CHEMISTRY LABORATORIES

THE CHANGING ROLE

OF

CHEMISTRY LABORATORIES

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ABSTRACT

Chemistry is an experimental science and many educators believe that the laboratory program is central to the teaching of chemistry. Introductory chemistry curriculum, as defined by senior secondary school and freshman university courses, has throughout its history placed varying degrees of emphasis on the laboratory component. In this project, a brief discussion of the historical background of chemical education is followed by a consideration of those constraints thought to interfere with the implementation of an effective laboratory program.

Safety is an issue currently receiving greater attention in educational institutions. This is reflected in the increased responsibilities required by both statute and tort law. A summary of these responsibilities and their effects on the teaching of chemistry is included in this project.

In order to remain faithful to the nature of chemistry, many educators employ student activities which act as alternatives to the laboratory experiment. Various such alternatives are examined. This is followed by recommendations on how a laboratory program may be effectively implemented.

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CHAPTER ONE

INTRODUCTION AND HISTORICAL BACKGROUND

According to Funk and Wagnall's Canadian College Dictionary, curriculum is "a regular or particular course of study". Curriculum may also be viewed as those interactions between students and teachers designed to accomplish certain educational goals. A definition cited by Miller and Seller (1985, p. 3) states that "curriculum is an explicitly and implicitly intentional set of interactions designed to facilitate learning and development and to impose meaning on experience". Explicit interactions may be regarded as those expressed in the written curriculum; implicit interactions, or the "hidden curriculum", are considered to be those norms and roles which underlie the explicit interactions. The main focus of this project will be on the explicit introductory chemistry curriculum; introductory chemistry is defined as the grade 11 and OAC courses in Ontario high schools and as introductory general level courses in the freshman year of university.

Curriculum development is an ongoing process, both explicity and implicitly. Throughout the evolution of the written chemistry curriculum different aspects of chemistry, such as descriptive facts, chemical theory and principles, and the frequency of student laboratory activities, have received varying degrees of emphasis. A component currently receiving increased consideration in the Ontario Ministry of Education Guidelines is the laboratory. This experience is considered by chemical educators to be central to the teaching of chemistry, yet the exact nature and extent to which it can be successfully employed as a method of instruction has been a topic of much discussion. The purpose of this project is to examine the role of the laboratory in the written curriculum as well as those factors which may hinder the effective implementation of this activity.

Those aspects of chemistry thought to contribute significantly to meaningful student learning should ideally determine the content of the curriculum. Following is a brief historical background of chemical education which illustrates how curricular content has changed with time. Particular attention is drawn to the role of the laboratory component of the chemistry curriculum.

CURRICULUM REFORM

Prior to the twentieth century introductory chemistry courses were predominantly descriptive in nature with limited amounts of theory and mathematics (Beach 1984). The major introductory textbook of the nineteenth century for example, Dmitri I. Mendeleev's Principles of Chemistry, was based on the periodic table and chemical facts known at the time. Chemistry courses at the introductory level were devoted to studying the elements and their compounds, syntheses and reactions (Zuckerman 1986).

Change in the presentation of chemistry began slowly. In the twentieth century Linus Pauling produced an influential advanced level textbook titled Nature of the Chemical Bond. While the content of this textbook was still somewhat descriptive, the factual material was joined together by discussions on the principles of chemistry, principles such as bonding and atomic structure. Movement had thus been made towards a greater emphasis in the curriculum on the theories and principles of chemistry.

This change in emphasis was further catalyzed by the Russian launching in 1957 of Sputnik. Popular opinion came to hold the view that Western scientific knowledge should advance beyond that of the Soviets. In an effort to upgrade the science curriculum the memorization of the basic facts and concepts was further de-emphasized as these were thought to bear little relevance to the modern world; importance was placed rather on principles and theories. As a result, introductory chemistry came to have a predominantly theoretical approach. The increasing amount of information from which to select basic facts also encouraged this reform. The consensus among educators became that a "knowledge of the principles makes it much easier to understand and learn facts" (Gillespie 1976, p. 24).

A consequence of post-Sputnik curricular reform was the production of high school chemistry curriculum documents such as The Chemical Bond Approach and CHEM STUDY. The one of major influence, CHEM STUDY, combined an increased emphasis on theoretical concepts with an experimental approach to chemisty. Previously, laboratory work had consisted of preparations of chemicals and qualitative analysis schemes based on solubilities; this approach was consistent with the more descriptive nature of the early chemistry curriculum. In CHEM STUDY, however, experiments were designed to demonstrate the validity of chemical principles taught in the class. The approach suggested by CHEM

STUDY was able to increase the student laboratory experience which, though considered central to the scientific process, was felt to be lacking from the implemented curriculum.

The influence of CHEM STUDY is seen in the introductory statements of the 1966 grade 12 and 1968 grade 13 Ontario curriculum guidelines. They read respectively: "Whenever possible each topic is illustrated by experiment and discussed in terms of theoretical principles . . ." (Curriculum S-17D 1966) and ". . . from experimental work the student discovers for himself the origin of chemical principles . . ." (Curriculum S-17E 1968). Curriculum reform, therefore, had led to official curriculum documents which de-emphasized the descriptive aspects of chemistry and instead placed greater emphasis on student laboratory activity and the theoretical concepts of chemistry.

CURRICULUM INNOVATIONS

Since the 1960's various other curricula innovations have also emphasized laboratory activities. In Michigan for example, Bronstein (1986) has implemented a high school chemistry course in which the students perform some thirty experiments during the academic year. The course, developed in the mid-1970's, is conducted as an individualized chemistry program based on mastery learning. This is an approach used by educators who are concerned that students succeed at least to a minimum level of knowledge. The thrust behind this program is that chemistry concepts yet to be learned depend on and use concepts previously learned, and that given the appropriate prior and current learning conditions anyone can learn these concepts (Novak 1984). The course is divided into a series of units, each with a prescribed set of learning activities. Students proceed through the units at their own pace and do not advance to the next unit until a minimum level of mastery, measured by a test, is demonstrated in the unit being worked on.

Discovery learning, or guided inquiry as it is sometimes referred to, is a curriculum innovation designed to create in students an awareness of the dynamic process of science. In traditional chemistry curricula the purpose of laboratory activities was to verify concepts introduced and expanded on by the teacher; emphasis was on subject content rather than the processes of science. An obvious drawback to this approach was the fact that the laboratory program was viewed as a "cookbook" exercise. Rather than reflecting on the concepts the experiments were designed to illustrate, the students merely followed directions (Faber and Martin 1983). Further, the student was "expected to produce a verification of something that he already knows, and so ends up trained to ask what a result is supposed to be, not what it in fact is" (Allen, Barker, and Ramsden 1986, p. 533).

Discovery learning addressed some of the concerns inherent in traditional chemistry courses. A main objective of discovery learning was to demonstrate to students the manner in which knowledge developed from raw experimental data. This would be accomplished by posing a problem or idea to the student and providing them the opportunity to experiment. Using their own experimental data the students would be required to formulate principles and generalizations applicable to the problem or idea set forth. Such an approach, while seemingly haphazard, was designed to follow a predetermined path such that the knowledge acquired could be fit into a pattern of learning. Discovery learning was also thought to provide a learning environment wherein students could learn the scientific process and develop the critical thinking skills necessary to this process (Baker 1985).

Although examples do exist describing environments where curriculum innovations have been implemented successfully (Faber and Martin 1983; Allen, Barker, and Ramsden 1986), their overall acceptance has been limited. Many programs purporting to be inquiry-based and employing numerous student-centered activities exhibited little evidence of such an approach. Classroom activities were primarily aimed at learning the information necessary for recall on tests or examinations. Student participation in small group activities, such as laboratories, were found to occur relatively infrequently in science classes; whole class activities were more common (Tobin and Fraser 1990).

CURRICULUM DEVELOPMENT IN THE 1980'S

The process of curriculum development continued in the 1980's. Advances in science and technology proceeded at increasing rates causing the need of the workplace to similarily change. A prevelant view held by educators was that chemical education should place a greater emphasis on personal skills development than on content. Notwithstanding, content was considered to be important but critical thinking and the ability to adapt to new situations was thought to contribute more significantly to a student's future success. The most effective manner in which to acquire these skills was through participation in broad learning experiences rather that the focused training evident in traditional science curricula (The Liberalization of Chemical Education 1986). A broad, more meaningful learning experience was to be achieved through the inclusion of activities such as field trips, laboratory investigations, library research and independent projects, activities believed to develop critical thinking skills, creativity and adaptibility (Ekpo 1988).

In 1989 the National Science Foundation hosted a workshop on Undergraduate Education in Chemistry. At this workshop discussion centered around the growing perception that undergraduate education in science and technology is in a state of crisis. Studies conducted in the United States indicated that shortages in the scientific and engineering workforce are pending and that the public in general have a lack of understanding in science and technology. Enrollment in undergraduate science education had also witnessed an alarming decrease. In the United States for example, 1.56 % of all bachelors degrees conferred in 1970 were in chemistry, in 1978 this percentage had fallen to 1.17 % and in 1986 the percentage had decreased further to 0.97 %, a drop of 17 % since 1978 (Report on the NSF Workshop 1989/1990).

The Workshop on Undergraduate Education in Chemistry set forth several recommendations in an effort to address those problems in the chemistry curriculum felt to contribute to declining numbers of students pursuing scientific careers, specifically careers in chemistry. These recommendations included:

> 1) . . . enhance laboratory instruction through programs that address the widespread, fundamental, and long-standing problems in the first two years of the undergraduate laboratory curriculum,

> 2) . . . establish a broad-based curriculum development program to support the formation of a commission empowered to generate up-to-date instructional materials in order to revitalize introductory courses in chemistry (Report on the NSF Workshop 1989/1990, p. 134).

In the spring of 1990 a national meeting of the American Chemical Society devoted considerable time to the discussion of the science personnel crisis and the issues regarding public literacy. Various speakers at the meeting believed that the situation could only improve if major restructuring of the introductory chemistry curriculum was undertaken. This task is considered of such great urgency that "the early college experience is one that has many chemical educators issuing impassioned calls for reform and revitalization in words that sound like revolution" (Krieger 1990). Educators are concerned over the irrelevancy of the current curriculum as well as the fact that laboratories are uninteresting and concentrate too much on the principles of chemistry and not enough on descriptive chemistry. Overall, introductory chemistry courses should be perceived by the student as exciting and ultimately stimulate them to pursue this as a field of study.

During the 1980s consensus grew towards developing chemistry curricula which was applicable to everyday events, more relevant, and that addressed the societal implications of the subject matter (Gardner 1989). The NSF Workshop recommendations reiterated the recurring theme that meaningful learning is enhanced by student involvment and laboratory activities. As science and technology continues to advance at an accelerating rate, it becomes increasingly necessary to properly educate our youth. Only through this endeavor will students be able to capably enter the workplace. This in turn is reflected in the nation's ability to remain competitive in the marketplace.

ONTARIO CURRICULUM GUIDELINES

In response to several Canadian studies indicating that "science is not taught in a way that reflects the nature of science nor is it taught in a way that has any relevance to students in terms of societal implications or applications" (Educator's Report 1989, p. 2), the Ontario Ministry of Education in 1987 produced new science curriculum documents. In Ontario, this was the first major reform of science education in twenty years. Relevant to this discussion are Part 1, Program Outline and Policy and Part 13, Chemistry, Grade 11, Advanced Level, and the OAC of the Curriculum Guideline Science Intermediate and Senior Divisions 1987.

These guidelines reiterate the necessity to emphasize the importance of process and content in science education. This is clearly stated as:

> In science courses both substantive content and scientific processes are essential. Opportunities for student activities are provided in all courses described in the guideline; in fact, many such activites are mandatory. The experimental nature of science is to be emphasized, since it is this characteristic that makes it a dynamic process of learning (Curriculum Guidelines Part 1 1987, p. 7).

This curriculum also reflects the view held by educators that essential to meaningful learning is a broad learning experience. The grade 11 chemistry course "permits coverage of a broad range of concepts rather than an in-depth treatment of a few" (Curriculum Guidelines Part 13 1987, p. 8). Analogous to the grade 11 course, yet concentrating on more theoretical concepts, the OAC course provides many opportunities for laboratory work. The incorporation of examinations of the technological applications and societal implications of chemistry are required in both the grade 11 and the OAC curricula. An independent study unit in the OAC course enable students to apply the techniques and principles of scientific inquiry that they have acquired.

