) Chemistry teacher from identical lesson plans. Students will perform 2-3 laboratory experiments per unit in groups of 3-4 students. Students will complete laboratory pretests, reports and posttests for each unit. These tests and laboratory reports are used in student course grading. There will be no disruption to the scheduling of Chem 12 as a result of the study.

Students taking part in this study will be asked to complete a brief questionnaire regarding their perceptions of their laboratory experiences. Qualitative data regarding student behaviour will gathered through videotaping of student laboratory groups on a random basis, with one group of experimenters taped per lab session. An observer will take notes and still photographs.
All student quizzes and lab reports will be evaluated and marks assigned by the regular teacher. Copies of this material will be wordprocessed into a standard format concealing both individual student identities and experimental procedures and technology.

Each class will serve as a treatment group once, and as a control once - all students will therefore be exposed to MBL technology. The two units will be analyzed as a quasiexperimental counterbalanced design with a non-equivalent control group.

Test results will be interpreted for evidence of statistical significance between treatment and control groups item by item, using pretest scores as a covariable. Student comments and an instructors' journal will be analysed using case study methodology for evidence of references to such MBL traits as Environmental Simplicity, Feedback Immediacy, Data Transformations, Student Control, Experiment Attractiveness and Student Interest. The comments and videotapes will be used to formulate questions for followup interviews to further characterize student and instructor opinions of the treatment.

13a. Approximately 75 grade 12 high school students will participate.
13b. All participants will act as both both control and treatment groups.
14. All participants will be Grade 12 Chemistry students from [DELETED] in Richmond, BC. Course enrollment is the only selection criterion.
15. Only those choosing not to participate will be exempt from this study.
16. By attached notice and parental consent form.
17. Not Applicable.
18. The grade 12 chemistry classrooms and laboratories of [DELETED].
19. Dr. J Stuart Donn and Dr Marv Westrom of the UBC Faculty of Education, Mr Daniel Maclsaac, MSED Graduate Student and [DELETED].
20. Yes. Informed consent will be given by signature by the parents or legal guardians of students not yet of the age of majority as necessary. See attached consent form.
21. As above.
22. There are no anticipated risks in this study.
23. None.
24. There will be no monetary compensation for participation in this study.
25. Each subject will be tested for a total of 30 minutes beyond regular curricular evaluation during this study. This testing will consist of completion of laboratory comment forms.
26. Alll subjects will dedicate 30 minutes as described above.
27. UBC Faculty of Education, Richmond School Board, the BC Department of Education and professional journals will all have access to the summarized data from this study. Individual data will be accessible only to those actually completing the study (see #19). The students' regular instructor will not have access to the laboratory comments before student grades are assigned.
28. All written data used to identify individuals will be destroyed after collation by individual. Code numbers will be used to collate the summarized data.
29. There are no future plans for the data collected beyond this study. All individual data will be destroyed after collation by code number. Summarized data will be retained for two years before destruction.

30. No. All such data will be eradicated after collation, coding and summarization.

31a-d. IGNORE.

32a-c. IGNORE.

32d-f. IGNORE. ADD BELOW NOTE AT BOTTOM.

Note that the Richmond School Board final approval is conditional upon successful completion of this ethical review. (see attachment).

33-35. IGNORE.
Appendix C: Hardware Design and Construction Details

This appendix is made up of several documents including an interim report describing hardware development at the Computers in Education Research Group entitled 'CERG and the DART Board', a second section describing the cabling required to link a Macintosh computer with a Spec 20D spectrophotometer, and a final section describing pH probe care and use.

DART Board History

The Digital-Analog Receiver-Transmitter (DART) Board was designed by Rob Hickman at the Computers in Education Research Group (CERG) offices of the UBC Dept of Mathematics and Science Education during 1986 - 1988 under the supervision of Dr Marv Westrom. The DART board (Hickman, 1988) is an interface for both digital (8 channels in and out) and analog (an 8 bit ADC with 8 multiplexed input channels from 0-5VDC, no analog out) signals, using an RS232C compatible interface capable of connecting to most personal computers, at various baud rates up to 9600 baud.

To date the DART Board has been solely used with the Macintosh computer, using software developed at CERG in MicroSoft BASIC and ZBASIC, as well as LightSpeed Pascal. The most extensive development to date has taken place in ZBASIC.

The first use of the DART board in educational research was during a pilot course offered at [DELETED] School entitled Computing Studies 10 (Locally Developed) which was primarily designed with the intent of teaching electronics and computer control (Schnider, 1974). Six DART boxes were constructed for the course, which involved software instruction in MS BASIC, digital circuit theory, boolean logic, analog to digital conversion theory, digital design and interfacing topics.
The second major use of the DART Board was during the MicroComputer Based Laboratory (MBL) Project by Dan MacIsaac (MacIsaac and Ramirez, 1989) during his MA Thesis Case Study with cooperating HS Chemistry teachers at [DELETED]. Twelve DART Boards were built using a modified design for the casing and power supply, along with various signal conditioning hardware (mainly preamplifiers) used to connect sensors to the analog input channels. Software development utilized ZBASIC, and hardware modifications are attached. A more detailed description of the project software and curricular developments is available elsewhere (MacIsaac, 1990).

Original DART Design

The DART interface board was designed with the intent of being readily constructible by teachers with some electronic expertise, and documents (Hickman, 1989) containing detailed technical instructions for the construction were specifically prepared for this. This was primarily due to a dearth of inexpensive, commercially-available interface boards at the time of the design.

The original stated cost of the DART Board was somewhat optimistically placed at $133.41 in materials, assuming economies of scale in the costing of some specialty components such as etched PC Boards and casings of formed sheet-metal and folded acrylic. This does not include any labour costs (about 15 - 20 hours depending upon expertise) nor instrument access (a DMM and oscilloscope are vital, documentation refers to a MHz-capable frequency counter not readily available) nor hand tools.

Several design aspects (apart from packaging) render the original DART Board difficult for an amateur to construct, and unsuitable for many interfacing applications. These include:

- an excessive use of wire jumpers upon the PC Board. Jumpers are numerous and are found upon both sides of the board, including jumpers to semiconductor components mounted upon the sheet metal casing (probably for reasons of heat dissipation). The placement of these jumpers requires a great deal of time.
- an inadequate power supply. The original DART design utilized a third-party external 12VDC power adapter as well as internal batteries to drive on-board components. The battery was easily discharged by accidentally leaving the power switch on for a few hours. A subsequent modification used to draw 50 mA across the digital outputs to drive a small toy car introduced a 2W resistor to the board (and probably drove one of the voltage regulators to the casing wall for adequate heat-sinking). To provide useable interfacing abilities, a device must supply a split 12 or 15 VDC of approximately 100 mA drawing current for the purpose of driving digital circuitry (ie CMOS), sensors and analog signal conditioning circuitry.

- inadequate off-board connectors. These are required for input and output signals, as well as power distribution. Originally, two PC block connectors using screw terminals sufficed, as only digital signals, and +5 VDC were distributed. No provision for split power distribution was made.

- excessive complexity. The original design made use of eight SPDT toggle switches with the third terminal cut from each for on-board digital inputs, as well as a ninth such switch to enable the other eight. This choice was determined by the availability of a particular component (the toggle switch) at reduced cost during the original design. The part is no longer available at the original cost. The presence of the switches is not required for analog digitization use, and is pedagogically undesirable as the switches are very distracting to students. The mounting of these switches upon the PC board also creates difficulty as they require epoxy bonding for physical stability and great precision in the alignment of access holes in the cabinetry.

- undocumented intolerance to substitute components. Due to marginal waveforms, the binary counter/oscillator IC must be of Motorola manufacture to function properly. Non-Motorola (ie SGS, ST) substitutes will not function.
- sampling speed constraints. The maximum sampling rate of the DART board is determined by the 9600 baud communications rate due to a lack of on-board memory. This rate translates to approximately 960 characters or samples/sec. Each sample taken by the DART requires computer initiation, halving this rate to 480 samples/sec. Theoretical constraints in digital sampling theory (the Nyquist theorem) further reduce the ability to uniquely determine sampled events to 240 Hz. While 240 Hz sampling detection is quite adequate for the chemistry experiments performed by the MBL Project, this rate would probably be insufficient for many Physics applications.

- in addition, some minor deficiencies in the documentation are discernable during DART construction - one of the ICs is mounted upside down (and will be destroyed if inserted incorrectly and not detected quickly) from the remainder, the troubleshooting guide is slightly misleading when describing the behaviour of the LEDs when the latch IC has unterminated inputs during assembly, etc.

MBL Project DART Implementation

The MBL Project made use of the DART design mainly due to the continuing dearth of affordable Mac interface boards, but made several design modifications to reflect the nature of the project. These included:

- recasing the instrument in a larger, premanufactured Hammond box.

- incorporating a separate internal AC power supply board capable of providing 1 A (slight overkill here) draw at +/- 5 and +/- 12 VDC. The supply design is attached to this document along with sensor preamplifier details.
- using DB9S connectors for the analog inputs. These connectors also provide all supply voltages and ground, and have room to allow digital and analog input and output as well. There is room for all I/O channels to have their own DB9S connectors (eight in all), but the project use only required a maximum of four, so only four were actually installed.

- eliminating the toggle switches, except for a single power On/Off switch.

These modifications proved adequate for the applications required by the MBL Project. An estimated cost per board for manufacture (now incorporating casing but again less labor and tools/instruments) is $225.00.

Should the DART Board be used again, further design changes that seem self explanatory might include:

- the elimination of all on-board digital connectors.

- downscaling, but retaining an AC power supply.

- other modifications as are cost-effective and desirable to the specific application.

- a completely relaid, double sided PC Board.

- suitably recasing the interface.
Recent Interface Developments

Recent commercial developments have rendered the DART Board both technically obsolete and financially noncompetitive. Several well-known and reputable firms are distributing interfaces, software and basic (usually temp) sensors for less than US$500.00 (IBM, 1990). One particular university-developed Mac device is available for US$350.00 (Vernier, 1990). The majority of these devices have much higher sampling rates, often incorporate on-board memory and CPUs, are RS232C compatible and their software, sensors and related signal conditioning amplifiers are available off the shelf.

Future CERG Interface Directions

While technically-desirable MBL hardware is now readily available for the Macintosh at reasonable cost, pedagogically-appropriate MBL software has not yet been designed nor have appropriate curricular methodologies for the employment of MBL technologies been designed or evaluated at the High School level, particularly in Chemistry and Biology. It is the opinion of this author that future CERG interface endeavours should be made in these areas, not in local hardware development and construction.

Dan MacIsaac

Tuesday, May 8, 1990
Power Supply Notes:

Components as follows:

- F1 - 0.5 A fast blow fuse (3AG)
- L1 - 120VAC Ne indicator light
- D1, D2 - 1N4005
- C1, C2 - 1000 μF@25V
- S1 - SPST toggle, 120 VAC@1.0 A
- T1 - 16 V Hammond L.V. Rectifier Xformer
- Hammond 166J16 (1A) or 166G16 (0.5A)
- C3/C6 - 0.1μF@50V

The power supply is intended to supply the DART Board interface (+/-15 and +5 VDC) and such supply voltages as might be desired by signal processing circuitry for the various sensors. Supply voltages are all available at the DB-9S connectors on the end of the DART as shown in Figure 40.

Figure 40: DB-9S Connector pinout

<table>
<thead>
<tr>
<th>Pin #</th>
<th>Signal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>+15 VDC</td>
</tr>
<tr>
<td>2</td>
<td>+5 VDC</td>
</tr>
<tr>
<td>3</td>
<td>Ground</td>
</tr>
<tr>
<td>4</td>
<td>-5 VDC</td>
</tr>
<tr>
<td>5</td>
<td>-15 VDC</td>
</tr>
<tr>
<td>6</td>
<td>n/c</td>
</tr>
<tr>
<td>7</td>
<td>n/c</td>
</tr>
<tr>
<td>8</td>
<td>n/c</td>
</tr>
<tr>
<td>9</td>
<td>Analog In to ADC</td>
</tr>
</tbody>
</table>
Temperature Preamplifier Notes:

Circuit after p. 219 Tompkins & Webster, Interfacing Sensors to the IBM PC, 1988.

R thermistor response is logarithmic in nature, and the curve $Y = 152.69 - 77.459 \log (X)$ where $Y$ is resistance in KΩ, $X$ is degrees C was fitted ($R^2 = 0.986$) to an average of the temperature responses for seven thermistors using CricketGraph.

$V_{\text{out}}$ is digitized by the DART board and interpreted as temperature; typical values are 0.15 VDC @ 100°C; 5.6 VDC @ 0°C; or 0.05 V/C average. Due to scale nonlinearities, a typical resolution of 1.0 - 0.5 degrees C is achieved in practice.

The CA 3140 is a BIMOS FET Op Amp pin compatible with the common 741. Any commonly available Op Amp will suffice for this application.

The preamplifier is on a small piece of veroboard and is housed in a separate Al project box. A 1/4" phono female in the box allows the thermistor (a standard thermometer of the type used in microwave ovens) to be plugged into the preamplifier; a 1 m cable ending in a DB-9P connects the preamplifier box to the DART box and carries required power and $V_{\text{out}}$ to be digitized. Note that the Al box is not grounded, but floats wrt instrument ground.
Figure 42: pH Probe Preamplifier

pH Preamplifier Notes:


The pH probe used is the Sargent Welch S-30076-42 Platinum/Calomel combination electrode, with a BNC cable connector. The solution under measurement is placed at instrument ground (the third prong of the AC outlet through the DART power supply) by the probe.

V out is digitized by the DART board and interpreted as pH; the 1 mΩ trimpot is used to set a value of 1.75 VDC @ pH 7.0; with a variation of approximately 0.25 V/pH unit. A resolution between 0.10 - 0.05 pH is achieved in practise, full scale used is only 0 - 3.5 VDC.

This circuit will not function without an extremely high input impedance amplifier (such as the CA 3140) due to an extremely low permissible probe current draw. (typically pA - more will cause ionic depletion of probe solutions; the electrode output impedance is on the order of $10^{12} \Omega$)

The preamplifier is on a small piece of veroboard and is housed in a separate Al project box. A chassis mount BNC female at one end of the box allows the electrode to be plugged into the preamplifier; a 1 m cable ending in a DB-9P connects the preamplifier box to the DART box and carries required power and V out to be digitized.
The Care and Feeding of Glass Combination pH Electrodes

This is intended to be a guide towards successful use of pH glass combination electrodes with computer instrumentation in student experimentation.

Probe Theory:

Glass pH electrodes are designed to act as electrochemical cells, supplying a voltage linearly proportional to the pH of a solution which can be sensed by a pH meter or computer interface. The electrodes contain a ionic solution of hydrogen and chloride ions (usually AgCl) in contact with a sensor wire (usually Ag/AgCl) upon one side of an extremely thin glass membrane (the bulb). Ions from this solution form an equilibrium with the interior surface of the membrane, which is permeable. The external surface of the bulb is placed in and thoroughly wetted by the solution to be measured, and an equilibrium between the hydronium ions in the external solution and the internal glass surface is established.

A second (usually Calomel) wire is immersed in a KCl solution in the outer sleeve of the glass tube. This KCl solution can exchange ions with the solution under measurement via a permeable plug in the side of the sleeve. Because there are actually two half-cells with attendant wires present, the complete apparatus is known as a combination electrode or simply a pH probe. To determine the pH of the solution, the ionic gradient (ie Voltage difference) between the internal and external surfaces of the glass bulb is measured (between the two wires).
Probe Storage:

Glass pH probes must be soaked before use so as to allow the highly hygroscopic glass bulb to form a gel layer upon its surface. While the probe can be stored dry for long periods of time, it must be soaked in distilled water for 1 to 2 days to rejuvenate the gel layer before use. In addition, dry probes must be cleaned of any coatings or films before use by soaking in the appropriate solvents, then alcohol, then distilled water. Typically, glass probes are kept soaking in pH 7.0 buffer or distilled water solution in regular use; ideally a 0.1M soln of KCl is used for storage to avoid ionic depletion of the AgCl internal solution. Do not allow dried or greasy films to form upon the bulb surface.

Probe Use:

Glass pH probes should be rinsed with distilled water and wiped with a non-abrasive material such as cotton wool or laboratory wipes before being transferred to a new solution for each individual measurement. Before use, a probe should be prepared by checking its response over the full pH range to be measured usually by immersion in two standardized buffer solutions, one at or below the most acidic sample be measured, the other above the most basic (aka 'swinging the probe'). This allows for calibration to reduce temperature-dependent measurement errors, as well as checking probe response time. A properly-cared for probe should respond quickly (within a second), but to achieve an error of less than 2% may take over 10 seconds. Typically two or three seconds is sufficient for interactive student experiments. Stirring of the solution under measurement is often desirable to assure solution homogeneity and to increase probe response time by refreshing the ions in solution near the probes' gel layer, but caution is required when stirring to avoid scratching the thin bulb of the probe. A protective plastic shield around the combination electrode which prevents banging the probe bulb should be used whenever possible.
Problems:

A jittery probe response may be evident if the probe surface is contaminated, or if an attempt is made to measure a pH at a large distance from the pH of the probes' storage solution (eg a probe stored in a pH 7.0 solution will not have a stable response when measuring between pH 11. and pH 13.5). To improve results at extreme ranges, storage in a more appropriate buffer solution (ie pH 10) may be desirable at the cost of a reduced probe lifespan due to ionic depletion. Slow probe response might be due to contamination or glass membrane clogging, in which case the probe may be cleared and 'rejuvenated' by alternately soaking in 0.1M HCl followed by 0.1M NaOH, then reimmersion in the acid for five-minute periods. Should this method fail, a more traumatic solution to the problem involves etching a new surface upon the glass bulb using a 10% HF acid for a few seconds, followed by an immersion in 5M HCl to remove the fluorides, then a rinse in distilled water. This final procedure should only be used as a last-ditch effort, as glass will be removed making the bulb thinner and ever more susceptible to cracking or breaking.

References:


Orion pH Electrode Catalog and Guide to pH Measurement. pHC&G/8830, Orion Research Inc, The Schrafft Centre, 529 Main Street Boston, MA 02129.


2 May 90
Appendix D: Software Design and Coding Details

Introduction

This appendix describes the software developed during the study. A discussion of and gives complete source code listings and resources.

Coding for the Macintosh

Software written for the Macintosh computer is constrained in very unique ways by the Macintosh operating system (The System) and the Macintosh Read Only Memory (ROMS). Apple has decreed a series of software guidelines known as the Human Interface Guidelines which are intended to ensure that all applications written for the Macintosh have a similar look and feel and therefore require less training for the user.

