Winter 1996

Implementation of Inquiry-Based Freshman Chemistry Laboratories

Elizabeth Ann Maschewske
Grand Valley State University

Follow this and additional works at: http://scholarworks.gvsu.edu/theses
Part of the Higher Education Commons, and the Science and Mathematics Education Commons

Recommended Citation
http://scholarworks.gvsu.edu/theses/298

This Thesis is brought to you for free and open access by the Graduate Research and Creative Practice at ScholarWorks@GVSU. It has been accepted for inclusion in Masters Theses by an authorized administrator of ScholarWorks@GVSU. For more information, please contact scholarworks@gvsu.edu.
IMPLEMENTATION OF
INQUIRY-BASED FRESHMAN
CHEMISTRY LABORATORIES

Elizabeth Ann Maschewske

Winter, 1996

MASTERS THESIS
Submitted to the graduate faculty at
Grand Valley State University
in partial fulfillment of the
Masters of Education
TABLE OF CONTENTS

Chapter 1: Project Proposal

A. Problem Statement--------------------------6
B. Rationale of Study--------------------------8
C. Background of Study------------------------12
D. Statement of Purpose-----------------------13
E. Limitations------------------------------16

Chapter 2: Survey of Literature-------------------17

Chapter 3: Project Descriptions and Conclusions

A. Project Components-------------------------57
B. Methodology, Data, and Results------------------57
C. Conclusions-----------------------------------68
D. Recommendations-----------------------------70
E. Further Study-------------------------------79
F. Plans for Dissemination----------------------79

References--------------------------------------80

Appendix A: Survey and Results-------------------99
Appendix B: Revised CURI Experiments-------------105
Appendix C: Workshop-----------------------------142
Acknowledgment

This thesis is dedicated to my family for all their support, help, patience and love.

The help of the faculty, staff, and students of the Grand Valley State University Chemistry Department is gratefully acknowledged.
Abstract

IMPLEMENTATION OF INQUIRY-BASED FRESHMAN CHEMISTRY LABORATORIES

The purpose of this thesis is to facilitate the implementation of inquiry-based chemistry curriculum devised by the College University Resource Institute (CURI) into the freshman chemistry labs at Grand Valley State University (GVSU) with the aim of retaining and enthusing chemistry students in general and women and minorities in particular. Pertinent educational research is reviewed and practical strategies are recommended for the process of curriculum implementation. A pilot laboratory section is taught incorporating as many of the recommendations as possible. Pilot labs study the process of implementation and look at student perceptions and academic achievement. An action plan is developed for possible implementation of all labs and sections to inquiry-based approach. A workshop is designed to teach lab instructors the pedagogical, curricular, and technological skills necessary for successful facilitation of these labs.
CHAPTER ONE

INTRODUCTION

Often when people find out one is a chemistry instructor their reaction is - "Oh, I could never do chemistry." Some students come into a classroom with similar defeatist, negative attitudes and fears; some are even physically shaking due to their science anxiety. In attempting to allay these fears and change negative attitudes, an informal study was made to determine which students were most affected and what caused the greatest problems.

Through classroom observation it was found that the students most affected by science anxiety were minorities, women and low socioeconomic status students. Of 13,887 students attending Grand Valley State University in the fall of 1995, 60% of the students were female, 40% male. A review of chemistry enrollment statistics at Grand Valley State University revealed a lack of minority representation, and low career goals of female students. Of four hundred students enrolled in chemistry only 2-3% were from a minority group, while the minority enrollment for the whole freshman class was 11% minorities, 89% white. The career goals of males were more often apt to be engineer, scientist, or pre-med, whereas the career goals of females tended more towards nursing, physical therapy and health sciences. The statistics on those students who dropped out of chemistry also proved to be most often minorities, women, or students of low socioeconomic status; approximately 90% or greater. In talking to the students, the
reasons most often expressed by them for their fears stemmed from (a) lack of knowledge, (b) the classroom environment, (c) the structure of the laboratory activities, and (d) the instructional methods used.

A. PROBLEM STATEMENT

Freshman chemistry laboratories need to be changed in the way they are approached and taught in order to: (a) accommodate a new population of students, (b) incorporate research on learning, and (c) increase retention in and enthusiasm for chemistry courses. Many students are turned off to science due to laboratory approaches of verification, manipulation, and memorization of scientific laws and previous findings. Often students never experience the true methods of scientific discovery. Although retention could be improved with increased support services, and minority representation could be increased by expanded recruitment efforts, changes in curriculum and pedagogy will help the most in retaining and enthusing those students we already have enrolled in freshman chemistry.

Learning through the traditional methods is not always the most effective method. Through research aimed at increasing the numbers of women and minorities in sciences, new methods originally designed to accommodate this group’s learning styles have proven better, not only for women and minorities, but for the majority of students. It is important that they be implemented for the greater benefit of all students. Cognitive learning research has also added to our understanding that approaches such as (a) inquiry-based studies, (b) open-ended experiments, (c) cooperative learning, and (d) relevancy improve
learning and should be integrated into chemistry teaching.

For several decades now, hundreds of educational researchers have been directing science teachers to teach the way students learn. Many science teachers, especially K-12, are increasingly teaching with approaches that excite students to the possibilities of scientific methods. *Tree Amigos* by Meadows (1990), an environmental approach to elementary science, *Fun with Chemistry: A Guidebook of K-12 Activities from the Institute for Chemical Education* (Sarquis, 1991), integrates chemistry throughout the curriculum, Van Cleave's (1991) books on science or math ... *For Every Kid,* *Project W.I.S.E.* (Michigan Department of Natural Resources, 1989) and *Project Wild* (Charles, 1983) are just a few of the many examples of hands-on K-12 curricula or supplements available for K-12 teachers. However, many colleges and universities have yet to integrate educational research into their science curriculum and teaching methods.

There are many reasons why implementing change at the university level is more difficult than creating changes in K-12 science classes. Large class sizes, standardization of approach due to numerous instructors teaching the same laboratory, and greater breadth and depth of content in the courses all contribute to the inertia to change. According to Lloyd (1992), in the review of the changes in chemistry courses from 1900 to the present, it has always taken an extended time for any significant changes to be made in chemistry teaching. Cornog and Colbert (1924, as cited in Lloyd, 1992) "attributed the slowness to the fact that ‘undignified haste is not to be numbered among the sins of teachers of elementary chemistry.’" Knoster’s (1991, Curriculum change and rational: Managing
complex change. Paper presented to TASH. Information from personal communication, February, 1996, with Loretta Konecki, Ph. D., Professor, School of Education, Grand Valley State University. Grand Rapids, MI.) study of managing complex change reveals that implementation of curricular change takes time: (a) time to develop the vision, (b) time to learn the new skills needed, (c) time to develop incentives and rational, (d) time to acquire resources, and (e) time to develop an action plan.

Finding curricula that will fit each universities' needs is another barrier to change. Only a few good sources of published, adaptable inquiry-based chemistry laboratory curricula are available (Abraham & Pavelich, 1979; Ditzler & Ricci, 1994, 1995; Kemer, 1986; Ricci & Ditzler, 1991). Presently the majority of colleges or universities that are making changes are designing their own curricula.

B. IMPORTANCE AND RATIONALE OF THE STUDY

According to the Bureau of Statistics (as cited in U.S. Task Force on Women, Minorities, and the Handicapped in Science and Technology, 1989) the United States is not educating enough scientists to supply the demand predicted for the year 2000. According to Bassam Shakhashiri (1990) of the National Science Foundation Directorate for Science and Engineering, the problem of fewer numbers of students taking and succeeding in science alarm him: "I am convinced that the situation in science education that our country faces today is far more critical and more consequential than the one we faced just after Sputnik was orbited in 1957." Numbers from the Bureau of Statistics also
show that the pool of talent for new scientists is predominantly from new entrants into the labor force which consist of women, minorities and handicapped; "... the very segment of our population we have not attracted to science ... careers in the past" (U. S. Task Force et al., p. 21). So not only are fewer students taking and succeeding in science courses, but the ratio of women and minorities in science courses is not in proportion to their representation in the population (U. S. Task Force et al.).

As the population composition and lifestyles in the United States change, the number of women and minorities entering the job market is increasing and is predicted to continue to increase. Creason (1992) looked at the changing demographics of the United States and found that, by the year 2000, 33% of the total population will be minorities, and 50% or greater will be minorities in the five states of California, Texas, New York, Florida, and Illinois. By the year 2030, the California Hispanic minority alone will be 39% (Creason, 1992). As of 1992, minorities already constitute 60-70% of the school populations in the United States' 25 largest cities (Creason). As more women and minorities enter the job market they will need to be more scientifically and technically educated for the jobs available now and for those predicted in the future according to Naisbitt (1982) and Naisbitt and Aburdene (1990) in Megatrends, and Megatrends 2000 (see also Campbell, 1982; Carnegie Commission on Science and Technology, 1993; Duckenfield, 1990; & Fouad & Arbona, 1995).

And yet, according to the National Aeronautics and Space Administration (as cited in U. S. Task Force et al.) the number of students earning degrees in science and math
fields has decreased dramatically since its peak in the 1970s. Creason (1992) in his United States demographics review focusing on Hispanics, found that 30% of all students drop out of high school, and 40% of all Hispanic students drop out of high school. Creason found that in urban areas the drop-out rate is even higher: 62% of Hispanics drop out of high school as compared to 20% of Caucasians, so many minorities never even make it to college.

According to statistics on women in science from the University of Michigan (Frazier-Kouassi, Malanchuk, Shure, Burkam, Gurin, Hallenshead, Lewis, & Soellner-Younce, 1992), the number of degrees granted in the science fields declined after 1970, in some fields as much as 60%. These same statistics show that women enter undergraduate and graduate degree programs in science in larger numbers than they did twenty years ago. But the total number of women earning degrees is down at all levels. Since the number of men earning degrees has gone down proportionally more, only the ratio of degrees awarded women has increased. Also, according to Manis (1989), about a third of today's students starting out towards a career in the sciences drop out, often citing reasons of (a) lack of skills, (b) science anxiety, and (c) frustration with traditional teaching methods (see also Keyser, 1993). Watkins (1992) reports that the Boston College freshman chemistry course has 415 students and only 20 of these are chemistry majors.

Every fall tens of thousands of academically-able students enter college planning to pursue science majors. Yet more than half these students change their intended major for other, non-science fields.... Indeed, the
sciences have the highest defection rates and lowest ‘recruitment’ rates of any undergraduate fields. (Narum, 1991, pg. 90).

The National Center for Educational Statistics (1990) reports that not only women but minorities as well, have been historically underrepresented in science (see also Garcia, 1993; Dix, 1987; & Kahle, 1983). The National Center for Educational Statistics (1995) found women and minorities tend to take fewer science and math courses which leads to a lower representation of women and minorities in careers requiring these courses (see also Kangas, 1993). The Center found that there is a significant difference between male, female and minority academic achievement, with males scoring higher. In addition, differences between the ethnicity groups is greater than the differences between the sexes. The most important factor to success in science is the socioeconomic status of the student, regardless of gender or race. Thus, the lower the socio-economic status of the student, the fewer science courses taken and the lower the academic achievement attained.

The Centers' statistics also showed that increasing numbers of students are entering science courses underprepared at virtually all colleges. Manis' (1989) survey found that women are less likely than White men to take advanced math in high schools, and that African American students are less likely than Whites to be tracked into college-prep courses. Hoffer, Rasinski and Moore (1995) in their analysis of statistics from the National Center for Educational Statistics found that the proportion of women and minorities who plan to pursue science careers or who enroll in prerequisite courses for science careers is substantially lower than the proportion of male peers following the same
tracks. Their analysis also determined that African Americans and Hispanics take fewer science and math courses, and those who do take science and math courses have lower grades than Whites. The National Science Foundation (1977) statistics indicate there are considerably fewer minority scientists of either sex. They state that, from the human resource point of view, underavailability of women and minorities trained in science and engineering is an economic problem that needs to be addressed. "We need to be cognizant of and sensitive to the personal tragedies and losses that may occur in the lives of individual students whose ambitions for a career in science are not realized," (Narum, 1991, pg. 90). Narum pointed out that the objective of science education should be the empowerment of all individuals and failure to meet that objective is not only personal loss but loss of talent to the nation.

C. BACKGROUND OF THE STUDY

Nationally, many colleges and universities recognize the problem of decreasing enrollment and the changes in the population of students in science courses. In particular, seven of these colleges and universities have focused on the poor representation of women and minorities in chemistry. These seven, along with Women in Chemistry (WIC), have developed a College-University Resource Institute (CURI) project that is called Chemistry Made Relevant. The College-University Resource Institute, Inc. (CURI), a 501(c)(3) organization, was founded in 1982 to promote and facilitate collaboration among colleges and universities in chemistry research and education projects. This project
is funded by the Jessie Ball duPont Fund, the National Science Foundation, the Camille and Henry Dryfus Fund, and the Miles and Glaxo Corporations. The CURI project involves faculty in developing and testing an inquiry-based curriculum that makes chemistry both interesting and relevant to women and minorities. The long-term goal is to change the way in which chemistry laboratories are taught and to publish twenty-four new modules for a laboratory based curriculum. In June of 1995 a conference was held to share, teach, demonstrate, and discuss the twenty-four newly developed modules. Several faculty from Grand Valley State University attended this conference and returned with a desire to pilot these modules.

Additionally, the lecture segment of the freshman chemistry course at GVSU is undergoing major modifications due to conflicting goals. The course was designed to be a content overview for students, especially in health sciences, who only needed one semester of college chemistry. Yet the course was expected to be rigorous for those pursuing a career in chemistry or other fields requiring an in-depth approach. With the changes in the lecture segment, it was judged to be a good time to align the laboratory segment with the lecture and with what educational research shows to be the best approaches in curriculum and pedagogy. The CURI labs were deemed a good starting point from which to update freshman chemistry laboratories.

D. STATEMENT OF PURPOSE

The purpose of this project is to facilitate implementation of inquiry-based chemistry
curriculum devised by the College University Resource Institute (CURI) into the freshman chemistry labs at Grand Valley State University (GVSU) with the aim of retaining and enthusing chemistry students in general, and women and minorities in particular. Pertinent educational research is reviewed and practical strategies are recommended for the process of curriculum implementation. A pilot laboratory section is taught incorporating as many of the recommendations as possible; next a student perception survey is developed, and academic achievement is compared. A workshop with recommendations for the implementation of these labs and instructional methods is prepared for presentation to educators.

More specifically, this project will undertake a review of the research studies that deal with (a) decreased science enrollment, (b) women and minority learning needs, (c) curricular implementation, (d) chemistry laboratory goals, and (e) instructional methods. From this review, recommendations as to the most important and applicable goals and methods will be discussed. Practical strategies for instruction and implementation will be given.