Implementation of the science curriculum guidelines was not required to begin until September 1989 and thus success cannot yet be measured. It is hoped, however, that as implementation of the new guidelines proceeds a balance between scientific content and processes will be attained. This will be evident in the inclusion of an increased number of student laboratory activities in high school chemistry courses.

FUTURE CURRICULUM REFORM

The process of curriculum development will continue into the twenty-first century and beyond. The continuing globalization of the marketplace demands that a critical evaluation of the educational infrastucture be made in order for Canada to remain competitive. Employers today require graduates with scientific expertise as well as the ability to communicate effectively, to work on multidisciplinary teams and who can adapt easily to new situations (Moore 1989). A properly designed science curriculum which makes effective use of the classroom and the laboratory would be able to achieve this.

Throughout the course of curriculum evolution the place and purpose of the laboratory has been an issue. The science curriculum guidelines of 1987 mandate that laboratory activities have a prominent role in student learning. Whether this will be successfully implemented will depend on the effect of external constraints. Notwithstanding, educators should remember that as an experimental science, the laboratory is central to chemistry; "it is the place where hand and mind together discover new chemical facts and ideas" (Moore 1989).

PROJECT DIRECTION

The preceding discussion has illustrated that laboratories are considered important to the teaching of chemistry. Their function, however, has been shown to change throughout the evolution of the written curriculum. As has been stated, the purpose of this project is to examine the laboratory component of the introductory chemistry course. Specific objectives of this project are:

1. To discuss the evolution of the chemistry curriculum.
2. To examine external constraints impinging on effective implementation of a laboratory program.
3. To identify the responsibilities required of school boards, administrators and teachers as determined by health and safety legislation and tort law.
4. To evaluate actual health and safety practices of several Ontario school boards and universities.
5. To determine whether alternatives to laboratory activities satisfy the aims and goals of the chemistry curriculum.
6. To make recommendation regarding effective implementation of a laboratory program.

CHAPTER TWO

THE ROLE OF LABORATORIES

> Chemistry is an experimental science. Observations of the behaviour of substances form the basis of chemistry. The facts of chemistry are established by many repeated experiments on the behaviour of substances. Theories and principles are developed in order to help us understand the facts. In the laboratory course you have the opportunity to carry out many of the reactions and to demonstrate many of the principles of chemistry that are discussed in the general chemistry course (Robinson et al. 1986, Introduction).

The above quote, found in the introduction of a laboratory manual designed for an introductory chemistry course, provides the reader with a sense of the importance of the laboratory experience to the learning of chemistry. Tobin (1990) defines learning as "the construction of knowledge as sensory data are given meaning in terms of prior knowledge." He believes that students, in order to make sense of what they are learning, need to directly experience and be given time to think about what they are to learn. The laboratory experience provides the students the opportunity to learn, or "construct knowledge", by doing science.

As discussed, curricular innovations placing increased emphasis on student laboratory activities have been implemented with limited success. In addition, new technologies are challenging the necessity of the laboratory and educational research has been unable to prove that the laboratory experience is actually beneficial to the students (Pickering 1988). Chemical educators, however, believe that the laboratory component is essential to teaching chemistry and there is growing consensus worldwide that laboratory learning and performance needs to be more strongly encouraged (Gardner 1989). Teaching chemistry without the laboratory is analagous to teaching cooking without the kitchen.

The degree to which a laboratory program can be effectively implemented is influenced by both the internal and external constraints to which the program is subject. A brief consideration of the purposes and the role of the laboratory in the chemistry curriculum will precede a discussion of those constraints thought to be most critical to a meaningful laboratory curriculum.

THE PURPOSE OF THE LABORATORY PROGRAM

The goals and objectives, or intended outcomes, of the chemistry laboratory experience are many and varied, and no attempt will be made to determine those which should or should not be incorporated into the laboratory curriculum. The goal is to draw attention to those main objectives considered by many educators to be requisite to the function of the laboratory. Chemical educators should realize, however, that essential to a valuable and meaningful laboratory experience is the necessity to identify and clearly state the purpose of the activity.

The laboratory provides an environment in which students may be able to learn the processes of science. One of the major objectives of the laboratory program therefore, as stated by Friedler, Nachmias, and Linn (1990), is to emphasize the processes of science and to develop in students the skills of scientific reasoning, skills such as the ability to define a scientific problem, state a hypothesis, design an experiment, observe, collect, analyze and interpret data, apply the results, and make predictions. Friedler et al. further indicate that critical to this process is the ability to make detailed objective observations; conclusions are based on observations and the students must be able to integrate their new knowledge with the knowledge they have already acquired.

Proficient observational skills need to be complemented with the ability to correctly manipulate the necessary experimental apparatus. Proper experimental technique enables the student to collect data whose accuracy is determined by the apparatus rather than the manner in which the apparatus was employed. An objective therefore, of many introductory laboratory programs is the development of experimental technique.

The development of experimental technique is an objective of particular importance to a school of thought calling for the return of descriptive chemistry to the introductory chemistry curriculum. Proponents to this philosophy of chemical education believe that the laboratory should be converted to an arena in which students are taught skills such as learning how to synthesize chemicals, and how to isolate and purify products (Zuckerman 1986). This approach is a movement away from the type of experiments aimed at demonstrating the principles of chemistry. Hudson (1980), however, points out that this instructional approach provides students a "thorough grounding in experimental chemistry and in the reactions of the elements and their simple compounds and provides a clear link to models of chemical thought".

Further, he notes that students are encouraged to learn to accept evidence contrary to established thought and to appreciate the fact that chemists produced a body of evidence before making conclusions. This would imply that developing experimental skills as encouraged by the incorporation of descriptive chemistry will inherently lead to the development of scientific reasoning skills.

Many experimental exercises are included in the laboratory curriculum to illustrate the theories and principles discussed in the lecture (Palladino and Figgins 1983). Additional aims of the laboratory experience may include the development of communication skills and the need for properly written laboratory reports (Werner 1986). Broad goals, such as attracting an increased number of students to the pursuit of scientific careers, many also be viewed as important (Hounshell 1989). For many scientists their interest in the subject was stimulated by the laboratory experience. Clearly there exist a number of potential outcomes to the laboratory program. A detailed list is provided by Moore (1989), who believes that the purpose of the laboratory curriculum has been achieved when students

> appreciate that chemistry is an experimental science;
> know and appreciate certain chemical substances and their properties;
> have encountered and dealt with problems of accurate measurement;
> have learned manipulative skills;
> have learned to design experiments;
> have learned to collect and analyze data and draw conclusions from it;
> have learned to communicate laboratory results;
> have seen numerous theories and principles illustrated.

Although specific laboratory objectives may differ between individual chemical educators, general consensus is that students must be taught the processes of science and that the laboratory program is essential to this endeavor.

ONTARIO SCIENCE CURRICULUM GUIDELINES AND THE ROLE OF THE LABORATORY

Evidence that the laboratory component is considered important to chemical education is shown in the science curriculum guidelines (1987) of the Ontario Ministry of Education. Produced in response to concern expressed over the quality of the implemented curriculum, these curriculum guidelines mandate that certain laboratory activities be undertaken and that chemistry courses stress the experimental nature of science. The Ministry of Education document Part 1, Program Outline and Policy for Science, Intermediate and Senior Divisions, details the goals and aims of the curriculum guidelines. Educational goals which may be accomplished through student laboratory activities include emphasis of:

1. The process of learning which includes observing, sensing, inquiring, creating, analyzing and synthesizing.
2. A variety of modes of inquiry such as reading, obtaining data, experimenting, designing testing techniques, changing variables, questioning, problem solving, theorizing and explaining.

The laboratory can also contribute to the fostering of creativity and leadership skills.

The goals of education are achieved in part through the aims of the curriculum. Those aims particularly applicable to the laboratory environment are:

1. An understanding of the process of science.
2. Skills that are essential for partcipation in scientific work and technology.

3. Facility in problem solving through science (Curriculum Guidelines Part 1 1987, p. 10, 4).

Throughout the science curriculum guidelines the need to stress both the content and processes of science is evident. For advanced level courses

> while the focus must be on academic preparation, activities that allow students to develop a variety of skills must be an integral part. . . . Through such activities students will experience the processes of inquiry . . . rather than simply learning the outcomes of the inquiry of others" (Curriculum Guidelines Part 1 1987, p. 19).

Therefore, essential to experiencing the processes of science is personal participation in laboratory activities. Further, it is stated that "any science course . . . that gives undue emphasis to content over process, or process over content fails to meet the aims of the science curriculum" (Curriculum Guidelines Part 1 1987, p. 22).

The importance of the laboratory activity as a method of instruction is also visible in the attention given to the evaluation of student achievment. A minimum of 15% of the final grade is to be derived from the laboratory component for all Intermediate and Senior Division science courses. The Educators' Report (1989) revealed that presently only 12% of the teachers in the study included the laboratory component when assigning final grades to their students. The new Guidelines specifically state that "evaluation must emphasize the philosophy of student exploration and problem solving" (Curriculum Guidelines Part 1 1987, p. 23).

The previous guidelines, although encouraging the use of laboratory activities in the chemistry curriculum as a means for effective learning, did not mandate their inclusion. Many teachers therefore, did not incorporate extensive use of student experiments into their curriculum. It is hoped, however, that under the more recent guidelines student experimentation will increase.

At the tertiary level, specific curriculum guidelines do not exist. There is, however, a general understanding among chemical educators as to which topics and laboratory exercises to include in general level courses. The consensus is that the laboratory is a necessary component of these courses but due to external constraints the frequency and manner in which they are applied varies with the institution. This variability is further discussed in chapter five.

CONSTRAINTS TO EFFECTIVE LABORATORY PROGRAMS

The curriculum reforms of the 1960s and 1970s resulted in curriculum innovations placing a greater emphasis on hands-on laboratory activities. Increasing the number of student performed laboratory activites also places more demand on the educational system; this in turn can cause stress to that system thereby reducing the significance of the laboratory experience. The challenge to the educator is to implement a laboratory program which achieves the aims of the science curriculum and which also translates into a meaningful learning experience for the students. Various internal and external constraints acting on the system may greatly affect the degree to which this endeavor can be accomplished.

A major concern of secondary school teachers in Ontario is the size of their classes. The Educators' Report (1989) indicates that most

(32%) class sizes are between 26 and 30 students; 16% of teachers reported class sizes greater than 31 students.

Large class size affects both teachers and students in a number of ways. The physical demand placed on the teacher can become excessive. Students in high school chemistry courses require much closer supervision when in the laboratory than students more experienced in experimental techniques. To provide the necessary supervision in a large class is difficult; the individual needs of the students cannot be adequately met. In addition, a large number of students per laboratory is believed to contribute to the loss of the discovery component of the experiment (Pickering 1988). To remove this element is to decrease emphasis on the processes of science, an objective considered essential to the learning of chemistry. This concern and its effects also hold true for the laboratory component of introductory chemistry courses at the tertiary level.

The effect of class size extends into the administrative aspects of a course as well. As the number of students increase, more time is devoted to student evaluation. In order to cope with the added demand instructors resort to timesaving methods of assessment. In chemistry laboratories, large classes tend to lead to fill in the blank type of laboratory reports (Pickering 1988). This type of report is more convenient and less time consuming to mark but does not permit the student the opportunity to develop scientific writing skills, a skill necessary in the workplace. The ability to communicate scientific knowledge is also one of the aims of the science curriculum which would not be achieved.

Large class sizes also directly affect the degree to which the learning environment is considered safe (Scholz 1988). The laboratory is an environment in which accidents do occur, even under the best of conditions. Students in an introductory course lack sufficient experience to know how to avoid all possible injury and thus the teacher needs to be more keenly aware of the activities taking place around the laboratory classroom. This is challenging for the teacher of a large class yet is especially important today as more attention is being directed to health and safety issues. To be aware of activities occuring in the laboratory is also a requirement of the curriculum guidelines wherein it is stated that "teachers must ensure that experiments are conducted in logical, organized steps while avoiding unnecessary movement or crowding in the lab" (Curriculum Guidelines Part 1 1987, p. 45).