The Macintosh Toolbox

The heart of the Macintosh operating system is a series of routines in the 128K Macintosh ROMs that are comparable to the BIOS in MSDOS. The Mac ROM routines contain code that direct the graphical input and output of the computer -- how to create images (QuickDraw), buttons, scroll bars, windows, dialog boxes, edit fields, menus, etc. The code in the ROMs is partially updated (patched) by code in the System file which is always resident in RAM. Much of Mac programming consists of knowing how to call and manipulate these ROM routines which make up the operating system and are collectively known as the Macintosh Toolbox.

Resources

Macintosh software is deliberately written so that all non-executable program information (usually display information such as pictures, text strings, fonts, menus, dialog box contents etc) is kept separate from executable code to the greatest degree possible. These individual pieces of information are known as program resources and are kept in a part of the program known as the resource fork. The data fork of a Macintosh application contains compiled program instructions which are executed by the CPU of the computer, and this code will include instructions to look up and display the contents of the resource fork when appropriate. This design makes it easy for a Macintosh application program to be modified (to a foreign language or a different menu layout) without the need to change and recompile source code.
A program exists to edit the resources of Macintosh applications programs. This tool is itself an application program known as ResEdit. The code written by the author for the study included a number of diagrams that showed students how to assemble the apparatus and how to calibrate sensors. These pictures were drawn with a paint program, then assigned unique identifying numbers and attached to compiled applications code using ResEdit to copy the images into the resource fork of the applications.

Event-Driven Programming

Another definitive programming characteristic of the Mac is known as event-driven programming. The Macintosh always is executing a loop at some level, and this loop merely awaits for things to happen such as mouse movement, button pressing, keyboard input, disk insertion, timer expiries and so forth known collectively as events. At the most basic level, the Mac operating system updates the desk accessories and clocks, updates mouse position and awaits mouse button clicks.

When an application program is started (or launched), the program is loaded into RAM and a series of operations preparatory to event trapping occurs. Menus are set up, windows are drawn, information is displayed, buttons and edit fields are created; then the computer is placed in the program's main event loop which executes until an event (almost always a user-generated event) occurs. Then the program either traps the event and executes code that takes an appropriate response or passes the event along to the operating system for handling (ie a call for a desk accessory). The whole program can be considered to be a series of event trapping loops with a series of routines that are called as appropriate activity for each event.

After the user has generated all of the appropriate events to make the program do the desired actions, a final program exit event is usually generated either by the program or the user. This event starts a final program housekeeping routine that closes windows and files, saves data etc then notifies the memory manager in the operating system that the RAM occupies by the application is free for reassignment and then finally transfers control back to the operating system.

Coding in ZBASIC

ZBASIC is a compiled, line numberless, structured programming language similar to QuickBASIC, TrueBASIC and TurboBASIC for the Macintosh. It contains structures taken from PASCAL such as the CASE statement, and a large number of unique statements which are actually calls to the Macintosh Toolbox ROMS.
ZBASIC handles Macintosh events through a structure known as the DIALOG statement. Passing a variable to DIALOG will return integers which correspond to event identification. Eg when DIALOG(0)=N (N<>0) and event of type N has occurred. Passing N back into the DIALOG statement will yield further information about the event (Table 23)

Table 23: Events trapped in ZBASIC

<table>
<thead>
<tr>
<th>DIALOG(0) Value</th>
<th>Event</th>
<th>DIALOG (N)</th>
<th>Further Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>DIALOG(0)=1</td>
<td>Button Selected</td>
<td>DIALOG (1)</td>
<td>Number of Button Selected</td>
</tr>
<tr>
<td>DIALOG(0)=2</td>
<td>Edit Field Selected</td>
<td>DIALOG (2)</td>
<td>Number of Field Selected</td>
</tr>
<tr>
<td>DIALOG(0)=3</td>
<td>Inactive Window Sel</td>
<td>DIALOG (3)</td>
<td>Number of Window Selected</td>
</tr>
<tr>
<td>DIALOG(0)=4</td>
<td>Close Box Select</td>
<td>DIALOG (4)</td>
<td>Number of Window Selected</td>
</tr>
<tr>
<td>DIALOG(0)=5</td>
<td>Window Update</td>
<td>DIALOG (5)</td>
<td>Number of Window Selected</td>
</tr>
<tr>
<td>DIALOG(0)=8,9</td>
<td>Zoom In/Out Select</td>
<td>DIALOG (8,9)</td>
<td>Number of Window Selected</td>
</tr>
</tbody>
</table>

DIALOGs also exist for edit field movements, disk insertion, keyboard entry etc.

Another unique call to the Macintosh operating system routines from ZBASIC is the FILES$ structure which calls the finder routines resident in RAM. These routines return a complete filename and address for any file upon any disk volume in a format known as the Macintosh Hierarchial File System (HFS). Other ZBASIC structures are fairly self-explanatory by name.

The Spectrophotometer

The spectrophotometer used during this study was a device manufactured by the Spectronic division of the Milton Roy Company called the Spec 20D (Figure 43). This device contains an RS232 driver capable of communicating with the serial communications ports of variety of computers including the Macintosh. The RS232 signals are available via a six pin female Jones connector upon the underside of the instrument, and the default protocol is 1200 baud, 8 data bits, 1 stop bit, no parity or echo. Commands sent to the Spec 20D used by this application include simple ASCII letters as shown in Table 24.

Table 24: Spec 20D commands

<table>
<thead>
<tr>
<th>ASCII</th>
<th>Operation Desired</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>Print (return data)</td>
</tr>
<tr>
<td>A</td>
<td>Set Asorbance Mode</td>
</tr>
<tr>
<td>T</td>
<td>Set Transmittance Mode</td>
</tr>
<tr>
<td>C</td>
<td>Set Concentration Mode</td>
</tr>
</tbody>
</table>

Data arriving from the Spec 20D appear in the following form:

574NM -01.5 A <Cr & LF>
Where the three digits are the wavelength in nanometers, then a three digit data value with decimal point, followed by a data identifier A, T or C for absorbance, transmittance or concentration, then a carriage return and line feed.

User Interface Design Notes

This application consists of a main menu screen displaying a labelled diagram of the Spec 20D for student review and three buttons: Calibrate, Get Data and Quit. All three call appropriate routines. This particular code was written for Experiment 16B and differs little from 19B code.

Source Code

---

The Spec 20D Spectrophotometer

![Spec 20D apparatus diagram](image)

©1990, Dan MacIsaac

Figure 44: Spec 20D Apparatus Diagram for Main Menu

'SPEC 20D 5/13/90

WINDOW OFF
COORDINATE WINDOW

'******************************************************************************************

GOSUB "Get Pictures"
GOSUB "Variables Setup"
GOSUB "Menu Setup"
GOSUB "Setup - Window #1"

"Main event loop"
MENU ON : DIALOG ON
A1=DIALOG(0)
IF A1<>0 THEN GOSUB "Main Event"
IF MainRefresh%=1 THEN
MainRefresh%=0:PICTURE, AppHandle&
GOTO "Main event loop"
'This about wraps up the main body of the program

"Main Event": Handles Close Box, Buttons for Main Window
MENU OFF : DIALOG OFF
B1=DIALOG(A1)
IF A1=4 GOSUB "Shutdown": Close Box
IF A1=5 THEN PICTURE, AppHandle&

LONG IF A1=1: 'Button events
SELECT B1
CASE 1
  GOSUB "Calibrate"
  WINDOW #1
  WINDOW CLOSE #2
CASE 2
  GOSUB "Collect Data"
  WINDOW #1
  WINDOW CLOSE #3
CASE 3
  GOSUB "Shutdown"
END IF
RETURN: 'End of "Main Event"

"Shutdown"
CLOSE
END
RETURN: 'end shutdown; end pgm

"Get Pictures"
'apparatus picture
RefNum%=FN
OPENRESFILE("spekpik8.res"): careful here!!!!
ResNum%=28878
AppHandle&=FN
GETRESOURCE(CVI("PICT"),28878%)
RETURN: 'end of "Get Pictures"

"Variables Setup"
P$="P": T$="T": A$="A": C$="C":
F$="F"
SpecFlag%=0
PlotFlag%=0
CalibFlag%=0:GetDataFlag%=0 :
MainRefresh%=0
DIM 8TimeDat$(100)
DIM AbsDat!(100)
DIM TransDat!(100)
DIM ConDat!(100)
DIM WaveDat!(100)
DIM CommentLine$(255)
DIM 63 A$(6)
CommentLine$="CommentLine"
RETURN

"Menu Setup"
MENU 1,0,1,"File"
MENU 1,1,1,"Quit /Q"
ON MENU GOSUB "Shutdown"
RETURN

"Open SPEC"
ON ERROR GOSUB "SpecGone"
OPEN"C",-1,1200,0,0,1,17
'HANDSHAKE#-1,12
WRITE#-1, P$; 1
'WRITE#-1, T$; 1: 'Say hello to SPEC
READ#-1, Z$; 16: 'SPEC replies to MAC
'PRINT@(10,20)"*\n;Z$; ": STOP
LONG IF LEN(Z$): 'yakky SPEC
SpecFlag%=1
ELSE
  Messl$="This MAC is not receiving SPEC 20D"
  Mess2$="signals. Please connect to the MODEM"
  Mess3$="Port to collect data or CANCEL to"
  Mess4$="view previously collected data."
  CALL PARAMTEXT(Mess1$,Mess2$,Mess3$,Mess4$)
  R%=FN STOPALERT (2,0)
LONG IF R%=2
SpecFlag%=0
RETURN
END IF
ERROR=0
GOTO "Open SPEC"
END IF
RETURN: 'end of "Open SPEC"

"SpecGone"
ERROR=0
CLOSE -1
RETURN

"Calibrate": 'Calibration Routine
QuitCalibFlag%=0
GOSUB "Calib Window Open"
GOSUB "Write Gibberish"
GOSUB "Open SPEC"
IF SpecFlag%=0 THEN QuitCalibFlag%=1
IF SpecFlag%=1 THEN GOSUB "Write Gibberish"

MENU ON: DIALOG ON
"Calibration Loop"
A=DIALOG(0)
IF A=4 OR A=1 THEN QuitCalibFlag%=1
IF A=5 THEN GOSUB "Write Gibberish"
IF QuitCalibFlag%=1 THEN GOSUB "CalibExit":RETURN
GOSUB "CalibRead"
GOTO "Calibration Loop"

"CalibExit"
MainRefreshFlag%=1
WINDOW CLOSE #3
WINDOW #1
RETURN

"CalibRead": 'Continuous read here
WRITE #1,TS;$1
WRITE#-1,P$;$1
READ#-1,B$;16
B$=MID$(B$,1,15)
WL%=VAL(MID$(B$,1,3)):'wavelength in
NM
AB#=VAL(MID$(B$,7,6)):'Transmittance in
% TEXT 2,12,0,0
PRINT@(5,14)"Wavelength in Nanometers:"
PRINT@(23,14)"(Set according to ion in
soln)"
PRINT@(3,16)"Percent Transmittance
(Adjust to 0 & 100):"
PRINT@(3,17)"(No Sample - Left Knob,
then with Blank - Right Knob)"
TEXT 2,12,1,0
PRINT@(18,14)""
PRINT@((18,14)WL%
PRINT@((23,16)"":'erase bits of minus
signs
PRINT@((23,16)USING "-###.#";AB#
TEXT 2,12,0,0

"Calib Window Open"
WINDOW #3,"Spec 20D Calibration",(1,40)
- (510,335),5
BX1=400:BY1=250:BUTTON
#301,1,"Done",(BX1,BY1) -
(BX1+65,BY1+20),0
RETURN

"Write Gibberish":'Explanatory Blurbs
CLS
PRINT ""
TEXT 2,12,1,0
PRINT " SPEC 20D Calibration
Routine"
TEXT 2,10,0,0:PRINT ""
PRINT" 1. Ensure that the SPEC 20D has
been turned on; that the MAC modem port is
connected"
PRINT" to the interface box, and that the box
is connected to the SPEC 20D bottom
interface port."
PRINT""
PRINT" 2. Adjust the SPEC 20D to your
desired Analytical Wavelength with the large
dial on top."
PRINT" Note the wavelength is displayed
below."
PRINT"
PRINT" 3. With the Sample Compartment
empty and cover closed, adjust the Amplifier
Control"
PRINT" Knob (front left) until the
Transmittance reads zero. Note the %T value
displayed below."
PRINT" 4. Place a Reference Blank (water only) into the Sample Compartment, close the cover"
PRINT" and adjust the Light Control Knob (front right) until the Transmittance reads 100%.
PRINT"
PRINT" 5. You are now ready to collect data.
'switch to Transmittance
RETURN

•*****GET DATA ROUTINES**************

"Collect Data":Data collection Routines
GetDataFlag%=1:DataQuitFlag%=0:PicFlag%=0
RefreshFlag%=0
GOSUB "Data Window"
GOSUB "Open SPEC"
IF SpecFlag%=1 THEN BUTTON #31,1:'turn START on
PICTURE ON:'store this one
GOSUB "Setup Graph"
PICTURE OFF, OrigGraphHandle&
PICTURE, OrigGraphHandle&
GOSUB "Data Loop"
MainRefresh%=1
RETURN:end of collect data routine

"Data Window"
WINDOW #3 ,"Absorbance % vs Conc mol/L",(1,37) - (511,345),5
GOSUB "Buttons"
RETURN:end of data window

"Buttons"
BUTTON #31,0,"Start",(20,285) - (80,304),1
BUTTON #32,0,"Scale",(100,285) - (160,304),1
BUTTON #33,1,"Load",(180,285) - (240,304),1
BUTTON #34,0,"Save",(260,285) - (320,304),1
BUTTON #35,0,"Print",(340,285) - (400,304),1
BUTTON #36,1,"Quit",(420,285) - (480,304),1
RETURN:'End buttons

"Setup Graph"
'Vert Axes
TEXT 2,10,0,0
PEN 1,1,1,8,0
DATA "0.00","0.02","0.04","0.06","0.08","0.10","0.12","0.14","0.16","0.18","0.2"
FOR X1%=34 TO 504 STEP 47:Plot vert axes
READ V1$
PRINT%(X1%-12,268);V1$:"Conc Scale
PLOT X1%,25 TO X1%,257
NEXT X1%
TEXT 2,10,1,0
PRINT%(180,281)"Ion Concentration in moles/L"

'Horiz Axes
FOR Y1%=257 TO 25 STEP -29:Plot horiz axes
H1!=(Y1%-25)
H1!=$0.80-H1!/290
TEXT 2,10,0,0
IFY1%<255THEN
PRINT%(17,Y1%+4);USING "###"-H1!*100
PLOT 34,Y1% TO 504,Y1%
NEXT Y1%

'Main PH Lable
TEXT 2,10,1,0
X1%=5:Y1%=55
Label$="ABSORBANCE %"
FOR D1%=12 TO (12*LEN(Lable$)) STEP 12
D$=MID$(Lable$,(D1%/12),1)
PRINT%(X1%,Y1%+D1%);D$
NEXT D1%
RESTORE
RETURN

"Data Loop"
Count%=0
MENU ON:DIALOG ON
"Data Loopo"
Count%=Count%+1
A3=DIALOG(0)
IF A3<>0 THEN GOSUB "Data Event"
IF DataQuitFlag%=1 THEN RETURN
GOSUB "HeaderUpdate"
IF Count%=25 THEN GOSUB "HeaderUpdate" : Count%=0
GOTO "Data Loopo"

"Data Event"
MENU OFF:DIALOG OFF
B3=DIALOG(A3)
SELECT A3
CASE 1:'Button events
SELECT B3
CASE 31:'START
GOSUB "Start"
CASE 32:'SCALE
'gosub "Scale"
CASE 33:'LOAD
GOSUB "Load"
CASE 34:'SAVE
GOSUB "Save"
PICTURE, OrigGraphHandle& CASE 35:'PRINT
GOSUB "Print"
PICTURE, OrigGraphHandle& CASE 36 :'Quit
DataQuitFlag%=l
END SELECT
CASE 4::'Close Box
DataQuitFlag%=l
CASE 5:'refreshes setup graph
PICTURE, OrigGraphHandle&
LONG IF RefreshFlag%=l
PICTURE, OrigGraphHandle&
RefreshFlag%=0
END IF
END SELECT
RETURN: end data event

"G&P Loop"
Count%=Count%+1
DIALOG ON:MENU ON
A33=DIALOG(0)
B33=DIALOG(A33)
IF A33<>0 THEN GOSUB "G&P Data Event"
IF GPQuitFlag%=1 THEN RETURN
IF Count%>10 THEN GOSUB
"HeaderUpdate":Count%=0
GOTO "G&P Loop"

"G&P Data Event"
DIALOG OFF:MENU OFF
SELECT A33
CASE 1:'Button events
SELECT B33
CASE 37:'Enter Concentration
GOSUB "EnterCon"
CASE 38:'Done
GOSUB "Done"
END SELECT
CASE 5:'refreshes setup graph
PICTURE, OrigGraphHandle&
END IF
IF SampNo%>0 THEN GOSUB
"PlotAllDemSuckers"

END SELECT
RETURN

"EnterCon":takes in Concentration, then plots it
BUTTON #37,0
BUTTON #38,0
DIALOG ON:MENU ON
TEXT 2,12,1
EF1$=STR$(Con!)
EDIT FIELD 1,EF1$,(247,285)-(303,301),1,2
Count%=0
"ConEditLoop"
Count%=Count%+l
IF Count%==25 THEN GOSUB
"HeaderUpdate":Count%=0
A4%=DIALOG(0)
TEXT 2,12,1
IF A4%<6 THEN GOTO "ConEditLoop"

DIALOG OFF: MENU OFF
Con!=VAL(EDIT$(l))
EDIT FIELD CLOSE#1

'wingy values for con
IF Con!>.2 THEN Vol!=.2
IF Con!<0 THEN Con!=0

'set matrix values
GOSUB "PlotDeSucker"
BUTTON #37,1
BUTTON #38,1
RETURN: end burette vol

"PlotDeSucker"
XCoord!=(34-2)+(ConDat!(Dummy%)/.02)*47
XCoord%=XCoord!
IF Xcoord%!>504 THEN Xcoord%=504
IF XCoord%!<34 THEN XCoord%=34
YCoord!=(290*(.8-2)-AbsDat!(Dummy%))+(25-2)
YCoord%=YCoord!
IF YCoord%!>257 THEN YCoord%=257
IF YCoord%!<25 THEN YCoord%=25
PEN 5,5,1,0
PLOT XCoord,YCoord
RETURN: end PlotDeSucker