A study employing these recommendations was designed. In a freshman chemistry class of approximately four hundred students, there were sixteen laboratory sections. Two freshman chemistry laboratory sections, one treatment and one control, were randomly chosen. The treatment section was taught utilizing the review recommendations and the control section was taught in the traditional manner. Of the fourteen labs taught in a semester, due to time and material constraints, only five were designed to be inquiry-
based. An open-ended opinion survey, was given to the students in each section at the beginning and end of the semester and answers were compared and categorized. The class mean laboratory grades were analyzed with an analysis of variance (ANOVA). The level of significance was $\alpha = .05$.

The purpose of this thesis is:

(1) To facilitate implementation of inquiry-based laboratory experiments.

(2) To analyze and recommend laboratory change rational, goals, skills, resources and develop an action plan.

(3) To compare perceptions and achievement of students in a pilot lab with those in a traditional lab.

E. LIMITATIONS

Although this thesis may be on-going with development of all labs to inquiry-based format, this thesis will focus on the process of implementing inquiry-based chemistry. Although there is funding and interest in bringing inquiry-based experiments to local high schools through the college initiative, this thesis will not address such an extension.

The pilot labs study is an informal exploratory study of limited sample size ($n = 23$) due to voluntary participation. (Although there were 17 students in the treatment lab and 23 students in the control lab, only 11 and 12 respectively choose to complete the questionnaire.) The pilot labs study is further limited by the novelty effect, the small number of experimental labs (five), and time and resource constraints.
The on-going nature of implementation of these inquiry-based labs will necessitate on-going evaluation which may incur additional difficulties. Training of new personnel and adaptations due to changes in technology and its degree of usage are other areas that will need recurrent attention.
CHAPTER TWO

LITERATURE REVIEW

This literature review will look at some of the causes behind decreased enrollment of women and minorities in science. The causes often point to possible methods or options for solving the problem. Next, the research about teaching science is reviewed, in particular, the research related to teaching chemistry laboratories. In order to revise and implement the methods and curriculum that research recommends, curriculum goals and implementation literature is reviewed. Innovative and exemplary laboratory designs are presented.

1. Factors and causes of decreased numbers of women and minorities in sciences

Factors involved in decreased numbers of women and minorities in the sciences and their lower academic achievement have been researched from several points of view. One group of researchers looks at the internal or individual perspective. Another group looks at the problem from a viewpoint external to the individual or the environmental influences.

Internal factors

Studies looking at the internal factors look at gender and ethnic differences in ability and the affective domain. In a meta-analysis of studies concerning gender and minority differences in scientific achievement (Fleming & Malone, 1983), performance was higher for males than for females (see also Garcia, Yu, Coppola, 1993; & Steinkamp & Maehr, 1983). Maier and Casselman (1971) found when studying students ability to
solve types of problems, males tended to outperform females on quantitative type problems, but females outperformed males on problems requiring abstract reasoning. Suits and Lagowski (1994) have found a reversal of expected gender differences. In Suits and Lagowski's study, males achieved higher on lower cognitive items and females achieved higher on higher cognitive items, and no gender difference was found on middle cognitive items. DeBoer (1984) reports that there was no difference in college math and science performance when the study was controlled for equal academic preparation.

In an interesting study of gender differences in chemistry problem solving by Schaff, Languis, and Russell (1989), a topographic brain mapping system was used to measure brainwave activity as students solved problems. Schaff, Languis, and Russell (1989) found definite differences between the genders in areas of the brain's electrical activity during cognitive functioning; the greatest differences were found between math analogies and spatial relationships. Garcia, Yu, and Coppola (1993) concluded that prior achievement and academic preparation underlie the consistent gender and ethnic differences in science achievement. Specifically, Garcia, Yu and Coppola (1993) found that there is a definite correlation for all groups between performance, prior achievement and one other variable. These other variables for the different groups were: motivation for African Americans, Hispanics, and males; and learning strategies for Asians, Caucasians and females (Garcia, Yu, & Coppola). Although results are mixed, meta-analysis shows that there seems to be growing agreement that gender differences in ability are not as important as preparation: a stronger preparation for females would tend to
remove remaining differences (Linn & Hyde, 1989; Hyde, Fennema, & Lamon, 1990).

Motivation, the will to select, persist and engage in an academic task, and relevancy, the subjective task value, are often given as explanations for lower women and minority science achievement (Eccles, 1984, 1987; Haynes, Comer, and Hamilton-Lee, 1988, as cited in Garcia, Yu, & Coppola, 1993). Watkins (1992) describes the approach that the faculty at Boston College have taken to “lure” students into chemistry. Chairman of the chemistry department, McFadden, and his colleagues decided that the way to excite the ‘media generation’ was to integrate technology into the curriculum with the use of electronic classrooms and computer-controlled instrumentation (Watkins, 1992). Relevancy is the approach that the CURI labs take along with increased instrumentation usage. Labs with titles like “What color is my t-shirt?” and “Where shall we store it?/Not in my back yard!” tend to relate well to student interests and hence help to motivate them to learn.

Synthesis of research on cognitive learning styles have correlated low student achievement to the fact that students were not taught in a manner conducive to their style of learning (Dunn, Beaudry, & Klavas, 1988). In fact Dunn, Beaudry, and Klavas (1988) suggest that schools are responsible for the failures of at least 20% of students. Not meeting the needs of the students learning style is a quick way to make them lose interest in school. The degree to which a person’s learning style is affected by their internal biology or external culture is still being argued. Hilliard (1992) believes that learning styles are really individual and cultural behavioral style distinctions. Hilliard (1992)
stresses that style is not equivalent to IQ or intelligence and is not an excuse to explain why some students do not learn. Instead, style exists, and its importance is how it influences pedagogical methods. Researchers do agree that there are significant differences between individual learning styles and that there are ethnic and cultural differences that can be generalized to some extent (Dunn, 1987; Dunn, Beaudry, & Klavas, 1988; & Dunn, & Dunn, 1978).

Hale’s 1986 research in Black children: Their roots, culture and learning styles, shows that African American students have a distinctly different learning style than majority students. Hale (1986) found African American learning styles to be more person-centered, affective, expressive, unique, global, and movement oriented. White (1992) tended to agree with Hale and described African American communities as high-keyed, animated, interpersonal, confrontational with characteristically heated discussions, whereas Caucasian communities were depicted as low-keyed, dispassionate, impersonal, non-challenging, detached, quiet, and without affect. White (1992) found African American methods of thinking, perception, and memorization are inseparably bound to patterns of activity, communication, and social relations of the group’s culture, whereas Caucasians processed information in predominantly visual, analytical or detail orientation. Mexican American and African Americans had many similarities, and most importantly, the common characteristic of “shared-function” groups, that is, group altruism; for example, child rearing is a shared function within the extended family versus the dominance of matriarch or patriarch (White).
Melear and Richardson's (1994) study of African American learning styles also supports Hale's research. Melear and Richardson (1994; see also Melear, 1995) compared Hale's research with the Myers-Briggs Type Indicator (MBTI). Melear and Richardson chose the MBTI since it is a leading personality type indicator and has no cultural bias charged against it to date. Although personalities go across the range of intelligences, and intelligences or learning styles are separate from personality types, they did find a correlation between personality types and learning styles.

The MBTI (McDaid, 1986) describes a person's preference for energy direction to be either Extroversion or Introversion, (people centered or private); perception of reality to be either Sensing or Intuition, (notices the specific and is detail oriented or notices patterns and looks at the global picture); decision making to be in a Thinking or Feeling mode, (logical or affective); and lifestyle to be Judging or Perceiving, (decisive, planned, and organized or spontaneous, flexible, and adaptable). Melear and Richardson (1994) found that Hale's description of person-centered and expressive elements paralleled with Extroversion on the MBTI. Hale's affective importance fit well with the MBTI Feeling dimension, and the movement orientation elements fit well with Sensing and Perceiving of the MBTI. Melear and Richardson studied African American 6th grade, 11th grade, and college science students and found that a larger percentage of pre-high school students used Feeling (versus Thinking) for decision making and Intuition (versus Sensing) for reality perception. As students progressed to higher levels, the number of students utilizing Feeling or Intuition decreased. Melear and Richardson attribute this
decrease to dropping or weeding out of those Feeling and Intuition students by schools, or that these students are just not taking science courses. Extroversion and Perceiving categories tended to predominate in all the African American students studied. Extroverts, according to the MBTI, need relationships and a lot of talking and thinking out loud. Perceivers need flexible, open, spontaneous learning environments or they tend to feel “imprisoned” in a highly structured classroom (Melear & Richardson).

McAlpine and Taylor (1993) studied Native American aboriginal cultures and the differences in instructional preferences of their teachers. McAlpine and Taylor (1993) found that three cultural traits stood out: (a) students are expected to have more interactions with peers than with elders, (b) economy of speech is valued (although Inuit have stronger language-based activity), and (c) individuals are not called on publicly in order to respect (save) face. Best learning takes place when Native American students work with their peers with limited supervision from the teacher (McAlpine & Taylor). The teacher’s role is to provide routine, support, and structure for students to complete the learning tasks among themselves (McAlpine & Taylor).

Jones and Jones (1990) discuss learning styles as being either field-dependent where learning depends on personalized social factors and concrete learning material related to interests, or field-independent, where impersonal, abstract material, and independent and competitive work is preferred. Creason (1992) also refers to field-dependent in the discussions on Hispanics, especially Mexican Americans. Creason also looked at studies of high and low achievers and found that those exhibiting
competitiveness and field independence achieve higher. Mexican American students are caught between a home culture that stresses compliance with authority, field dependence, and cooperation and a school culture that stresses field independence, individuality, and competition. Gordon (1988) stresses that the evidence on field dependence is equivocal since there is a tendency for higher status groups to favor field independence and for low status groups to favor field dependence.

McCarthy and Lieberman (1988) discuss brain hemisphere dominance and learning styles. These on-going studies have found that the brain is divided into two hemispheres, each able to process information differently and on its own and each of equal importance (McCarthy & Lieberman, 1988). The right-mode processing is described as global, visual, holistic and able to see patterns and connections. The left-mode processing is systematic, solves problems by looking at the parts, works sequentially, analytically, plans well, and is rational and verbal. Hemisphericity studies have led Gardner and others (1993; see also Armstrong, 1994; & Fogarty & Stoehr, 1995) to develop the Multiple Intelligence Theory. Individuals do not have one fixed intelligence, but at least seven distinct ones that can be nurtured, developed, and influenced over time. These intelligences are: 1. Verbal-linguistic, 2. Logical-mathematical, 3. Visual-spatial, 4. Musical-rhythmic, 5. Interpersonal-social, 6. Bodily-kinesthetic, 7. Intrapersonal-introspective (Gardner, 1993). The first two are most highly prized in this society because people with these abilities do well on tests that supposedly measure intelligence, but the relative importance of these intelligences shifts over time and varies from culture to culture (Gardner). According to
Gardner, it is task of educators to nurture all seven intelligences in order to achieve the full development of each human being in whom these intelligences exist in unique combinations. Gardner refers to Kolb’s (as cited in Boyatzis & Kolb, 1991) experiential learning theory as one of the best ways to teach to many different intelligences.

In order to better understand learning style differences, Kolb (as cited in Boyatzis & Kolb, 1991) juxtaposed two scales, one for how people see reality, the other for how they process experiences and information, and make it their own. McCarthy (1980) developed The 4-MAT System based on Kolb’s grid which yields four quadrants or types of learners for facilitation of understanding and adapting learning styles to teaching methods. From this grid arrangement comes a cycle of learning that can be used to improve pedagogy. This cycle appeals to each student’s most comfortable learning style in turn and stretches them to learn to function in less comfortable modes. The cycle starts from concrete experiences, (through quadrant 1, favoring the imaginative learner), to reflective observation, (through quadrant 2, favoring the analytic learner), to abstract conceptualization, (through quadrant 3, favoring the common sense learner), to active experimentation, (through quadrant 4, favoring the dynamic learner), and back to the beginning to start over again. Schools presently teach in the second and third quadrants by giving information to passive receivers and requiring writing and workbook approaches to learning. This accommodates students that like to conceptualize, imagine, practice and tinker, but leaves out all those students that learn best by doing, sensing, feeling, transferring, creating, or connecting learning to values and beliefs.
Learning styles is a large, active field of investigation and whether it turns out that learning styles are truly innate but adaptable as Gardner (1993) and others believe or more culturally induced as Hilliard (1992) believes, will be interesting to find out. In the meantime, the concept of learning styles is useful for pedagogical practices. Hilliard (1992, pg. 375) said "...any reform that benefits those students who are poorly served always works to the benefit of all." The pedagogical practice issue is "... less a matter of style influencing learning than it is one of style influencing teaching and then teaching influencing learning" (Hilliard, pg. 375). Dunn, Beaudry and Klavas (1988) remind instructors that, despite significant differences, all groups (ethnic, academic, socioeconomic, male or female) include all types of learning styles.

Another internal cause of lower science achievement may be due to learning behavioral strategies. Behavioral strategies of time management and control of one's effort and study environment were found to optimize learning by Weinstein & Mayer (1986) (as cited in Corno, 1993). Good cognitive strategies such as "surface" processing (e.g., rote rehearsal) and "deep" processing (e.g., planning, monitoring, and regulating) help a student optimize cognitive tasks, according to Pressley, Symons, Snyder & Cariglia-Bull (1989).

Studies in the affective domain, such as, Belenky, Clinchy, Goldberg, and Trule's (1986) Women's Ways of Knowing, emphasize that for women there is no divorcing the emotional aspect from knowledge about something. Belenky's, et al. (1986) interview analysis found that women integrate life's complexities whereas men prefer to
compartamentalize life into thought and feeling, work and home, self and others. Furthermore, since women integrate everything, their learning is connected to relationships. Baker's (1995) study of women's affective and psychological needs found that women like to learn in an interactive social context rather than participating in activities that isolate them. In fact, Baker (1995) believes that the absence of the relational values of cooperation, working with people and helping others may account for the low numbers of women in science. Peterson and Fennema's study (1985) found similarly that women perform better when activities require the students to cooperate with each other, but that the reverse was true for men; men perform better in competitive activities.