Related to the issue of overcrowding is the fact that many laboratory classrooms are substandard; this is particularly true in the secondary schools. They are often too small, even for a normal class size, and ill-equipped in terms of laboratory tables, ventilation, storage facilities, and basic safety equipment (Hounshell 1989; James 1989; Scholz 1988). The helplessness a chemical educator feels when required to teach under these conditions is captured by Scholz (1988) who states:

> We agree wholeheartedly with the new guidelines that urge us to let students taste success by collecting evidence for themselves, increase their psychomotor abilities and reach their own conclusions, **but** we cringe at the many near-accidents due to the unavoidable jostling in our overcrowded labs, we abhor the helpless, futile feeling of not being able to be in 35 places at once, and we

> breathe a sigh of relief, when at the end of the lab, once again, none of the minor mishaps have turned into a major one.

In response to concern expressed on the issue of overcrowded facilities in the secondary schools of Ontario, the Science Teacher's Association of Ontario in December 1988 issued a draft position statement regarding class size and recommended that it be accepted as STAO's official position. According to this statement class size should not exceed 24 students per teacher for advanced level classes, 20 students for general level classes, and 16 students per teacher for basic level classes (Report to STAO Board 1989). The draft position states that:

> . . . for most science classes, to increase the number above that recommended is to jeopardize the educational value of the science experimentation and inquiry. Furthermore, STAO believes that the risk to student safety and to expensive equipment escalates rapidly as the number of students in the laboratory at one time increases (Report to STAO Board 1989).

Mention has been made of the fact that health and safety issues are receiving greater attention in educational environments. This is reflected in a number of new pieces of legislation as well as a wider concern among science teachers of possible litigation due to negligence. Chapters three and four will further discuss the responsibilites required of school boards, administrators and teachers as demanded by both statute and tort law.

Safety strictures exist disallowing the use of various chemicals in the high school. In a discussion of the implication of these regulations, Beach and Stone (1988) note that some educators consider this to be counterproductive. By not permitting the use of certain chemicals thought to be too toxic, students with untrained noses will fail to identify many of the common smells found in the world around them, smells such as those emitted from automobile exhaust pipes or rotting sewage. Some of these smells are considered to be a component of chemical literacy and while these educators do not encourage the production of copious amounts, they do recommend carefully controlled demonstrations. This article further identifies the concern that would be authors have over the litigious nature of our society and their reluctance to publish safe alternatives for experiments deleted by safety restrictions. Both of these conditions result in the denial of a laboratory experience which is meaningful to the students.

The demands placed on teachers is clear, but students also are faced with educational expectations that they may not be able to achieve. Johnstone and Wham (1982) in discussing the demands of practical work indicate that students acquire the manual skills to varying degrees of success and that the theoretical concepts the experiments are designed to illustrate are not usually learned by the students. A reason given for this failure in the laboratory experience is the excessive amount of information the student is required to process should all the aims of the activity be accomplished. The student, for example, is provided with written instructions, verbal instructions, often unfamiliar pieces of apparatus, must recall theory and previous skills used, and observe everything. In order to cope with this information overload the student treats the experiment as though it were a recipe. Suggestions provided by Johnstone and Wham to reduce the amount of information processing required of the student include:

1. Giving a clear statement as to the purpose of the experiment.

2. Making clear to the student what is preliminary and what is peripheral.

3. Teaching important manual skills for their own sake before they are to be used in the context of an investigation.

Several other constraints affecting the implementation of an effective laboratory program include class periods which may be too short to allow for proper completion of the experiment, permitting only one laboratory period in which to attempt the experiment, widely varying student abilities, being required to cover a certain amount of content in a specified period of time, and employing teachers who are not adequately trained in the necessary skills (Krieger 1990). Each of these conditions places stress on both the teacher and the student.

A constraint to effective laboratory programs particularly unique to the university environment is the level of commitment the faculty have towards instructing introductory general level chemistry courses. As stated, "Doing a good job in a large freshman course is a tremendously taxing responsibility. However, research brings more distinction than teaching" (Worthy 1990). Faculty therefore, often direct minimal effort towards the building of an effective laboratory course at the introductory level and rather place such responsibility on other university staff. The degree to which these individuals are committed to the development of an effective laboratory curriculum is in turn affected by the faculty's lack of commitment. Other factors, such as the quality of the demonstrators one is able to hire, the number of students each demonstrator is responsible for, the degree to which change is acceptable in the particular environment, and the budget within which the course is required to operate, also contribute to the success of the laboratory program. The ultimate result is a group of students entering their second year of university with inadequate laboratory skills and the misconception that experiments are cookbook exercises.

Given the constraints to which the laboratory component is subject, it is clear that an instructor is under considerable physical and emotional pressure. Adding to this demand is increased health and safety responsibilities. If chemistry teachers are to work effectively in their environments these issues need to be addressed. If not dealt with, fewer teachers will be compelled to teach science, students will be deprived of a valuable and meaningful science education, and the quality of science education will continue to deteriorate.

CHAPTER THREE

STATUTE LAW AND SAFETY PRECAUTIONS

The Ontario Ministry of Education science curriculum guidelines reflect an increased emphasis on "hands-on" student activities. As a consequence, the students may be exposed to greater risk than under the previous guidelines. The greater emphasis on laboratory activities comes at a time when society is becoming increasingly conscious of the adverse effects of various substances and the need to work in a safe environment. This in turn is changing the legal climate as parents are more prepared to become involved in lawsuits should injury occur in the classroom or laboratory.

The legal requirements pertaining to safety in the educational environment are covered by a variety of provincial acts and codes. In addition, the Ministry of Education outlines general policies and guidelines. These pieces of legislation and the Ministry guidelines are directed mainly towards administrators and teachers. The duty to keep abreast of legal matters relevant to school safety, therefore, lies with the school boards and the teachers. Since these are the individuals ultimately responsible for ensuring the safety of the students through the establishment of appropriate procedures, it is vitally important that they be fully knowledgeable of the applicable pieces of legislation. Following is a discussion of the Acts, Regulations and guidelines having the greatest impact on the classroom experience.

THE EDUCATION ACT

The safety related duties of teachers, administrators and school boards are provided mainly in the Education Act, R.S.O., Chapter 129 and Regulation 262. Hester (1987) provides a brief discussion of these in his paper "A Discussion Regarding School and School Board Safety as Directed by the Ministry of Education"; a short summary follows.

The duties of the school board as stated primarily in section 149 of the Education Act are:

> every board shall keep the school buildings and premises in proper repair and in a proper sanitary condition, provide suitable furniture and equipment and keep it in proper repair, and protect the property of the board: make provisions for insuring adequately the buildings and equipment of the board and for insuring the board and its employees and volunteers who are assigned duties by the Principal against claims in respect of accidents incurred by pupils while under the jurisdiction or supervision of the board.

Under subsection 236(j) of the Education Act,

> it is the duty of the Principal, in addition to his duties as a teacher, to give assiduous attention to the health and comfort of the pupils, to the cleanliness, temperature and ventilation of the school, to the care of all teaching materials and other school property and to the condition and appearance of the school buildings and grounds.

The duties of the principal are further expanded on in section 12 of Regulation 262. According to this regulation the principal is required to supervise the teaching process, advise and assist the teacher, and inspect the school building and property at least once a week. Any maintenance requirements that may arise are to be reported to the school board.

The duties, as found in the Education Act, demand that the teacher take every precaution reasonable to the activity to be conducted. Regulation 262 specifically states that the teacher shall "ensure that all reasonable safety procedures are carried out in courses and activities for which the teacher is responsible".

By law, therefore, school boards, principals and teachers must provide a safe learning environment for the students. This includes maintaining classroom facilities which are safe and adequately supplied with the necessary safety equipment, informing students of potential hazards in the science classroom, and educating them in methods of proper laboratory techniques and precautions. While the legal duties described apply to all teachers and administrators, science personnel must be particularily concerned that the learning environment is safe and that safety measures are understood and adhered to by all the students.

OCCUPATIONAL HEALTH AND SAFETY ACT

In 1984 teachers were included in the Occupational Health and Safety Act (OHSA). Under this Act the school board or institution is the employer and teaching and non-teaching staff are its employees; the term supervisor refers to principals, vice-principals and department heads. This piece of legislation imposes strict legal duties on the person in charge, worker and supervisor, and makes everyone responsible for health and safety in the workplace. All employees are required to correct or report for correction any known hazards.

An important provision of the OHSA is for the formation of joint health and safety committees. These committees have equal representation of employer and employee. This permits the employee to make recommendations to the employer who is then also party to these suggestions. The employer is obligated to consider these issues and comply with the legislation. The purpose for maintaining joint health and safety committees is to provide an arena in which the interests of both labour and management are recognized. The belief is that co-operation in matters of health and safety is beneficial to both parties.

In his discussion of the application of the OHSA to the school setting Angus (1987) notes that under the Act, unless the health and safety of the student is in jeapordy, teachers are permitted to refuse work in an unsafe environment. The OHSA does not otherwise require that the teacher ensure the safety of the student; this is dealt with in the Education Act and tort liability.

While specific regulations regarding educational facilities do not exist, Angus (1987) directs attention to the fact that the Act does state that in safety related circumstances the employer and supervisor shall take "every precaution reasonable". In matters of litigation the courts determine a reasonable minimum standard of care by referring to Regulations for Industrial Establishments. Note however, that this standard of care will mostly likely be higher than demanded by these Regulations when the health and safety a minor is affected by the decision. Teachers are able to use this as a legal defense should refusal to work be deemed necessary.

As teachers become more aware of their legal rights, it is conceivable that many will exercise the right to refuse work. Comments are often heard regarding the lack of proper safety equipment and overcrowded facilities (Scholz 1988; Jane 1989), conditions which contribute significantly to an unsafe learning environment. School boards will therefore necessarily need to be aware of what acceptable minimum criteria are if science education is to continue.

A new piece of legislation under the Occupational Health and Safety Act, Workplace Hazardous Materials Information System or WHMIS, came into effect in October 1988 and is presently receiving much attention in educational institutions.

WHMIS

Workplace Hazardous Materials Information System (WHMIS) is right-to-know legislation. It outlines a comprehensive plan for providing employer and employee information on the hazardous materials they are required to handle in the workplace. Given this information, rational decisions can be made regarding the work environment.

WHMIS requires that all suppliers label and prepare material safety data sheets for products intended for use in the workplace which meet the hazard criteria outlined in the Controlled Products Regulation under the Hazardous Products Act; products packaged as consumer products are exempt. The material safety data sheets include information on the hazards of the product, how it should be handled and what to do in case of emergency (Appendix 1). This information must be passed on to the buyer.

Employers are required by WHMIS legislation to develop appropriate workplace labelling of all containers of hazardous materials, make the material safety data sheets readily available to the employee, and provide for worker education on the safe use of hazardous materials.

WHMIS legislation applies to all workplaces, including educational institutions. Consistent with this legislation is the fact that all teachers, regardless of their teaching subject, are required to participate in the training program. One needs only to be reminded that many teachers are called on to perform duties outside of their regular classroom. These duties may involve handling hazardous materials or working in close vicinity to hazardous substances (Scholz 1989). All teachers therefore need WHMIS training.

The worker education aspect of this legislation is the most extensive component to its implementation, especially for school boards. As Scholz (1989) points out, unlike the industrial workplace, most school boards have provided little in the way of safety training for their staff. With the onset of WHMIS the school boards were required to implement on very short notice effective worker training programs to a very large number of people, a task considered massive even to those environments familiar with safety training programs. School boards have, as a result of their inadequate resources, proceeded with the labelling and material safety data sheet requirements and have left worker education as the last component to which to attend. This approach to WHMIS implementation has led to employee frustration, especially to teachers formerly unaware that hazards surround them. The legal ramifications of this approach could also be costly should an incident occur which could have been avoided had the teacher been given the required training. In his article, Scholz (1989) details a more effective way in which schools boards can implement this legislation.