"PlotAllDemSuckers"
FOR Dummy%=1 TO SampNo%
GOSUB "PlotDeSucker"
'LSQ value track
SumX! = SumX! + ConDat!(Dummy%)
SumY! = SumY! + AbsDat!(Dummy%)
SumXY! = SumXY! + ConDat!(Dummy%)*AbsDat!(Dummy%)
SumX2! = SumX2! + ConDat!(Dummy%)*ConDat!(Dummy%)
SumY2! = SumY2! + AbsDat!(Dummy%)*AbsDat!(Dummy%)
NEXT Dummy%
RETURN

"Done": new pik, draw line
CLS
PICTURE ON
GOSUB "Setup Graph"
IF SampNo%!<2 THEN GOTO "WereOut"
'initialize LSQ values
SumX!=0; SumY!=0; SumXY!=0; SumX2!=0;
SumY2!=0; A!=0; B!=0
GOSUB "PlotAllDemSuckers": stick the sucker up
'Calculate LSQ Fit from tracked values
A!=(SampNo%*SumXY!-SumX!*SumY!)/(SampNo%*SumX2!-SumX!*SumX!)
B!=(SumY!-A!*SumX!)/SampNo%
IF (B!<0.00001 AND B!>-0.00001) THEN
B!=0
H1$="Best Line Fit is Y = mX + B;  m = ",
H2$="B = ",
'Display LSQ Fit
TEXT 10,10,0
PRINT%(130,22);H1$; USING"-###.###"; A!; H2$; USING"-#.#####"; B!
GPQuitFlag%=1
'******************************************************************************
***DEBUGGERS
HERE!! ********************
'PRINT "SumX! is":SumX!
'PRINT "SumY! is":SumY!
'PRINT "SumXY! is":SumXY!
'PRINT "SumX2! is":SumX2!
'PRINT "SumY2! is":SumY2!
'PRINT "A! is "; A!
'PRINT "B! is "; B!
'STOP

'Low Point to plot
LONG IF B%!>0.00001: B is pos, InitConc is zero; InitAbs is B
LowYCoord! = 290*(0.8-B!)+(25-2)
LowXCoord! = (34-2)+(.02)*47
LowYCoord%=LowYCoord!
LowXCoord%=LowXCoord!
ELSE: B is neg, InitConc is -B/A; InitAbs = 0
LowYCoord! = 290*(0.8-0)+(25-2)
LowXCoord! = (34-2)+((-B!/A!)/.02)*47
LowYCoord%=LowYCoord!
LowXCoord%=LowXCoord!
END IF: LowCoords taken care of

'High Point to plot
FinalConc! = -8.8/A!
LONG IF FinalConc! < 20000: FinalAbs is .80; Final Conc is (.8-B)A!
FinalXCoord!=(34-2)+(FinalConc!/.02)*47
FinalXCoord%=FinalXCoord!
FinalYCoord! = 290*(0.8-0.8)+(25-2)
FinalYCoord%=FinalYCoord!
XELSE:'FinalConc is .2; FinalAbs is .2A+B
FinalXCoord!=(34-2)+(.2/.02)*47
FinalXCoord%=FinalXCoord!
FinalYCoord!=290*(0.8-(.2*A!+B!))+(25-2)
FinalYCoord%=FinalYCoord!
END IF:'Finalcoords taken care of

'actually draw the silly thing
PEN 1,1,1,8,0
PLOT LowXCoord%+2,LowYCoord%+2
TO FinalXCoord%+2,FinalYCoord%+2

"WereOut"
PICTURE OFF, OrigGraphHandle&
RETURN

"HeaderUpdate":'for headerdata read
PEN 1,10,1,8,0
PLOT 2,2 TO 510,2
LONG IF SpecFlag%=1
WRITE #1,A$;1
WRITE #1,P$;1
READ #1,Z1$;16
Z1$=MID$(Z1$,1,15)
WL%=VAL(MID$(Z1$,1,3)):'wavelength in
NM
Sorb!=VAL(MID$(Z1$,7,6)):'Transmittance
in %
IF Sorb!>99.999 THEN Sorb!=99.999
IF Sorb!<99.999 THEN Sorb!=99.999
DELAY 100
WRITE #1,T$;1
WRITE #1,P$;1
READ #1,Z2$;16
Z2$=MID$(Z2$,1,15)
Trans!=VAL(MID$(Z2$,7,6)):'Transmittance
in %
IF Trans!>99.999 THEN Trans!=99.999
IF Trans!<99.999 THEN Trans!=99.999
WRITE #1,A$;1
TEXT 2,9,1,0
PRINT%(5,10)"Wavelength is ";USING
"###",WL%
PRINT%(110,10)"NM"
PRINT%(135,10)"Absorbance is ";USING
"-####.#";Sorb!*100
PRINT%(263,10)"%"
PRINT%(287,10)"Transmittance is ";USING
"-####.#";Trans!
PRINT%(432,10)"%"
PRINT%(450,10)"\%"
END IF
TEXT 2,12,1
RETURN

"Shutdown S&D"
BUTTON CLOSE #37
BUTTON CLOSE #38
GOSUB "Buttons"
FOR X%=1 TO 6
BUTTON 30+X%,1
NEXT X%
BUTTON #32,0
RETURN

"Save":'puts our data out for re-use
'ON ERROR GOSUB "FileError"
Dummy$=FILES$(-9999,"",",Myvolume%)
FileName$=FILES$(0,"Name for our
Graph?","Freddy Krueger's
Graph",Myvolume%)
IF FileName$="" THEN
RefreshFlag%=1: RETURN
DEF OPEN="TEXTSPEC"
A$(1)="Now saving Spec data as"
A$(2)="
A$(3)=FileName$
A$(4)="
A$(5)="
A$(6)="Please stand by ..."
GOSUB "MyDialog"
OPEN"O",1,FileName$,,Myvolume%
PRINT#1,"MBLSpec20Vers#1"
PRINT#1,FileName$
PRINT#1,MaxCon!,"MinCon!
PRINT#1,SampNo%
FOR Count%=1 TO SampNo%
PRINT#1,Count%","AbsDat!(Count%)","Tra
nsDat!(Count%)","ConDat!(Count%)","Wav
eDat%(Count%)","TimeDat$(Count%)
NEXT Count%
PRINT#1,"EOF"
CLOSE#1
GOSUB "KillMyDialog"
GOSUB "Done"
RETURN

"MyDialog":' locks pgm and disp my
message
MENU OFF
DIALOG OFF
WINDOW #10,(100,75) - (410,225),2
TEXT 3,12,1
PRINT """;USING
PRINT """;USING
PRINT """;USING
FOR 1%=1 TO 6
PRINT "",A$(1%)
NEXT 1%
RETURN

"KillMyDialog":' unlocks pgm
"Load": grabs data from disk to see
FileName$ = FILES$(1, "TEXT", "Myvolume%"
)
IF FileName$ = "" THEN RefreshFlag% = 1:
RETURN: null file; none wanted
OPEN "T", 1, FileName$, "Myvolume%"
A$(1) = "Attempting to open previous"
A$(2) = "Spec data file:"
A$(3) = FileName$
A$(4) = "Please stand by ..."
A$(5) = ""
INPUT#1, Line1$
GOSUB "MyDialog"
LONG IF Line1$ <> "MBLSpec20Vers#1"
CLOSE
PRINT "Not a Spec data file!"
GOSUB "KillMyDialog"
RefreshFlag% = 1
RETURN
END IF
INPUT#1, CommentLine$
INPUT#1, MaxCon!, MinCon!
INPUT#1, SampNo%
FOR Count% = 1 TO SampNo%
INPUT#1, Dumbo%, AbsDat!(Count%), TransDat!(Count%), ConDat!(Count%), WaveDat!(Count%), TimeDat$(Count%)
NEXT Count%
CLOSE#1
GOSUB "KillMyDialog"
CLS
GOSUB "Done": new pik, draw line
BUTTON #34, 1: 'turn on Save
BUTTON #35, 1: 'turn on Print
RETURN

"Print": printout routine
DEF PAGE
IF PRCANCEL THEN
RefreshFlag% = 1: RETURN
DEF LPRINT
IF PRCANCEL THEN
RefreshFlag% = 1: RETURN

A$(1) = "Now Printing Beers' Law graph"
A$(2) = ""
The temperature probe used was a commercially-available microwave oven temperature sensor containing a thermistor. The electrical characteristics of the thermistor are described in Chapter 4, and the device is shown in Figure 45.

**Temperature Probe Calibration**

1. Place the probe and thermometer into a cold water bath. Wait 90 sec and enter the bath temperature into the computer.

2. Repeat with a hot water bath. Wait 90 sec and enter the bath temperature into the computer.

3. Click the DONE button.
'The All New, totally procedural version
'And here's the opening play

WINDOW OFF
COORDINATE WINDOW

'**********PROGRAMMING
PARAMETERS****
'TRON
'BREAK ON:
'GOSUB "Collect Data"

'*******************
************

GOSUB "Get Pictures"
GOSUB "Variables Setup"
GOSUB "Menu Setup"
GOSUB "Setup - Window #1"

"Main event loop"
MENU ON : DIALOG ON
A1=DIALOG(0)
IF A1<>0 THEN GOSUB "Main Event"
GOTO "Main event loop"
'This about wraps up the main body of the program

"Main Event":' Handles Close Box, Buttons
for Main Window
MENU OFF : DIALOG OFF
B1=DIALOG(A1)
IF A1=4 GOSUB "Shutdown":'Close Box
IF A1=5 THEN PICTURE, AppHandle&

LONG IF A1=1:'Button events
SELECT B1
CASE 1
  GOSUB "Calibrate"
  WINDOW #1
  WINDOW CLOSE #2
CASE 2
  GOSUB "Collect Data"
  WINDOW #1
  WINDOW CLOSE #3
CASE 3
  GOSUB "Shutdown"
END SELECT
RETURN:'End of "Main Event"

"Shutdown"
CLOSE

END
RETURN: 'end shutdown; end pgm

"Get Pictures"
apparatus picture
ResNum%=30944
RefNum%=FN
OPENRESFILE("trial1.res.2/14/90")
AppHandle&=FN
GETRESOURCE(CVI("PICT"),30944%)
calibration picture
ResNum%=13641
RefNum%=FN
OPENRESFILE("cal.res.3/2/90")
CalibHandle&=FN
GETRESOURCE(CVI("PICT"),13641%)
RETURN :end of "Get Pictures"

"Setup - Window #1"
WINDOW #1,"Heating & Cooling
Behaviour of a Pure Substance",5
PICTURE, AppHandle&
BX1=67:BY1=262:BUTTON
#1,1,"Calibrate",(BX1,BY1) -
(BX1+80,BY1+30),1
BX3=214:BY3=262:BUTTON #2,1,"Get
Data",(BX3,BY3) -(BX3+80,BY3+30),1
BX4=361:BY4=262:BUTTON
#3,1,'Quit',(BX4,BY4) -
(BX4+80,BY4+30),1
RETURN :end of "Setup - Window #1"

"Variables Setup"
A$=CHR$(128+16*3):'port 4
B$=CHR$(255)
DartFlag%=0
ColdCalib%=0:ColdTemp!=0:HotCalib%=0:
HotTemp!=0

PlotFlag%=0
CalibFlag%=0:GetDataFlag%=0
DIM TempDat!(2500)
DIM 8TimeDat$(2500)
DIM CommentLine$(255)
DIM 2Zoo$(3)
RETURN

"Menu Setup"
MENU 1,0,1,"File"
MENU 1,1,1,"Quit     /Q"
ON MENU GOSUB "Shutdown"
RETURN

"Open DART"
OPEN"C",-1,9600,0,0,1,2000
HANDSHAKE -1,-2
FOR X%=1 TO 3
  WRITE#-1, A$;1: 'Say hello to DART
  DELAY 250
  WRITE#-1, B$;1: 'Say hello to DART
NEXT X%
READ#-1, Z$;0: 'DART replies to MAC
LONG IF Z$="": 'silent DART
  Mess1$="This MAC is not receiving
  Mess2$="signals. Please check that the"
  Mess3$="DARTbox is connected to the"
  Mess4$="MODEM port."
  CALL PARAMTEXT(Mess1$,Mess2$,Mess3$,Mess4$)
R%=FN STOPALERT (2,0)
LONG IF R%=2
  DartFlag%=0
END IF
ERROR=0
GOTO "Open DART"
XELSE
  DartFlag%=1
END IF
RETURN: 'end of "Open DART"

*******CALIBRATION ROUTINES*******

"Calibrate": 'Calibration Routine
CalibQuitFlag%=0:CalibField%=21:SetColdFlag%=0:SetHotFlag%=0:CalibFlag%=1
GOSUB "CalibWindow"
GOSUB "CalibValueShow"
GOSUB "Open DART":IF DartFlag%=0
RETURN: 'No
DARTbox: '*******RESET*****
GOSUB "Calibration Loop"
GOSUB "Calibration Calculation"
RETURN: 'end of Calibrate

"Calibration Loop"
MENU ON:DIALOG ON:'TIMER ON

IF HotCalib!<>0 THEN ON TIMER(1)
GOSUB "TempDisp"
"Actual Loop"
A2=DIALOG(0)
IF A2<>0 THEN GOSUB "CalibEvent"
IF CalibQuitFlag%=1 THEN RETURN
IF SetColdFlag%=1 THEN GOSUB "SetCold":SetColdFlag%=0
IF SetHotFlag%=1 THEN GOSUB "SetHot":SetHotFlag%=0
GOTO "Actual Loop"

"TempDisp"
TEXT 2,10,1
PRINT%(165,205)"Current Temp is:"
'DEF FN CalcTemp(Z$) = ASC(Z$)
RETURN

"CalibEvent"
MENU OFF:DIALOG OFF:'TIMER OFF
B2=DIALOG(A2)
SELECT A2
CASE 1: 'buttons
  SELECT B2
  CASE 21: 'Cold
    SetColdFlag%=1
  CASE 22: 'Quit
    CalibQuitFlag%=1
  CASE 23: 'Hot
    SetHotFlag%=1
END SELECT
CASE 4: 'quit
  CalibQuitFlag%=1
CASE 5: 'refresh
  PICTURE,CalibHandle&
  GOSUB "CalibValueShow"
END SELECT
RETURN

"SetHot"
BUTTON #21,0
BUTTON #22,0
BUTTON #23,0
WINDOW #4,"Hot Calibration",(350,50)-(460,325),2
TEXT 2,10,1
PRINT%(300,5)" Hot Calibration"
TEXT 2,10,0
PRINT%(300,30)" Hot Bath Temp "
PRINT%(300,45)" (Deg C)"
PRINT%(300,100)" Hot DART Value"
PRINT%(300,115)" (0-255)"
PRINT%(300,175)" Enter the "
PRINT%(300,190)" Temperature"
PRINT%(300,205)" from the"
PRINT%(300,220)" thermometer,"
PRINT%(300,235)" and press"
PRINT%(300,250)" return when done."
EF4$=STR$(HotTemp!)
EDIT FIELD 4,EF4$, (30,65)-(80,77),1,2
"SetHotLoop"
Cntr%=0
DIALOG ON: MENU ON
"RealLoop"
Cntr%=Cntr%+1
IF Cntr%=3 THEN GOSUB
"ShowHotDART"
A4%=DIALOG(O)
IF A4%<>6 THEN GOTO "RealLoop"
DIALOG OFF: MENU OFF
HotTemp!=VAL(EDIT$(4))
IF HotTemp!>100 OR HotTemp!<10 THEN
HotTemp!=0
HotTemp!=INT(HotTemp!*10+.5))/10
HotCalib%=ASC(Z$)
EDIT FIELD CLOSE#4
WINDOW #2
WINDOW CLOSE #4
BUTTON #21,1
BUTTON #22,1
BUTTON #23,1
RETURN
"ShowHotDART"
Cntr%=0
TEXT 2,10,1
WRITE*-1, A$; 1: 'Get info from DART
READ#-1, Z$; 0: 'DART replies to MAC
PEN 1,12,1,8,19
PLOT From 340,140 TO 510,140
PRINT%(45,150)USING"###";ASC(Z$)
RETURN
"SetCold"
BUTTON #21,0
BUTTON #22,0
BUTTON #23,0
WINDOW #5,"Cold Calibration", (12,50)-(122,325),2
TEXT 2,10,1
PRINT%(2,10)"Cold Calibration"
TEXT 2,10,0
PRINT%(2,30)" Cold Bath Temp "
PRINT%(2,45)" (Deg C)"
PRINT%(2,100)" Cold DART Value"
PRINT%(2,115)" (0-255)"
PRINT%(2,175)" Enter the "
PRINT%(2,190)" Temperature"
PRINT%(2,205)" from the"
PRINT%(2,220)" thermometer,"
PRINT%(2,235)" and press"
PRINT%(2,250)" return when done."
EF5$=STR$(ColdTemp!)
EDIT FIELD 5,EF5$, (20,65)-(70,77),1,2
"SetColdLoop"
Cntr%=0
DIALOG ON: MENU ON
"ReelLoop"
Cntr%=Cntr%+1
IF Cntr%=3 THEN GOSUB
"ShowColdDART"
A4%=DIALOG(O)
IF A4%<>6 THEN GOTO "ReelLoop"
DIALOG OFF: MENU OFF
ColdTemp!=VAL(EDIT$(5))
IF ColdTemp!>50 OR ColdTemp!< -10 THEN
ColdTemp!=0
ColdTemp!=(INT(ColdTemp!*10+.5))/10
ColdCalib%=ASC(Z$)
EDIT FIELD CLOSE#5
WINDOW #2
WINDOW CLOSE #5
BUTTON #21,1
BUTTON #22,1
BUTTON #23,1
RETURN
"ShowColdDART"
Cntr%=0
TEXT 2,10,1
WRITE*-1, A$; 1: 'Get info from DART
READ#-1, Z$; 0: 'DART replies to MAC
PEN 1,12,1,8,19
PLOT From 2,140 TO 200,140
PRINT%(45,150)USING"###";ASC(Z$)
RETURN
"CalibWindow"
WINDOW #2,"Temperature Probe Calibration", 5
PICTURE, CalibHandle&
TEXT 2,10,1
BX1=67:BY1=262:BUTTON #21,1,"Set Cold", (BX1,BY1) - (BX1+80,BY1+30),1
BX3=214:BY3=262:BUTTON #22,1,"Done", (BX3,BY3) - (BX3+80,BY3+30),1
BX4=361:BY4=262:BUTTON #23,1,"Set Hot", (BX4,BY4) - (BX4+80,BY4+30),1
RETURN:`end of CalibWindow
"CalibValueShow"
PEN 1,12,1,8,19
"Calibration Calculation"
' IF (HotCalib%-ColdCalib%)<1: old test for validity
'Slope!=(HotTemp!-ColdTemp!)/(HotCalib%+ColdCalib%)
'AvgTemp!=(HotTemp!+ColdTemp!)/2
'AvgCalib%!=(ColdCalib%+HotCalib%)/2
'Intercept!=AvgTemp!-Slope!*AvgCalib%
' IF ABS(Intercept!)<.1 THEN Intercept!=0
'DEF FN
CalcTemp!(Z$)=Slope!*ASC(Z$)+Intercept!
!'old formula here
'*****New calib rnte for new
precamp******
DEF FN Log10!(X!)=LOG(X!)/LOG(10)
P!= 1/(273.15 + ColdTemp!)
Q!= 1/(273.15 + HotTemp!)
M!=Q!-P!
V0! = ColdCalib%
V1! = HotCalib%
B!= LOG(V1!/V0!)/M!
LONG FN CalcTemp!(Z$)
VALUE!=ASC(Z$)
Calc!=1/((LOG(VALUE!/V0!)/B!)+P!)-273.15
END FN= Calc!
RETURN