Much research has been done on anxiety and its role in college men, women and minorities' learning differences. At a symposium on science anxiety research, presenters Westerback, Czerniak, Davis, Primavera and Campbell (1992) agreed anxiety is real and measurable with the State-Trait Anxiety Inventory. Results of Westerback, et al. (1992) (see also Westerback & Primavera, 1992) studies found that anxiety toward science is correlated to (a) self efficacy (control), (b) academic performance in science, (c) student curiosity, inquisitiveness, and imagination, and (d) academic and general self concept. More general variables could be cited by Westerback et al. (1992) as influencing anxiety, for instance, information overload, testing, and certain instructional strategies. Zoller & Ben-Chaim (1988) found a correlation between the examination type, the anxiety state and academic achievement in college science students. In a comparison of the studies done
by Worthy (1986a, & b), Westerback, et al. (1992), and Garcia, et al. (1993), women and minorities are not more test anxious than men, and their anxiety is not due to a lack of self confidence; rather, their anxiety stems from the lack of framework of prior knowledge to help order new knowledge. Sometimes, simply missing segments of knowledge can cause students to stumble and plunge them into the lack of success/failure/low self-esteem spiral (Marks, 1969). Other problems such as learning disabilities, in particular, discalculia, can also be the root cause of science and math fears (Tobias, 1978,1987; Tobias & Tomizuka,1992).

**External factors**

Studies looking at the external factors of the problem of decreased numbers of women and minorities in the sciences look at influences from outside the individual or from the environment. In a poll of college students, as reported by Powell (1990) in the article “Factors Associated with the Underrepresentation of African Americans in Mathematics and Science”, in the *Journal of Negro Education*, scientists are associated with negative stereotypes. Other factors that Powell (1990) discusses are fears of failure, poor attitudes from the family environment, crowded living conditions, and uncontrollable noise. Societal and ethnic stereotypical views of science and math either help (as in the case of Asian-Americans) or hinder (often apparent in African Americans and Hispanics) their approach to learning science and math (Morris, & Kratochwill, 1987). Peer pressure in a group that is not doing well in science and math can lead to fear of success or fear of ridicule (Diamond, 1985). Young and Fraser (1993) found that
home background or the student's socio-educational level best explained student differences in scientific achievement and attitudes. Tate and Schwartz (1993) in their study of why American Indians drop out of college, found the three major factors to be: (a) difficulties in acculturation and cultural isolation, (b) problems associated with being a non-traditional student (older, family commitments, job/part-time student, etc.), and (c) faculty support. Faculty support is needed for American Indians not only for academic advising, but for emotional support as well as for role models.

Crawley and Koballa (1991) connect attitude, social support, and perceived behavioral control with motivation. Underlying these three areas of motivation are the student's perception of personal, social and situational consequences of actions (Crawley & Koballa, 1991). Crawley and Kobella designed an intervention strategy to develop positive attitude-behavior to increase chemistry course enrollment, and found the persuasive message made the greatest difference when it was delivered by peer presenters. Jones and Jones (1990) have described motivation as the multiplication of expectations with value and climate. Where students expect to succeed, find value in the task, and complete the task in an environment supportive of their basic needs, there you will find motivated, energized, excited students (Jones & Jones, 1991). Jones and Jones state that the greatest motivator for students is having their academic needs met (these needs are reviewed in the next section).

Manis' survey study (1989) determined the major reasons for women's difficulties in science courses were due to being less prepared and less confident in the adequacy of
their academic preparation, as well as to an overwhelming dislike of the aggressive, competitive atmosphere. Tobias' (1990) project revealed that science courses have a heightened sense of competition as well as a lack of community among students. Frazier-Kouassi et al. (1993) found that a competitive atmosphere in the classroom was cited most often as the reason that women dislike science courses, chemistry in particular.

Fraser (1986) has devoted more than twenty years to studying classroom environment and has developed the Science Laboratory Environmental Inventory (SLEI) specifically to study science laboratory environments; SLEI has been used internationally (Fraser, Giddings, & McRobbie, 1992). Sizable associations are found between inquiry skills, science-related attitudes, and classroom environment utilizing the standardized SLEI (Fraser & Fisher, 1982). Fraser and Fisher also found that both students and teachers prefer a more positive classroom environment than they perceived was present, with teachers tending to see the classroom environment more positively than their students (Fraser & Fisher, 1986). McRobbie and Fraser (1993) analyzed outcomes versus environment and found that the nature of the classroom environment accounted for appreciable variance in both cognitive and affective outcomes beyond those attributable to general ability. Using a similar inventory (the Learning Environment Inventory developed by Harvard Project Physics, Anderson & Walberg, 1974 as cited in Tamir & Caridin, 1993), Tamir and Caridin (1993) found that better academic achievement came from “good” environments. According to Tamir and Caridin (1993), the best classrooms were those that have cohesiveness, satisfaction, and goal direction. Tamir and Caridin
also studied the environment of biology versus chemistry laboratories and found that students rated biology laboratories as meeting the criteria of "good" laboratories, whereas chemistry laboratories are more formal, rule oriented, rushed, have more tension, are more difficult to understand and the work is harder. Tamir and Caridin suggest that much of this difference may be explained by the curricula. Hofstein, Ben-zvi, and Carmeli (1989) in their "Quantitative and Naturalistic Research Study on Exemplary Chemistry Teachers" found good teachers were characterized as having (a) control of the subject matter, (b) good classroom management, (c) awareness of student's learning difficulties, (d) varied approaches, and (e) were well organized and prepared. Classes taught by exemplary teachers had environments that were less formal, more satisfaction, more goal directed, and more varied than average teachers' classes (Hofstein, Ben-zvi, & Carmeli, 1989). Student attitudes in the exemplary teachers' classes were more positive towards chemistry, retention was greater and enrollment in further chemistry courses was increased (Hofstein, Ben-zvi, & Carmeli).

Believing the greatest influence in the environment is the student-teacher interaction, Barba and Cardinale (1991) studied the differences between teacher interactions with males and females. Barba and Cardinale (1991) found that females are not actively engaged in classroom discourse in the same manner as males. Barba and Cardinale concluded that instructors, regardless of their gender, tend to interact with males to a greater extent than with females and minorities (Dunn, 1987), and that when they do interact, they involve them with lower level questions.
In summation, the most important factors involved in decreased numbers of women and minorities in chemistry fall into the areas of (a) previous preparation, (b) environmental atmosphere, (c) appropriate curriculum and instructional strategies that take into account student needs. The first area, the lack of preparation, is most often cited as a reason why more women and minorities are underrepresented in chemistry. Women, minorities and students from low socioeconomic backgrounds often have limited access to, have limited success in, and/or take fewer preparatory science and math courses. The lack of knowledge of behavioral learning strategies necessary for success in science and math courses often contributes to the problem of lack of appropriate preparation. Instruction in study strategies would help students to make better use of their study time.

The second area, the lack of a relational, supportive environment is especially important for students that feel unsure of the appropriateness of their preparation. According to Belenky et al. (1986), “connected teaching”, or determining what the learner needs and composing a message “courteous” to the learner, is the best way to establish a cohesive classroom. Decreases in student frustration levels come with a supportive atmosphere that satisfy student’s interests and needs, and lessons that are presented in a way conducive to the students learning style and have clear goal directions.

The third area, the lack of appropriate curriculum and instructional strategies, relate to the previous two areas. If the student is overloaded with information or information that they can not relate to or connect to previous learning, there is no framework on which to build new knowledge. Proper instructional cycles, taking into
account many different learning styles, could better prepare students since they would be learning in their preferred style. If testing and classroom management strategies do not take into account the needs of the students, then frustrations, anxiety, self-doubt, and self-efficacy spiral into lack of success and possible dropping or discontinuation of science courses.

2. Methods or options for solving the problem

Just as there are many reasons for low representation of women and minorities in the sciences, there are also many methods or options for solving the problem. In order to better analyze the available methods and options, they are grouped into the categories of (a) understanding the needs of the students, (b) support service options, (c) science teaching skills, and (d) curriculum revisions.

Understanding the needs of the students

In their 1990 book Comprehensive Classroom Management: Motivating and Managing Students, Jones and Jones generated a list of 13 needs of students that enhance motivation and learning. Students’ needs are to:

1. Understand and value the learning goals
2. Understand the learning process
3. Be actively involved in the learning process
4. Relate subject matter to their own lives
5. Control the learning environment by setting goals or following their own
interests

6. Experience success

7. Receive realistic and immediate feedback that enhances self-efficacy

8. Receive rewards for performance gains

9. See learning modeled by adults as an exciting and rewarding activity

10. Experience an appropriate amount of structure

11. Have time to integrate learning

12. Have positive contact with peers

13. Receive instruction matched to their cognitive level, skill level and learning style (pg. 167).

Belenky, et al. (1986) in their analysis of women’s needs for learning, found that women need to know that they already know something about what they are learning; therefore, the use of analogies and connectedness of subjects is important. Connectedness between class participants is important, as well, as Belenky et. al. found that women need to understand personalities behind people in order to really work well together. “The connected class constructs truth not through conflict but through consensus” (Belenky et. al.). Women also tend to need more praise, due to lower self-esteem, and understand better through experiential versus theoretical learning (Belenky, et al.).

Teaching using relevancy helps to meet students’ interest needs (Briscoe, 1991). Briscoe’s (1991) case study found that shifting emphasis from a teacher- and content-centered approach to a student- and relevancy-centered approach facilitated learning and
decreased anxiety in chemistry classes. To increase interest in chemistry, Ellis, et al. (1993) developed an instructional approach to general chemistry where materials science is emphasized and found the results positive for both students and instructor. Ross (1994) reviewed several approaches which enhance relevancy in chemistry teaching, such as teaching from the perspective of environmental science, forensic science, historical content, and materials analysis. Holme (1994), at the University of South Dakota, has found that students are motivated to learn chemistry by replacing the first few weeks of introductory chemistry lectures with a frontiers in chemistry approach, i.e. where recent research is taught at a level that students can understand.

Anxiety reducing approaches such as guiding a fearful student through the first steps of a lab or problem is the first recommended approach according to Marks (1969). Classes, counseling, and support groups comprised of other students experiencing science or math problems have proven helpful (Marks, 1969). Anderson and Clawson (1992) reported that the modification effects of thoughts on feelings were important ways of reducing anxiety. Thoughts of scenes that relax the student and having students use positive and directive self-talk helps to calm fears and move the student to effective intervention strategies (Anderson & Clawson, 1992). Westerback, et al. (1992) found that student anxiety towards science can be changed mostly through experience or more time in science courses and through training in the proper way to learn science. Approaching science courses in the most beneficial way is Tobias’ whole approach in her student handbooks; Overcoming Math Anxiety (1978), Succeed with Math: Every
Students Guide to Conquering Math Anxiety (1987), They're Not Dumb They're Different; Stalking the Second Tier (1990), and Breaking the Science Barrier (Tobias & Tomizuka, 1992). The Supplemental Instruction Program developed by Martin (1993) at the University of Missouri focuses on the academic content of specific courses, helping students develop learning strategies for that particular content (as cited in Marcus, Cobb, & Shoenberg, 1993). Marcus, et al. (1993) also recommend the University of Rhode Island’s Chem-Tutor, a computer assisted instructional system which allows first-year chemistry students to practice solving complex problems with an infinitely patient tutor.

Since there are multiple intelligences or learning styles it is important that these styles influence teaching and hence learning (Hilliard, 1992). Instructors need to understand the different learning styles of students and teach to accommodate all styles, not only to make each student comfortable some of the time, but to also stretch the student in other ways of understanding (Boyatzis, & Kolb, 1991). Understanding MBTI (McDaid, 1986), 4-MAT (McCarthy, 1980), learning behavior, and cultural behavior styles of students (Hilliard, 1992) all are important to optimizing students’ learning and motivation.

Support services

Twenty years ago counseling services were predominantly used, whereas today support services for women, minorities and low socioeconomic status students take many different forms. Purdue University offers a one credit course for high potential academically disadvantaged freshmen called the Counselor Tutorial Program, which has
successfully increased retention and graduation rates and has had a positive effect especially on women and minorities (Budny, 1994). Byrne’s (1992) study lists those factors found to be positive influences for educating women in science, and they are: (a) same sex role models, (b) mentors, (c) the image of the discipline (stereotypes and technical or social orientation), (d) single sex courses versus coed, (e) success in prerequisites, (f) support networks, and (g) positive math experiences. Shmurak and Handlers’ historical review (1992) of Mt. Holyoke College’s success in preparing women for science careers concluded their success was due to the large number of female role models on the faculty. Because minorities tend to learn mostly through oral communication, the importance of role models is great, in fact, so great for disadvantaged students, that the match of each student with a mentor should be of high priority according to Smith (1981; see also Roche, 1979; Pfeeger, 1995; Fouad, 1995; & Fouad and Arbona, 1995). Coleman (1995) reports that experiments are being tried with single-sex classrooms in response to research that shows teachers pay more attention to males than females in science classrooms (see also Barba & Cardindale, 1991). Martinez (1992) addressed the female perspective in science classrooms by increasing cognitive level, mastery approach and social appeal. Martinez’s study found that females responded positively to the increased social aspects and the males responded positively to the increased mastery aspects.

Courses broken down into small units or modules pertaining to one area can help remediate deficiencies by focusing on the areas that need work (Keyser, 1993; Mason &
Remediation using computer assisted instruction has been shown to be helpful by reducing anxiety due to lack of confidence (Harris & Harris, 1987). Leonard's (1989) review of research found that some computer-based applications of laboratory exercises were as productive or more productive than the conventional laboratory exercises.

Peer and other tutor arrangements focusing on individual needs have historically been successful. Van Der Karr (1994) analyzed student-facilitated study groups and found that groups with less authoritative leaders had greater involvement and those with leaders that exhibited no authority or expertise frustrated students. In the fall of 1993, GVSU opened a Math Science Student Support (MS³) office where, in the fall 1995 semester, drop-in peer tutoring, and facilitated study groups accommodated 920 chemistry students, 80-90% of which were freshman (personal communication with P. Hoban & C. Baisden, February, 1996). Since the number of math and science students being served has increased each semester (personal communication with P. Hoban & C. Baisden, February, 1996), it would be interesting to know if improved science teaching skills resulted in a decreased need for student support.

Science teaching skills

According to Spencer (1991), in order to change what is wrong with chemistry instruction, instructors first need to better understand how the mind works. Bodner, (1986), Clarke, (1994), Roth and Roychoudhury, (1992), and Saunders, (1992), all urge
The constructivist perspective holds that meaningful learning or understanding is constructed in the internal world of the learner as a result of her or his sensory experiences with the world (hence, it cannot be told to the student by the teacher) and, that while these understandings or schema tend to resist change they can change as a result of disequilibrium. The implications for classroom instruction include the ample use of hands-on investigative laboratory activities, a classroom environment which provides learners with a high degree of active cognitive involvement, use of cooperative learning strategies, and the inclusion of test items which activate higher level cognitive processes (Saunders, 1992).