WHMIS legislation provides the criteria by which hazardous materials are to be identified and labelled. Employers must ensure that all containers have the appropriate WHMIS supplier label or workplace warning. In schools, therefore, quantities of less than ten kilograms require workplace labels stating the name of the product, information regarding handling of the product, reference to material safety data sheets and any protective equipment essential to its use. Amounts made for immediate use in the classroom laboratory must at least have a label with the name of the product on it; large amounts made for the laboratory purpose must have proper WHMIS labelling.

The obligation to label all containers poses minimal problem to the teaching staff. Labels can be purchased from various companies and many school boards will make their own labels. Concern over labelling of containers does result, however, when the teacher obtains chemicals for classroom use from sources other than the supplier. Products such as acetic acid (vinegar), sodium chloride (salt) and household bleach are less expensive to purchase from the neighbourhood store where they are considered consumer goods, yet material safety data sheets are required for these items when they are to be used in the school. Often a teacher will bring substances from home for use in the classroom. These substances may be listed as hazardous and thus require appropriate WHMIS labelling. The nuisance caused by the labelling requirement necessitates discretion on the part of the teacher when considering the use of personal purchases in the classroom. School boards are well advised to follow a policy which is in compliance with the legislation.

The material safety data sheet expands on the information provided on the label. WHMIS legislation states the minimum content requirement for the material safety data sheets but exact form is not mandated. As noted above, these sheets must be readily available to the employee.

The immediate implication to full implementation of WHMIS is an increase in administrative work. Once fully in place, workers will be better equipped to safely work with hazardous materials. Workplace morale should also improve.

WHMIS legislation represents occupational rather than curriculum safety and its implementation only slightly precedes the introduction of the Ministry of Education science curriculum guidelines. These guidelines, which were to be fully adopted by Septemer 1989, necessitate the use of more chemicals in the classroom and also place greater importance on safety issues. WHMIS legislation and the science curriculm guidelines complement each other and, if employed correctly, will create environments in which the students will become scientifically literate as well as safety conscious.

MINISTRY OF EDUCATION GUIDELINES

Under the curriculum guidelines, "Safety Considerations" are a mandatory portion of each unit of study. The guidelines state:

> The ultimate aims in regard to safety are to prevent accidents and to enable students to engage in scientific investigations and experimentation, to design their own techniques with confidence, and to enjoy their participation in the process of doing and learning

> science without fear of injury (Curriculum Guidelines Part 1 1987, p. 45).

To achieve this aim, students are to perform only those experiments where they are fully aware of the possible hazards and the precautions required to avoid accident. Attention to safety is to be stressed in all student investigations and teacher demonstrations.

For each unit of study outlined in Part 13 of the curriculum guidelines, Subsection 6, titled "Safety Considerations", reminds teachers of some of the safety measures applicable to the unit under investigation. A more thorough, but in no way comprehensive, discussion of safety issues is supplied in Part 1, Program Outline and Policy, section 9 and subsection 12.1. Included in this consideration of safety and recommended procedures are the responsibilities of administrators, principals, science teachers and students.

The Ministry of Education also publishes Safety Memoranda which are to be consulted by school boards as they develop safety procedures. The Ministry replaces and updates these Memoranda as required. Safety Memoranda particularily applicable to the chemistry classroom are:

No.	Subject
2	Electical Safety
3	Fire Drill and Evacuation Procedures
4	Gas Installations in Secondary Schools
5	Safety and First Aid Education
8	Eye Safety
12	Fire Safety in School Activities, Classrooms, Laboratories, and Technical Shops
13	Disposable Butane Lighters

14	Chemical Gas Cylinders
15	Asbestos Hazard
18	Hazards Associated with Methyl Alcohol
24	First Aid Requirements for Employees

Safety Memorandum No. 1 outlines school and school board policy. Issued in December 1984, this memorandum suggests that supervisory officers, principals and teachers should review present Ministry safety policies as found in Acts and Regulations, school board documents and Ministry memoranda. Recommendation is also made that in-service training programs be arranged to assist staff in identifing and reacting properly to hazardous situations. A framework which may be used by school boards when developing safety policy is also oulined in this memorandum. Note the relevancy of this memorandum to the safety issues currently receiving attention in the schools.

The purpose of Ministry Safety Memoranda is to provide to school boards and teachers a resource; their use is for clarification of safety procedures only. Other resources available for this intent include journal articles, textbooks and school board documents. It must be stressed that each of these resources serve as an aid to the educator but the main responsibility to remain abreast of legal matters in regard to safety issues lies with the school board.

OTHER LAWS AFFECTING SCHOOLS

Brief mention is directed to other Codes and Acts having effect on the educational environment. A student is protected as a member of the general public under the Health Protection and Promotion Act. Under this Act inspectors may issue orders to schools under whatever standards deemed appropriate to the circumstance. Other Acts affecting schools, but not implemented solely for their purpose, include Fire Code (Fire Marshall's Act), Building Code, Electrical Safety Code, Public Health Act. Again, the responsibility for understanding how these Acts affect the educational institution falls on the shoulder of the school board.

IMPLICATIONS

The various Acts, Regulations and guidelines discussed place considerable responsibility with the school boards, administrators and teachers. Strict adherence to these duties seems necessary, but science teachers in particular may become overwhelmed by the demands placed on them. As stated previously, should these demands become excessive fewer individuals may pursue science teaching as a vocation. In light of concerns expressed over the present state of science education, such a consequence should be avoided as it will only exacerbate the situation.

CHAPTER FOUR

CHEMISTRY TEACHERS AND TORT LIABILITY

A wide variety of situations expose chemistry teachers to potential libility. While many causes of action for personal injury are derived from statuatory provisions, chemical educators are becoming increasingly concerned of the possibility of lawsuits alleging negligent action in the performance of their teaching duties. With increased emphasis on student experimentation in the chemistry curriculum, it is important that teachers be aware of their susceptibility to such action and the precautions necessary to avoid them. Attention therefore is directed to the requirements imposed by tort law.

LAW OF TORTS

A tort is a civil wrong. Torts may be intentional or unintentional; in both cases damages are caused by a breach of duty. The purpose of tort law is to compensate the injured party for loss suffered due to the actions of another. All tort cases therefore deal with liability and the amount of the loss (also called damages) suffered. The courts quantify the loss and shift it to the one who committed the wrong. Liability is based on the fault concept.

A variation of the fault concept is the principle of vicarious liability. According to this principle the employer is liable to compensate the parties injured by the actions of the employee in the course of employment. Although the employee remains personally liable for his torts, damages are best recovered from the employer. As a result, employers are often insured against such losses. The Education Act requires school boards to be insured to cover damages in such cases (Nimmo 1989). In the context of the educational environment therefore, should a teacher be named in a tort action, it is the school board's insurance company that pays damages, not the teacher. Note, however, that in any civil suit, even though the teacher does not personally pay damages, his reputation does come into question.

In civil suits it is necessary only to prove fault on the basis of a balance of probabilities. On hearing the factual evidence presented by both the plaintiff and the defendant, the judge decides on a balance of probabilities which one is more credible. In the criminal courts judges are required to be convinced of the facts "beyond a reasonable doubt".

Judges' decisions are also influenced by the doctrine of stare decisis -- the doctrine of following precedents already established by the courts. In Canada, lawsuits involving negligence in the science laboratory have been few and thus little precedent has been set (Armour 1987). In fact, there is only one recorded lawsuit involving negligence on the part of the teacher in the science laboratory. Many similar suits, however, may have been settled out of court. Discussions of negligent actions against teachers other than science teachers (Lee 1987; Nimmo 1989) provide insight as to how the Canadian courts make decisions in civil actions, specifically with respect to factors constituting negligence and determination of liability. This in turn can be used as a guide to the chemical educator in the performance of his duties.

NEGLIGENCE

The most common unintentional tort, especially in the field of education, is negligence. This tort also exemplifies the fault concept of liability. By definition negligence is "unreasonable or imprudent action or failure to act; especially, the failure to take reasonable precautions to avoid injury to persons or property " (Funk and Wagnall's College Dictionary, p. 905). Negligence is accidental, not deliberate harm. According to the concept of negligence, anyone who carelessly causes injury to another party must compensate that party for the injury. The concept is broad and applicable to many circumstances. The burden of proof is on the plaintiff, and in order to recover compensation he must satisfactorily prove to the courts the following three things:

1) the defendant owed the plaintiff a duty of care,
2) the defendant broke the duty of care by acting as he did, and
3) the defendant's breaking of the duty caused the injury.

The success or failure of a negligence suit usually depends on one of these three factors.

DUTY OF CARE

In order to determine liability in a negligence action, the plaintiff must first show that a duty of care was owed by the defendant. If no duty exists the case goes no further.

Within the context of the classroom, it is understood that teachers have a duty to exercise care for the health and welfare of the student; this is also mandated by various statutory provisions. Of particular relevance is Regulation 262 under the Education Act for the Province of Ontario which states that teachers shall "ensure that all reasonable safety procedures are carried out in courses and activities for which the teacher is responsible." Also recall that included in the duties of the principal is the requirement "to give assiduous attention to the health and comfort of the pupils . . ." (Education Act for Ontario, Chapter 129, Section 236(j) 1985).

In addition, Section 229(1) of the Education Act more generally describes the duties of the teacher as:

> a) to teach diligently and faithfully the classes or subjects assigned to him by the principal;
> b) to encourage the pupils in the pursuit of learning;
> c) to maintain, under the direction of the principal, proper order and discipline in his classroom and while on duty in the school and on the school ground.

From statute law it is clear that the teacher owes a duty of care to the student while at school. Although complex lawsuits involving students and school personnel are possible, the purpose of this discussion is to determine the duty of care required of a chemistry teacher in a laboratory classroom by tort law, not by statutory law.

In general, the law places a duty on everyone to conduct all activities taking reasonable care to avoid foreseeable harm to people and their property. The chemistry classroom is an environment in which students encounter some inherently hazardous situations and thus a duty of care is clearly owed. Legislation may set out appropriate standards of care for various activities, and although a person may be in breach of the statutory standards, this does not of itself make them civilly liable for injury caused by the breach, especially if it can be shown that the offence which occurred was not that person's fault. Recall that negligence is based on the fault concept. In Canada there is no tort of a "breach of statutory duty" (Smyth, Soberman and Easson 1987, p. 78).

The owing of a duty of care necessarily requires the establishment of a standard of care. The standard of care normally called for is that of an ordinary reasonable person. In schools this translates to that of a "reasonably careful parent" (Lee 1987; Armour 1987). This standard of care requisitely varies with the activity in question, the level of ability of the students undertaking the activity, and various other such factors. For example, a higher standard of care is required when instructing disabled students than when teaching able students. Due to the variability of the standard, teachers need to be aware of their students' abililties, the appropriateness of the activity, potential hazards, etc. This is no small task to a teacher who is responsible for many students, ability levels and classes.

The duty to take care is based on foreseeability of injury. According to the doctrine of foreseeability the duty owed will only arise where the defendant could have reasonably foreseen a risk of harm to the plaintiff. It does not follow, however, that because harm is foreseeable that the activity should not be pursued; rather, in pursuing the activity there is a duty to take reasonable measures to avoid that harm.

The doctrine of foreseeability places a heavy burden on school administrators and teachers. The teacher will be found negligent if the courts conclude that the injury could have been foreseen and was not, or that appropriate action was not taken even though risk of harm was foreseen. A greater burden is imposed by the fact that even though a given situation has supposedly never before resulted in injury, school teachers and administrators are still expected to foresee possible injury. School personnel are also expected to know of any similar circumstances which have led to injury. Since the duty imposed by this doctrine is quite severe, it is vital that school boards, administrators and teachers pay attention and be fully aware of any litigations involving negligence. This is especially important since our society is becoming more litigious at a time when the chemistry curriculum is mandated to become more experimentally based.

BREACH OF DUTY

In negligence actions against schools and school personnel often the question is not whether a duty was owed but rather whether the duty owed was breached by the defendants. A breach of duty may arise from an act of commission or an act of omission. In the context of the school, an alleged breach of duty is generally the result of an inaction and a common claim against a teacher is that of inadequate supervision (A Legal Memorandum 1989).