'Horiz Axes
PEN 1,1,1,8,0
DATA " 0"," 1"," 2"," 3"," 4"," 5"," 6"," 7"," 8"," 9"," 10"," 11"," 12"," 13"," 14"," 15"," 16"
FOR X1%=24 TO 504 STEP 30:Plot vert axes
READ V1$
PRINT%(X1%-10,275);V1$:Lable times
PLOT X1%,15 TO X1%,265
NEXT X1%
PRINT%(225,284)"Elapsed Time (Minutes)"
RETURN

'Collect Data':Data collection Routines

'*GET DATA ROUTINES*****
DATA
"30","35","40","45","50","55","60","65",
"70","75","80"
FOR Y1%=265 TO 15 STEP -25: plot horiz axes
READ H1$
IF Y1%<265 THEN
PRINT%(12,Y1%+4);H1$: 'Label temps
PLOT 24,Y1% TO 504,Y1%
NEXT Y1%
'Main Temp Lable
X1%=3:Y1%=40
Label$="Temperature in Deg C"
FOR D1%=10 TO 210 STEP 10
D$=MID$(Label$,D1%/10,1)
PRINT%(X1%,Y1%+D1%);D$
NEXT D1%
RESTORE
RETURN

MENU ON:DIALOG ON:TIMER ON
"Data Loop"
A3=DIALOG(0)
IF A3<>0 THEN GOSUB "Data Event"
IF DataQuitFlag%=1 THEN RETURN
ON TIMER(1) GOSUB "HeaderUpdate"
GOTO "Data Loop"

"Data Event"
MENU OFF:DIALOG OFF:TIMER OFF
B3=DIALOG(A3)
SELECT A3
CASE lr 'Button events
SELECT B3
CASE 1: 'Button events
SELECT B3
CASE 31: 'START
GOSUB "Start"
CASE 33: 'LOAD
GOSUB "Load"
CASE 34: 'SAVE
GOSUB "Save"
CASE 35: 'PRINT
GOSUB "Print"
PICTURE, OrigGraphHandle&
CASE 36 : 'Quit
DataQuitFlag%=1
END SELECT
CASE 4: 'Close Box
DataQuitFlag%=1
CASE 5: 'refreshes setup graph
PICTURE, OrigGraphHandle&
'and replot numerical data
END SELECT
RETURN:'end data event

"Start"
PICTURE ON
GOSUB "Setup Graph"
GOSUB "Setup Variables"
GOSUB "Get&Plot Data"
PICTURE OFF, DataGraphHandle&
GOSUB "Shutdown S&D"
RETURN

"Setup Variables"
'Turn OFF All Except STOP Buttons
FOR X%=1 TO 6
BUTTON 30+X%,0
NEXT X%
BUTTON #32,1
GPQuitFlag%=0: SecCnt%=0
SampNo%=0:OldYCoord%=263:OldXCoord%=24
RETURN

"Get&Plot Data"
DIALOG ON: TIMER ON: MENU ON
"G&P Loop"
A33=DIALOG(0)
B33=DIALOG(A33)
IF A33=1 OR A33=5 THEN RETURN
IF GPQuitFlag%=1 THEN RETURN
LONG IF SecCnt%=2:'this is a point to be plotted
SecCnt%=0
SampNo%=SampNo%+1
IF SampNo%=2499 THEN RETURN
TempDat!(SampNo%)=FN
CalcTemp!(Z$)
TimeDat$(SampNo%)=TIME$
XCoord%=24+SampNo%
YCoord%=INT(263.5-((FN
CalcTemp!(Z$) * 5-30*5))
IF YCoord%>264 THEN YCoord%=264
IF YCoord%<13 THEN YCoord%=13
PEN 3,3,1,8,0
PLOT XCoord,YCoord
PEN 1,1,1,8,0
PLOT OldXCoord%+1,OldYCoord%+1
TO XCoord%+1,YCoord%+1
OldXCoord%=XCoord%
OldYCoord%=YCoord%
END IF
GOTO "G&P Loop"

"HeaderUpdate": for headerdata read
SecCnt%=SecCnt%+1
PEN 1,10,1,8,19
PLOT 150,2 TO 320,2
TEXT 2,9,0,1
PRINT%(165,10)TIME$
LONG IF DartFlag%=1 AND CalibFlag%=1
'WRITE #-1,A$;l
'READ #-1,Z$;0
FOR Qweer%=1 TO 3
'WRITE #-1,A$;l
'READ #-1,Zoo$(Qweer%);0
NEXT Qweer%
Z$=CHR$((ASC(Zoo$(1)) + ASC(Zoo$(2)) + ASC(Zoo$(3)) )/3)
Temp!= FN CalcTemp!(Z$)
PRINT%(215,10)"Temp is ";USING "###.#";Temp!;" deg C"
END IF
RETURN

"Shutdown S&D"
FOR X%=1 TO 6
BUTTON 30+X%,l
NEXT X%
BUTTON #32,0
RETURN

"Save": puts our data out for re-use
SaveName$=FILES$(0,"Name for our Graph?","Freddy Krueger's Graph")
DEF OPEN="TEXTMBL1"
OPEN"O",1,SaveName$
PRINT#1,"MBLTempVers#1"
PRINT#1,CommentLine$
PRINT#1,USING"###";ColdCalib%,USING "###.#";ColdTemp!
PRINT#1,USING"###";HotCalib%,USING "###.#";HotTemp!
PRINT#1,USING"###";SampNo%
FOR Count%=1 TO SampNo%
PRINT#1,Count%,USING "###.#";TempDat!(Count%),TimeDat$(Count%)
NEXT Count%
CLOSE#1
RETURN

"Load": grabs data from disk to see
Root$=FILES$(-1,"",Vol%)
PRINT@ (20,15);"**”;Root$;"**",Vol%;ST OP
LoadName$=FILES$(1,"TEXT")
IF LoadName$="" THEN RETURN: null file; none wanted
OPEN"T",2,LoadName$,,VOL%
INPUT#2,Line1$
IF Line1$<>"MBLTempVers#1" THEN CLOSE#2:RETURN
INPUT#2,CommentLine$
INPUT#2,ColdCalib%,ColdTemp!
INPUT#2,HotCalib%,HotTemp!
INPUT#2,SampNo%
FOR Count%=1 TO SampNo%
INPUT#2, Count%
TempDat!(Count%),TimeDat$(Count%)
NEXT Count%
CLOSE#2
'Now show that data!
GOSUB "Setup Graph"
BUTTON #34,1: turn on Save
BUTTON #35,1: turn on Print
RETURN

"Print": printout routine
DEF PAGE
IF PRCANCEL THEN RETURN
DEF LPRINT
IF PRCANCEL THEN RETURN
PICTURE, OrigGraphHandle&
ROUTE 128
COORDINATE 850,1100
PICTURE(10,10) - (840,540),DataGraphHandle&
CLEAR LPRINT
CLOSE LPRINT
RETURN
The pH Probe

The pH probe has been described in detail in Appendix C. The probe itself is shown in Figure 47.

![Figure 47: Main Menu Illustration for pH Apparatus Setup](image)

![Figure 48: Illustration for Calibration Procedure for Calibration Menu](image)
pH code 4/27/552
'The All New, totally procedural version
'And here's the opening play

WINDOW OFF
COORDINATE WINDOW

'*******PROGRAMMINGPARAMETERS
*******
'TRON
'BREAK ON:
'GOSUB "Collect Data"

'**********************************************

GOSUB "Get Pictures"
GOSUB "Variables Setup"
GOSUB "Menu Setup"
GOSUB "Setup - Window #1"

"Main event loop"
MENU ON : DIALOG ON : TIMER OFF
A1=DIALOG(0)
IF A1<>0 THEN GOSUB "Main Event"
IF MainRefresh%=1 THEN
MainRefresh%=0:PICTURE, AppHandle&
GOTO "Main event loop"
'This about wraps up the main body of the program

'Main Event": Handles Close Box, Buttons for Main Window
MENU OFF : DIALOG OFF
B1=DIALOG(A1)
IF A1=4 GOSUB "Shutdown":Close Box
IF A1=5 THEN PICTURE, AppHandle&
LONG IF A1=1:'Button events
SELECT B1
CASE 1
GOSUB "Calibrate"
WINDOW #1
WINDOW CLOSE #2
CASE 2
GOSUB "Collect Data"
WINDOW #1
WINDOW CLOSE #3
CASE 3
GOSUB "Shutdown"
END SELECT
END IF
RETURN:'End of "Main Event"

"Get Pictures"
apparatus picture
ResNum%=8289
RefNum%=FN OPENRESFILE("pH app.res")
AppHandle&=FN
GETRESOURCE(CVI("PICT"),8289%)
'calibration picture
ResNum%=8696
RefNum%=FN OPENRESFILE("pH calib.res")
CalibHandle&=FN
GETRESOURCE(CVI("PICT"),8696%)
RETURN :end of "Get Pictures"

"Setup - Window #1"
WINDOW #1,"Titration Curves",5
PICTURE, AppHandle&
BX1=67:BY1=262: BUTTON #1,1,"Calibrate", (BX1,BY1) - (BX1+80, BY1+30),1
BX3=214:BY3=262:BUTTON #2,1,"Get Data", (BX3,BY3) - (BX3+80,BY3+30),1
BX4=361:BY4=262:BUTTON #3,1,"Quit",(BX4,BY4) - (BX4+80,BY4+30),1
RETURN :end of "Setup - Window #1"

"Variables Setup"
A$=CHR$(128+16*3):'port 4
B$=CHR$(255)
DartFlag%=0
ACIDCALIB%=0:ACIDPH%=0:BASECALIB%=0:
BASEPH%=0
PlotFlag%=0
CalibFlag%=0:GetDataFlag%=0:
MainRefresh%=0
DIM PHDAT!(100)
DIM 8TIMEDAT$(100)
DIM VOLDAT!(100)
DIM COMMENTLINE$(255)
DIM 2ZOO$(3)
DIM 63 A$(6)
COMMENTLINE$="COMMENTLINE"
RETURN

"Shutdown"
CLOSE
END
RETURN: 'end shutdown; end pgm
"Menu Setup"
MENU 1,0,1,"File"
MENU 1,1,1,"Quit  /Q"
ON MENU GOSUB "Shutdown"
RETURN

"Open DART"
OPEN"C",-1,9600,0,0,1,2000
HANDSHAKE -1,-2
FOR X%=1 TO 3
  WRITE#-1, A$;1:'Say hello to DART
  DELAY 250
  WRITE#-1, B$;1:'Say hello to DART
NEXT X%
READ#-1, Z$:0 :DART replies to MAC
LONG IF Z$="":'silent DART
  Mess1$="This MAC is not receiving
DARTbox"
  Mess2$="signals. Please check the
DART"
  Mess3$="connection, or CANCEL to "
  Mess4$="retrieve data from disk."
  CALL
PARAMTEXT(Mess 1 $,Mess2$,Mess3$,Mess4$)
  R%=FN STOPALERT (2,0)
  LONG IF R%=2
    DartFlag%=0
  RETURN
  END IF
  ERROR=0
  GOTO "Open DART"
XELSE
  DartFlag%=1
END IF
RETURN:'end of "Open DART"

**********CALIBRATION
ROUTINES**********

"Calibrate": 'Calibration Routine
CalibQuitFlag%=0:CalibField%=21:Set Acid
Flag%=0:SetBaseFlag%=0:CalFlag%=1
GOSUB "CalibWindow"
GOSUB  "CalibValueShow"
GOSUB "Open DART":IF DartFlag%=0
RETURN:No
DARTbox:**********RESET*****
GOSUB  "Calibration Loop"
GOSUB  "Calibration Calculation"
MainRefresh%=1
RETURN:'end of Calibrate

"Calibration Loop"
MENU ON:DIALOG ON
"Actual Loop"
A2=DIALOG(0)
IF A2<0 THEN GOSUB "CalibEvent"
IF CalibQuitFlag%=1 THEN RETURN
IF SetAcidFlag%=1 THEN GOSUB
"SetAcid":SetAcidFlag%=0
IF SetBaseFlag%=1 THEN GOSUB
"SetBase":SetBaseFlag%=0
GOTO "Actual Loop"
RETURN

"CalibEvent"
MENU OFF:DIALOG OFF:TIMER OFF
B2=DIALOG(A2)
SELECT A2
CASE 1:'buttons
  SELECT B2
    CASE 21:'Acid
      SetAcidFlag%=1
    CASE 22:'Quit
      CalibQuitFlag%=1
    CASE 23:'Base
      SetBaseFlag%=1
  END SELECT
CASE 4:'quit
  CalibQuitFlag%=1
CASE 5:'refresh
  PICTURE,CalibHandle&
  GOSUB "CalibValueShow"
END SELECT
RETURN

"SetBase"
BUTTON #21,0
BUTTON #22,0
BUTTON #23,0
WINDOW #4,"Base Calibration",(350,50)-
(460,325),2
TEXT 2,10,1
PRINT%(300,5)" Base Calibration"
TEXT 2,10,0
PRINT%(300,30)" Base Soln"
PRINT%(300,45)" pH"
PRINT%(300,100)" Base DART Value"
PRINT%(300,115)" (0-255)"
PRINT%(300,175)" Enter the "
PRINT%(300,190)" actual pH"
PRINT%(300,205)" of the "
PRINT%(300,220)" buffer soln,"
PRINT%(300,235)" and press"
PRINT%(300,250)" return when done."
EF4$=STR$(BasePH!)
EDIT FIELD 4,EF4$,(30,65)-(80,77),1,2
"SetBaseLoop"
  Cntr%=0
  DIALOG ON;MENU ON
"RealLoop"
  Cntr%=Cntr%+1
  IF Cntr%>=3 THEN GOSUB "ShowBaseDART"
  A4%=DIALOG(0)
  IF A4%<>6 THEN GOTO "RealLoop"
DIALOG OFF ; MENU OFF
BasePH!=VAL(EDIT$(4))
IF BasePH!>14 OR BasePH!<1.0 THEN BasePH!=0
BaseCalib%=ASC(Z$)
EDIT FIELD CLOSE#4
WINDOW #2
WINDOW CLOSE #4
BUTTON #21,1
BUTTON #22,1
BUTTON #23,1
RETURN
"ShowBaseDART"
Cntr%=0
TEXT 2,10,1
WRITE#-1, A$; 1 :'Get info from DART
READ#-1, Z$;0 :DART replies to MAC
PEN 1,12,1,8,19
PLOT From 340,140 TO 510,140
PRINT%(47,150)USING"###";ASC(Z$)
RETURN
"SetAcidLoop"
  Cntr%=0
  DIALOG ON;MENU ON
"ReelLoop"
  Cntr%=Cntr%+1
  IF Cntr%=3 THEN GOSUB "ShowAcidDART"
  A4%=DIALOG(0)
  IF A4%<>6 THEN GOTO "ReelLoop"
DIALOG OFF ; MENU OFF
AcidPH!=VAL(EDIT$(5))
IF AcidPH!>50 OR AcidPH!<10 THEN AcidPH!=0
AcidCalib%=ASC(Z$)
EDIT FIELD CLOSE#5
WINDOW #2
WINDOW CLOSE #5
BUTTON #21,1
BUTTON #22,1
BUTTON #23,1
RETURN
"ShowAcidDART"
Cntr%=0
TEXT 2,10,1
WRITE#-1, A$; 1 :'Get info from DART
READ#-1, Z$;0 :DART replies to MAC
PEN 1,12,1,8,19
PLOT From 2,140 TO 200,140
PRINT%(47,150)USING"###";ASC(Z$)
RETURN
"SetAcid"
BUTTON #21,0
BUTTON #22,0
BUTTON #23,0
WINDOW #5,"Acid Calibration",(12,50)-(122,325),2
TEXT 2,10,1
PRINT%(2,10)"Acid Calibration"
TEXT 2,10,0
PRINT%(2,30)" Acid Soln"
PRINT%(2,45)" pH"
PRINT%(2,100)" Acid DART Value"
PRINT%(2,115)" (0-255)"
PRINT%(2,175)" Enter the "
PRINT%(2,190)" actual pH"
PRINT%(2,205)" of the "
PRINT%(2,220)" buffer soln,"
PRINT%(2,235)" and press"
PRINT%(2,250)" return when done."
EF5$=STR$(AcidPH!)
EDIT FIELD 5,EF5$,(20,65)-(70,77),1,2
"CalibWindow"
WINDOW #2,"pH Probe Calibration",5
PICTURE, CalibHandle&
TEXT 2,10,1
BX1=67;BY1=262:BUTTON #21,1,"Set Acid", (BX1,BY1) - (BX1+80,BY1+30),1
BX3=214;BY3=262:BUTTON #22,1,"Done", (BX3,BY3) -
  (BX3+80,BY3+30),1
BX4=361;BY4=262:BUTTON #23,1,"Set Base", (BX4,BY4) -
  (BX4+80,BY4+30),1
RETURN:end of CalibWindow
"CalibValueShow"
PEN 1,12,1,8,19
PLOT From 120,232 TO 300,232
PLOT From 420,232 TO 500,232
PLOT From 120,247 TO 300,247
PLOT From 420,247 TO 500,247
TEXT 2,10,1
PRINT%(20,240)"Acid pH:"
PRINT%(125,242)USING"#.##";AcidPH!
PRINT%(320,240)"Base pH:"
PRINT%(422,242)"USrNG "-##.#" BasePH!
TEXT 2,10,0
PRINT%(320,255)"Base DART Value:"
PRINT%(422,257)"USrNG "###" BaseCalib
PRINT%(20,255)"Acid DART Value:"
PRINT%(125,257)"USrNG "###" AcidCalib
RETURN

"Calibration Calculation"
Slope!=(BasePH!-AcidPH!)/(BaseCalib%-AcidCalib%)
DEF FN
CalcPH!(Z$)=BasePH!+Slope!*(ASC(Z$)-BaseCalib%):'old formula here
RETURN

"**********GET DATA
ROUTINES*************
"Collect Data":Data collection Routines
Vol! = 50.0
GetDataFlag%=1:DataQuitFlag%=0:PicFlag%=0
RefreshFlag%=0
GOSUB "Data Window"
GOSUB "Open DART"
IF DartFlag%=1 AND CalibFlag%=1 THEN BUTTON #31,1:'turn START on
PICTURE ON:'store this one
GOSUB "Setup Graph"
PICTURE OFF, OrigGraphHandle&
PICTURE, OrigGraphHandle&
GOSUB "Data Loop"
TIMER OFF
ON TIMER(86400) GOSUB
"DummyRoutine"
MainRefresh%=1
RETURN:end of collect data routine

"Data Window"
WINDOW #3,"pH Data Display",(1,37) - (511,345),5
GOSUB "Buttons"
RETURN:end of data window

"Buttons"
BUTTON #31,0,"Start",(20,285) - (80,304),1
BUTTON #32,0,"Scale",(100,285) - (160,304),1
BUTTON #33,1,"Load",(180,285) - (240,304),1

BUTTON #34,0,"Save",(260,285) - (320,304),1
BUTTON #35,0,"Print",(340,285) - (400,304),1
BUTTON #36,1,"Quit",(420,285) - (480,304),1
RETURN:end buttons

"Setup Graph"
'calibration legends
TEXT 2,9,0,1
PRINT%(20,10)"AcidCalib ";
PRINT USING "###";AcidCalib%" at pH
";
PRINT USING "-##.#";AcidPH!
PRINT%(385,10)"BaseCalib ";
PRINT USING "###";BaseCalib%" at pH
";
PRINT USING "-##.#";BasePH!