Clarke’s (1994) study using the constructivist approach required students to take more responsibility for their learning and construct their own understandings. Clarke’s findings indicate that students liked practical application or experiential learning in a personalized classroom and that there was a strong link between what students liked and what they claimed helped them to learn better. Roth and Roychoydhurys’ study (1992) with a constructivist laboratory learning environment showed that students had “remarkable” ability and willingness to generate, design, and develop open-inquiry research problems. Belenky, et al. urges instructors to make use of constructivist approaches since they “...make connections that help tie together pockets of knowledge” (p140).

Besides a constructivist perspective, Finster (1992) recommends an understanding of cognitive processes. By using a reflective judgment cognitive filter, Finster (1992) says instructors can better understand students, their alternative concepts (misconceptions), and help move them to higher levels of critical thinking. Finster describes the development
of reflective thinking in chemistry in seven stages. The prereflective stages (1-2) are
where the student tends to believe that everything can be known. This stage tends to be
strongly reinforced by most chemistry textbooks since the social and historical context are
often left out (Finster). Finster's middle stages (3-4) find students recognizing the
uncertainty of knowledge and that there are situational and temporal considerations.
Finster's advanced stages (5-7) find students' understanding of knowledge as contextual
in which they tend to weigh arguments in light of evidence. These cognitive stages are
moved through more readily if constructivist and contextual approaches are used
(Finster).

The constructivist epistemology stresses the importance of hands-on learning in
order for students to construct their own understanding of the world. "Exemplary science
learning is promoted by both hands-on and minds-on instructional techniques - the
foundations of constructivist learning" (Loucks-Horsley, et al., 1990, p. 48). Hands-on
learning is defined as learning where the "students work directly with materials and
manipulate physical objects to physically engage in experiencing science phenomena"
(Worth, chair of National Science Educational Standards Projects, as quoted in Haury, &
reviews, hands-on learning has many benefits: hands-on learning (a) increases learning and
achievement in science content, (b) causes students to rely on evidence versus authority,
(c) provides students with similar sets of shared experiences which creates a "level playing
field" regardless of socioeconomic status, (d) convinces the learner that they, as well as
the instructor, can interpret data and that many interpretations are possible, (e) promotes cause and effect thinking, (f) develops critical thinking skills, (g) fosters independent learning, and (h) allows students to discover scientific concepts on their own which increases retention of learning. LeBuffe (1993) describes hands-on learning as employing visual, tactile, kinesthetic, auditory, and in chemistry, even olfactory senses. As a proponent of hands-on science, LeBuffe (1993) believes that this teaching method will attract more minority and female students to science.

Butts and Hofman (1993) emphasize that in order to optimize learning, hands-on science must be "brains-on" also, meaning that words must be used to engage the mind and describe the experiences. This "brains-on" approach is further supported by Pinkerton's (1994) brain-based learning studies. Pinkerton (1994) describes the brain as triune, with neural networks between cognition, emotion, and inborn behavior. Use of the brain's language center, the cognitive power of human speech, is crucial for the formation of complex and redundant neural networks to be established as remembered learning. Ivins & Markle's study (1989) showed that optimum learning is achieved when hands-on activities were done before theory or discussion was presented, however, this caused less material to be covered but in greater depth.

Inquiry-oriented instruction is related to hands-on learning, however these terms are not synonymous (Haury & Rillero, 1994). "Inquiry-based learning involves the thinking, reading and writing or research that gives meaning to hands-on learning" (Worth, chair of National Science Educational Standards Projects, as quoted in Haury, & Rillero,
For inquiry learning, "students probe, collect and analyze data; draw conclusions and ask new questions" (Bruder, 1993, p. 23). One of the tools of inquiry-based learning is an open-ended approach to labs, or problem solving. Amyotte (1991) defines open-ended as "... something which goes beyond the 'given this and this, calculate that' type of problem for which there is typically only one answer: ... the intent is to promote and encourage creativity and an inquisitive nature." Incorporating open-ended activities allows students to experience trial and error learning which is a very important and powerful way to learn, and eliminate misconceptions (Drake, 1993; & Zoller, 1990, 1994).

Inquiry-based learning, in that it involves hands-on, minds-on, verbalization, and open-ended approaches, lends itself well to cooperative learning (LeBuff, 1993). It is especially important in the teaching of science because of the prevalent method of grouping students for lab work, and because science in actual practice involves collaborating with others (Johnson, Maruyama, Johnson, Nelson, & Shon, 1981). Over 600 studies have supported the efficacy of cooperative learning versus competitive and individualistic efforts (D. Johnson, R. Johnson, & Smith, 1992; Slavin, 1983). Studies have found that cooperative learning promotes (a) positive interdependence, (b) individual accountability, (c) social skill development, (d) increased academic achievement, (e) higher level thinking skills, and (f) positive attitudinal responses (Kealy & Witmer, 1991). Basili's study (1989) found that alternative (or mis-) conceptions were more successfully changed by use of cooperative learning than by use of demonstrations. Thusty's study
(1993) found that cooperative learning strategies had positive effects on reducing negative self perceptions of ability, interest, and effort among females specifically in chemistry (see also Bier, 1993).

Besides the previously mentioned teaching skills, there are other teaching methods and skills that would benefit chemistry laboratory approaches. Mastery learning increases academic achievement when used in a non-threatening environment, according to Kysilka and Zapico (1992), and works especially well for learning nomenclature and other basics necessary for freshman chemistry. Meledin (1991) emphasized the importance of estimation, the skills needed, and benefits from ‘ballpark’ estimation in problem solving. Patton (1992) noted the potential usefulness of pre-reading activities in chemistry classes to establish disequilibrium in students minds before doing experiments. Cullen (1990) found concept maps to be a positive instructional technique.

Writing to learn or writing across the curriculum movements have increased the writing done in science classes and Beall and Trimbur (1993) give some good ideas for extending writing in chemistry courses. Swan (1994), at Princeton University, approaches the lab report as a composition which she says illuminates writing and science. Williams and Woodruff (1994), at the University of Southern Mississippi, have students cooperatively write MSDS sheets for unknown materials. Robson (1994), editor of Chem Matters, encourages instructors to utilize reading or writing of news articles to go along with labs that demonstrate the chemical principals involved. McNeal (1989) found that teaching students to read primary research papers empowered and motivated the students
learning and desire to do inquiry research of their own. Students appreciated reading the ‘real thing’, instead of being talked down to. They were able to construct scientifically answerable questions and define and answer their own research questions with better understanding of differences between testable hypotheses, assumptions and data (McNeal, 1989). McNeal found that faculty were motivated, stimulated and felt more responsible when educating instead of training of science students with this approach.

Some of the most important tools for instructors are methods of assessment. There seems to be a general consensus that assessment, directly or indirectly, influences what and how much a student learns, even though the causal link between assessment and student learning has not been firmly established (Marcus, Cobb, & Shoenberg, 1993). Tobias (1990) feels that if the student is to understand broad concepts and see inter-relationships, then those types of questions must be asked. When students do not understand in depth the nature of the problem they solved, it makes science seem intellectually unsatisfying (Tobias, 1990).

Interest in assessment has shifted from standardized tests and external examiners to self-assessment, portfolios and interviews (Marcus, Cobb, & Shoenberg, 1993). In chemistry labs, the shift has been to hands-on lab tests to assess lab techniques, observation skills and summarizing ability (Doran & Hejaily, 1992). If teaching is done with inquiry-based approaches, then lab grades need to be based on the quality of the process and the written report rather than content-driven quizzes and problem sheets (Marcus et al.). McCloskey and O’Sullivan (1993), and Smith, Ryan, and Kuks (1993),
recommend methods such as open-ended questions, student journals, computer simulations, concept maps, and formal and informal observation of the student as part of lab assessment. Rogers (1995) recommends detailed laboratory reports and finds assessment of them is facilitated with a holistic grading approach that takes only about three minutes to grade each lab write-up.

Shavelson and Baxter’s (1992) study, starting from a premise that by changing the nature of achievement tests, teachers who teach to the test will automatically improve their teaching, found this assumption to be only half true. Teachers must have high quality assessment tools and concurrent staff development in quality instruction or they may not improve their instruction; in other words, Shavelson and Baxter (1992) established that there is symmetry between assessment and teaching. Parker and Rennie (1989) put it well; constructivism and gender- and minority-inclusive science, in order to be successful, is dependent on concomitant changes in assessment of student learning. Those assessment strategies must be aligned with the objectives, content and instructional methods of the course (Parker & Rennie, 1989).

Improved pedagogy by using diverse strategies in a cycle of learning will best meet students needs (McCarthy and Lieberman, 1988). Gordon (1988) emphasizes that if instructors adjust learning environments and instructional strategies to the unique characteristics and needs of the specific learner, individualized learning, the best of all learning, will take place. If science teaching skills are improved such that the needs of students are better met, then support service requirements should decrease -- indeed,
Ditzler and Ricci (1995) found this to be the case, concomitant with curricular changes.

3. Curricular revisions

Any revision in curriculum at the university level is a complex change. Schwab (1974), in his philosophical treatise, “Decision and Choice -- The Coming Duty of Science Teaching”, prepared for the National Institute of Education, felt that the most complicated and necessary of all our educational problems is how to implement inquiry-based learning and insure that all the goals are ‘fairly and fruitfully’ met. Appropriate dialogue between appropriate parties to the dialogue to determine priorities of goals is of as much importance as imaginative use of resources and skills (Schwab, 1974). Schwab found few clear rules for implementation, but stressed the importance of doing steps in concert with others, doing some steps simultaneously, and the importance of deliberation, or due process to insure good choices, as the quality of students’ lives may be greatly affected.

Wiske and Levinson (1993) pointed out the major obstacles to change are: (a) incompatible texts and material, (b) inaccessible technology, (c) inappropriate assessments for hands-on learning and cooperative learning, (d) inadequate professional development, (e) incompatible educational paradigm, and (f) lack of time. Wiske and Levinson (1993) recommended that implementors be careful to align texts, tests, technology, and pedagogy. Wiske and Levinson stressed the importance of providing support for professional development. Since inquiry learning is neither sequential nor predictable, instructors need
practice and coaching in meshing content knowledge with appropriate pedagogy. For example, instructors need to learn how to form groups, pose questions that nudge, not pull, handle student propositions that are unexpected, and encourage students to take responsibility for and to organize their own learning (Wiske, & Levinson). Implementors also need to be sure to attend to details of the particular school’s culture and structure, especially class times and sizes, and availability of materials and technology (Wiske, & Levinson).

King, Morris, and Fitz-Gibbon (1987), in How to Assess Program Implementation, present a paradigm for initial implementation which includes:

1. define the target population, and its changes
2. determine the needs that must be met that are not now being met
3. translate the needs into the rationale for change
4. rationale should lead to the goals.

From the goals, program development resources and skill needs should be defined and an actual implementation time frame be developed (King, Morris, & Fitz-Gibbon, 1987).

According to Knoster (1991, “Curriculum change and rational: Managing complex change.” Paper presented to TASH. Information from personal communication, February, 1996, with Loretta Konecki, Ph. D., Professor, School of Education, Grand Valley State University, Grand Rapids, MI.), managing complex change is best handled with a paradigm that includes: vision + skills + incentives + resources + an action plan = change. If any of these addends are missing or weak, the result will be ineffectual change.
or frustration in the attempt to implement change (Knoster, 1991). Knoster along with
King, Morris, and Fitz-Gibbon essentially agree on their approach to curricular change
and their blended approaches are used as a model to implement change in GVSU
chemistry laboratories, as described in the next chapter.

Curriculum goals

The goals of general science instruction have had a lot of recent attention with
study groups such as Project 2061, Science for All Americans (American Association for
the Advancement of Science, 1989), U.S. Task Force on Women, Minorities and Handicapped
in Science and Technology (1989), Project Kaleidoscope (Narum, 1991), the Society for
College Science Teachers Position Statement on Introductory College-Level Science
Courses (Halyard, 1993), and Assessing New Directions in Science: Blueprint for the
Michigan Educational Assessment Program in Science (1994). Combining the findings of all
these groups gives an overview of the recommended goals for science education in the
United States today. These goals include:

1. Increase the scientific literacy and critical thinking ability for all students.

2. Increase the number and diversity of students graduating from sciences through
increased recruitment and graduation goals.

3. Improve retention with increased support services.

4. Generate an academic atmosphere in which women and minorities are expected
to succeed and which sufficient numbers of successful women and minorities
are visible at all levels.
5. Redesign courses to provide an interesting and challenging curriculum taught with greater skill and with more awareness for the environmental factors that affect women and minorities' learning.

6. Increase in-depth coverage of topics and concepts.

7. Increase linkage of scientific knowledge with societal issues.

Number five above is the emphasis of this project, and as such, the particular goals of chemistry laboratory curricula are reviewed next. Spencer (1994), in "The General Chemistry Curriculum: Different Times, Different Students, Same Course", lists the things there are too much of and not enough of in the current chemistry curriculum. In the 'too much' list, Spencer (1994) cites; too much material, too much emphasis on the perceived needs of chemistry majors, too much theory, and too much emphasis on rules of calculations. In the 'not enough' category, Spencer cites; not a balanced curriculum, not enough relevant chemistry, not enough new chemistry, not enough emphasis on process, not enough involvement of students, and not enough actual experimentation in lab. Spencer recommends fixing the chemistry curriculum by throwing out the 'too much' and adding in the 'not enough', with special emphasis on exciting new discoveries.

In Lloyd's historical review, "The 20th Century General Chemistry Laboratory: Its Various Faces" (1992b), the goals of chemistry laboratory teaching are analyzed. According to Lloyd (1992b), the goals of chemistry labs since the early 1900s, in order of priority, have been:

1. To verify principles.
2. To reinforce facts to learn and remember.

3. To learn standard methods of analysis.

4. To learn to use simple apparatus and instruments.

5. To learn how to keep records.

6. To develop habits of honesty, accuracy, self-reliance, cleanliness and orderliness.

7. To satisfy curiosity and develop interest in chemistry.

Lloyd found that through two earlier curricular changes that were in response to the change in the nature of chemistry and new knowledge, these chemistry laboratory goals have remained unchanged. Even through the 1970s, when relevancy was emphasized, and the 1980s, when increased problem solving ability was emphasized, the laboratory goals held constant. But the curricular changes being called for now are in response to the way students learn, which requires a change not only in curriculum but also in methods of instruction and assessment.

Lloyd’s (1992b) analysis of the new goals necessary to accommodate appropriate curricular changes for chemistry laboratory education in the 1990s, in order of priority, are:

1. To excite interest in chemistry and methods of scientific investigation.

2. To appreciate measurement methods.

3. To become familiar with instrumentation and apparatus techniques.

4. To become aware of practical methods for real systems, as opposed to theoretical ideals.
5. To develop skill in the design of experiments.