In determining whether a breach of duty occurred, the courts must ascertain if the defendant acted as a reasonably prudent teacher would have behaved in the same circumstances. Central to this conclusion is the establishment of what the teacher should have foreseen given the situation. Teachers are held to a standard based on their level of training and their skills.

Decisions of breach require examination of all the facts surrounding the incident. Factors such as the plaintiff's age, level of maturity, level of training, the nature of the risk to which he/she was exposed, the instruction given by the teacher before and after the injury, and common practice in the school industry are considered by the courts in arriving at a decision. These considerations are but a few of many possibilites; circumstances differ with each negligent action.

Four criteria which have come to be standard tests for breach of duty are set forth by Judge Carrothers in Thornton et al. versus Board of School Trustees of District No. 57 (Prince George) et al. In this case Thornton filed a suit against his teacher, the principal and the school board for an injury incurred while attempting a somersault from a springboard in his Physical Education class, rendering him a quadrapeligic. These same four tests can be applied to a potential chemistry experiment when the term "manoeuvre" is substituted by the word "experiment". This also illustrates how precedents are applied to new lawsuits. The four tests are:

> 1. Was the manoeuvre suitable to the plaintiff's age and condition (mental and physical)?
> 2. Was the plaintiff progressively trained and coached to do the manoeuvre properly to avoid danger?
> 3. Was the equipment adequate and suitably arranged?
> 4. Was the manoeuvre, having regard to its inherently dangerous nature, properly supervised? (Judge Carrothers in Thornton et al. v. Board of Trustees of District No. 57 (Prince George) et al. 1976).

A teacher considering these tests each time a hands-on activity is to be performed by the students, is well on the way to creating an environment subject to fewer negligent actions.

CAUSATION

Essential to recovery of damages is the establishment that the breaking of a duty owed caused the harm claimed. No matter how negligent a person's actions may have been, they will not be held liable for harm that was not caused by the negligent action in question. If it can be shown that the teacher's conduct did not cause the injury, the teacher will not be found liable.

LEGAL DEFENSES

The most effective manner in which to avoid liability for negligence is to take the appropriate steps to avoid the injury. This should be the first line of defense. Should an instructor be named in a tort action, however, there are several legal defenses to recovery. Two such defenses are discussed here, contributory negligence and assumption of risk.

Contributory negligence arises when the plaintiff contributes to his/her own loss. For example, the plaintiff driving a car has a collision with the defendant who, driving another car, failed to stop for a red light. In studying the facts, it is shown that the plaintiff was found to be speeding and thus contributed in some measure to his own loss. A legal defense of contributary negligence is applicable -- the plaintiff has a duty to drive safely and within the speed limit. In such circumstances the Negligence Act requires that the courts apportion damages according to the respective degrees of responsibilities of the parties.

In the educational setting there are difficulties with this line of defense. In an introductory chemistry course, the knowledge of the teacher far exceeds that of the learner. Students therefore, given their limited training, do not have the ability to adequately foresee possible harm. Other than instances of horseplay, this leaves little room for contributory negligence on the part of the student. Examples exist, however, of cases in the United States in which the plaintiff was a student and failed to recover damages because of contributory negligence (Gass, Part II 1990).

The second legal defense potentially available to chemistry teachers is known as assumption of risk. Chemistry laboratories are places of obvious danger and an individual is said to have assumed risk when he/she knowingly and voluntarily subjects himself/herself to that danger. Both knowledge and volition are requirements of assumption of risk. It can be argued that students in introductory courses cannot fully know of the risks in the chemistry laboratory. This legal defense is often more appropriate in suits involving colleagues or more advanced graduate students of chemistry (Sweeney 1977).

Some educational institutions employ some type of release of liability form that students are required to sign (Appendix 2). These forms may be considered a contract in which the student assumes risk in exchange for instruction. In introductory chemistry courses the risk assumed is usually greater than that agreed on in the contract and thus the effectiveness of such forms is questionable and cannot often be used as a legal defense supporting assumption of risk. These contracts do, however, impress upon students the importance of safety in the laboratory classroom.

AVOIDING NEGLIGENCE

Although in Canada there is only one recorded lawsuit of negligence against a science teacher, the number could conceivably increase when implementation of the science curriculum guidelines of 1987 is complete. Many factors contribute to a greater burden being placed on chemical educators to conduct their duties in an appropriately safety conscious fashion. These factors include the prominence being given to health and safety issues, the implementation of new regulations such as WHMIS, a public more informed of their rights as citizens, and the fact that few legal defenses are available to teachers. The ramifications of not performing ones duty responsibly can be costly and thus educators are well advised to create an environment subject to minimal potential litigations. In order to protect themselves from possible lawsuits the following precautions are suggested.

1. Be knowledgeable of the general level of competence and previous training of the students.

2. Before the experiment or activity begins, warn the students of all potential hazards and advise them on the precautions necessary to avoid harm. Instructions may include actions to take in the case of an emergency. Demonstration of the activity may also be advantageous.

3. Be cognizant of school regulations, and federal and provincial statutes that impose legal responsibilities. Those regulations

addressing adequate laboratory facilities may be of particular importance at this time.

4. Select appropriate activities, equipment and materials.
5. Actively supervise the activity and do not leave the students alone.

These are some of a number of steps a teacher could possibly take to mitigate against negligence suits. Possibly the greatest influence to students is the personal example of the teacher. An instructor who is positive and enthusiastically committed to safety impacts tremendously on students and also fulfills the requirement of the curriculum guidelines that students not be fearful in the chemistry laboratory.

IMPACT OF TORT LIABILITY ON THE CURRICULUM

In view of the growing emphasis on safety and the potential hazards inherent in student laboratory activities, many high school chemistry teachers in the past have avoided frequent use of student experimentation as a method of instruction (Ray 1987). With implementation of the science curriculum guidelines this avoidance is no longer possible. Adherance to these guidelines, however, comes at a time when teachers should become more informed of their legal responsibilities as related to health and safety. Expectations of what is required of a science instructor is increasing, and tort liability in particular places a heavy burden on the teacher. In light of the various other factors to be considered in the operation of an effective laboratory program, and the costly ramifications of acting inappropriately, teachers may be unwilling to adopt the approach to chemical education demanded in the curriculum guidelines. To do so would be to deny the students the experience of doing science and would fail the objectives of science education.

CHAPTER FIVE

THE LABORATORY SITUATION TODAY

In an attempt to determine whether safety concerns were purely academic or whether educational institutions were actually reacting to these issues, letters were sent to various Ontario school boards and universities. While this is in no way to be considered a comprehensive survey, the replies did offer some insight into actual practices being followed in these educational institutions. In general the responses received addressed occupational safety and not curriculum safety. Inferences, therefore, regarding actual safety practices and their effect on the implemented curriculum are difficult to make. Following is a summary of the activities and policies that have been adopted by the participating schools.

THE HIGH SCHOOL LABORATORY SITUATION

BOARD OF EDUCATION DOCUMENTS

Several school boards provided safety documents which they had produced for their employees and students. These documents addressed occupational safety, and informed both teachers and students of their duties and responsibilities.

The York Region Board of Education developed a pocket book titled Occupational Health and Safety Manual and WHMIS. This manual is a guide to health and safety practices for School Board employees. Included in the manual are:

1. Emergency procedures.
2. Duties and responsibilities of all levels of employees of the School Board as required by the Occupational Health and Safety Act.
3. Details on matching protective equipment to the task at hand.
4. General safety rules for both the classroom and the office.
5. Chemical substance safety as it relates to storage and handling and WHMIS.
6. The role of joint health and safety committees as required by the Occupational Health and Safety Act.
7. Directions on conducting a safety audit as required by the Occupational Health and Safety Act.

The York Region Board of Education also publishes a procedures manual which further outlines the responsibilites of science teachers, science students, and more specifically chemistry students, in maintaining a safe learning environment. Regulations regarding storage of chemicals and science equipment is included, as are ventilation requirements for storage areas and science laboratories.

The Halton Board of Education has a similar manual titled Halton Science Safety Committee Manual. Outlined in this manual are suggestions and advice for safety in science laboratories. The responsibilities of administrators, science department heads, science teachers, and students are described; the use of safety equipment and chemical storage are also addressed. One suggestion in the manual is the use of a student declaration form indicating that he/she has read the safety rules and will abide by them, otherwise laboratory privileges will be withdrawn. This edition of the safety manual was by no means comprehensive and it was determined that revisions are presently being made.

The Hamilton-Wentworth Roman Catholic School Board issues a safety monograph to students of science thus making them aware of their responsibilities and the possible hazards that they may encounter. Students are also informed of teacher responsibilites, an important item to be aware of given the nature of negligence suits. This school board also requires that students sign a declaration form on reading of the safety monograph. In general, it is believed that signing such a form will impress upon students that they are responsible for their own safety.

The Hamilton Board of Education similarily distributes to all year one secondary school students a pamphlet titled Student Lab Safety. This document draws attention to the various dangers encountered in a science laboratory, the measures that need to be taken in order to avoid these hazards, and the emergency procedures to follow should an injury or fire occur. Specific dangers addressed are cuts and burns, eye damage, electric shock, poisoning, and fire or explosion. Tips are also included on how to behave responsibly and safely in the science laboratory.

THE HAMILTON REGION INTERBOARD CHEMISTRY CURRICULUM

The Hamilton Region Interboard Chemistry Writing Team consists of representatives from five school boards in the Hamilton area. The curriculum documents produced were written in an effort to provide the educator with a complete course curriculum guide consistent with the requirements of the 1987 Ministry of Education science curriculum guidelines as well as Board Curriculum documents; they were not designed to replace the Ministry guidelines. The curriculum documents for Advanced Chemistry SCH OA, 1988 Draft, and Advanced Chemistry SCH 3A, 1986 Draft, were reviewed.

Each document contains a warning to chemistry teachers. It is emphasized that even though every effort had been taken to produce curricula containing only those procedures which could be conducted and supervised safely by qualified staff, no procedure should be undertaken unless first attempted by the competent instructor, who also ensures that the activity is in accordance with the appropriate regulations and classroom environment.

Each unit of each document consists of five sections. Science policy of both the Ministry of Education and the Board Curriculum documents is addressed in the "Introduction". The "Teachers' Guide" contains specific teacher-learning objectives as well as strategies which may be utilized to achieve them. Safety considerations relevant to the implementation of the unit are also referred to. Specific student activities and teacher demonstrations supporting the teaching strategies found in the "Teachers' Guide" are provided in the "Student Activites" portion of the document. In both the SCH 3A and the SCH OA documents, laboratory exercises consist of a mixture of validation type and discovery type activities. Minimal theory is provided in the introduction of the exercises and questions the students are required to answer on completion of an experiment attempt to guide them through the types of reasonings a scientist may follow. Safety precautions are noted in only some of the activities, thus it is important that chemistry teachers attempt the activity before introducing it in the classroom. Laboratory tests are also included in this section. The "Teachers' Resources" section and the "Appendices" provide more information useful in the classroom as well as solutions to the activities described in "Student Activities". Teachers should take special note of Appendix A wherein is described the responsibilities of teachers, the responsibilities of students, and some recommended safety procedures.

EDUCATORS' REPORT

In the spring of 1988 the Ontario Ministry of Education conducted a provincial review of Senior Division Advanced Level Chemistry, the results of which are summarized in Senior Division Advanced Level Chemistry Educators' Report (1989). The motivation behind this provincial review came from increasing concern regarding the state of science education in Ontario (Wrigglesworth 1989). The data required for this study was gathered from over 12 000 Ontario students and their teachers. Data was collected for the intended curriculum, represented by the Ministry of Education Guidelines, the implemented curriculum and the attained curriculum which was obtained by assessing student achievement on a variety of questions. The results of those variables considered relevant to this discussion are summarized here.

1. Class size: 32% of the teachers participating in the review reported that most classes have enrolments between 26 and 30 students; 16% reported class sizes greater that 31 students; 26% of the classes had between 21 and 25 students.

2. Computers: 67% of the students reported no use of the computer at school.

3. Classroom activities: A variety of activities were reported by the students but the most common were copying notes from the blackboard/overhead projector into their notebooks; experimental activities were reported to be relatively infrequent with more than half of the students reporting involvement less that twice a week. Teachers, however, reported that approximately half of the time spent in class was on student-centered instructional activites.