'Vert Axes
PEN 1,1,1,8,0
DATA " 0"," 5","10","15","20","25","30","35","40","45","50"
LableFlag%=1
FOR Xl%=24 TO 504 STEP 48:'Plot vert
axes
READ Vl$
PRINT%(Xl%-10,275);Vl$:'Lable times
PLOT Xl%,14 TO Xl%,266
NEXT X1%
PRINT%(225,284)"Volume of Titrant in mL"

'Horiz Axes
DATA " 0"," 1"," 2"," 3"," 4"," 5"," 6"," 7"," 8"," 9","10","11","12","13","14"
FOR Yl%=266 TO 14 STEP -18:'Plot horse axes
READ Hl$
IF Yl%<264 THEN
PRINT%(12,Yl%+4);Hl$: Lable pHs
PLOT 24,Y1% TO 504,Y1%
NEXT Y1%

'Main PH Lable
X1%=3:Y1%=40
Lable$="pH units"
FOR D1%=70 TO 140 STEP 10
D$=MID$(Lable$,(D1%/10)-6,1)
PRINT%(X1%,Y1%+D1%);D$
NEXT D1%

RESTORE
RETURN
"Data Loop"
ON TIMER(1) GOSUB "HeaderUpdate"
"Data Loopo"
MENU ON:DIALOG ON:TTMER ON
A3=DIALOG(0)
IF A3<>0 THEN GOSUB "Data Event"
IF DataQuitFlag%=1 THEN RETURN
GOTO "Data Loopo"

"Start"
PICTURE ON
GOSUB "Setup Graph"
GOSUB "Setup Variables"
GOSUB "Get&Plot Data"
PICTURE OFF, OrigGraphHandle&
GOSUB "Shutdown S&D"
RETURN

"Data Event"
MENU OFF:DIALOG OFF:TTMER OFF
ON TIMER(86400) GOSUB
"DummyRoutine"
B3=DIALOG(A3)
SELECT A3
CASE 1: 'Button events
   SELECT B3
   CASE 31: 'START
      GOSUB "Start"
   CASE 32: 'SCALE
      'gosub "Scale"
   CASE 33: 'LOAD
      GOSUB "Load"
   CASE 34: 'SAVE
      GOSUB "Save"
      PICTURE, OrigGraphHandle&
   CASE 35: 'PRINT
      GOSUB "Print"
      PICTURE, OrigGraphHandle&
   CASE 36: 'Quit
      DataQuitFlag%=1
      ON TIMER(86400) GOSUB
"DummyRoutine"
END SELECT
CASE 4: 'Close Box
   DataQuitFlag%=1
CASE 5: 'refreshes setup graph
   PICTURE, OrigGraphHandle&
   LONG IF RefreshFlag%=1
      PICTURE, OrigGraphHandle&
      RefreshFlag%=0
END IF
END SELECT
ON TIMER(1) GOSUB "HeaderUpdate"
RETURN: 'end data event

"Setup Variables"
'Close All Buttons
FOR X%=1 TO 6
   BUTTON CLOSE #30+X%
NEXT X%
BUTTON #37,1,"Enter Burette Volume",
(20,285) - (180,304),1
BUTTON #38,1,"Done",(420,285) -
(480,304),1
GPQuitFlag%=0:SecCnt%=0
Vol!%=0.0
SampNo%=0
RETURN

"Get&Plot Data"
ON TIMER(1) GOSUB "HeaderUpdate"
"G&P Loop"
DIALOG ON:TTMER ON:MENU ON
A33=DIALOG(0)
B33=DIALOG(A33)
IF A33<>0 THEN GOSUB "G&P Data Event"
IF GPQuitFlag%=1 THEN RETURN
GOTO "G&P Loop"

"G&P Data Event"
DIALOG OFF:MENU OFF:TTMER OFF
SELECT A33
CASE 1: 'Button events
   SELECT B33
   CASE 37: 'Enter Burette Volume
      GOSUB "EnterBuretteVolume"
   CASE 38: 'Done
      GOSUB "Done"
   END SELECT
CASE 5: 'refreshes setup graph
   PICTURE, OrigGraphHandle&
   IF SampNo%>0 THEN GOSUB
   "PlotAllDemSuckers"
END SELECT
ON TIMER(1) GOSUB "HeaderUpdate"
RETURN: 'end data event

"PlotAllDemSuckers"
"G&P Loop"
"PlotAllDemSuckers"
FOR Dummy%=1 TO SampNo%
GOSUB "PlotDeSucker"
NEXT Dummy%
RETURN

"EnterBuretteVolume"; takes in Volume, then plots it
BUTTON #37,0
BUTTON #38,0
DIALOG ON: MENU ON: TIMER ON
TEXT 2,12,1
EF1$=STR$(Vol!)
EDIT FIELD 1,EF1$(247,285)-(303,301),1,2
"BurEditLoop"
A4%=DIALOG(0)
TEXT 2,12,1
IF A4%<>6 THEN GOTO "BurEditLoop"
DIALOG OFF : MENU OFF TIMER OFF
Vol!=VAL(EDIT$(1))
EDIT FIELD CLOSE#1
'wingy values for volume
IF Vol!>50 THEN Vol!=50
IF Vol!<0 THEN Vol!=0
SampNo%=SampNo%+1
Dummy%=SampNo%
PHDat$(SampNo%)=FN CalcPH!(Z$)
TimeDat$(SampNo%)=TIME$
VolDat$(SampNo%)=Vol!
GOSUB "PlotDeSucker"
BUTTON #37,1
BUTTON #38,1
RETURN: end burette vol

"PlotDeSucker"
XCoord!=22+(VolDat!(Dummy%)/5)*48
XCoord%=XCoord!
IF Xcoord%!>504 THEN Xcoord%=504
YCoord%=267-PHDat!(Dummy%)*18
IF YCoord%!>264 THEN YCoord%=264
IF YCoord%!<13 THEN YCoord%=13
PEN 5,5,1,0
PLOT XCoord,YCoord
RETURN: end PlotDeSucker

"Done"; new pik, draw line
CLS
PICTURE ON
GOSUB "Setup Graph"
GOSUB "PlotAllDemSuckers"
GPQuitFlag%=1
PEN 1,1,1,8,0
'first of the points
XCoord!=22+(VolDat!(1)/5)*48
OldXCoord%=XCoord!
OldYCoord%=267-PHDat!(1)*18
FOR N%=2 TO SampNo%: and the rest
XCoord!=22+(VolDat!(N%)/5)*48
XCoord%=XCoord!
YCoord%=267-PHDat!(N%)*18
PLOT OldXCoord%+2,OldYCoord%+2
TO XCoord%+2,YCoord%+2
OldXCoord%=XCoord%
OldYCoord%=YCoord%
NEXT N%
PICTURE OFF, OrigGraphHandle& RETURN

"HeaderUpdate"; for headerdata read
PEN 1,10,1,8,19
PLOT 147,2 TO 375,2
TEXT 2,9,0,1
PRINT%(195,10)TIME$
LONG IF DartFlag%=1 AND CalibFlag%=1
WRITE #1,A$;1
READ #1,Z$;0
PH!=FN CalcPH!(Z$)
PRINT%(195,10)"pH is "; USING 
"##.##",PH!
PRINT" Burette Vol is "; USING 
"##.##",Vol!; " ml"
END IF
TEXT 2,12,1
RETURN

"Shutdown S&D"
BUTTON CLOSE #37
BUTTON CLOSE #38
GOSUB "Buttons"
FOR X%=1 TO 6
BUTTON 30+X%,1
NEXT X%
BUTTON #32,0
RETURN

"Save"; puts our data out for re-use.
Dummy$=FILES$(-9999,""Name for our Graph?","Freddy Krueger's Graph",Myvolume%)
FileName$=FILES$(0,"Name for our Graph?","Freddy Krueger's Graph",Myvolume%)
IF FileName$="" THEN
RefreshFlag%=1: RETURN
DEF OPEN="TEXTMBL1"
A$(1)="Now saving pH data as"
"Load": grabs data from disk to see

FileName$=FILES$(1,"TEXT",,Myvolume%
IF FileName$="" THEN RefreshFlag%=1:
RETURN: null file; none wanted
OPEN",1,FileName$,,Myvolume%
A$(1)="Attempting to open previous 
A$(2)="pH data file:
A$(3)=FileName$
A$(4)="
A$(5)="Please stand by ..."
A$(6)="
INPUT#1,Line1$
GOSUB "MyDialog"
LONG IF Line1$=""MBLPHVers#1"
CLOSE
PRINT "Not a pH data file!"
GOSUB "KillMyDialog"
RefreshFlag%=1
RETURN
END IF
INPUT#1,CommentLine$
INPUT#1,AcidCalib%,AcidPH!
INPUT#1,BaseCalib%,BasePH!
INPUT#1,SampNo%
FOR Count%=1 TO SampNo%
INPUT#1, Count%, PHDat!(Count%),
VolDat!(Count%),TimeDat$(Count%)
NEXT Count%
PRINT ",EOF"
CLOSE#1
GOSUB "KillMyDialog"
GOSUB "Done"
RETURN

"Print": printout routine
DEF PAGE
IF PRCANCEL THEN
RefreshFlag%=1:RETURN
DEF LPRINT
IF PRCANCEL THEN
RefreshFlag%=1:RETURN

AS$(1)="Now Printing pH graph"
AS$(2)="
AS$(3)=FileName$
AS$(4)="
AS$(5)="
AS$(6)="Please stand by ..."
GOSUB "MyDialog"
WIDTH LPRINT-2

Page 215
ROUTE 128
COORDINATE 850,1100
PICTURE(10,10) -
(840,540),OrigGraphHandle&
TEXT 4,9,1
PRINT @(0,35);"MBLPHVers#1"
PRINT FileName$
PRINT "AcidCalib:
";USING"###";AcidCalib%;" @ pH
";USING"-##.#";AcidPH!
PRINT "BaseCalib:
";USING"###";BaseCalib%;" @ pH
";USING"-##.#";BasePH!
PRINT "Total of
";USING"###";SampNo%;" data points"
PRINT
PRINT "Sample Number"TAB(20)"pH Value"TAB(40)"Volume (mL)"TAB(60)"Time (HH:MM:SS)"
FOR Count%=1 TO SampNo%
PRINT
TAB(1)USING"#####";Count%TAB(20)USING
".
###.";PHDat!(Count%)TAB(43)USING"###.
###.";VolDat!(Count%)TAB(66)TimeDat$(Count%)
NEXT Count%
ROUTE 0
WIDTH LPRINT-1
CLEAR LPRINT
CLOSE LPRINT
COORDINATE WINDOW

'kill my dialog
WINDOW CLOSE #10
DIALOG ON
TIMER ON
MENU ON
RETURN
Appendix E: Interview Transcripts

June 11 1990
TAPE 11 Richmond School Interviews Side 1
SIDE I -- All students from X's class -- Grade 11, demonstrated 2A and did 16B
Total run time 21 minutes approximately

S (Female)

Q. During this past semester in Mr. X's class you used a computer in some of the labs. Do you remember which labs those were?

A. One of them was the paradichlorobenzene. I didn't actually work on the computer at that time. I think some other people worked at it, but we got the results from the graph, and the spectrophotometer we did also. That one I actually worked on it. I actually did punch the things into it.

Q. What I say to you, or if I tell you that you're going to do a computerized lab tomorrow, what do you think when I say that? What kind of reactions does that bring, good, bad, different?

A. I find it interesting because you're getting the results a lot quicker. It's not all done manually, your just punching in things and you get the results. It's all pretty technical, but it isn't like there's less direct involvement. If I'm actually working on a computer, it's more so because there's less computers, and I was thinking like when we have our own labs, then that's when you know that your actually mixing chemicals. Not that I don't enjoy doing computerized work or anything, but you see it's because there wasn't as many computers; however, I'm not usually the one that gets involved so I'll stay back and watch what's going on.

Q. You talked about that there seemed to be a little less doing things in the lab when you're using computers. Can you tell me a little more about that? Why are you less involved?

A. I guess actually entering the information into the computer. Like the paradichlorobenzene one, we did of course go through all the processes of letting it sit there and melting, but I actually didn't understand that one as much as doing the graphing and stuff.

Q. Do you think that there's a problem with not having enough computers?

A. Oh yes, because there were 6 of us, and what happened is that another girl punched everything into the computer, and I just did the actual manual process of putting the test tubes in, but then the other four people just sat around. Which wasn't their fault.

Q. What positive aspects are there to using an MBL, when you just said getting the results? Like what plus's do you see in using a computer?

A. I think that computers are just becoming part of our world now and that you have to accept it, and it's good because the other way we had to do the graphs and everything else, writing up notes, writing up the information, but this way it comes up automatically, and it doesn't take as much time. We actually had to go through the whole process of drawing up the graphs before. We know all the observations, and we know how to do it. Now it takes less time to get the results, and they're also more accurate because of the information in the computer.

Q. We were talking about punching in results and getting them a lot more accurately. So those are some benefits. Do you think their worth the losses that you were saying, the fact that there aren't as many of you on the computers?

A. Well not to do it all the time. We only did it twice this year. I think it's good to do it, but not for every lab because I think for some of them, obviously you can't use computers. For the ones that
you can, I think it's beneficial to do it. It's interesting, and it gets us involved with computers, because I never thought that we could use computers in a chemistry lab. This was all new to me.

Q. Do you think we should carry on using computers in Mr. X's class?

A. Yes, but not for every lab. You have to do it a couple of times and you have to make sure that people are getting involved because in our group some people took advantage of the fact that they didn't have to use it. I must admit that in the first lab, that's what I did too. I just sat back and I didn't totally understand the process of how we got the results on what we were doing?

Q. There were only 2 set-ups in the first one, in the later one there were 3 or 4, I believe?

A. Yes, in the beginning there were only a couple of groups that worked on those two, and I didn't really watch what was going on, I just sat on a back seat and watched other people work on the computer.

Q. I wanted to ask you a couple of questions about your survey sheet. You talked about the process of using the computer. You said that you had some troubles, there was some confusion about using the computer?

A. Yes, but that was probably my fault. I didn't get full involved enough, and also because of the lack of computers in the class.

Q. Well besides bringing more computers in, how can I make it clear?

A. Probably getting everyone to pay attention more, because we only had 2 computers, they thought they could get away without using the computer at all. I think that everyone was sitting in groups of 4 maximum, in front of the computer, and as you explained it, they could be kind of doing it at the same time, like making a list, because it's kind of difficult to have to explain it, especially when it's their first time using a computer. You would get it all explained, and then do the whole process. It's a lot easier that way. If there was something written or handed out that they could follow, it would be a lot easier too.

C (Female)

Q. I have a number of questions about the computerized experiments that you did in Mr. X's class. First of all, can you remember the experiments that were computerized that you did in this class?

A. We did one with paradichlorobenzene, and we did another one with the spectrophotometer. I think the paradichlorobenzene, if I remember correctly, it was a boiling point of something, and the spectrophotometer was with the graphs that we had to have printed out.

Q. So you did two labs. So you've had a little bit of experience with those processes. In the first one we only had two stations, and for the second one we had probably 4 computers set up. So you've seen some computers in the lab so far. If I tell you that you're going to do a lab with a computer, what do you think of when I say that?

A. Well the first thing that I thought was that we would have to do all the computer stuff ourselves. It was really funny because I didn't know anything about computers, but then he explained that you were going to come in, so then it was okay. Actually, I thought it was good because it just seemed more scientific, it was a lot better because you wanted to find out what it could do, and it was interesting.

Q. What negative aspects did you see about using a computer in a lab?
Q. Those are kind of negative aspects. What positive aspects, or real improvements or changes in the lab did you see?

A. Well when we did it, you really concentrated a lot more. You paid a lot more attention because you didn't want to do anything wrong like the graphs and stuff.

Q. Do you think I should computerize more labs?

A. Yes, I do.

Q. When you used the computers, you had to calibrate. Do you remember anything about calibration, can you tell me what it means in your own words?

A. I'm not quite sure, what is it again?

Q. It's when you use a measurement of some kind at the n, and then use that as a guide to all other measurements, like with the distilled water in the spectrophotometer, or putting the temperature probe in hot or cold water.

Q. There was a lot of effort we went through a lot of work in setting them up, you went through a lot of extra work trying to deal with calibration, and doing extra work like trying to get extra printouts. Do you think it was worth doing?

A. Well I guess it's something new, and something new is always interesting. I think that if I heard another class was doing it, I don't know if it would of changed my mind or anything. But if you did bring it in, it would be interesting because it's something new.