6. To interpret instructions, analyze data, and write reports.

7. To obtain and interpret data to answer questions.

8. To learn safety in handling and disposing of chemicals.

In comparing the two sets of goals, number one of the new goals corresponds to the last of the old goals; priorities have completely reversed. In the former set of goals there is no mention made of experimental processes. In number one of the old goals, if a student is to verify principles, then the entire procedure must be known to verify it, and the student just follows a ‘cookbook’ procedure to get to an expected value. On the other hand, students engaged in scientific investigations use specific procedures for the purpose of collecting data to be analyzed to derive meaning from the experiment. Inquiry-based or opened-ended labs without specific procedures often best fit these goals.

Pavelich and Abraham (1977) simplified their goals to the three they felt were most important:

1. Acquaint the student with the fundamental laboratory techniques and procedures.

2. Enhance the student’s thinking ability, i.e., toward more abstract thinking processes. (In Piagetian terms, help move the concrete operational student into the stage of formal operations and the formal operations student to deepen his abstract thinking ability.)

3. Give the student experience with some aspects of scientific inquiry, especially
data interpretation, hypothesis formation and experimental testing of hypotheses.

McNeal’s goals (1989) as stated in “Real Science in the Introductory Course” are
to have students learn how to:

1. Analyze problems.
2. Ask testable questions.
3. Distinguish among data, assumptions and hypotheses.
4. Develop expository writing, data analysis, oral presentation and discussion.
5. Search and retrieve bibliographic information.

Inquiry-based curricula pros and cons

Mellon’s 1978 literature review found there were seven characteristics of open-ended laboratory exercises:

1. Students design open-ended experiments, or
2. Students select among, or are assigned, different instructor-prepared experiments.
3. Procedures include remedial loops.
4. Students are placed in the appropriate laboratory according to their demonstration of competency.
5. Work is self-paced, often in open labs.
6. Experiments are projects or integrated labs.
7. Students perform variations of an experiment and pool data for analysis.

These open-ended labs of the late 70s and 80s had many drawbacks to implementation in
freshman chemistry labs. Some students need more structured experiences (Mellon, 1978). Marcus, et al. (1993) found drawbacks from completely open-ended labs were due to the fact that students found them more difficult and time consuming, had insufficient skill levels to effectively perform experiments, lacked sufficient time for thoughtful development of experiments, and increased demands on the creativity and resources of instructors. “Although the more negative global response clearly focused on work demand, perhaps it resulted from what beginning students believe is the nature of learning. Because the lab sections had more to do with understanding a process than with memorizing facts, students were not clear about just what it was they learned” (Marcus, et al., 1993). Fife (1991) found that the lower student to teacher ratio needed to teach open-ended labs and the narrower coverage of material were also drawbacks, but that the benefits far outweighed the difficulties.

Fife (1991) found the benefits of inquiry-based labs to be increased learning and intellectual stimulation due to new designs and unexpected results. The students acquired higher level thinking skills, improved performance abilities, increased creativity, and were encouraged to be active scientists (Fife).

Many benefits of innovative inquiry-based approaches to teaching freshman chemistry courses at large colleges and universities were shared at the 13th Biennial Conference on Chemical Education: Celebrating the 200th Anniversary of the Emigration of Joseph Priestley, in July of 1994. Among those attending the conference, Kluiber (1994) at Rutgers University, Sharpe (1994) at Grinnell College, and Sprague (1994) at
the University of Cincinnati, all mention updating chemistry labs with modern instrumentation such as: capillary GC, GC-MS, AA, FTIR, UV-Vis spectroscopy, magnetic susceptibility, computer interfaced and interactive devices such as pH meters, colorimeters, etc., and computer use for collaborative learning, data collection, lab report analysis, software programs, recordings of instructions, and remediations (see also Sokoloff, 1992). Some of the benefits these chemistry instructors found with these increased instrumental approaches were: (a) greater enthusiasm was generated, (b) students observed and participated in what chemists do, (c) learning was stimulating and meaningful, and with computer assistance, (d) teaching and grading was standardized.

Kildahl and Berka (1994) at Worcester Polytechnic Institute have had success with a two-theme approach to chemistry lab. One theme was to incorporate greater instrumental use, and the other theme emphasizes the construction of principles from experimentation versus verification. They found students greatly benefitted from state-of-the-art technology experiences that anticipated workplace experiences.

Several learning institutions are reorganizing the complete chemistry course around a greater laboratory emphasis. Foster (1989) at Hampshire College feels that understanding how to do research is more important than a body of knowledge and that students need more time in lab to learn quantitative and reasoning skills. "Intensive and open-ended laboratory experience is the only way in which a crucial type of learning for science students can take place" says Foster (1989, pg. 39). Foster has students do exercises (versus experiments) to acquaint them with techniques and quantitative problem
solving. Students then design their own experiments, for which there are no right answers, only reliable data obtained by methods whose principles are understood. Fortman (1994) at Wright State University has approached educating students about chemistry instead of training them to do chemistry and has organized the course around applications such as the chemistry of living things, materials, and energy, instead of principals. Stratton and Hansen (1994) at Earlham University have organized their freshman course around environmental chemistry, and Ege and Coppola (1994) at the University of Michigan have used organic chemistry as their context. Kovac, Schell, Grimm and Hazari (1994) at the University of Tennessee have fully integrated the lab into the lecture course with chemicals as the center of the curriculum and with the integration of technology wherever possible. Owens and Costella (1994) at the U. S. Military Academy teach the first two thirds of the course traditionally. For the last third, they emphasize materials science, chemistry of life, environmental chemistry and military chemistry, with a goal of providing students with literacy in key technologies from which they can make informed decisions as citizens and leaders.

**Leading laboratory curricula**

Those laboratory approaches that seem to hold the most promise have been called "guided-inquiry" by Pavelich and Abraham (1979). In order to move students to open-inquiry, Pavelich and Abraham (1979) start with a two-phased format of guided-inquiry followed by open-inquiry. For guided-inquiry, background in the techniques available and in pertinent concepts of chemistry are given. No theoretical introduction or methods of
data analysis are given, but only what problem to investigate and what experiment to do. The student must generate their own analysis and explanation of the data. Lecture on the topic then follows and the next lab is open-inquiry. Clear ground rules are established that make the investigations of possible systems a cooperative and/or collaborative effort. The gains in abstract thinking abilities were significantly greater in classes taught with guided-and open-inquiry approaches. Kerner (1986), in Chemical Investigations, has designed a general chemistry laboratory manual that makes the students' laboratory experience a truly scientific inquiry by the utilization of guided- and open-inquiry experiments in an approach similar to Pavelich and Abrahams', but with an approach to the guided-inquiry that emphasizes introductory information.

Barnes & Adsmon (1994) at Morehead State University use an approach similar to guided-inquiry where students perform experiments in which they make an increasing number of decisions themselves and then in the last eight weeks of the semester, have two experiments due for which literature and previous lab experiences are utilized to design, collect data, and report on their findings.

Ditzler and Ricci (1994 & 1995), in their "Discovery Chemistry" format, focus on the rediscovery of fundamental principles of chemistry using inquiry-based approaches. Though less applied in nature, these labs emphasize chemistry as an investigative laboratory science. Ditzler and Riccis' (1994/95) labs are structured into three parts. The first part is the prelaboratory discussion where students focus on a question, design hypotheses, discuss experimental approaches, and consider possible data trends. The
The second part is the actual labs which are characterized by division of the labor, with each group investigating a unique variation. Class data is pooled. The third part is the postlab session where the data is interpreted either individually or in groups. Throughout the lab, the instructor is integral in insuring that student creativity is managed in small increments, that is, carefully guided.

The College-University Research Institute (CURI) labs that were utilized for this project are based on relevant issues and are adaptable to guided- or open-inquiry but are not as open-ended as Kerners', Pavelich and Abrahams', and Ricci and Ditzlers'. They are a start at moving away from verification labs and are designed to go across the total chemistry curriculum, including, not only freshman level general chemistry labs, but also labs more applicable to more advanced students in organic, biochemistry, polymer or physical chemistry labs. Many of the labs are multi-leveled, in that they could be expanded or contracted for various student ability levels. The increased dependence on instrumentation is very appropriate in the CURI labs, as technology usage and computer integration is already widely used in industry. Increased use of instrumentation can be a powerful motivator, according to Watkins (1992), and does not take anything away from learning chemistry.
CHAPTER THREE

A. Components

Utilizing the knowledge learned from the literature research, a pilot laboratory section was taught to determine the benefits and problems that would be associated with wider implementation of inquiry-based laboratories. The components of this thesis are: first of all, a study to compare academic achievement differences and student perceptions between an inquiry-based laboratory approach and a verification-based laboratory approach; secondly, to make recommendations for how to implement an inquiry-based laboratories curriculum; and thirdly, a workshop for instructors to educate them to the vision, rational, goals, skills, and resources necessary for implementation of inquiry-based laboratories.

B. Methodology, Data, Results and Discussion

In an effort to facilitate implementation of inquiry-based laboratory experiments, a pilot study was designed and analyzed, where one section of first year chemistry students was taught from an inquiry-based approach and a control section was taught in the traditional verifications approach. From this study, along with literature research, recommendations are made to help improve the curriculum implementation process. The aim of this pilot study is to analyze student academic achievement differences and perceptions between traditional verification labs and inquiry-based labs.

Traditional methods of laboratory instruction include (a) prelab lecture, (b)
individual or partner laboratory work, and (c) individual completion of lab data, and question sheets. The actual laboratory work is verification labs, that is, the students perform chemical manipulations following written step by step directions and fill in the blank data sheets. Abraham (1988/89) calls this approach "inform-verify-practice". Others have called it 'cookbook' or 'recipe' approach (Lloyd, 1992a, 1992b). The inquiry-based labs were taught with author-modified CURI labs, and utilized supportive classroom environmental modifications, cooperative learning, relevancy, write-to-learn techniques, and open-ended questioning techniques.

There are other researchers that study the benefits of inquiry-based laboratory instruction versus traditional instruction. The two research study sources found in literature that most closely paralleled this study were by Pavelich and Abraham (1979), and Kosinski (as cited in Marcus, 1993).

Pavelich and Abraham (1979) had two study groups of about 600 students each; the experimental or inquiry format at the University of Oklahoma, and the control or verification format at Oklahoma State University. Pavelich and Abraham were able to eliminate the novelty effect, as it was unknown to the students that they were in an experiment. Pavelich and Abrahams' first goal, to increase abstract thinking ability, was tested for by pre- and post-tests consisting of tasks from the Cognitive Analysis Project. Pre-test results showed the levels of student abstract thinking abilities were 14% formal, 78% transitional, and 8% concrete. Post-test results showed significant gains in abstract thinking ability in the experimental over the control group. Pavelich and Abrahams'
second goal, to give students experience in scientific inquiry, was evaluated with the use of the Laboratory Programs Variables Inventory (LPVI). Using the Spearman Rank Correlation Coefficient, they found a significant difference between experimental and control, or inquiry and verification laboratories, which means that, indeed, the students were experiencing more truly scientific inquiry. The problems Pavelich and Abraham encountered they felt were due to attempting to effect a measurable change in only one hour per week, and with superficially-trained, inexperienced instructors.

Kosinski (as cited in Marcus, 1993) at Clemson University divided his students into three groups: group 1, were students taught inquiry (investigative) labs by instructors who taught both traditional and inquiry sections; group 2, were students taught traditionally by instructors who taught both traditional and inquiry sections; and group 3, were students taught traditionally by instructors who only taught traditional sections. Mean lecture exam scores, pre- and post-tests on writing skills, process skills and the nature of science all showed no significant difference between the three groups. Opinion surveys were favorable toward individual parts, but unfavorable overall due to higher demands and greater time consumption than traditional labs. “A majority agreed that they were more confident in their abilities to analyze problems scientifically, design experiments, analyze data and present their conclusions orally and in writing. The majority did not agree that they would have learned more about science in a traditional section” (as cited in Marcus, 1989, pg. 98). Kosinski suggests that results would have been better if students had taken the pre- and post-tests more seriously, but did not because
they knew the results were not part of their grades.

The 1995 fall semester GVSU freshman chemistry class was comprised of approximately four hundred students in sixteen laboratory sections. Two freshman chemistry laboratory sections, one treatment and one control, were randomly chosen. The make-up of the student sample in each section is described in Table 1. Since part of the reason for using inquiry-based labs was to entice females and minorities and increase retention, these categories were looked at in particular. The number of males, females, minorities and drop-out occurrences present in each class were determined but not matched. In the future it would be better to have more equally balanced sections, but due to instructor and time constraints, matched sections were not used. The treatment section was taught utilizing inquiry-based laboratories and the control section was taught in the traditional verification laboratories manner. The experimental section was taught by the author and the control section was taught by another instructor.
Table 1

Make Up of Students in Treatment and Control Sections

<table>
<thead>
<tr>
<th></th>
<th>Treatment</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original number</td>
<td>17</td>
<td>24</td>
</tr>
<tr>
<td>Final number</td>
<td>16\textsuperscript{a}</td>
<td>22\textsuperscript{b}</td>
</tr>
<tr>
<td>Minority</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Special needs\textsuperscript{c}</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Males</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>Females</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td># Completing survey</td>
<td>11</td>
<td>12</td>
</tr>
</tbody>
</table>

\textsuperscript{a}One student dropped out the third week.

\textsuperscript{b}Two students dropped out the seventh week.

\textsuperscript{c}As determined by those students with letters from the Academic Resource Center.

Of the fourteen labs taught during the semester to the treatment section, only five (Numbers 1, 2, 7, 8, and 14) were designed to be inquiry-based, due to time and material constraints (see Appendix B). Lab number 1 exposed students to safety with laboratory chemicals such as strong acids and bases, oxidizing and reducing agents, and their effect on everyday materials such as clothing, hair, contact lenses, biological materials, plastics and metals. Lab number 2 dealt with determining mass and volume using precision and accuracy to find the densities of different types of soda pops. Lab number 7 dealt with types of reactions, such as, single and double displacement, combination, and decomposition reactions, utilizing molecular, ionic and net ionic equations, along with
conductivity tests and precipitation reactions. Lab 8 was the study of acid and base reactions, or the study of proton transfer reactions. Lab number 14 dealt with solubility product constants.

Student laboratory achievements were compared by the mean grades for each lab and by overall class lab grades. Simple analysis of variance (ANOVA) was used to determine any significant difference between the inquiry-based and verification lab achievements (see Table 2) at a .05 level of significance. An open-ended perception survey was given to the students in each section at the beginning and end of the semester (see Appendix A). The results of each question were analyzed and are discussed below.