4. Teaching resources: The resources used by teachers included textbooks, computer software, videotapes, field trips, guest speakers, etc. Analysis of the data, however, reveals that the traditional use of resources such as laboratory worksheets, chalkboards, overhead projectors and commercially produced apparatus and equipment was most frequent.

5. Instructional approaches: Instructional approaches presented were class instruction, group instruction, individualized instruction, textbook, socratic, demonstration, guided discovery, laboratory, project and science kit. The socratic method and the laboratory were the approaches most frequently used by the teacher; group instruction, project, guided discovery, and individualized instruction were employed relatively infrequently.

6. Evaluation: The most common methods of evaluating students were found to be the traditional tests, examinations, quizzes and laboratory reports. Approximately half of the teachers reported testing laboratory skills but only 12% incorporated them into determination of a final grade.

7. Experimental activities: Traditional experiments using worksheets and laboratory manuals were performed most often by the students. Many students also observed their teacher conducting a demonstration. Students were also found to analyze data or draw conclusions from data not collected in a student experiment but from other sources such as teacher demonstrations or textbooks. In pursuing experimental activities, a great deal of emphasis is placed on learning how to analyze data and less attention is given to hypothesis generation or experimental design. Many teachers believe that experiments should be used to discover laws rather than verify them and that it is important to stress the application of the process to other aspects of life.

8. Computers: 21% of students had access to computers in the classroom, but their use of spreadsheet, data base or wordprocessing programs was low. The use of educational software was also only very occasional.

SUMMARY

Clearly the school boards which responded are producing documents and implementing policies addressing both health and safety issues and the requirements of the science curriculum guidelines. It should be noted that joint health and safety committees producing safety related material are responsible for safety in all areas of the school and thus the extent to which safety is a concern in the science classroom is unknown.

The Educators' Report (1989) reflects the requirements of both the 1966 and the 1987 science curriculum guidelines. While the data obtained is for the grade 11 course only, the implication is that the implemented science curriculum is not yet fully laboratory oriented, although efforts are being made in this direction. This effort is particularily evident in the Hamilton Region Interboard Chemistry Curriculum.

THE UNIVERSITY LABORATORY SITUATION

QUEEN'S UNIVERSITY

Students in first year Chemistry at Queen's University perform a three-hour laboratory activity each week for a total of 24 weeks. The objectives of the laboratory activities are threefold.

> 1. Developing a few skills to a point where, in using those skills, the accuracy of the experiment is deteremined by the accuracy of the equipment rather than the way in which the equipment is used.
> 2. Developing an understanding of the meaning and accuracy of a scientific measurement.
> 3. Becoming familiar with a range of common chemicals (First Year Laboratory Manual, Queen's University 1989, p. 1).

These objectives are reiterated in the first experiment where the students perform a simple synthesis of potassium trisoxalatoferrate(III). In this laboratory it is stated that

> we are not so much interested in the synthesis itself as we are in acquiring techniques. . . . There is nothing more important in these labs than that you develop a professional attitude toward obtaining data. . . . Such an approach is central to generating the reliable data on which all science and engineering is based (First Year Laboratory Manual, Queen's University 1989, p. 12).

To achieve these objectives, the first term is largely devoted to developing the technique of volumetric analysis, six weeks of the second term is spent on a systematic scheme of qualitative analysis, and the remainder of the laboratory course demonstrates chemical principles introduced in the lectures and if possible utilizes techniques developed earlier.

Safety is addressed in one page of the laboratory manual. Various regulations are listed regarding appropriate behaviour in the chemistry laboratory and procedures to follow in the event of an emergency. Violation of these regulations is deemed to be grounds for expulsion from the laboratory. Individual experimental procedures also state any necessary warnings and precautions.

Although no further information regarding the place of safety in the laboratory program was provided it is assumed that safety is adequately emphasized by the graduate student laboratory demonstrator. These demonstrators are responsible for the supervision of approximately 24 students.

The experiments are presented in the style consistent with the "cookbook" approach to laboratories. The experiment is introduced with a brief summary of the required theoretical background and is followed by a detailed experimental procedure. Appropriate questions are listed in the "Results and Calculations" section of the experiment and are to be answered in the laboratory report. Other than two formal laboratory reports, the laboratory write-up need only contain the student's data and those calculations required in the "Results and Calculations" section.

MCMASTER UNIVERSITY

The first year Chemistry course is one in which descriptive chemistry is integrated with principles and theories; emphasis is not placed primarily on theory. The course textbook, Chemistry by R.J. Gillespie et al. places a greater emphasis on descriptive chemistry than is traditionally seen in an introductory course. The textbook also incorporates the philosophies of mastery learning; no chapter can be mastered as an independent unit but relies on previously acquired knowledge.

The purpose of the laboratory program, while not stated explicitly, is to provide an opportunity for the students to handle and respect chemicals, to learn the name of and use of various apparatus, to observe and record experimental data, and to formulate conclusions based on these observations. Some experiments validate theories introduced in the lecture and others, more descriptive in nature, introduce students to chemical facts. Both types of laboratory exercises complement the lecture topics.

Ideally the laboratory exercises are to be completed before the relevant concepts have been discussed in the lecture. This is believed to develop a better understanding of the need to collect data prior to formulating an hypothesis. In practice, however, laboratory exercises usually follow the lecture material, and should the occasion arise where an experiment does precede the lecture discussion, faculty concern is expressed.

As has been alluded to, the majority of the experiments are performed after the theory has been presented in the lecture. In an effort to illustrate that facts and experimental findings precede the development of theory, lecture demonstrations and/or videos of experiments are frequently incorporated into the lecture discussion. Visual presentation of the reaction under consideration is believed to be important to the learning process as the impression left with the student is more lasting than a mere reading of the reaction. If delivered correctly and competently this instructional approach also emphasizes the experimental nature of chemistry.

Students participate in a three-hour laboratory exercise every other week. The total number of experiments performed on completion of the course is eleven and they contribute 10% to the final course grade. In the laboratory manual each experiment is introduced with a brief summary of the relevant theory. This is followed with detailed experimental instructions as well as questions or guidelines on information to be included in the laboratory report. A proper laboratory report is required for each experiment. Although the course instructors in theory attempt to stress inquiry, the laboratory component is typical of the traditional approach to introductory experiments and is often referred to by the students as a "cookbook" exercise.

Safety is brought to the students' attention in the first laboratory period. They are required to complete a safety quiz (Appendix 3), read the Safety Bulletin provided in the laboratory manual, and sign a form stating that they have read the required safety material and will abide by the regulations set forth (Appendix 2). Throughout the laboratory program the students are reminded of safety through appropriate precautions written in the laboratory manual and by promptings from the laboratory demonstrators. As in other university laboratory settings, laboratory demonstrators are responsible for the supervision of approximately 24 students.

UNIVERSITY OF TORONTO — ERINDALE CAMPUS

Students of introductory chemistry at the University of Toronto's Erindale campus in Mississauga, Ontario perform eleven experiments and are required to write formal laboratory reports for six of these exercises. The experiments contribute 25% to their final grade.

One objective of the laboratory program is to teach students to carefully and accurately observe and record, both quantitatively and qualitatively, data from the experiment they are conducting. Other major objectives include adding to the understanding of well understood concepts and theories, a validation objective, and improving experimental technique. These objectives are summarized in one statement: "The object of a laboratory course, therefore, is not simply to mindlessly get "correct" answers but to learn to understand how to handle common laboratory apparatus and what needs to be done to get reliable results" (Chemistry 135Y/150Y Laboratory Manual 1989/1990, p. 5).

Each experiment in the laboratory manual is introduced with a very brief summary of any relevant theory. The purpose of the exercise may also be stated in the introduction. Each experiment is characterized by detailed experimental instructions which are followed by questions to be addressed in the laboratory write-up. Experiments not requiring a formal report are summarized on data sheets provided in the laboratory manual.

Laboratory exercises at Erindale Campus are designed to develop experimental technique and this is achieved by using chemicals and reaction types under consideration in the lecture. In other words, an effort is made to have the laboratory experiments complement the lecture material, thus enforcing the experimental nature of chemistry.

A portion of the first laboratory period is devoted to safety issues. This is accomplished through a lecture and a movie on safety. In addition, safety rules and regulations are outlined in the laboratory manual and appropriate precautions are noted in the experimental procedure as necessary. At the University of Toronto the emphasis of the introductory laboratory is the development of experimental technique and thus the use of dangerous chemicals is avoided as much as possible.

UNIVERSITY OF GUELPH

Several introductory chemistry courses are offered at the University of Guelph. Chemistry 19-100 is the course in which the majority of the students enroll and is the one to be discussed here.

A perusal of the laboratory manual and additional course material obtained indicated that the laboratory functions as an environment in which the student is introduced to basic experimental techniques and exercises reinforcing concepts introduced in the lecture. Specific objectives of the laboratory are stated as:

1. To illustrate certain principles of chemistry which you will learn in Chemistry 100 and to help you to understand and remember these priniples.
2. To provide some appreciation of the manner in which chemical knowledge is obtained, and for the difficulties involved in experimental measurement.
3. To learn a few of the basic experimental techniques of chemistry.
4. To give you some idea of the kinds of things chemists do (Laboratory Outline for Chemistry 100 1988, p. 1).

Of the responses received from post-secondary institutions, the University of Guelph was unique in that the laboratory comprises five hands-on, or "wet", laboratories and four computer laboratory simulations. The inclusion of computer simulations into the laboratory curriculum was purely an economic decision.

The wet laboratory activities enforce the development of experimental technique while the computer simulations tend to emphasize concepts taught in the lecture. The experiments performed in the laboratory contribute 9% to the final grade and the computer simulations contribute 7%.

The computer simulations are not considered to be a substitute for the actual laboratory experience. They do, however, provide a medium through which a student can change variables and obtain experimental data much more quickly. This is believed to broaden the learning experience and contribute to the sense that chemistry is an experimental science. Simulations are performed in volumetric analysis, gas phase equilibrium, pH titration curves and the determination of molecular geometry. They are treated as experiments in that data is obtained, entered into the laboratory notebook, calculations are completed and conclusions are made.

The activities of the wet laboratories are typical of those conducted at the other universities considered. They are introduced with a summary of the relevant theory which is followed by a detailed experimental procedure and questions whose answers are to be addressed in the laboratory report. Reports are handed in on data sheets provided in the laboratory manual.

Safety is addressed through a variety of means. General rules are provided in the laboratory manual; instructions of emergency procedures are also given. Included in the safety section of the laboratory manual is a discussion on the use of material safety data sheets as required by WHMIS. It is not known whether the other post-secondary institutions inform their students as to the use of these sheets.

Final year undergraduate students are hired as laboratory demonstrators. The "Demonstrator Notes" provided to the laboratory demonstrators, stress the need to strictly enforce safety regulations; eye protection is strongly emphasized. Directions are also supplied for actions required in various emergency situations such as acid or alkali burns, cuts, acid or base spills and splashes in the eyes. A short, five minute talk on safety is included in the first laboratory period and the demonstrators are directed as to what information should be included in this discussion. Laboratory demonstrators are responsible for approximately 24 students.

SUMMARY

Safety concerns in the university do not receive the attention believed to be currently present in the secondary schools. Facilities are generally better equipped and health and safety committees are also in existence.

The adequacy of introductory laboratory chemical education in the university environment is questionable. Replies indicated that most of the introductory programs enable students to perform at most ten experiments; Queen's University was the exception. Several schools also reported that laboratory reports were submitted in fill in the blank forms; few universities required properly written reports for all the laboratory activities. The element of discovery and inquiry was not prevelent or obviously encouraged by many of the schools.

The adequacy of laboratory supervision is also doubtful. The laboratory demonstators at the introductory level are often students in their final undergraduate year and do not have the experience or teaching skills necessary to supervise 24 freshman students. Other demonstrators may be foreign students who lack the language skills required to properly communicate; experience has shown that graduate students weak in this area are often assigned to the freshman course. Most faculty feel that real chemical education begins when students are in the second year of a chemistry major and thus suitable laboratory instructors are not essential in the introductory program.

In general it may be said that students enrolled in an introductory chemistry course at the university level are deprived of a valuable and meaningful laboratory experience.