Q. I have a question you asked here, "How do you use a printer?"

A. Yes, we had a lot of trouble with the printers. It printed out a lot of weird things so we had to spend a little bit more time trying to figure it out.

Q. How do you think I could make the printer easier to use, or how could I improve that?

A. Well I wasn't working at the computer, I was watching the girl who was, and she had to switch to all these different screens all the time. It just seemed all so complicated. It would be easier if it were all on one screen, or just have it set up and just press the button on the printer.
M (Female)

Q. I'm going to ask you a couple of questions about the computerized lab experiments you did in Mr. X's class using the computers. You did two experiments. Can you recall those experiments?

A. One was the temperature with the mothballs, and the other one with the spectrophotometer, I think.

Q. The first one, the temperature, there was only 2 computers in the classroom, so you may not have had the opportunity to use it. The spectrophotometer, definitely everybody got the chance of getting the data, but I don't know if they got a chance to actually use the devices.

If I were to tell you that your going to do an MBL lab tomorrow, a micro-computer lab, what's the first thing that comes to mind?

A. Okay, so what are we going to do.

Q. So nothing special? It doesn't worry you?

A. Well it doesn't scare me.

Q. So you've had some computing experience. What background have you got in computers?

A. Well my dad's a computer programmer. We have a computer at home.

Q. So you have a Mac at home, or a PC?

A. No, we have a PC -- Compu-Colour. It looks like a TV with a floppy disk drive in it. It must be about ten years old.

Q. How did you see the computer as being of an assistance then in the class?

A. Well I thought for the spectrophotometer it was a lot easier. You could see the plots, and having the computer do it all itself. You could see it better, and you could see what it was suppose to look like.

Q. Did it take anything away from the lab? Do you think it made it too easy?

A. No, I don't think so.

Q. So you still learned as much?

A. Yes, you just didn't have to do as much manual labour.

Q. How do you see the use of the computer taking away from the lab?

A. I just think that maybe you don't have to think as much. I don't really see how it changes anything. I didn't see much of a change in the lab.

Q. There was one thing that we did when we did the temperature experiment. We had calibrate probes when we went to use the computers. Can you remember anything about that?

A. Well, you put it into hot water and you did the temperature with the thermometer, you typed it in, and then you got cold water and you did the same thing. I think the probe we used was too long or something, because when we actually did the lab, it sort of got lost.
Q. What was the purpose in doing the calibration?
A. Well I guess it's because of the temperatures. It tells the computer what the temperature is.

Q. Calibration is one way that a lab was made more complicated, do you think that extra work is worth while in the lab?
A. Yes.

Q. So even though there's that extra work, it's still worth while to use a computer?
A. Yes.

Q. You had some comments about the spectrophotometer lab. You mentioned that it would be an experiment you might want to plot another point, an you might want to graph percent transmittance as well? Could you tell me a little bit more about those?
A. Well I thought if you had more, than we could see maybe if you made an error on one of them so that you have a chance of getting it right. Also, I thought of graph percent transmission just to see what it looks like.

Q. Did you have to do the graph with the percent transmission?
A. Yes, I had to re-do both of them because it didn't have the graduation on it, so that could help also.

Q. Do you think we should computerize more labs?
A. I don't see why not. If it's something like this. Some of them I don't think would be appropriate.

Q. Do you think we should go ahead and computerize more than just the two?
A. Well it's like the last year we had a little program that we had to do, and it had typing and stuff to do. I thought it was really good.

L (Male)

Q. I have some questions about the computerized experiments you've done in Mr. X's lab. Do you recall which one those were?

Q. One of them was with the water, and one with the temperature.
A. If I tell you that you're going to have another computer experiment tomorrow, what do you think of if I tell you you're going to have a computer experiment tomorrow. What do you think of coming into the lab?

A. If it's set up, then they'll be more classroom, but if it isn't, instead of doing a lab, then it will take more time to do it. The first one, it was unprepared for. We didn't actually finish it. The spectrophotometer was hooked up and it was a lot faster. We didn't have to do the graphing.

Q. Do you think that you learn less if the computer does the graphing for you?
A. I don't think so. You can still see what's happening, you just have to watch what you're doing.

A. What other positive things does a computer do in the lab that makes a lab better?
A. You can share the information, and it's a lot quicker.

Q. What negative aspects that take away from the lab, or make a lab more difficult because of bringing in computers?

A. You have to know the computer, and you will have to know how to use it.

Q. Do you a background in computers, have you used computers before?

A. Yes, just now I'm taking a course.

Q. So adding the computer didn't make it too mysterious?

A. No.

Q. There was a lot of effort involved in bringing these computers in. There also was a lot of effort done on your part like doing calibration, and dealing with the printers. Do you think all the extra work was worth it?

A. Yes, if it's always going to be there. If it's only there for a couple of days, then it's not worth it. If we have them for the whole year and always use it, then it's worth it.

Q. So should we computerize more labs?

A. Yes.

Q. When I say that making the lab more complicated using the computer, one example of that is calibration, we had to calibrate the computer or calibrate the instruments. Can you tell me a little bit more about what calibration is in your own words?

A. We just used a piece of paper, then we calibrated. We just divided the moles or something like that.

Q. There's something I didn't understand. For this question here, "Which parts of today's experiments are clearly understood?" You said everything was clear, nothing was not straightforward. When I said, if you were to repeat today's experiments tomorrow, what would you do differently? You said, "Don't use computers." I don't understand why you said not to use computers?

A. It's because the experiment where they talked about computers, well that sort of ruined the experiment. It wasn't on the procedure.

Q. How do you think I could do better than that? How could I improve that?

A. You just have to show us how to use the computer. For those who don't know how to use it, and if it's not on their procedure, than they probably won't use it.
June 12, 1990
TAPE 11 Richmond School Interviews Side 2
SIDE II -- Y's Class -- Grade 11, demonstrated 2A only
Total run time 18 minutes approximately

E (Female)

Q. I'm going to ask you some questions about the labs that you've been doing in grade 11 chemistry, and in particular, about the computer lab that you had an opportunity to use the temperature one. Do you remember much about the temperature lab?

A. I don't really remember. It was quite some time back.

Q. Did you have an opportunity to play with the apparatus while it was in, or did you use it?

A. No, I was watching it.

Q. If I told you that I was going to try computerizing some more labs in grade 11, what do you think about that?

A. Well it's more helpful for us.

Q. So you think it's a good thing then?

A. Yes.

Q. How is it helpful?

A. You get to try out new computer stuff, and the graphs are really great. The way you can play with all these apparatus is great.

Q. So it's more interesting, and you like the graphs?

A. Yes

Q. You know that you have to put some extra time in the computer lab, you have to learn other things, for example, when we did that heat experiment, we had to calibrate the computer. So there was extra work there. Do you think that it's worthwhile doing that extra work in a computer experiment?

A. Learning more things is better than learning just the simple things. If you learn more advanced things, then it might help you later on. You might have to go into a place and they ask you to do something, and you have all this different equipment, and if you know something about a computer program, or the apparatus, it helps to figure out how to work the apparatuses.

Q. How did you think the computer didn't help the lab, where was it not helpful?

A. One thing, there wasn't enough computers in the room. The one is was watching didn't really work. You need the teacher to introduce them. The teacher should know enough about the computers.

Q. Do you think more of the experiments in grade 11 chemistry should be computerized?

A. Some of the labs you should. Others aren't appropriate.
Q. I'm going to ask you a couple of questions about your sheet. This is what you wrote on it at the time, and in fact, you had the opportunity to do the experiments with and without the computer. Which parts did you see, clear and easily understood, after the temperatures were in the computer, it was easy because the computer did the plotting. If the computer does the plotting, do you think you learned as much as if you did it yourself?

A. Well I think you should have it so that you can do it on the computer, but first you should do it by yourself, and then just compare. This way you have two ways of comparing.

Q. Another one here, "information along the way helped, even for people who didn't know how to use the computer." So you like the diagrams that I used with the computer. How else could I make the computer lab easier to do for students?

A. Well I put a bit of information on the bottom saying what to do, why you have to do that, and other things like that.

Q. Do you think they should have a class on the computer?

A. If we have a class on learning how to use computers, than it kind of takes away from the other things. Maybe we should just learn as we are doing it, like on the job training.

M (Female)

Q. Did you have an opportunity to do the temperature experiment? The paradichlorobenzene?

A. I had the opportunity of seeing it done, but I didn't do it. I didn't get to use the computer.

Q. If I told you that tomorrow you're going to come into school and that you're going to do a computer lab, what do you think?

A. Probably I think it would be easier, because you don't have to write up the data.

Q. You said it would be easier because you don't write up the data. If it's easier, do you still learn as much?

A. Well it depends on the person. If you want to learn it, you would look at it and learn it, and you don't have to write down data because the computer does it for you.

Q. So having the computer do it for you affect that?

A. No I don't think so.

Q. You mentioned the fact that you don't have to write it down because the computer does it for you. What other positive things do you see about using the computer?

A. Probably more accuracy.

Q. What about negative things then? Things that didn't turn out to be good about the computer?

A. Well sometimes the computer wouldn't work, and a lot of people didn't know how to use the computers, so then you would have to learn how to use computers before you use it in the lab.
Q. Do you think it would be worth the expense, and learning about the computer, to use the computer in the chemistry lab?

A. Yes. I think that these days, more and more people use computers. So you would have to learn about computers. It's more common.

Q. Do you think we should computerize more grade 11 school labs? Do you think you would like to do a computerized lab on a regular basis?

A. Yes, I would.

Q. Computerized labs take a little bit more effort sometime, there a little bit more work and you've got to do things like calibrations and printouts. Is it worthwhile doing this extra work?

A. Yes, I don't think it's a waste of time.

W (Female)

Q. I'd like to ask you some questions about the labs that you did or saw in grade 11? First of all, do you remember the computerized labs that you did? Can you tell me a little bit about it?

A. I remember doing a moth balls ones, where we would take the probes and put it in the test tube, and it would record the melting point. That's what I remember about that one. I don't remember any other one.

Q. About the temperature one, did you have the opportunity to use the equipment?

A. No, I watched other people use it.

Q. What kind of impression did you get from it?

A. I thought it was a bit more work, because it wasn't very quick to get the data, and it needed adjustments all the time.

Q. What about the idea of using a computer to do that lab?

A. I think it's a good idea.

Q. What advantages would there be in using a computer to do a lab that way?

A. Well it teaches students about using the computer, and it would give them experience of using that sort of thing because I've never had computer experience.

Q. What specifically about the lab, become better, easier, or what are the advantages?

A. I can't see any advantages with the lab specifically, but just getting experience with the computer is something that would be an advantage.

Q. What would be the negative aspects, or what would be bad about using computers in the labs?

A. Well I wouldn't have the first idea as to what to do. I really know nothing about computers. If it was a guided thing, where right on the screen it would say do this, then it would be easier.

Q. What other things do you think would be negative aspects about using the computer?
A. I really can't think of anything else.

Q. Did you learn as much science using a computer, as not using the computer?

A. I wouldn't think so, because if we still mixed our own formulas and chemicals, then I wouldn't say so. It would just be recording our temperatures or graphing for us. We would still have to analyze our own data so then we would still learn.

Q. So it's still the same even if the computer does the graphing for you?

A. Yes.

Q. I have a couple of questions here from the sheet that you filled out. The parts of the experiment that did not appear to be straightforward were setting up the apparatus and calibrating the probe. I would like to ask you a little bit more about calibrating the probe, do you remember probe calibration?

A. I don't really remember that, but I remember you had to do something first with the room temperature, and putting it into something hot. I was just confused about the way you do it. I never really understood that.

Q. What would I do to correct that?

A. Like you could give out hand-outs, or instructions before hand on how to do it.

Q. You also mentioned here, "Design a practice activity, help the student familiarize himself or herself with the apparatus and programs. What kind of practice activity do you think would be a good exercise for the temperature one?

A. I don't really remember. I had something in mind, but I think it was just a basic thing that would take you through all the procedures on calibrating or even a graphing activity.

Q. Do you think we should computerize more grade 11 labs?

A. Certainly.
Q. I have some questions about the lab that you say demonstrated, the paradichlorobenzene lab, and I'd like to ask you if you had the opportunity to play with the apparatus during the lab?

A. Yes, I did.

Q. What did you think of the computer in the lab?

A. Well the apparatus was set up okay. The computer part of it was pretty easy to use. I took a little while, but I got it. As far as I can remember, I don't think there was anything wrong with it.

Q. Have you used computer before, are you familiar with computers?

A. Yes I have used computers before and I am familiar with computers. I'll be taking a course next year.

Q. What parts of the lab do you think were positive, or better? What parts in the chemistry lab were made better by using the computer?

A. The process of the information. It was a lot easier to complete it. The procedure was putting it on to a computer so you didn't have to refer to your lab book. It was pretty clear instructions.

Q. Those are the advantages of using a computer. Now, what would be the disadvantage of using a computer?

A. Probably if you didn't know how to use a computer, you would really be stuck for how to get it into the program itself, let alone printing it. I think that's about it.

Q. You mentioned calibration a few moments ago. What is calibration in your own words?

A. With this particular thing, it was the calibration of the heating lab to get set to certain amounts, so that the computer would know to work off of. It would know how high to go for the heat to be accurate.

Q. How could I improve the experiment set up, and actually doing the experiment? How could I make that more straight forward?

A. I can't really remember what I was thinking when I wrote that down. I think more instantaneous, when you turn on the computer the program is there so you don't have to worry about finding it. Well we didn't have a task to save it for ourselves, so we didn't have our own information, it was all on your own disk so we couldn't go back to reference raw materials.

Q. There's a lot of extra work when you're doing a computerized experiments. You've got to do things like calibration, and getting printouts, and bringing all the computers in the lab. Do you think that would be a worth while thing to do for some labs?

A. For some labs. It would be worth while if we all had our own disk to copy on information, and bring it up later. It certainly makes it easier, but we don't know how to use computers so it would probably be a lot more difficult to get results.
Q. Do you learn as much when the computer does your data table and graph for you, as to when you've got to do it yourself?

A. Well you're not getting any verbal instructions, you're just getting visual information and sometimes you just might want to skip pass that part. With instructions, if you just go to the lab you might not learn what exactly you're suppose to do, unless of course you had to read it first. Someone who flips through all the instructions and goes right to the lab part wouldn't know what to do. They would have to restart going through the instructions.

Q. Let me try this question at a different angle. If I do a chemistry test on a student that uses the regular laboratory, and a chemistry test on a student that does the computerized lab, who do you think would do better?

A. I think the person that does it manually might have a chance to reference notes, because he doesn't have a Mac computer at home so he can't study, so he wouldn't be able to look at his notes and he doesn't have the lab to look at, unless he prints it out.

Q. Supposed he printed it out?

A. Well if he printed it out, it might just print out the table and maybe some information. It might not give the procedure and the questions or whatever.

June 12, 1990
TAPE III Richmond School Interviews Side 1
SIDE I -- All Students from Z's class -- Grade 11, demonstrated 2A only
Total run time 22 minutes approximately

A (Female)

Q. Do you remember the computerized lab that we demonstrated here? Can you tell me a bit about it?

A. Yes, I do. Isn't that the lab where you melted stuff, and then cooled it again. I can't really remember.

Q. Did you get a chance to use the equipment during that demonstration?

A. Yes I did. What was the experiment about, I don't remember?

Q. It was actually the freezing point of paradichlorobenzene (Mothballs).

Q. What did you think about the labs? What impressions did it leave you with?

A. I thought it was really interesting, and using the computers was really interesting. It really helped because it made up the graphs.

Q. So not having to make up the graphs was an advantage?

A. Yes.

Q. Do you think you learned less during a lab, if you don't make the graphs and the computer does?
A. Well, if you the graphic skills, which they teach you how to graph first, and then to say that you can do it up on a computer, I think that's okay. But, I still think they should teach you about graphs because I don't really think that the lab isn't really for learning about graphs, right?

Q. What do you find about it that made the lab more complicated, or had a bad effect on it?

A. I guess just learning how to use all the equipment, and some people don't use the computers because they're afraid that they don't know how to use a computer properly and that they might screw everything up. A lot of people don't have computer skills, and that makes it hard. If you have a detailed procedure to follow, things won't be so hard.

Q. Do you think that going through those procedures, and teaching that extra stuff really makes it worth while?

A. Yes, I think so because it has a lot to do with computers. I don't know much about computers, but just working with them it sort of makes you worry less about them.

Q. Do you think that regular labs in grade 11 should be computerized?

A. Yes, a lot of them. However, some of them should be but not all of them. The longer labs where you have to do a lot of steps with graphs, and where it has a lot of data, like data tables, should be entered on a computer because it makes it easier. There's no point in writing it down when you can just stick it into the computer.

Q. Just as much science would be learned do you think doing it that way?

A. Yes, I think so. As long as the computer does not do too much for you. If it's just used for storing information, and like printing it up. Like some of the labs we do is just learning basic skills. We should still have all the basic skills.

D (Female)

Q. If I were to tell you that you are going to do a chemistry lab using a computer? What does that make you think of?

A. Well it would be very controlled. There wouldn't be a lot of errors. People do labs and they make a lot of errors. They don't time it correctly or whatever. Computers just seem a lot more efficient.

Q. Does this make you feel better or worse about labs?

A. Well I don't know, but for some reason I have a prejudice against computers. I think that they might do a job better, most of the time they do (and I use them myself for reports and stuff), but I just think that people seem to lose touch with what they should be doing. They should be doing the experiments themselves. I don't think computers should be used for in a lab.

Q. So you think that they're kind of a barrier between you and the experiment?

A. Well I know it sounds kind of funny, but I don't think computers should be used. Well actually, they should be used, but I think you still should do the experiment yourself. It's a lot easier to understand if you do it yourself. If you tell the computer what to do, they'll just do it themselves. Computers are not as personal.

Q. Do you learn as much science when you use a computer as to when you don't use it?
A. Yes, I think so. I don't usually learn anything when I do the lab until afterwards, and then the fact that I did do a lab makes sense. While I'm doing it I don't understand.

Q. How could computers be made more personal do you think?

A. Well, like I said, I do have a prejudice against them. I don't think most people do find that their impersonal, so I don't think there would be a problem there. I can't really think of anything else right now.

Q. I do agree with you about the impersonality of computers -- and the fact that I've written other stuff on where computers are for instance, and totally opposing to using computers to instruct small children -- but what I want to get at is the reasons. I want to get more details on this event. Just because it isn't common, it doesn't mean that it doesn't exist, or just because it's not widely perceived by many people, doesn't mean it doesn't exist. Its something that is just not recognized in a majority of cases and that's what made me most interested in your case, is the fact that you brought the point up. For instance, here you talked about a chance to plot a graph. The graph is simpler to plot, but the students didn't get a chance to plot the graph, but you still say it's fine the way it is?