**Academic achievement results**

Table 2

Comparison of the Mean Grades

<table>
<thead>
<tr>
<th></th>
<th>Treatment</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lab #1. Out of 20 Pts.</td>
<td>19.7</td>
<td>17.6</td>
</tr>
<tr>
<td>Lab #2. &quot;</td>
<td>19.0</td>
<td>18.4</td>
</tr>
<tr>
<td>Lab #7. &quot;</td>
<td>17.7</td>
<td>17.2</td>
</tr>
<tr>
<td>Lab #8. &quot;</td>
<td>16.0</td>
<td>18.0</td>
</tr>
<tr>
<td>Lab #14. &quot;</td>
<td>19.2</td>
<td>18.4</td>
</tr>
<tr>
<td>Mean Labs #1,2,7,8,14, %</td>
<td>91.6</td>
<td>89.8</td>
</tr>
<tr>
<td>Mean Labs #1-14, %</td>
<td>89.9</td>
<td>91.8</td>
</tr>
</tbody>
</table>

ANOVA found no significant difference at the .05 level (or even at .10 level). Therefore,
there was no significant difference between the academic achievement of students in the control and experimental laboratory sections.

Survey results

A copy of the survey is presented in Appendix A. Students were asked to rate and describe their attitude or feelings for chemistry both at the beginning and the end of the semester. These descriptors were normalized for the number of respondents and are presented in Appendix A, Table 3 for the experimental section and Table 4 for the control section. The actual percentages are presented in Figures 1 and 2, Appendix A.

Although the experimental section started out with a greater overall positive response to chemistry, they also showed a greater gain in positive responses to chemistry at the end of the semester in comparison to the control section. (In fact, one student from the experimental section enjoyed chemistry laboratory so much that he changed his major to chemistry -- a nice switch from all those students that drop, or are turned off to chemistry.) At the beginning of the semester, the positive descriptors that students from the experimental section gave were: good, curious, happy, optimistic, and interested. There were no positive responses from the control section. The negative descriptors from both control and experimental sections were: nervous, anxious, scared, confused, overwhelmed, apprehensive, uncertain, worried, withdrawn, and exhausted. Indeterminant descriptors were responses like: indifferent, undecided, and unassuming.

At the end of the semester the positive descriptors from the experimental section included such terms as: great, exciting, interesting, confident, better than I thought, happy,
fun, satisfied, and enjoyed. Positive descriptors from the control section were: good, ok, happy, and optimistic. Negative descriptors from the experimental group included: relieved, and disappointed, with similar descriptors from the control group. Indeterminant descriptors were: “yeah, we’re done”, indifferent, tired and no responses.

The survey results showed that all students prefer a supportive, informal, relaxed, cooperative, quiet talking, not chaotic atmosphere or laboratory environment. Students preferred frequent and easy access to peers and the instructor and suggested the presence of a laboratory teaching assistant would be helpful as the instructor was unable to reach all students within a few minutes. There was an even split between students preferring groups or partner work, with comments favoring groups like: groups help you see more points of view, groups help reason out the problem better. Those not favoring groups cited problems like: groups are distracting, groups sometimes get off task, partners are better than groups, especially if you are compatible and can chose your own partner. One student in each section stated that they preferred to work individually with no accompanying comments.

Questions on preference for learning cycle order showed 80-90% of students opted for theory (lecture) on the material first and experiential (laboratory) learning second, “to back up lecture”. This high percentage of reversed order preference from the constructivist approach may be due to the fact that this is the only order that most students have ever experienced.

Questions about the structure of lab time led to responses favoring both less pre-
lab instruction: “let us experiment, and ‘play’ around more”, “we can read, let us follow the directions”, and more pre-lab instruction: “explain more practical applications”, explain in more detail. Eighty percent of the students would prefer to spend more time with hands-on learning and less on calculations. Many students also commented that they needed more lab time, that two hours was not enough time in which to complete the labs.

In the experimental lab section, students showed a slight preference for lab write-ups to be due in one week, sighting the need for time to do a good job on a complete write-up, the need for time to think about what they had done, in order to increase understanding, and so they did not have to hurry through the lab. Most students in the experimental section felt they learned more from the longer CURI lab write-ups than the fill-in-the-blanks labs, and learned more by taking the regular labs home to complete than when they hurried to finish the labs during class time. Experimental section students also were allowed to take extra question sheets home for additional practice, which many found helpful. In the control section, students showed a preference for lab write-ups to be due in class, sighting that having the lab due in class eliminated worrying over it for a whole week, “we can forget about it for a week”, allowed them to finish up while the information was still fresh and the instructor was right there to answer questions. The control section students did not have a week to finish their labs but felt there should be no punishment for completing labs in one week.

Presently, the weight of the lab grade in the course is 10%. The majority of students in the experimental section felt 10-15% was an appropriate weight for the labs,
with students' comments similar to: "...because lab should be a place for experiential learning", "When the emphasis is on the grade, the focus shifts to points rather than learning." Those students in both the experimental and control sections expressing a desire for an increase in the lab grade weight, up to 25%, said that "...for the amount of time we put in" it should count for more. Other students compared chemistry lab to biology lab where the lab grade weight is 25%.

When asked if they used any support services, most students said they utilized their partner, or group members and the instructor. Only one student had utilized the Math/Science Student Support (MS3) and one student utilized the Academic Resource Center.

When asked to give suggestions for the improvement of the laboratory experience, comments were: allow more time to do the labs, do not emphasize significant figures so much, not so many calculations, decrease the amount of information, spend more time on less material, show us where this stuff fits into our lives, and make all the labs CURI labs. What students found good about the labs were, in particular, the model building lab, "molecules lab was great- we didn’t have to wear our safety glasses and it really was helpful" and the CURI labs really "stuck in their minds" the best.

C. Conclusions

Due to the limitations of the study, the conclusions are not as clear as they could have been. The experimental section was definitely influenced by the novelty effect and
as such had a higher appreciation for the comments they made. Not withstanding this effect, there were probably true differences in the positive attitude increases seen. The student opinion survey mirrored the 'too muches' and 'not enoughs' cited by Spencer (1991) when they judged the lab course of not having enough relevancy, or emphasis on scientific processes, or chance to do actual experiments, and too much material, theory, and concentration on rules and calculations.

The inability to have all labs be inquiry-based in the experimental section created both positive and negative effects. Having five labs that were inquiry-based did not influence the academic achievement of the experimental section students. Without an appropriate instrument to measure actual abstract thinking increases it is impossible to say if there was a difference in this area, however, this would be an appropriate area for additional research. The treatment section students had an opportunity to compare both traditional and inquiry-based approaches to laboratory learning and felt they definitely learned more through the inquiry-based approach. The atmosphere and classroom management approaches of the traditional sections were difficult to imitate once the supportive, cooperative environment was established in the experimental section. The study would have been more valid had there been a method to change environments for each type of laboratory approach.

The increase in positive responses and the educational research recommendations of a more constructivist approach with a more supportive atmosphere leads to the conclusion that the curriculum of an inquiry-based laboratory warrants implementation.
The pilot study showed that students are enthused by an inquiry approach and that they are able to do the work and learn the material. This study was unable to tell if there was a definite difference for minorities as there were so few present, but for females, there was an increase in positive affect and an even greater increase for males.

Although the CURI labs are a step in the right direction towards inquiry-based laboratory experiences, it would be better to have an even stronger inquiry approach such as Abraham and Pavelich's, 1991, Inquiries into Chemistry, or Ricci and Ditzler's "Discovery Chemistry" approach.

D. Recommendations

As Schwab (1974) pointed out and this study has collaborated, curriculum change at the university level is complex. Because it is so complex, once a change takes place, it usually is not changed again for a long time. Therefore, it is important to be sure that the change is made with all due consideration since changes made may influence generations of students coming through the university's science programs.

Establish communication

The first and most important step is establishing good communication between all those affected by the curriculum changes. Those instructors, administrators and support staff most interested and concerned about the changes should be on a laboratory curriculum change committee. Although it may be impossible to have all those affected on the committee, the committee can communicate by posting minutes and decisions on
a bulletin board, both physically and electronically, to facilitate two-way communication.

Define the problem

The committee's first step would be to define the problem. There is a need to accommodate a new generation of students. Demographics have changed, and with these changes in the population, needs have changed. Women, minorities and low socioeconomic status students are becoming a bigger portion of the class and are predicted to increase. Keeping in mind these students' needs for increased warmth, support, and informality in the environment, instructional methods must change. There is a need to integrate educational research into laboratory chemistry to optimize learning. Educational research has shown that understanding constructivist theory, multiple intelligences/learning styles theories, classroom environment and other areas of research can lead to inquiry-based, individualized and cooperative learning that greatly improves learning and abstract thinking abilities. There is a need to increase interest and motivation in chemistry which can be best accomplished by meeting students' needs of hands-on activity, relevancy, increased control in decisions, and involvement in actual research and experimentation.

Rationale for change

Being united or sharing the vision or the rational behind the change is the next step, according to Knoster, (1991, "Curriculum change and rational: Managing complex change." Paper presented to TASH. Information from personal communication, February, 1996, with Loretta Konecki, Ph. D., Professor, School of Education, Grand
Valley State University. Grand Rapids, MI.). This would entail defining the target population, in this case freshman chemistry students, and determining their composition and unsatisfied needs (King, Morris, & Fitz-Gibbon, 1991). Keeping in mind the way these students best learn and their many different learning styles, it is important that the complete learning cycle, from (a) the first concrete experiences, through (b) the reflective observations, and (c) the abstract conceptualizations, to (d) the active experimentation be provided for each student. The rational will most likely contain the idea that implementing a more appropriate curriculum and its concurrent changes in teaching methods in order to meet the needs of the changed population will best meet the needs of all students, thus improving retention, learning, and increasing enthusiasm towards chemistry. A shared vision and a clear understanding of the rationale behind the changes will make all subsequent decisions easier.

Determining goals

Determining the goals and the priorities of the goals would be the next step in the committee’s process. The goals of chemistry education, and specifically, laboratory education as reviewed in Chapter 2 of this thesis, could be a starting point from which to list and prioritize those goals deemed most important to those involved. The goals of MEAP (1994) that should definitely be part of the list for consideration are:

- Redesign courses to provide an interesting and challenging curriculum taught with greater skill and with more awareness for the environmental factors that affect women and minorities’ learning.
• Increase in-depth coverage of topics and concepts.

• Increase linkage of scientific knowledge with societal issues.

The goals of Pavelich and Abraham (1977) are three other goals that should most definitely be included:

• Acquaint the student with the fundamental laboratory techniques and procedures.

• Enhance the student’s thinking ability toward more abstract thinking processes.

• Give the student experience with some aspects of scientific inquiry, especially data interpretation, hypothesis formation and experimental testing of hypotheses.

These would be the most important goals to include, according to this author, but other goals enumerated by Lloyd (1992b) and McNeal (1989) may be considered equally important to other chemistry instructors.

Skills to reach goals

Once the goals have been clearly established, they will help to define those skills necessary to reach the chosen goals. The necessary skills will need to include (a) instructional methods for establishing a supportive environment, (b) teaching to reach many different learning styles, (c) teaching in the learning cycle, and (d) training in holistic assessment methods to match the new curriculum approaches. Most importantly, laboratory instructors will need to become familiar with the whole idea of inquiry-based instructional approaches so that they feel comfortable pushing, prodding, leading, and facilitating students to inquire, research, and experiment to find answers to their questions. Open-ended questioning techniques need to shift the focus from “Is this the correct
chemical equation?” to “Could this be what is happening chemically?” with greater emphasis on what is involved or the process and less emphasis on the correct chemical formulas and equations.

**Establishing incentives**

Pedagogy is the reform area that is most resistant to change due to lack of incentive to change and lack of knowledge of how to change (Ross, 1994). Traditional pedagogy, where the teacher transfers knowledge to passive students, must be replaced with constructivist, student-centered, cooperative learning (Ross, 1994). Establishing incentives to change will come partly from the knowledge that the changes are for the greater benefit of all students, making ‘selling’ of the chosen curriculum important. As instructors start to teach with improved skill, they will feel better about how they are interacting with and teaching their students.

Additional incentives will need to come from the administration in the form of support and enthusiasm for the new changes and accommodations for the increased demands on the instructor that inquiry-based approach entails. Pavilich and Abraham (1979) found that graduate assistants were able to handle fewer inquiry laboratory sections than the previous verification lab sections.

**Defining and obtaining resources**

Defining and determining the curriculum content, approach and actual texts or laboratory experiments will set the tone for the whole course. Since chemistry is an experimental science, ideally it should be structured around the laboratory (Foster, 1989;
& Kovac, Schell, Grimm & Hazari, 1994). Ricci and Ditzler (1991) in their “Discovery Chemistry” approach have designed such a laboratory-centered approach to teaching general chemistry. Instead of the traditional lecture-centered approach their course is structured around the laboratory. New topics are first introduced in the lab and then later discussed in the lecture. Fundamental concepts are derived from exploratory laboratories in a collaborative process. Others have structured general chemistry curriculum around the laboratory by adjustments in scheduling, such as three two-hour sessions per week rather than the traditional three or four one hour-long lectures and single two- or three-hour laboratory (Marcus, Cobb, & Shoenberg, 1993).