CHAPTER SIX

ALTERNATIVE LABORATORY ACTIVITIES

Laboratory activities provide educators the opportunity to teach scientific reasoning skills and students the environment in which to develop problem solving skills. Previous mention of the purposes of the laboratory component of the chemistry curriculum has made this clear. Discussion has also supplied insight into the various constaints which make implementation of an effective laboratory program a challenge to the chemical educator. Wishing to remain faithful to the true nature of chemistry, yet desiring not to employ student experimentation if possible, the instructor will seek alternative activities. These activities are chosen with the objective of achieving the aims and goals of the chemistry curriculum. Consideration will be given in this chapter to a number of possible alternative laboratory activities.

COMPUTERS AND COMPUTER SIMULATIONS

Computer simulations provide a useful alternative to the laboratory activity. Chemical educators may also employ computer simulations to augment an experiment. Lagowski (1989) suggests that simulations can be used to anticipate the laboratory experience by being completed prior to the actual laboratory exercise. Alternatively, he recommends that simulations can be employed to extend the laboratory exercise thereby providing for a much richer experience.

Obviously computer interaction does not develop the manipulative skills necessary in the practice of proper experimental technique, but simulations of experiments do provide other advantages. Moore and Moore (1986) suggest that simulations enable students to experience experiments that are too dangerous, expensive, slow or fast to perform in the laboratory. They also help students to make more efficient use of their time in the laboratory, and programs capable of plotting and analyzing data teach skills that individuals will carry with them into the workplace. Computer simulations also permit students with minimal laboratory skills to experience the scientific method and thus their chemistry experience is broadened and made richer.

Through the use of simulations it is possible for students to see the results of their own experiments immediately (Friedler et al. 1990). Properly designed simulations also present the opportunity to vary parameters and observe the effect without taking up considerable class time (Cauchon 1986). This makes the experimental results more meaningful and aids in the development of problem solving skills.

Simulations can be a valuable educational tool for institutions experiencing the effects of budget constraints. After the initial implementation costs, simulations are economically more viable than traditional wet laboratory activities. Recall that students at Guelph University participate in computer simulations for this very reason.

Several studies have indicated that a carefully designed computer simulation can be an effective educational tool. A study completed by Jackman and Moellenberg (1987) indicated that the computer simulation was the most effective of three instructional methods (traditional, learning cycle, and computer simulation) in chemistry laboratory achievement of spectrophotometry at the freshman level. Bourque and Carlson (1987) concluded that coupling of a computer simulation as a post-laboratory activity with the experiment would optimize student learning. While conclusions on how exactly to incorporate simulations into the laboratory curriculum may differ, the general impression is that this innovation can be used to enhance student learning. Cauchon (1986), who recognizes the advantages to the use of computers in the classroom, does not believe, however, that they should completely replace wet chemistry; the true experience of watching chemical reactions is not adequately captured.

The use of computer technology in the chemistry classroom is not limited to experimental simulations. Friedler et al. (1990), for example, investigated the effect of a microcomputer-based laboratory (MBL) curriculum on the development of students' scientific reasoning skills, particularly the development of observation and prediction skills. MBL enables the student to use the computer to collect, record and manipulate data much as a research scientist does. Through the analysis of written tests, interviews and classroom observation, the researchers found that students cultivated improved observational and predictive skills when taught using microcomputer-based activities.

Johnstone and Wham (1982) indicated that the laboratory curriculum places a high cognitive demand on the students, one many students are unable to cope with. The use of the computer can reduce this workload. Through the use of wordprocessing and database programs, students can attend to the problems at hand rather than focusing on many of the peripheral technical details.

"Computers play a major role in science and should be seen as an essential component of the Intermediate and Senior Division science curriculum . . . " (Curriculum Guidelines Part 1 1987, p. 64); this is the policy suggested in the science curriculum guidelines. Results of the Ontario Provincial Review of Physics and Chemistry indicate, however, that implementation of the computer as a tool in the science classroom is minimal (Wrigglesworth 1989).

Moonen (1989) describes fifteen challenges facing the adoption of computers as educational tools. In particular he notes that teachers must personally feel confident in the use of computers and thus need to be appropriately trained. Teachers also require access to the necessary hardware and software, both at home and in the classroom. Jolicoeur and Berger (1988) recognize that incorporation of suitable quality software into the curriculum can be extremely difficult. The ability to schedule computer time for the students also presents a challenge to the many schools lacking adequate computing facilities.

The use of the computer in the laboratory is becoming essential. One of the aims of the science curriculum is for students to acquire the "skills that are essential for participation in scientific work and technology" (Curriciulum Guidelines Part 1 1987, p. 10); a major requirement in the scientific workplace is computer literate individuals. The challenge to educators is to employ computer technology in such a manner that synergy between the laboratory and computer use is present.

INTERACTIVE VIDEO DISKS

Laboratory exercises enable students to touch, see and smell chemicals and chemical reactions. Safety considerations, however, interfere with the extent to which students may be provided this experience. In an effort to enhance student exposure to the real image of chemistry, educators may use interactive video disks as an alternative to the laboratory activity. This instructional technique, through the combination of television pictures, computer graphics and computer-aided instruction, enables students to interact with realistic images of chemical reactions.

Smith and Jones (1989) discuss the incorporation of computer- and video-based technologies into the chemistry curriculum. Included in their examination is the use of interactive video disks. The use of computer controlled video images permits the student to study reactions which are too hazardous, time consuming, or expensive to complete in the laboratory; these advantages were also noted in the use of computer simulations. Various other advantages of this instructional tool include: the ease in which the student is able to switch between experimental techniques making it possible to examine a number of possible strategies in the development of a concept; the ability to control reaction conditions; the ability to view a reaction a number of times, in slow motion if necessary; and the ability to introduce students to instrumental methods. A preliminary study completed by the authors of this article indicated that students found this instructional approach helpful to their learning of chemistry and preferred it to the traditional laboratory experience.

DEMONSTRATIONS

Lecture demonstrations are an effective method by which to introduce the experimental nature of chemistry. Much of the excitement of chemistry lies in the observation of reactions and the ability to recall related concepts is enhanced through the visual presentation of them. Through the use of carefully chosen demonstrations, students are left with the impression that chemistry is relevant, interesting and experimentally based.

Lecture demonstrations enable students to observe reactions too hazardous for them to conduct personally. Video-taped demonstrations are available for those experiments considered too dangerous for even the instructor to perform in the classroom. Smith and Jones (1989) believe that demonstrations are extremely useful in generating images of real chemistry even though the students are not personally involved. Humphreys (1986) encourages the use of demonstrations in the lecture to motivate and interest students, stimulate thought and discussion, and reinforce the experimental nature of chemistry.

In light of the present unsafe conditions found in many schools, Hounshell (1989) suggests that students be introduced to the experimental nature of chemistry solely through the use of demonstrations. He recommends that hands-on student laboratory activities become part of the curriculum when conditions are such that the learning environment in the laboratory is effective and safe. This conclusion is not suprising considering that paper and pencil tests give no indication that laboratory exercises are more advantageous to the learning of chemistry than demonstrations (Lagowski 1989).

HYPERMEDIA

Hypermedia is a technological innovation presently receiving greater attention in some educational circles. Traditionally information is presented in what are termed linear means through books, films, and videotapes; one starts a certain point and continues along a predetermined path to an endpoint. Hypermedia is a nonlinear representation of information. A variety of media, such as graphics, animation, sound and text, are linked to each other and the user is able to proceed through these various media on a path of their own choosing. The result is a multisensory experience.

Macnaughton (1989) in a discussion of hypermedia illustrates how the student may use this innovation in learning about the chemical elements. In travelling through the hyperdocument the user may read a description of an element of interest, access a database describing the life a scientist, complete with pictures, access another database consisting of setups of experimental apparatus, come in contact with newspaper articles related to scientific issues in yet another database, and so the journey continues. Databases in the hyperdocument may include information of scientific discoveries provided through a video disk of the scientist discussing his discovery; focusing on the year of the discovery the user is provided historical information for that entire year and important terms, names and years would further lead to other databases of information. The size of the hyperdocument is determined only by the programmer and the possibilities of how to organize a hyperdocument are endless.

Clearly vast quantities of information in a variety of media are readily accessible through this innovation. This quality, combined with the high level of control the user has over this environment, causes some educators to view the use of hypermedia as a potentially useful student-centered educational activity (Macnaughton 1989; Marchionini 1988). Chemical educators need to be aware of this technology and consider the effects it may have on the laboratory experience. Could it possibly replace the laboratory component of introductory chemistry courses completely?

OTHER RESOURCES

One of the aims of science education is to develop in students critical thinking skills. Baker (1985) suggests that studying how scientists have made their discoveries and developed their models and theories is one approach by which this may be achieved. Reading about the lives of scientists enables students to become involved in the excitements and frustrations of doing science. This instructional tool does not replace the laboratory experience, but it does promote an understanding of how science progresses.

Another goal of science education is to instill in students that science is relevant and that many of the endeavors undertaken by scientists have lasting societal implications. Courses therefore are encouraged to promote an interest in scientific applications. The National Film Board of Canada has produced an interactive video series exploring science, technology and society titled "Perspectives in Science". Topics explored in the series are toxic waste, water and biotechnology. While this series is not an alternative laboratory activity per say, it is an instructional approach suitable for the senior highschool OAC course "Science in Society". This course may be able to provide useful background information for those students wishing to pursue careers in science, or any other discipline for that matter. If implemented skillfully, this course is able to bring to the fore the relevance of science.

Other instructional activities which can be used to promote the relevancy of chemistry include field trips to chemical industries, guest speakers in the classroom, and reviews of recent magazine and journal articles.

Films, videotapes, slides and filmstrips also have potential instructional value. The National Film Board, TV Ontario and the CBC each produce programs suitable for use in the chemistry classroom. Catalogues can be obtained and the desired media rented.

This discussion has not focused solely on activities capable of replacing the chemistry laboratory, but has included brief consideration of resources which are able to augment traditional instructional approaches. Educational tools which instructors may implement as a substitute for student-centered experimental activities are lecture demonstrations, computer simulations, interactive video disks, and possibly in the future, hypermedia. Properly designed and executed, these methods may be successful in achieving many of the objectives of the traditional laboratory program. However, the degree to which manipulative skills are developed is questionable and educators will need to determine at what level in a student's chemistry education these skills are to be taught.

CHAPTER SEVEN

RECOMMENDATIONS AND CONCLUSIONS

An important and agreed on goal of chemical education is the provision of a meaningful laboratory learning experience. Throughout the evolution of chemical education, curricular changes have sought to achieve this. Despite these noble efforts, the educational community is concerned about the current perceived inadequacy of science education. Several of the factors contributing to ineffective laboratory programs have been discussed and recommendation is now made towards reducing the effects of these constraints.

TEACHER TRAINING

In an effort to determine what type of strategies are instrumental in promoting student learning, studies of exemplary practice were conducted (Garnett and Tobin 1988; Tobin and Fraser 1990). These studies indicated that exemplary chemistry teachers had strong chemistry and education backgrounds, emphasized the development of understanding, managed their classroom efficiently and effectively, placed emphasis on laboratory work, and made efforts to show the relevance of chemistry to society. These studies would seem to imply that the teacher is the essential ingredient to effective learning.

Since exemplary teaching impacts on the level of student learning achieved, it is requisite that chemical educators have adequate training. The need for improved teacher education is recognized and programs have been developed to strengthen the educator's scientific knowledge (Gardner 1988; Gardner 1989). In addition, teacher training institutions, such as the University of Toronto, Faculty of Education, are acknowledging the need to offer prospective teachers a preparation package on the topic of safety (Teacher Pre-Service Training 1989).

With the increased use of computer technology in the workplace it is essential that educational institutions incorporate the use of computers more fully into the curriculum. This can only be accomplished if school facilities are adequately supplied with computer hardware and software and if teachers are motivated to make use of them. This may necessitate computer training programs for teachers. Only when the instructor feels competent in the use of the computer and is able to recognize the importance of this innovation will effective implementation be realized. When this is achieved, instruction in the chemistry laboratory will be greatly broadened through more extensive use of computer-based data analysis, simulations and interactive video disks.