A. Well you know how the computer just prints it up by itself, it could kind of ask you what to do, but you could end up doing it wrong still, and then you get the chance to learn what you did wrong.

Q. Do you think it would be appropriate to computerize grade 11 labs?

A. I don't think so. Some computers are alright, but I don't think the whole school should be computerized. It just doesn't seem like science, well computers are science, but of a different kind. I mean that it just didn't seem like chemistry anymore.

A (Female)

Q. I have some questions about the lab that you were demonstrated several months ago on paradichlorobenzene. Do you remember that? Can you describe to me what happened?

A. Yes, trying to find the melting and freezing points of paradichlorobenzene and used the computer to find the temperatures and graph it up for us.

Q. If I told you that you were going to come in and do a computerize lab tomorrow, how do you react to that?

A. I don't know. I think it was an interesting experience using the computers, and once I got use to the system, I really enjoyed it a lot more than I did then because I didn't have much practice.

Q. What positive things do you think comes out from using the computer? What are the advantages to using a computer?

A. It does all the graphing for you, so that your information is set out right in front of you and that you don't have to copy down all your numbers. It's faster, probably more precise because you're not looking to human errors.

Q. What disadvantages are there?

A. Maybe setting it up, it might not calibrated it properly and that would effect your results, or if there is any kind of bug into the computer system.

Q. Given the fact that it is more complicated, like setting up the computers, printing, and calibrating, do you think it's still worth while to do a computerized experiment?
A. Yes, I think professionally it would be a good idea because if you need to do experiments over and over again, and if you have a computer it's quicker to do it with the computer, than that would speed up scientific discoveries.

Q. Do you think you learn as much science when you use the computer or when you don't use the computer? Do you think you learn as much chemistry with computers experiments?

A. I think it's important that before using the computer, to learn how to do the graphing on your own, and then once you know how to do it, then its just repetitiveness for you, so you might as well let the computer do it.

Q. So you think you've learned just as much by doing the computer version as to doing the regular version?

A. Pretty much so, yes.

Q. You mentioned calibration, can you describe what calibration is? Use your own words?

A. What we did was we took the temperature stick or whatever, and we tried to get it to O degrees and 100 degrees, so that when we did the experiments that were going to have the proper gages to what temperatures it was at.

Q. Do you think more grade 11 labs should be done on the computer?

A. Yes. I think it would be beneficial to several of the labs here.

Q. Several, what about all the labs?

A. Well some of them aren't worth it. Some of them are just little things like looking at chemicals and looking to see if there's a reaction. It's not worth it.

Q. Okay, so they not readily computerizable?

A. Right

M (Male)

Q. You had an opportunity to see a demonstration earlier this year, of a computerized version of the paradichlorobenzene lab. Can you remember, and describe to me what happen there?

A. Basically in the lab, we measured the heating and cooling of paradichlorobenzene that using, I don't know exactly what you might call it, it's a little metal rod?

Q. It's a thermometer.

A. Right. The computer took the heat information in through, processed it, and put it into the computer whereby the computer printed the graph temperature results of the heating and the cooling of the paradichlorobenzene.

Q. If I told you that you were going to do a similar experiment, or you're going to do a chemistry experiment tomorrow using the computer, what's your reaction to that?

A. Basically, I like that idea. Mostly for the reason that ordinary chemistry labs are sort of boring. It's neat to get a computer in there and get it to graph your results for you. It's quite a bit more accurate. To have a computer, it's sort of like the computer does some of your lab for you, and does it much more accurately than you could possibly do it. It's sort of like almost a fun way to learn.
Q. Okay, so it's more interesting?

A. Yes.

Q. You mentioned having the computer do the graph for you, do you learn as much science when the computer does the graph, as to when you do the graph? Or do you learn as much chemistry?

A. Well it's hard to say. It depends if the computer prints out the graph and you look at the graph, and you study it after the computer has printed it out, then yes you learn quite a bit. But basically, for the sake of learning, it's better that you actually do the graph yourself because then you could see the trends as you're plotting them out.

Q. What negative aspects are there to the computer, or what are the bad aspects of using a computer in chemistry?

A. The bad aspects for one, just temperature recording. The computer basically does stuff for you that if you were to get into science later and be involved in research, for example, your doing labs in a laboratory for some large chemical company or something, it's a good idea for you to get into the habit of say, taking the temperature yourself instead of having the computer doing it for you. Then there's also the fact that probably computers are being used more and more to do chemistry labs such as this, and therefore, to get us to computers in a chemistry lab is also a good thing.

Q. If you knew how to graph, and you obviously do, and you use the computer to graph your experiment, is that okay?

A. I think it's good because if you know how to graph, if you understand the trends that are going to be happening throughout the experiment, the computer will do a more accurate job of it for you, and it will save you work, and save you from doing all those tedious boring things and the computer does that for you. In that case it's very good.

Q. But in teaching it isn't always good?

A. Yes. Like if you don't know how to graph, for example, or if you don't know what trends are suppose to be in the heating or cooling, for example, then it's better for you to do it yourself.

Q. The computer makes things more complicated in other ways too. For instance, in order to use a computer, temperature probe, you have to calibrate it. Do you remember the calibration procedure from this experiment?

A. It was quite a while ago. There's something about matching temperatures or something like that. I can't really remember now. But the one thing that didn't strike me about the experiment, it's been rather a bother, was having to calibrate. If there was no anyway to not have to bother calibrating, like it's already positioned, like if there was anyway to do that, that would be a lot better.

Q. There is extra work in this lab particularly, with the calibration there. There's all sorts of things, like trying to get things printed out, getting computers in the lab, there's a lot of work for both you and the teacher. Do you think it's justified to do that for some chemistry labs?

A. Well for the sake of learning, I'm quite sure that in many chemistry labs these days, they get computers to do much of the work and to check temperatures and the what not, and it's good to learn the old-fashioned way, where you're doing everything yourself. But to get a computer into a lab and to get people to work with computers; these days, it's become more like a computer age and everything. Computers are becoming more and more involved in people's every day lives. It's good to get people involved in computers and science at the same time because that's the way everything's headed. So I think, not all the time, like not all the time it would be worth to bring a computer into a
lab, but every several labs for example would be quite worth while to bring a computer in and get people to use the computer, and let them get the feel of computers and science combined.

Q. What makes a lab better to computerize, than other labs? Which ones would you make computerize and which ones would you leave?

A. Basically the labs that I would computerize would be labs that required the input of a lot of data. For example, labs that would require that the computer produce graphs for them, labs that require certain exact timings for example, that you get the computer to keep track of it.

Q. So computers are for accuracy and plotting data?

A. Yes, for example, simple reactions like an acid-base reaction or something that produces salt and water that computer isn't any good for a reaction like that because it just involves maybe one or two temperature readings, and some observations that could be written down in English, or whatever, and don't need any data. That would not be an ideal lab for a computer.

Q. When students are given instructions on how to do a computerized lab, what's the best way of doing that?

A. Basically the best way would be to tell students what is going to be done in the lab, what's going to happen, and then introduce them to the computer, and tell them how the computer works, how the computer is going to achieve various parts of the labs, and do some of this work for you (take the data observation for you, and how this works), and then introduce them to the computer and show them how to operate it. So that you get first told what the lab is, so when your introduced to the computer you can understand what the computer is doing with regards to the lab.

Q. Shouldn't we be talking about computers in chemistry class?

A. Oh yes, definitely. Computers, as I said earlier, it's sort of like computers are technology, and more computers are becoming more and more involved in science; therefore, it's a good idea to introduce computers in chemistry class, in physics class, and in any class at all. Any science class, except for biology, because we don't need computers for biology, but physics and chemistry definitely. It's good to inter-mingle among computers.

Q. How could I better explain calibration to students? How would I go about doing that?

A. I can't exactly remember the calibration process? I put the probe in cold water, took the temperature, and typed into the computer. I put it in hot water, took the temperature off the thermometer and typed it into the computer. Than the computer knew what was cold and what was hot, it had a scale, and it read between the two. Right. I think the logics of it are quite simple basically. Even if a person doesn't know how to do it, all you have to do for a lab is basically, if you want to get them to calibrate, just teach them the procedures of how to do it several times until they know how to do the calibration even if they don't understand how it works, because there's really know need to understand how it works, you just need to know how to do it?

Q. Do you think I should teach the theory behind the calibration as well?

A. Well that depends if you really want to get into computers in the laboratory, and how this computer works, but for a chemistry lab for example like cooling and heating, how the calibration works and the functioning behind it is really not that important. All that the student has to know how to calibrate precisely so that the rest of the experiment will work out fine.

June 26, 1990
Richmond School Tape IV Teacher Interview -- Teacher Y

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Q. What do you think of the approach of having someone come in from the university to do research in the schools, and to come back several times, and be held accountable to the teachers and students that they're working with?

A. I think it's a good procedure for several reasons. One reason being that students too often at this age group don't interact with people from Tertiary Institutions from universities or colleges, and to actually have an adult student who's doing real research in science education I think is a real eye opener for these students. The fact that also you do come back, there's a commitment, it's not just a flash in the frying pan and off you go and we don't see any results or any supportive work from you, I think it's been good that you have been with the students on 2 or 3 occasions in my class. I think that just the fact that you are a science researcher, and they you are able to actually see a real person doing this research and the fact they are able to be involved with that procedure in the process, excites a lot of students.

Q. What about the contributions that teachers and students make to the research itself and their contributing in an aware sort of way, such as you are making recommendations about the equipment that I'm changing and bringing back? How does that strike you? Do you see weakness or strengths with this?

A. Well for you I can see a lot of weaknesses perhaps, because it is random, and it is part of research of course. You have to sit through a lot of dead wood perhaps, before you can grasp something important, but again that's research isn't it? So it is obviously tedious and a lot of hours for something though that may pay off. Certainly when it is part of a curriculum. Computer involvement is something that's would be a dynamic part of a curriculum, has been ignored certainly in the text books point of view up until now.

Q. So you see the computers as being able to play a larger role in a curricula than the curriculum that they do now?

That's if assuming that you're not part of the curriculum at this point. Your an innovation.

Q. But you see in the future down the line that there are going to be more computer involvement in the high school chemistry curriculum?

I hope so. That's one good part of this research is that it forced me to be involved. I gave the o.k. too. I know it's just a small involvement. That's why I liked it. It forced me to use something that was a nice idea, but I'd probably be too, well I'm not computer illiterate enough, to want to go ahead and do this kind of stuff on my own. Technical capabilities or mental laziness, or what prevents me. It was a great opportunity. I welcomed it and I could see it on the faces of the students, it was a good change of pace. No doubt this is the way labs are operated in industry and government research centers.

Q. With the specific application, bringing computers into the laboratories, what do you see are the strengths in incorporating computers into your standard laboratories into your teaching?

Well the strength for one thing, it is more up-to-date, it's perhaps a reflection of industry and research government labs. It also takes the tedium out of science education which too often is put in where students feel they're working hours on tables and graphs, consequently, the computer takes over, and the students don't have to understand how to set it up, how to plug in the data, how to interpret the data; therefore, the tediums are removed. It's efficient, impressive, it's high technology, and it gives the students a closer touch of reality than we normally do with our emphasis maybe on an old Bunsen burner tests too often.

Q. Now there have been a great number of difficulties in incorporating this technology. What do you see as being the greatest difficulties in bringing computer or MBL technologies in this class?
A. One thing that impressed me, and sometimes when it happens to me, I kick myself, why is it going wrong? or why isn't it working the way it should. But that's real science. Too often we expect these students to come in, to a lab situation that they've read about in the textbooks perhaps, but they've never done this before. They've never mastered the psychomotor skills necessary. Then we expect them to do it once, and do it real well, and they're marked on that, and then we're off to another different type of assignment that require different skills. Once again, it's a one shot effort. Here you were doing something yourself and you were making mistakes. Now, normally we penalize students for making mistakes on something they do for the first time, and here you have been doing this many times and you still not quite getting it right, but your adjusting and that's the real world--trial and error. We don't see that enough in science education. We pay lip service to trial and error.

Q. So you think that it's educational science as opposed to real science?

A. Exactly. I think that's a real positive asset that you've brought in, is the fact that here's a student who's still trying to refine the techniques, admits to making mistakes and learning from these mistakes. You can help him learn from these mistakes. I really enjoyed that. That was the most impressive thing I got from the first session, when things weren't going well.

Q. The actually the latest research is built on repeated iterations where I'm coming in, and getting closer approximations each time I come in. It's deliberately laid out, and you will see that when I'm writing this stuff up. It will be done as a series of success of approximations.

Q. Negative aspects of technology in chemistry classrooms?

A. Well the fact that not enough students could get directly involved with the computer was the big minus. That prevented half the students of being involved, or chose not to be, they just used the standard equipment, or just stood around and watched others do it. It was interesting that the students had tended to be really involved in this. Many of them were students that I knew were on consentive programs. So you'd really spark the interest of the highly motivated students. I think a number of monitors and computers, which we had 2 or 3, was a limiting factor in the success. I assumed that we would of had a higher interest if we would of had more computers.

Q. What other aspects do you see as being riveting aspects?

A. Well I don't know how many more labs you could apply for the curriculum, but I think those two labs you chose were well suited for the interface with the computer.

Q> Obviously, the majority of the labs are probably not available?

A. No, so its something that won't be used fairly often. Not in the grade 11 end of it, which is the only curriculum that I could speak of right now.

Q. What about the technical particulars of bringing this hardware and materials in? Do you think that it would be very daunting for a chemistry teacher to get into?

A. I don't think so. I think you'd have to get them corralled into a workshop before, so you could see how it works, so you can get your hands on it, and you get bitten by the bug. At first I was bitten, and thought a computer, big deal. After a while, I got quite enthusiastic. You would have to do workshops to get the teachers involved. I'm not sure of the pricing that's involved either, with the budgets being so limited as far as hardware, the space, and the facilities.

Q. What would you suggest to teachers who are considering getting involved, and using computers in their laboratories?
A. I'd suggest that it's certainly worth the experience, because it is going to be a high interest generator for the students, and yourself you're also going to learn. It's just a nice change from the normal routine that we can get ourselves into, and I think all teachers do. We do things that are safe, that we've done many times before very well, and I don't think there's as much learning that goes on. It's a different type of learning, and that's always exciting. You could probably excite some student that's been bored in class, or that has just gone along with the flow of the lessons, and are not really excited. You can see that. You can see strengths come out of students, and abilities come out of students that were latent throughout most of the course. You see the leadership come out too. I was impressed the way some students just took control when something when things went wrong for me, and not being an expert at computers, they were able to solve problems with other students, you've got cooperative learning there which has a real place in research, and assumed leadership roles that before the students were just content to just sit back and let the teacher be the guide. Now their the teachers, and the teachers are the students. I think it's a humbling experience, but I think its a real life experience and I think that this computer brings us up to the 20th century.

June 26, 1990
Richmond School Tape IV Teacher Interview -- Teacher X
Total tape run 19 minutes approximately

Q. What do you think of the methodology of doing research in a working classroom, and bringing people in from UBC and having teachers, and researchers, and students all together deciding on how the research is being done?

A. I think its an excellent method of that type of research. You have a global idea of what the project's all about, you have input from different sources, and once you have collected all your data, you have a firm background to refer to. I think that doing the actual research in the classroom is great opportunity. Your right where the action is.

Q. Because its in the classroom, and because the teachers and the students are involved, its a more real thing than just sitting back at the university.

A. Absolutely. Its more than about time for people to get out into the actual situation of a classroom, and see what's happening in an actual classroom situation.

Q. Obviously we were looking at making some changes in the curriculum during this project. Do you see a role for the computer in the science curriculum in a few years time? or at present?

A. Absolutely, I haven't been involved in the latest curriculum division of chemistry, but I think that we've made a breakthrough in 1985 when we started the revision, in that at least we had an opportunity to incorporate just some computer items such as, small references to software and so on, for students and teachers to use that they never had before. This is the first time that any curriculum guide, this type of situation has occurred in the curriculum after a revision of a course. So, I'm very pleased to see that we have the approval of the powers that be, to implementation. It goes along with the guidelines that we need to incorporate the technology that is presently available, and at least make our students aware that their are technological changes in the computer world that could be applied in a science situation like a laboratory. I think that if nothing else with this type of approach of incorporating of the computer in the curriculum, the student will be at least exposed to what's happening in the real world. They go out of here, and they will go unto any kind of science labs, and there will be computer interface galore, everywhere they go. Even if they don't take science anymore, at least they will have had a taste of what's going on in the real world. I think that more and more of this we should see in the curriculum, and I think that the revision committees should keep that in mind when their upgrading the curricula. I think that they should have full back up support from the minister of education.

Q. What are the strengths that you see in bringing computers into the high school chemistry?
A. Well for one thing, as I said, its the corporation of the most advanced technology into a classroom, into a laboratory situation. Secondly, you have a motivation factor for the students. Its an innovative type of situation where the student can be excited, with the novelty of the computer in the science lab. They can effectively apply some of the techniques learned, and some of the theory that could be arrived at by a laboratory experience. I think a laboratory experience is more meaningful with a computer used as a laboratory aide.

Q. How is it made more meaningful?

A. The students do not have to waste an enormous amount of time in doing some basic things that should have been learned before, ie: graphing, or unnecessary computations that could be done either before or after this step could be performed. They can get instantaneous feed back out of what's happening in the lab, instead of having to interpret their own, I think that's the meaningful part of it.

Q. What do you see as being the negative aspects of bringing computers into the labs?

A. Well the negative aspects of computer, I wouldn't say negative aspects of bringing computers into the labs, but the negative aspect of implementing the computers is that we don't have enough computers for all of us to use; consequently, some students may be using this tool, as some students may not be making full use of the computers because of lack of it. I think that's one of the major obstacles is implementing a curricula using the computers, simply not having the availability of computers in science labs, and I think that's part of the problem that we probably have to work on in the future. See that we get the funds to get the appropriate number of computers so that we can implement them. I really do not see any other negative aspects of computer usage, maybe there might be some people who say "okay, well you are replacing the experiments with computers, and that is not so, the experiment is still being done, performed. All were doing is using a computer as a tool to more effectively implement some of the techniques that are learned.

Q. What about the administrative tangles of getting computers in the classroom?

A. Well, that's again another aspect of not having the computers allocated for this particular project. It's been a little bit of a headache trying to assemble and get the computers, such as borrow, beg, steal, type of situations until we get the computers here. But once we have over come those obstacles, than everything went smoothly.