The next best approach to teaching chemistry, if it is not laboratory centered, is to use an inquiry-based laboratory approach. Kemer’s Chemical Investigations (1986) is an inquiry based approach, but it uses extensive introductions to each experiment instead of hands-on exploration. It is confusing for students to be overwhelmed with information and to try to discern what is important and what is not. Abraham and Pavelich’s second edition of Inquiries into Chemistry (1991) is the best source found to date that utilizes a learning cycle approach with cooperative learning and technological advances. Inquiries into Chemistry also incorporates some micro-scale experiments and utilizes instrumental methods and computers. The CURI laboratories utilized in this study employ an inquiry approach, but not in a learning cycle and need considerable modification for adaptation for use at each institution. The CURI labs biggest asset is the amount of relevancy they incorporate. The various curricula approaches are charted in Table 5 for their various
Table 5

<table>
<thead>
<tr>
<th></th>
<th>Prelab Info.</th>
<th>Learning Cycle</th>
<th>Relevancy</th>
<th>Guided Inquiry</th>
<th>Open Inquiry</th>
<th>Greatest Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>CURI</td>
<td>1-2</td>
<td>2-3</td>
<td>1</td>
<td>2-3</td>
<td>3</td>
<td>Relevancy Adapts across the curriculum</td>
</tr>
<tr>
<td>Inquiries into Chemistry</td>
<td>5</td>
<td>1</td>
<td>2-3</td>
<td>1</td>
<td>1</td>
<td>Micro scale &amp; technology oriented</td>
</tr>
<tr>
<td>Abraham and Pavelich</td>
<td>3-4</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Lab-centered</td>
</tr>
<tr>
<td>&quot;Discovery Chemistry&quot;</td>
<td>5</td>
<td>1</td>
<td>3-4</td>
<td>1</td>
<td>1</td>
<td>Can stand alone or use with text</td>
</tr>
<tr>
<td>Ricci and Ditzler</td>
<td>3-4</td>
<td>1</td>
<td>3-4</td>
<td>1</td>
<td>1</td>
<td>Lab-centered</td>
</tr>
<tr>
<td>Chemical Investigations</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>Can stand alone or use with text</td>
</tr>
<tr>
<td>Kerner</td>
<td>3-4</td>
<td>1</td>
<td>1-2</td>
<td>2-4</td>
<td>5</td>
<td>Text and lab in one book</td>
</tr>
<tr>
<td>Materials Science</td>
<td>1</td>
<td>3-4</td>
<td>1-2</td>
<td>2-4</td>
<td>5</td>
<td>Micro scale &amp; technology oriented</td>
</tr>
<tr>
<td>Ellis</td>
<td>1</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>Micro scale &amp; technology oriented</td>
</tr>
<tr>
<td>Chemtrek</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Thompson</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Traditional Verification</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Laboratories</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Scale: 1 = strength, or a lot present  5 = weakness, or not much present
The next most important resource is the cadre of properly trained instructors. Anywhere from a two-hour in-service program to a two-day staff retreat have been utilized to acquaint or immerse instructors in the new curriculum, pedagogy, and technology involved in the changes (Ditzler & Ricci, 1995; Abraham & Pavelich, 1979; Thompson, 1990; & Ellis, Geselbracht, Johnson, Lisensky, & Robinson, 1993). The approach of a two-day workshop seems to be the best arrangement. Two days allows time for instructors to experience several labs themselves and time for pedagogical instruction and practice with new teaching techniques and new technology. The workshop developed for this thesis is presented in Appendix C and could be made shorter or longer depending on the amount of instruction desired or necessary, experience of the participants, and number of labs that are experienced.

Technology, in the form of computers available in the laboratory and instrumentation for analysis of chemicals, is a very important resource and will become increasingly important as computer usage increases. Having a computer available in the laboratory for video disc instruction, entering data for collaborative work, and analysis of data is essential in the 1990s. Computer availability outside of the laboratory needs to be available for programmed learning, remediation units, problem solving and tutoring purposes.
Action Plan

According to Knoster (1991), developing an action plan is the final step in managing complex change. Allowing sufficient time to implement each step in the implementation process is important. Steps in the action plan might include the following:

1. Choose the curriculum.

2. Pilot test labs. Once the curriculum is chosen, pilot labs need to be run to find out what problems are involved, both from the students’ and instructors viewpoint, and for the sake of instrumentation, chemicals, and equipment supply needs. Pilot labs are more important in the case where a published curriculum is not used or if many modifications have been made. If a previously published and used curriculum is chosen, there is less need for pilot labs to work out unforeseen problems.

3. Laboratory preparation. Time must also be allowed for laboratory preparation, that is, obtaining and setting up chemicals, equipment, and glassware for performing a lab. Depending on the curriculum, chemicals may or may not need to be purchased, and special equipment obtained.

4. Hold a workshop. Once the majority of the problems have been satisfactorily worked out, either by curriculum choice and/or pilot labs, the next step is to educate pre- and in-service instructors. Having all instructors understand and utilize the same standards of instruction and assessment is important in making the whole laboratory/lecture/discussion complex go
smoothly.

5. Implementation. Although these steps appear progressive, they can be done somewhat simultaneously. Pilot labs can be from different curriculums, and laboratory preparation can be analyzed as pilot labs are run. A workshop of instructors trying out several different inquiry-based curricula could be one possible way to explore which curricula are best for each university's unique situation.

6. Evaluate and revise. Once the change has been implemented, it is important that it be analyzed, critiqued and revised as deemed necessary and appropriate.

E. Future Research

Several different areas need further research as highlighted by this study. More studies need to be conducted to develop better methods of student evaluation (predictors of success) to appropriately place students into the proper introductory level class to match their abilities. House (1993) and Coppola (1992) found that traditional predictors for success do not correlate with student performances. Assessment of learning strategies, motivation, attitudes and math abilities need to be combined into a new evaluation instrument. Studies following the implementation of inquiry-based chemistry labs would be appropriate to measure increases in abstract thinking and attitudinal changes towards chemistry. Retention studies of the number of females, minorities and low
socioeconomic status students dropping out or repeating the course would be helpful to determine if this approach is making a difference in students' understanding of chemistry and to determine if students' needs were being met. An analysis of what student needs are still not being met would be helpful, such as, studies on the need for certain support services, time and learning styles management, or for an even 'warmer' supportive environment. It would be helpful to perform an experiment similar to Pavelich and Abrahams' (1979) with the use of an evaluation tool that measures abstract thinking ability and an instrument like Science Laboratory Environmental Inventory (SLEI) (Fraser, Giddings, & McRobbie, 1992) to measure attitudinal changes that are occurring.

Other related areas for further research that were found through the literature search for this thesis include (a) misconception education, (b) technology's proper implementation or best use approach, (c) study-group facilitator training (Van Der Karr, 1994), (d) dynamics of group formation, and (e) attitudinal, behavioral, persuasion and motivational methods and strategies. Research on teaching in order to correct alternative conceptions, or misconceptions, is an area that currently has a lot of interest (Zoller, 1990). Being relatively new, computer-based applications, such as remediation and review units, laboratory exercises, data compilation, laboratory report writing, video disc instruction, and instrumental interfacing for the classroom, are areas that need further development and research (Leonard, 1989, & Bruder, 1993). The dynamics of groups, partner and group selection and the "albatross effect" (the feelings of an individual that their performance will negatively affect the group) are all areas that affect cooperative
learning and lack research (Tlusty, 1993). Attitude-behavior intervention strategies and methods of persuasion and motivation need more research and are important areas for increasing the number of students taking chemistry (Crawley & Koballa, 1991).

F. Plans for Dissemination

The plans for dissemination are to:

1. Circulate this thesis among the faculty and staff of the GVSU chemistry department.

2. Hold a workshop to educate those instructors affected by the curriculum changes and their concurrent instructional method changes. The material included is described in Appendix C in the format of a two day workshop where curriculum, pedagogy and technology changes will be used, analyzed and practiced.

3. Publish a summary article, if there is sufficient interest, in order to better disseminate the information included in this thesis, to facilitate inquiry-based chemistry implementation at other colleges and universities.
REFERENCES


Creason, P. (1992). Changing demographics and the importance of culture in student learning styles. (Printed by EDRS no. 361270.)


Research in Science Teaching, 21, 95-103.


Eccles, J. S. (1987). Gender roles and women’s achievement-related decisions. Psychology of
Women Quarterly 11, 135-172.


Appendix A

Pre- and Post- Semester
Chemistry 111 Laboratory Survey

Section __________
Gender __________
Ethnicity __________
Date __________

1. Would you prefer to finish a lab write-up during the two hour lab or have the write-up due in one week?

2. Do you feel you learn better by working with a group, a partner or alone?

3. What is your preferred learning style?

4. Would you prefer the lab atmosphere to be structured or unstructured, cooperative or competitive, quiet or conversational, formal or informal? Or use your own words to describe the lab atmosphere in which you could best work.

5. Would you rather spend more time in the lab doing hands-on chemistry or more time in the lab performing calculations?

6. Currently, the lab grade counts as 10% of your final grade in Chemistry 111. Would you like the lab grade to count more toward your final grade? If so what percentage do you think would be appropriate?

7. How much time do you expect to spend, or did you spend, preparing for each laboratory experiment before class?

8. How much time do you expect to spend, or did you spend, writing up a lab report?

9. Would you spend more time preparing for and writing up experiments if the lab counted more toward your total chemistry grade?

10. What grade do you think you will receive in Chemistry 111?

11. Would you rather receive more or less information and detail in the prelab? What amount of time is appropriate for prelab introduction?
12. Would you prefer to experience something in a lab and then learn about it in a lecture or the other way around?

13. Do you expect to, or did you, use support help such as:
- tutor
- study group
- peers
- instructor
- teaching assistant
- ARC (Academic Resource Center)
- MS^3 (Math/Science Student Services)
- Learning Center
- Other support?

What support help worked best, is needed, or needs improvement?

---------------------------------------------------------------------------------------------------------------------
(post-lab only)

14. Which experiments stick in your memory best? Why?

15. Which experiments did you consider the worst? Why?

16. What ideas do you have to improve the lab or specific experiments?
Pre-semester

SCIENCE/MATH OPINION SURVEY

Section

Date

Gender

Ethnicity

0. Starting out this semester what is your attitude towards chemistry?

Positive  Negative  Undecided

What words would you use to describe your feelings?

Please put the number of the appropriate answer in the space provided.

1. strongly agree  2. agree  3. uncertain  4. disagree  5. strongly disagree

1. I have difficulties in science/math courses.

2. I am afraid of science/math courses.

3. I am clear about my career goals and what I need to meet them.

4. I will be taking more science/math than I originally planned on.

5. Science/math courses are not important for the career area in which I am interested.

6. I do not need to be technically skilled for my career area.

7. Taking science/math courses can help me succeed in other subject areas.

8. You need to study with different methods for science/math courses than for other subject areas.

9. I understand my learning style and make appropriate study plans.

10. I plan on using a tutor in order to succeed in my science/math courses.

11. I plan on using a study group to help me succeed in my science/math courses.
Appendix A 102

Post-semester
SCIENCE/MATH OPINION SURVEY

Section
Date
Gender
Ethnicity

0. What is your attitude towards chemistry now at the end of this semester?
   Positive  Negative  Undecided

What words would you use to describe your feelings?

Please put the number of the appropriate answer in the space provided.
1. strongly agree  2. agree  3. uncertain  4. disagree  5. strongly disagree

1. I have difficulties in science/math courses.

2. I am afraid of science/math courses.

3. I am clear about my career goals and what I need to meet them.

4. I will be taking more science/math than I originally planned on.

5. Science/math courses are not important for the career area in which I am interested.

6. I do not need to be technically skilled for my career area.

7. Taking science/math courses can help me succeed in other subject areas.

8. You need to study with different methods for science/math courses than for other subject areas.

9. I understand my learning style and make appropriate study plans.

10. I used a tutor in order to succeed in my science/math courses.

11. I used a study group to help me succeed in my science/math courses.
## Attitudes

**Experimental**

![Bar chart showing attitudes](image)

### Table 3

Percentage of Responses Positive, Negative and Indeterminate to Learning Chemistry in the Experimental Section

<table>
<thead>
<tr>
<th>% Responses</th>
<th>Pre-</th>
<th></th>
<th></th>
<th>Post-</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Females</td>
<td>Males</td>
<td>Females</td>
<td>Males</td>
<td>Females</td>
<td>Males</td>
</tr>
<tr>
<td>Negative</td>
<td>62</td>
<td>54</td>
<td>50</td>
<td>43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>14</td>
<td>9</td>
<td>30</td>
<td>43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indeterminate</td>
<td>24</td>
<td>37</td>
<td>20</td>
<td>14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Attitudes

Figure 2

**Table 4**

Percentage of Responses Positive, Negative and Indeterminate to Learning Chemistry In the Control Section

<table>
<thead>
<tr>
<th>% Responses</th>
<th>Pre- Female</th>
<th>Pre- Male</th>
<th>Post- Female</th>
<th>Post- Male</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative</td>
<td>73</td>
<td>62</td>
<td>60</td>
<td>52</td>
</tr>
<tr>
<td>Positive</td>
<td>00</td>
<td>00</td>
<td>28</td>
<td>31</td>
</tr>
<tr>
<td>Indeterminate</td>
<td>27</td>
<td>38</td>
<td>12</td>
<td>17</td>
</tr>
</tbody>
</table>
In order to best succeed in this lab you will need to be carefully prepared for each lab experiment. Read and study the lab, plan the work you will do, summarize the experiment, emphasizing your hypotheses about what might occur and why, and prepare any data tables needed before class begins.

The purpose of a laboratory report is to communicate clearly to others what the problem was you investigated, why it was important, how you went about the investigation, what you learned, and what you would change or do differently next time. The ability to communicate information will increase if you communicate not only in writing but verbally also. Therefore, talk with others in your group, and your instructor to learn to present your information orally also. The lab report will be graded on how complete, neat, and correct it is. Work together with others in the lab to increase your inventiveness and ingenuity.

Report write-up

The laboratory report for this class should include the following items:
Page one as the title page; lab title, course name and number, instructor name, section number, time, place, your name, address and phone number.

An introduction; what the problem is that is being investigated, any hypotheses you have about the experiment, etc. The introduction should state the purpose of the experiment and also summarize what you will be doing, the procedure.

Observations for each part of the experiment using words, equations or numbers.

Data in neat tables (use a ruler) with clear headings, or titles, should present your results in an easy to read format.

Calculations, where necessary, should be written out or at least one example of a typical calculation given.

Answers to questions from the lab should be clear and concise.

The conclusion should:
1. summarize your finding(s) and highlight the most important thing(s) learned.
2. include any approaches you would change to increase the fun or the safety of the experiment.
3. relate the principals of each lab to applications in everyday life, the environment or industry.
4. it should also include your suggestions for further investigations or research and other similar problems to which you might apply your learning.
In order to avoid round-off errors, you should carry through the calculation of all the digits allowed by the calculator and round off only at the end of the problem. Rounding off in the middle can introduce significant errors.

Significant Figure Rules

1. All nonzero integers are significant.
2. All Zeros to the left of (or preceding) the first nonzero digit are not significant, since they are used to locate the decimal point.
   
   0.00567 has three significant figures.

3. All zeros between nonzero digits are significant.
   
   207.08 has five significant figures
   0.0401 has three significant figures

4. All zeros at the end of a number that has a decimal point are significant.
   
   34.070 has five significant figures

5. Zeros at the end of a whole number that has no decimal point cause confusion since they may or may not be significant. Confusion can be avoided by putting the number in scientific notation.
Appendix B  107

CURI Lab I:  REACTIONS TO AVOID!
SAFETY WITH REAGENTS AND EVERYDAY MATERIALS

I. Introduction

Safety is defined as freedom from harm or injury. When you cross the street, you practice safety by looking in both directions. Likewise, you keep yourself safe while riding in a car by wearing a seat belt. Safety in the laboratory can be achieved in two ways. The first way is to physically separate yourself from the chemicals and equipment by wearing protective equipment such as safety glasses, lab coats, and rubber gloves. The second equally important way to protect yourself from laboratory hazards is to be knowledgeable about the materials with which you are working and respectful of the danger they may present. Some of these hazards, such as spilling acid on the skin, are obvious; others, such as wearing contact lenses in the lab, are less evident.