INFORMATION REDUCTION

Several researchers (Johnstone and Wham 1982; Johnstone and Letton 1988/1989; Byrne 1990) have addressed the demands placed on students in a laboratory exercise and recommend reduction of information as a means by which to improve the learning experience. In addition to the recommendations stated in chapter 2, Johnstone and Wham (1982) suggest a reorganization of the laboratory. The first few laboratory periods are devoted to the development of various laboratory skills which are subsequently used, in a carefully prescibed manner, in a number of experiments. The final stage of this reorganization provides opportunity for the students to use their new found skills in a problem situation. To reduce information load in this manner also enhances safety in the laboratory since students will be better trained to carry out the experiments.

The instructional approach suggested above requires that the laboratory component be taught in isolation of the lecture; this may not be considered acceptable to some educators. Information reduction must then be achieved through alternative means. Byrne (1990) has shown that rewritting of laboratory manuals, such that objectives were explicitly stated and enough information was provided to enable understanding of the theory and principles behind the experiment, enhanced student learning. Kozma (1982) also found that explicitly stated objectives, examples, reviews and feedback were conditions required for effective learning. By reducing the amount of information the student must process, attention can be directed to the problem of central importance and not to the peripheral details; meaningful learning is thereby encouraged.

SAFETY

Safety is a concern of all chemical educators, and as has been shown, the safety responsibilities of school boards, administrators and teachers have increased. All educators must become aware of their legal duties and act accordingly.

Although included in the science curriculum guidelines is a description of safety considerations relevant to each unit of study, teachers are responsible for identifying the hazards associated with the particular demonstrations and experiments to be used. This requirement is of utmost importance to the avoidance of possible negligence suits and can only be satisfactorily accomplished by competent chemistry teachers. This supports the need for chemistry teachers with strong chemical and education training.

In tertiary institutions laboratory demonstrators should be aware of the hazards inherent in the introductory experiments. A laboratory safety course addressing the specific dangers present in the freshman laboratory program would prove to be beneficial in this regard. Requiring demonstrators to complete the laboratory exercise prior to their role as instructor may also increase their awareness of potential dangers.

Education of the student population is a means by which to reduce the number and potential severity of laboratory accidents. Proper respect for the chemistry laboratory is best achieved when safety education begins early in the students' science education. Traditional approaches, such as filmstrips, demonstrations, and lectures, are useful. A video-tape considered especially helpful for all secondary school science teachers is "Laboratory Safety -- A Practice for Life" which was produced jointly by Safety Associations of Ontario, STAO, and Workers' Compensation Board of Ontario. Alternatively, safety modules reminding students of relevant laboratory hazards prior to the actual performance of the experiment are effective in developing safety awareness (Ekpo 1988).

While many more comments can be made regarding safety related activities, they are only meaningful if the significance of the laboratory experience is enhanced. Safety concerns, as have been discussed, may be purely academic and thus have little impact on the types of instructional methods employed by the teacher; off-hand comments by chemical educators would tend to support this observation. If this is truly the case, then adoption of the 1987 science curriculum guidelines should pose no additional safety problems to the chemistry teacher and students will be provided a course which effectively places greater emphasis on hands-on laboratory activities. If implemented successfully, the learning experience in the chemistry course will be more meaningful.

The literature implies, however, that safety issues are receiving greater attention. Educators, already burdened by many lesson preparations and extra-curricular activities, must now also contend with the increased responsibilities placed on them by health and safety issues and legislation. In order to cope with all of these demands, teachers may refuse to fully implement a laboratory oriented curriculum. This practice would further reduce the quality of science education and contribute to the ever decreasing number of students choosing careers in chemistry.

FACILITIES IMPROVMENT

Related to the issue of safety is the physical state of the laboratory classroom. The energy placed into the production of Ministry of Education science curriculum guidelines and the mandating of student laboratory activites is comendable, but classroom facility concerns need to be addressed before educators will be comfortable with their implementation.

The requirement of adequate laboratory classroom facilities is essential when one is reminded that teachers are permitted by law to refuse to work in conditions considered unsafe. Should this right be exercised, students attending schools with inadequate laboratory facilities may be denied any practical laboratory experience. As a substitute, teachers may employ some of the afore mentioned alternatives, or, in extreme cases, instruct chemistry solely by the socratic method. To do so would be to fail in meeting the aims and goals of the curriculum guidelines; to participate in any experimental activity that has an associated unreasonable level of risk could result in an unwelcomed law suit.

Essential to a safe learning environment is a facility which meets building code requirements and which is supplied with the necessary safety equipment. Chemistry laboratories should be equipped with a shower, eye wash fountains, first aid boxes, sand pails, fire blanket and fire extinguisher. Proper ventilation is also vital in the chemistry classroom.

The issue of overcrowding must also be addressed at both the secondary and tertiary levels. Reduction of the number of students per laboratory reduces the demand placed on the teacher as well as creates a safe more meaningful learning environment. Instructors are better able to attend to the individual needs of the students and are also more aware of the activities taking place around them. In addition, smaller class sizes will decrease the time spent on evaluation and may, therefore, motivate teachers to demand properly written laboratory reports from their students and to incorporate an increased number of hands-on laboratory activities into their curriculum. Should the physical facilities be acceptable and the class size be manageable, a return to a laboratory oriented chemistry curriculum can become a reality.

CONCLUSIONS

While the recommendations suggested may be able to diminish the effects of various constraining factors, the question remains will the laboratory program remain central to introductory chemical education? Current innovations call for a return to a laboratory oriented chemistry curriculum yet technological advances have provided educators with exciting alternative educational tools. Competent instructors are able to effectively implement these tools while remaining faithful to the experimental nature of chemistry.

The ability to instruct chemistry using alternative methods may prove to be attractive given the safety concerns inherent in the traditional approaches. In establishing the implemented curriculum educators must examine each mode of instruction, evaluate its strong and weak points, and then use that method which is shown to be more effective than the alternatives. Total elimination of the laboratory program however, appears doubtful given the concerns expressed by the educational community and the worldwide consensus that return to a laboratory oriented chemistry curriculum is necessary. Efforts undertaken to improve chemical education are to be recognized, but the laboratory component must remain part of the chemistry curriculum.

APPENDIX ONE

SAMPLE MATERIAL SAFETY DATA SHEET

MATERIAL SAFETY DATA SHEET

SECTION I - PRODUCT IDENTIFICATION AND USE

Product Name/Material Name/Trade Name		Product Code	
Manufacturer's Name and Address		Supplier's Name and Address	
Business No.	Emergency No.	Business No.	Emergency No.
Product Use			

SECTION II - HAZARDOUS INGREDIENTS

Hazardous Ingredients	Approximate Amount (%)	CAS Numbers	Exposure Limits

SECTION III - PHYSICAL DATA

Physical State - ☐ Gas ☐ Liquid ☐ Solid

Appearance and Odour	
Odour Threshold (ppm)	Specific Gravity
Vapour Pressure (mm Hg)	Vapour Density (air = 1)
Evaporation Rate	Boiling Point (C)
Freezing Point/Melting Point (C)	Solubility in Water (20C)
% Volatile (by volume)	pH
Density (g/ml)	Coefficient of Oil/Water Distribution

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

Flammable - ☐ Yes ☐ No	If YES, under which conditions?
Extinguishing Media	TDG Flammability Classification
Flash Point (C) and Method	Autoignition Temperature (C)
Upper Explosive Limit (% by volume)	Lower Explosive Limit (% by volume)
Special Procedures	Hazardous Combustion Products
Explosion Data	
Sensitivity to Mechanical Impact	Sensitivity to Static Discharge

SECTION V - REACTIVITY DATA	
Stable - ☐ Yes ☐ No	If NO, under which conditions?
Hazardous Polymerization - ☐ Yes ☐ No	If YES, under which conditions?
Incompatibility with Other Substances - ☐ Yes ☐ No	If YES, which ones?
Hazardous Decomposition Products	

SECTION VI - TOXICOLOGICAL PROPERTIES/HEALTH HAZARD DATA	
Route of Entry/Exposure ☐ Skin Contact ☐ Skin Absorption ☐ Eye Contact ☐ Inhalation ☐ Ingestion	
LD_{50}	LC_{50}
Effects of Acute Exposure to Product	
Effects of Chronic Exposure to Product	

SECTION VII - FIRST AID MEASURES			
Skin	Eye	Inhalation	Ingestion

SECTION VIII - PREVENTIVE MEASURES		
Engineering Controls (e.g. ventilation, enclosed process)		
Personal Protective Equipment		
Gloves (Type of Material)	Respiratory Protection	Eye Protection
Clothing	Other	

SECTION IX - STORAGE AND HANDLING
Storage Requirements
Handling Procedures and Equipment

SECTION X - SPILL AND LEAK PROCEDURES
Clean-up
Waste Disposal

SECTION XI - ADDITIONAL INFORMATION		
Special Shipping Information		
Sources Used		
Prepared by (group, department, etc.)	Phone Number	Date

APPENDIX TWO

STUDENT DECLARATION FORMS

DEPARTMENT COPY – Please sign and give to your Teaching Assistant on your first lab day.

I acknowledge receipt of the Chemistry Lab Manual, and have read the Safety Bulletin therein. I agree to abide by the safety rules prescribed and take full responsibility if I do not obey them.

1. I must never work in a lab room by myself.
2. I must always wear safety glasses in the lab room.
3. I must tell my demonstrator if I wear contact lenses. I realize that I have been warned against wearing my lenses in the lab and take full responsibility if I do wear them.

I also acknowledge the fact that to obtain a pass or better in this course (Chemistry 1A6) I must, in addition to the theory requirements given elsewhere, **COMPLETE AND HAND IN WRITTEN REPORTS FOR ALL LAB EXPERIMENTS.**

Signature: ____

Name: ______________________________ Student No.: ____________________

Lab Day: ________________ Room No.: ____________ Group (A or B): __________

Date: ____________________ Demonstrator: ______________________________

ATTENDANCE AT ALL LABORATORIES IS MANDATORY; SATISFACTORY COMPLETION OF ALL THE EXPERIMENTS IN THE COURSE IS NEEDED BEFORE CREDIT IS GRANTED FOR CHEMISTRY 1A6.

STUDENT DECLARATION FORM

I acknowledge having read the safety monograph and I understand the safety precautions that are described therein.

I agree to :

1. wear protective eye covering at all times while performing experiments.

2. abide by the Laboratory Safety Rules for my own safety and the safety of those around me.

1. THE FIRE EXTINGUISHER IS LOCATED ____________________

2. THE FIRE BLANKET IS LOCATED ____________________

3. THE EYE WASH STATION IS LOCATED ____________________

NAME : ____________________

TEACHER : ____________________

ROOM : ____________________

COURSE : ____________________

STUDENT SIGNATURE : ____________________

PARENT'S SIGNATURE : ____________________

DATE : ____________________

PLEASE COMPLETE THIS PAGE AND RETURN TO YOUR SCIENCE TEACHER

APPENDIX THREE

SAFETY QUIZ

NAME: ______________________________

DATE: ______________________________

LAB SECTION (DAY/GROUP/ROOM): ______________________

SAFETY EQUIPMENT HUNT

1. What type of fire extinguisher is in the laboratory? ______________

   Where is it located? ______________

   What types of fires is it good for? ______________

   What types of fires is it not good for? ______________

2. Where is the bucket of sand/soda ash located? ______________

   What is it used for? ______________

3. Where is the distilled water tap? ______________

4. Where is the emergency shower located? ______________

   When would this be used? ______________

5. Where is the nearest fire blanket located? ______________

   What is it used for? ______________

6. Where is the eye-wash fountain? ______________

7. Experiments in which gases are produced or volatile liquids are used should be done in fume hoods.

   Where are the fume hoods located? ______________

   Where is the lever to control the air uptake? ______________

   How is this lever used? ______________

8. Where are the gas jets? ______________

9. Where are the chemical waste disposal containers located? ______________

   Complete this page and hand in to your demonstrator when leaving the lab.

This signed statement acknowledges the careful reading, and clear understanding of the Safety Bulletin provided in the laboratory manual. I agree to abide by the rules described therein and agree to take full responsibility if I do not obey them.

DATE: ______________ SIGNATURE: ______________

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