Q. Besides just getting the money and the computers, what preparation would teachers need to have?

A. Well the teachers will need to have a minimum amount of computer literacy. They have to be familiar with the basic operation of a computer. The technical, chemistry, or science aspects should be no problem at all. But if you have basic and very clear instructions on how to start an experiment with the aide of a computer, I think it should be no problem. Any teacher with a minimum amount of knowledge of computer usage, like the mouse, the keyboards, any teacher with those basic concepts of computer operation should have no problem what so ever in implementing the type of project that we have.

Q. What words of advice would you give to a teacher who's thinking about getting into computers, and is his or her science lab? How would they go about it? What kind of bits of advice that you could give them?

A. Well in order to implement a science course using a computer as a laboratory tool, I would say that they would have to present a solid case regarding the pedagogical positive aspects of using the computer in a science lab. They have to have to a good proposal, a good project to back up the requirements or whatever. I think that if the programs are in place, if the labs are in place, all the
Teacher has to do is say "Hey, we have an excellent application of computers in a science situation that's applied. That all depends on how strong the proposal is. How well administration will take it. I think its a selling job. If they can show the pedagogical validity of the proposal, then there is no problem. I wouldn't be surprised if in the near future that there will be more computer applications in science.

June 30, 1990
Surrey School Tape IV - Teacher Interview -- Teacher Z
Total tape run 11 minutes approximately

Q. We just came off a long project together working on the MBL experiments. I'd like to ask you what you think about involving teachers and students in the design of classroom research?

A. First of all, increase in technology in the classroom is a great benefit. So much of what happens so far in chemistry is involving dumping one liquid into another liquid in a test tube, and where we have the technology being used that become more familiar, particularly beneficial with the girls. They very often are excluded from technology and this is one way of giving them equality with the guys.

Q. Why is this specifically important for the girls?

A. In the past, they have had a much more passive role in our society, and to a large extent, people assume that they are not as able to do things involving equipment. Whenever a situation in a classroom is designed where the girls have to be completely equal with the guys, they get the same sort of experiences and overcome their fears of operating equipment like this. This is also a benefit of having them do laboratory experiences in the classroom. I actively make sure that the girls have the same equal status or participation in the lab, and that we don't have the girls, as they sometimes want to do, become the helper, and the guys become the leaders in the lab situation. The technology of using the MBL project further encourages that and it seems to give them a lot of positive feedback in using the technology and being more competent with the equipment.

Q. This study in particular, incorporated your own suggestions and things that you suggested to prove what was going on during the research design. How do you feel about teachers interrelating with university people or researchers to do this research? What kind of role do you think a teacher has to play?

A. I see two aspects of this. One as my own personal input. I am very much looking to expand my experience in these areas, and I have been very excited to work with your project because I have learned a lot. I have come to understand better how the students work in a project like this one. So, I've been expanding my own personal goals, if you like, working with you, and being able to give feedback on the developmental software. I am quite interested in computers, and if the opportunity presents itself, I may do a little programming or possible modification of what you've done. In a general sense, I don't believe that all teachers would want to be involved in the nitty gritty of working in an MBL type project, and helping in the design in it. Teachers tend to be over burdened with tasks, and day-to-day activities. One, to have a completed project that fits into the curriculum that they can essentially take off the shelf and put it into practice in a very easy manner, especially in the cases where some schools don't have lab assistance with a set up like this that can be put together very easily without a lot of hassle, and that can be done and utilized simply. To summarize that, I think that teachers generally would not want to be involved in this type of project, but personally I quite enjoyed it.

Q. Do you think that its important that new changes that are brought into the schools be reviewed?

A. This is what makes education much more effective. I think that more teachers are able to be involved with universities and develop new materials. The teachers who would work in this area,
would be more aware of what other teachers are having to say, and be able to initiate situations that
they've heard of from other teachers. Not all of my own ideas have come from myself. I've heard
people making passing comments, and I thought that it was a good idea, and then maybe in some
situations, I decided to pursue it myself where they wouldn't have had the time or anything.

Q. Getting to the actual topic of this study, and not so much on the design of the study itself, what
do you feel is going to be the role of computers in science education in the next 5 or 6 years?

A. Well, it's nice to think about what would be ideal, but I think funding is going to be the major
limitation to this sort of thing. It's going to be slow to be brought in. I could see an MBL laboratory
designed, which would be accessible to students throughout the school. In our school, we are just
now setting up a Mac lab. This coming year we'll be getting funding for the other half of the lab.
We'll have 25 computers then in the lab with a Scanner and overhead projector device. Were now
finding ways for teachers to use a school wide accessible Mac lab and the same ways that our
library's used now, where teachers will book a class into the library for a period and maybe a series
of 3 or 4 periods to do a project in some kind of research in the library. A similar kind of lab could
be set up where teachers would book a series of classes to do an MBL project, and then to possibly
take the result of that back to the classroom to analyze it, or maybe to the other general purpose
computer lab to do some further analysis of the data. But in order to have a separate classroom put
aside for laboratories, for instance, is going to take some time to set up equipment and all the other
things.

Q. How did you think the students felt about the incorporation of computer technology into their
laboratories?

A. They were generally quite excited about doing it. When we had to delay a class because of
other difficulties that we had, the students continuously kept asking me when they were going to do
a lab. I gather from this that they were quite excited and were looking forward to being the first to
be involved in using computers to do a lab. Then I saw the understanding that happened because
they were able to do an activity in the lab which they put a certain volume of liquid into the solution
and to see the pH change dramatically on the graph when it was going alone for a while. To make a
reading on a buret is not as understandable as to see the flat curve on a graph, so they could see
much more dramatically when something was happening. Not having to think about the process of
plotting, or not having to think about how the variables were changing, but simply to observe the
changing. They were able to jump into higher levels of questioning right away, and understand the
process of it more quickly.

Q. What negative aspects did you see involving, first of all, the students use of MBLs, and general
for a teacher to incorporate MBL into the classroom?

A. Well as far as the students use, there were some of the students who were anxious about using
the equipment, but hesitated a bit. Also having groups of 4 students at a time, I think was not so
optimum. It would be better to have groups of 2 working on it. Of course, it's not possible to have
so much equipment available. In one situation, we had to wait to get the printout, so then the
students had to come back at the end of the day to receive their printouts. However, some students
didn't return to pick them up. That was a negative. It would be much better if things were available
immediately. About the actual process of doing the lab, I don't see any major draw backs from the
students point of view. From the teachers point of view, setting up the equipment was a major
problem. That was very time consuming. We had to borrow computers from the Mac lab, which in
the future they're going to be tied down with cables, it will be much more difficult than setting up
for next year, so those computers won't be available next year. Then the problem of getting enough
computers from other sources is going to be a challenge. Then, all of the process of setting up the
equipment so that it can be used, and checking out each one to make sure it works is very time
consuming. I'm sure that process could be simplified. I guess lab set up is the biggest drawback.
The rewards of having the students getting the feedback on the lab much more quickly, may off set
it. A major problem with many teachers is not having lab assistance in the first place to do this type

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of set up. If the teacher has to do all of the set up, than this type of project might not occur in that particular school.

Q. Do you see this kind of experiment as having an increasing role in the curriculum in years to come?

A. Well I think it's inevitable. This is the direction of change, which is to have more technology. As time goes on, if more teachers have the proper support and the funding is in place to purchase this type of equipment, and providing that the teacher learns enough about the equipment to understand how to operate the computer, and to do it, then the teacher may use it. I think whenever something is easy to put into place and accessible, then the teachers will take the advantage of it, unless the teachers are not involved in technology itself.

Q. Do you feel that the technology is appropriate to a curriculum?

A. Yes, very much so. This project was exploratory in my opinion. We chose some areas that were already existing in the current curriculum, and attempted to develop them so that they would function in the class room. There are more areas that have not been thought of and need to be developed, which much more work would need to be done to link these directly to the curriculum may possibly change the curriculum. More things can be done with this, and this area has not been explored in any great extent. This is something that I personally would like to be involved in. As a result of taking part in this project, I've learned quite a bit and saw that it was a very useful thing for me to do. I quite enjoyed doing it.

Q. So you feel all the heartaches and the headaches were worthwhile then?

A. Yes, I do. Its an area that I see expanding in the future. I've learned a lot from you, Dan, from doing this and I hope you feel that we've helped each other.
Experiment #19B was covered today by all three block of Chem 12 students at [DELETED] this morning. The lab procedure involved a prelab quiz, followed by a lab demo by the teacher. Then various strength concentrations of SCN- and Fe+++ were prepared by the students through dilution of stock solutions. The students then mixed these solutions, which formed a brown suspension of FeSCN++. The strength of the reaction products was determined through the use of a spectrophotometer which determined the optical density of the solutions. Students have covered reaction and equilibrium theory and had previously used the SPEC 20 before this lab period. Students worked in groups of 3 to 5 on the procedure (limited by the # of SPEC 20s).

The MBL demonstration consisted of the connection of four SPEC 20Ds (two were loaned to increase the # available) to four Macintosh computers. Cabling and software produced by CERG allowed the students to calibrate the Spec 20Ds with assistance, then to record SPEC 20 measurements, enter calculated solution strengths and plot a graph of Optical Density vs concentration of FeSCN++ (the infamous Beers' Law). The program also allowed students to print out their graphs and data tables as shown in the attachment.

The first two classes (approximately 45 students) used the MBL equipment linked to the SPEC 20D to complete their experiments. The remaining class (25 students) used the SPEC 20D alone in the traditional approach. The prelab quizzes were collected, written observations were made of student behaviour and the final lab reports will be examined in this summary. The observations made were entirely passive; I asked less than a dozen questions during the entire morning. All demonstrations and activities were conducted by the regular classroom teacher. All quizzes and lab procedures were taken from the standard Grade 12 curriculum.
The First Treatment Group (8:20 - 9:33 am; 22 students)

- The students did not seem to do well upon the prelab quiz; they appeared unprepared. Most had read the lab procedure and had done the prelab calculations of solution strengths.

- They enjoyed the equipment demonstration by [DELETED]; they seemed intrigued or piqued by the equipment. The dilutions went quickly (first group 15 min; one group having misdiluted), and the students encountered some confusion over the SPEC 20 calibration procedures. After finding the calibration section of the program, the problem seemed rectified.

- Several (unsolicited) comments from the collection of data through the Mac included:

  "Do we hand in the printout?"

  "Do we each need a printout?"

  "How long did it take you to write the program?" (To me)

- No group did not produce a graph and printout of that graph and table. All students seemed familiar with the Mac and the standard Mac Interface (mouse, buttons etc). The only two questions asked regarding the program were about an unused (shaded) button and the length of time required to write the program. Due to printer speed and time constraints, there was inadequate time for all students to produce individual copies of the group results, although many students obtained their own personal printouts as well. Students seemed concerned that they each got their own hardcopy of the results ("...can we photocopy?"). and seemed to enjoy producing them.

- Most groups repeated measurements (three out of five) due to incorrect data entries on the computer, mistaken solutions or concentrations or the slight thermal drift (inconsequential) of the SPEC 20D. Some students repeated for greater accuracy after discovering the SPEC 20D readings took some time to settle to the final value.
The Second Treatment Group (9:39 to 10:55 am; 20 students)

This group was quite similar to the first, but perhaps a little more awake and aware (due to the time?) - they also did not do well on their prelab quizzes. They took slightly more time to do their dilutions (first group 20 min), but got more time on the computers taking measurements due to the smaller numbers involved.

- Their (unsolicited) comments from the collection of data through the Mac included:

"Now THIS is the way to do a lab" (upon printout of a graph and data table)

"Don't copy it down - its on the printout"

"Will we do more experiments the same as this?" (with the computer)

Several of these students seemed particularly satisfied with the computer equipment; one girl was very curious about the program and how I had "...done it...", another boy printed out several additional copies of the results for his own personal reasons.

One group overdilated this time as well; they proceeded to produce a graph nonetheless and discovered their error by comparison of graphs (lower slope) with their neighbours.

The Third, Nontreatment Group (11:15 to 12:28 am; 25 students)

During the class break, I removed all of the computers and printers from the counter holding the SPEC 20Ds, none of the students noted that they did not have access to the equipment. ([DELETED] class usually contains several computers; students use computer-based review materials regularly when completed assigned work and [DELETED] uses an Applle //e with MBL instrumentation to demonstrate titration and thermal laboratory phenomena.)

This group was the most poorly prepared of all; many had neglected to read the lab procedures or do calculations. The first group took more than 25 min to complete their dilutions. They did enjoy using the SPEC 20D, but not enough to make any noteworthy unsolicited comments. Note that due to my own time constraints I left before this group had complete their procedure - at 12:15.
Appendix G: The Laboratory Questionnaire

The MBL Project Laboratory Questionnaire

The Microcomputer-Based Laboratory (MBL) Project is evaluating computer equipment and programs developed at UBC for use in BC science courses, and we would appreciate 5-10 minutes of your time to complete this questionnaire. Your completion of this form indicates that voluntary consent has been given to participate in the MBL Project study and your responses will not effect your mark, grades, class standing or access to school programs. You may withdraw from the MBL Project study at any time with similar assurances as to your grades, class standing and access to school programs. All questionnaire responses will be kept strictly confidential, and only summarized data in which individual student responses cannot be identified will be made available during this study. If you have any questions, you may contact either [DELETED] or Dan MacIsaac.

1. What is your name? ____________________________
2. Todays' Date? _____
3. What Experiment did you work upon today? ____________________________
4. Briefly explain the experimental procedure from todays' experiment:

5. Briefly explain the purpose of todays' experiment:

6. Which parts of todays' experiment seemed clear and easily understood?
7. Which parts of the experiment did not seem to be straightforward?

8. If you were to repeat today's experiment tomorrow, what would you do differently?

9a. If you had the opportunity to entirely redesign the experiment, what improvements would you make?

9b. Which parts would you retain?

Thank you for your time and effort. Your assistance to the MBL Project is appreciated.
Appendix H -- The pH Review Test and Analysis

The Instrument

The pH Review Test was an instrument designed to duplicate some of the research done in student learning of graphical analysis skills using MBL apparatus (Linn & Songer, 1989; Thornton & Sokoloff, in press). The test format used is a combination of the CEG test designed by Linn (1980) and the B.C. Provincial Chemistry Examinations. The test was administered to a small number of students (Chapter 4) as a pilot for further development and as a review exercise for the students involved with the MBL Project.

Analysis shows that the instrument is flawed at present and requires further development. Some of the questions supplied are too easy (eg. number 3 is trivial), while other are poorly presented. There are a few outstanding items (eg. items 4, 7 and 9), while the others require further improvement.

An instrument of this nature could be used to gain some indication of possible improvements in student graphing abilities on questions taken directly from the B.C. Chemistry curriculum.
The MBL Project pH/Acid-Base Titration Review Test

The Microcomputer-Based Laboratory (MBL) Project is evaluating computer equipment and programs developed at UBC for use in BC science courses, and we would appreciate 10 - 15 minutes of your time to complete this review test (which is designed similar to the BC Provincial Chemistry Exam). Your completion of this form indicates that voluntary consent has been given to participate in the MBL Project study and your responses will not effect your mark, grades, class standing or access to school programs. You may withdraw from the MBL Project study at any time with similar assurances as to your grades, class standing and access to school programs. All questionnaire responses will be kept strictly confidential, and only summarized data in which individual student responses cannot be identified will be made available during this study. If you have any questions, you may contact either [DELETED] or Dan Maclsaac.

What is your name? ___________________________ Todays' Date? ______________________________

Did you use computerized data collection during experiment 20H? _______ Score: ____/10

Use the following diagram to answer questions 1 & 2

1. Which of the labelled regions in the above titration contains the Stochiometric Point?
   A. Region I   B. Region II
   C. Region III   D. None of the Regions

   ANSWER:______

2. What type of titration occurred in the above graph?
   A. A Weak Acid was titrated with a Weak Base.
   B. A Strong Acid was titrated with a Weak Base.
   C. A Strong Base was titrated with a Weak Acid.
   D. A Strong Base was titrated with a Strong Acid.

   ANSWER:______
The above titration curve was obtained for the titration of a 0.010 M concentration of NaOH with a 25 mL sample of an unknown acetic acid solution.

3. What was the initial pH of the unknown acetic acid sample?
   A. pH 8.0  
   B. pH 3.0  
   C. pH 13.0  
   D. pH 7.0  
   ANSWER:_____

4. What was the pH at the Stoechiometric Point?
   A. pH 8.0  
   B. pH 10.0  
   C. pH 7.0  
   D. pH 11.0  
   ANSWER:_____

5. What was the final pOH in the sample after titration?
   A. pOH 13.0  
   B. pOH 7.0  
   C. pOH 1.0  
   D. pOH 3.0  
   ANSWER:_____

6. What was the final $[H_3O^+]$ in the sample after titration?
   A. 1.0 M  
   B. $10^{-7}$ M  
   C. $10^{13}$ M  
   D. $10^{-13}$ M  
   ANSWER:_____

Page 248
Use the following diagram to answer questions 7 - 10

The above titration curve was obtained for the titration of an unknown concentration of HCl with a 50 mL sample of an NaOH solution.

7. What was the [NaOH] in the original NaOH sample?
   A. 1.00 M  
   B. 0.10 M
   C. 0.001 M  
   D. $10^{-13}$ M
   ANSWER:____

8. What was the [H$_3$O$^+$] at the Stochiometric Point?
   A. 0.0000001 M  
   B. 1.0 M
   C. 0.1 M  
   D. 0.001 M
   ANSWER:____

9. What was the final [NaOH] in the sample after titration?
   A. 1.0 M  
   B. $10^{-13}$ M
   C. 0.1 M  
   D. $10^{-13}$ M
   ANSWER:____

10. What was the [HCl] used in the burette during this titration?
    A. 1.00 M  
    B. 0.10 M
    C. 0.001 M  
    D. $10^{-13}$ M
    ANSWER:____
The Analysis

Analysis output is extracted from the LERTAPS computer software used by the Education Computing Services Centre (UBC ECS). The key notes upon the report are point-by-serial correlations, and question response probabilities for each item response.

### SUBTEST 1

**TYPE** 
ACHIEVEMENT  
**CORRECTION FOR CHANCE OFF**  
**WEIGHT** 1.000  
**SCORE TYPE** RAW  
**NUMBER OF ITEMS** 10  
**NUMBER OF ALTERNATIVES** 4

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STANDARD DEVIATION = 2.29

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ITEMS                   9.00    8.39    0.93
RESIDUAL                423.00  61.31   0.14
TOTAL                   479.00  94.33   0.20

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STANDARD ERROR OF MEASUREMENT = 1.14