During this lab you will investigate the effects of strong acids, strong bases, oxidizing-reducing agents, and solvents on various materials. As you go through the different experiments outlined below, focus on the things that you can do to make lab a fun and safe experience for everyone.

A. Properties of Strong acids

Acids are well known to be corrosive substances. The potential hazard of a given acid depends on a number of factors including the strength and the concentration of the acid. Acids are most readily defined as proton (H+) donors or electron pair acceptors, the ease with which an acid donates a proton determines its strength. Strong acids are extremely reactive and readily lose a proton or gain an electron pair.

The vast majority of acids are weak and do not readily lose H+ or gain electron pairs. Weak acids are commonly used in cooking. For example, vinegar is a 5% (by volume) solution of the weak acid, acetic acid (HC2H3O2), while citric acid is the weak acid which gives the tangy taste to lemons.

Acids are usually used as solutions in water and the acid concentration is described using the term molarity (M), which is defined as the number of moles of a substance in a liter of solution. This description can be a bit confusing, however, because strong acids of the same molarity are much more reactive than weak acids of the identical molarity and therefore have greater corrosive effects.

Today you will be working with various concentrations of three different strong acids, hydrochloric acid (HCl), nitric acid (HNO3), and sulfuric acid (H2SO4). Nitric and sulfuric acids are examples of oxoacids because they contain oxygen and they have the ability to act as oxidizing agents when concentrated. For this reason they are described as oxidizing acids, whereas hydrochloric acid is a non-oxidizing acid. In addition, concentrated sulfuric acid can also act as a dehydrating agent. This means that it has a high affinity for water (H2O) and will even "grab" it out of a molecule such as sugar (C12H22O11).
B. Properties of Strong Bases

In a sense, bases are the opposite of acids: they are proton acceptors or electron pair donors. Strong bases do this readily and are very corrosive, while weak bases are much less reactive. Many students think of a base only as something which contains an -OH group. This is not necessarily the case, however, since lithium hydride (LiH) and ammonia (NH₃) are both bases. Common strong bases include sodium hydroxide (NaOH), potassium hydroxide (KOH), and barium hydroxide (Ba(OH)₂); most bases however are weak. Common examples of weak bases include ammonia (NH₃) which is the base present in dilute solution in household ammonia, and sodium bicarbonate (NaHCO₃, baking soda).

Like acids, the concentration of a base is measured in molarity (M) or, less often, in weight/weight percentage (%w/w). Once again a strong base of a given molarity is much more reactive than a weak base of the same molarity.

C. SAFETY WITH ACIDS AND BASES

Because acids and bases are corrosive to clothing and the skin, it is most important they be handled with care and kept off of clothing and skin. If acid or base gets on your skin or clothing, immediately flush the area with plenty of water and report the incident to your instructor. If an acid spills on your lab bench, neutralize it with sodium bicarbonate (baking soda) provided. If a base spills, neutralize it with dilute acetic acid solution, (vinegar).

An acid added to a base or to water generates heat. A base added to an acid or water also generates heat—take precautions! Two important safety rules in working with acids and bases are:

1. Always do as you oughtta, add the acid to the water!
2. If you want to save your face, add the acid to the base!

D. Solvents

Acetone is a common solvent in most organic chemistry laboratories. It has the structure of

\[
\begin{array}{c}
\text{O} \\
\text{H} \\
\text{H} \\
\end{array}
\quad
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{H} \\
\text{C} \quad \text{C} \quad \text{C} \\
\text{H} \\
\text{H} \\
\end{array}
\]

and is neither an acid nor a base. It is highly flammable and must be kept away from heat and open flames. In addition, if it comes in contact with plastic or synthetic fabrics, it may damage or destroy them. When using acetone to clean glassware, do the cleaning in the hood and dispose of the acetone in an organic waste jar, not down the drain.
E. Oxidizing and Reducing Agents

Strong oxidizing agents and strong reducing agents are also chemicals which warrant respect. An oxidizing agent is a substance which oxidizes something else; it is itself reduced. Likewise, a reducing agent reduces something else; and is itself oxidized in the reaction. Reactions involving oxidation and reduction are termed oxidation-reduction (redox) reactions. You will later learn more about these terms mean in terms of electron transfer. In this lab we will experiment with household bleach (Chlorate) which is a potent oxidizing agent; household bleach is a dilute solution of sodium hypochlorite, NaOCl. Remember, nitric acid and sulfuric acid are oxidizing acids; thus part of their reactivity is due to their ability to oxidize other substances.
II. Experimental

In this experiment you will be making a lot of observations which you need to record. In lab you will record your observations neatly on paper in as much detail as seems appropriate under separately labelled sections. Use the data sheets provided as models for your tables and answer all the questions in your lab write-up.

PART A. Hair (demo)
Hair is made up of melanin, a pigment, and proteins which are linked by hydrogen bonds and sulfur bridges. This investigation will test the ability of a strong acid, base and oxidizing agent to react with the proteins in hair. Note: this section will be done as a class demonstration.

Observe four small piles of hair of the same type and place them on separate large watch glasses. Describe the type of hair used.

To each of the hair samples add a sufficient quantity of one of the reagents so that some of the hair is immersed in the reagent. Allow the hair to react for the duration of your lab. Record your observations towards the end of your laboratory period. Describe any color or structural changes in the hair. (Reagents: tap water, 6M NaOH, 16M HNO₃, Clorox.)

Table 1 (title)

| Question 1 | Compare the results of the various compounds tested on hair with the control (tap water). Were any of the compounds not harmful to hair? If so, which one(s)? |

PART B. Reactions with Clothing
In this part you will explore how concentrated strong acid solutions, a strong base, and a strong oxidizing agent affect common clothing materials.

Obtain four or five different types of material, and describe the materials you actually use for your experiment: color, type of material followed by the fabric makeup

- nylons- 100% nylon
- towel- 100% cotton
- denim - 100% cotton
- colored T-shirt - polyester/cotton blend

Place four spots of reagents on each piece of material. Record observations for all the materials at your table, together with the treatment needed to produce them. (Reagents: 12M HCl, 18M H₂SO₄, 12.5M NaOH, Clorox.)

The easiest way to test a material is to stretch a square piece over a small (50mL) beaker and fasten it with a rubber band. Then add two drops of the reagent to a small area of the fabric. If no change is evident after 5 minutes, try poking the area with a stirring rod. If there is still no change, rinse the fabric with tap water and dry with a hair dryer. Then poke the area again with a stirring rod: now are there any changes?

Table 2 (title)
Appendix B 111

Question 2. Which material reacted the most - the cotton towel or the denim - with
(a) 12.5M sodium hydroxide?
(b) 18M (concentrated) sulfuric acid?
In each case give evidence to justify your answer.

Question 3. Is the polyester or the cotton being disintegrated in the polyesters/cotton
material when the 18M $H_2SO_4$ is added? What observations and evidence
can you use to back up your answer?

Question 4. Is sodium hydroxide more reactive with natural (cotton) or synthetic (nylon,
polyester) materials? Give evidence to back up your answer.

Question 5. Which of the fabrics you tested would you recommend as a suitable material
for a lab coat? Explain your reasoning.

Question 6. Based on the behavior of nylons with acids and bases, would you say that
nylon is an acidic or basic material? Explain your reasoning.

Part C. Contact Lenses

Contact lenses, first introduced in the late 1930's, have revolutionized the way
people see the world around them. Lenses are not only used to correct vision problems,
but also to treat injured and diseased eyes and to hide cosmetic disfigurements. In the
laboratory, however, contact lenses are viewed as a hazard! Depending on the reagent
encountered, lenses can become stained, distorted, curled, opaque, destroyed or become
sticky and adhere to the eye. If you were wearing contact lenses when a solvent, acid, or
other chemical was splashed into your eye, it would be very difficult to get at the eye itself
to flush it out.

The following solutions will be tested with the lenses:
1. fluorescein indicator (a fluorescent dye)
2. 18 M H$_2$SO$_4$ (concentrated sulfuric acid, a strong acid.)
3. 2% KMnO$_4$(aq) (potassium permanganate, a strong oxidizing agent)
4. 6 M NaOH (sodium hydroxide, a strong base)
5. acetone (an organic solvent)

Make up a data table in your lab report. Be sure to leave sufficient room to record your
observations.

Your group will test a new lens in each of the different solutions. Wipe the lens
and container dry with a Kimwipe, feel the lens for rigidity, look through the lens and
return it to the container. Place two drops of the test solution on the center of the lens, and
observe. After a few minutes rinse the lens with distilled water. Record any changes in
the lens size, shape, color, and opacity; be sure to look through them again. Place the lens
on a piece of white 3x5 card labeled with the reagent used, and place it where other
students can observe it easily.

Table 3 (title)

Question 7. Which (if any) of the reagents tested was not damaging to contact lenses?

Question 8. If a reagent splashed into your eye in lab, what would you do? How could
you prevent this accident from happening?

Part D. Biological Materials

1. Sugar. Table sugar (sucrose) is a simple carbohydrate with the molecular formula, C\textsubscript{12}H\textsubscript{22}O\textsubscript{11}. Transfer a small amount of sugar (about a half-teaspoon) to the bottom of a 100 mL beaker. Carefully place ONE drop of concentrated (18M) H\textsubscript{2}SO\textsubscript{4} on the sugar. Record your observations.

2. Egg White. Egg white (egg albumin) is mostly protein and so can serve as a model for your skin, and mucus membranes; e.g. eyes, mouth, etc. Place a small blob of egg white on a watch glass and investigate the effect of 6 M HNO\textsubscript{3} (nitric acid) on the egg white. Observe carefully, and record your observations. Also test the egg white with 6 M NaOH (sodium hydroxide) and Clorox. (Optional: test the egg yolk similarly.)

3. Skin. Drip a few drops of very dilute (0.12 M) sodium hydroxide solution provided. Rub your fingers together and report how it feels in your laboratory notebook. Rinse your hands immediately with plenty of cold water.

Table 4 (title)

Question 9. If the concentrated sulfuric acid is extracting water molecules from the sucrose (C\textsubscript{12}H\textsubscript{22}O\textsubscript{11}), what is the black product obtained? (Hint: Think about the elements that make up sucrose; notice the ratio of H to O in the sucrose formula.)

Part E. Polystyrene and Starch Packing Peanuts (Optional experiment)

Polystyrene, also known as Styrofoam, is used in molded and plastic items. An environmental concern is that polystyrene is non-biodegradable. Starch peanuts have been developed to be "environmentally friendly". Place a small piece of Styrofoam peanut on a watch glass and place a few drops of acetone on it, (in the hood). On another watch glass, place another piece of Styrofoam peanut and place a few drops of water on it. Do the same tests with pieces of a starch peanut and record your results in a table form in your lab book.

Table 5

Question 10. You undoubtedly noticed the volume loss when the Styrofoam "peanuts" reacted with acetone. If the lost substance was air (and the remaining substance pure polystyrene), what purpose does the air have in the Styrofoam "peanuts"?

Part F. Aluminum Foil (Optional experiment)

So far in your investigation of common laboratory reagents you may not have seen the dangers of sodium hydroxide (NaOH). This investigation will show you just how corrosive, and deserving of respect, NaOH can be. It will also introduce you to the chemistry of aluminum.

Place a piece of aluminum foil in the bottom of a beaker. Bend the foil so that it will form a cup to hold a small amount of liquid. Add a small amount (about 10 drops) of 6 M NaOH. Observe continually until a definite reaction has occurred. Record all observations. Be patient and cautious!
Appendix B 113

Question 11. Both bits of aluminum metal and NaOH (solid) are constituents of Draino™, a common drain cleaning product. Based on your observations in this lab, why do you think the aluminum is included as a component of Draino™?

Question 12. What problems would you anticipate if your bathroom sink had aluminum plumbing?

IV. Conclusion

Safety in the laboratory is not something that can be learned in one lab session. It is an ongoing process involving much thought, foresight, and respect. Include in your lab report, under Conclusion the most important thing(s) you learned from this laboratory. What experiments would you suggest for further research on this topic?

Acknowledgment:

Development of this laboratory was made possible by CURI, 1001 Connecticut Ave., N.W., Suite 901, Washington, D.C. 20036.

I-7
Instructor notes

Divide students into groups of four students each. You may assign students to groups, allow the students to group themselves or use any arrangement convenient. It often works well to assign the students to different groups the first few labs and then allow them to form their own groups after they have gotten to know each other.

Parts A through F do not all need to be performed by every group. Have some groups start at F and work backwards, others start at B and work forwards, and still others can start at D or E.

Part A is a demo, be sure to use the same type of hair in each watchglass, and leave a portion out of the liquid for comparison purposes. It will take most of the lab time to see clear results.

Part B Suggest to the students that they place the drops of acid or base in the same position relative to the spout for ease in comparison.

Part C We hope to get some soft contact lenses but have lots of gas-permeable-hard on hand. A greater amount of change will be seen with soft contacts. Be sure to have students look through the lens before and after treatment with chemicals.

Questions
1. tap water -> no rxn
   NaOH -> curls and eventually dissolves
   HNO₃ -> "burns" "smokes"
   clorox -> bleaches

2. rxns vary with the material
3. polyester is disintegrating
4. varies
5. denim would usually be best for a lab coat
6. nylon is -----

7. Damage will depend on use of hard or soft contacts
8. use of safety glasses

9. the black is carbon

10. air acts as a cushion, or space filler for protection
Note!!! Please check that droppers work properly and bottles do not leak or drip!

Part A. Hair Demonstration
Hair (obtain from a hair dresser)
4 large watch glasses
6M NaOH: 3 mL, in small dropper bottle
16M HNO₃ = conc. nitric acid (Warning on label): 3mL
Clorox: 3mL

Part B. Material
50 mL beakers: 24
Rubber bands: 24
3x3 squares of materials
denim, nylon (pantyhose), cotton towel, colored T-shirts (cotton-polyester blend)
Clorox: 6 small dropper bottles
Dropper bottles of conc. acids and base
12M HCl = conc. hydrochloric acid (Warning on label)
18M H₂SO₄ = conc. sulfuric acid (Warning on label)
12.5M NaOH: 50% w/w sodium hydroxide (Warning on label)

Part C. Contact Lenses
Contact lenses, one per student or one per pair of students
Fluorescein indicator, 2% solution, 1 g fluorescein powder in 49 g of 1% NaOH
(18M H₂SO₄, from Part B above)
2% KMnO₄ (aq), potassium permanganate
(6 M NaOH, from Part A above)
Acetone: one dropper bottle per hood

Part D. Sugar and Eggs
Sucrose (table sugar): half-teaspoon per student pair, (12)
(18M H₂SO₄, from part B above)
Egg white, one egg per 4 students (6 eggs)
Egg yolks, optional
6M HNO₃: two dropper bottles, one for each bench
(6 M NaOH, from Part A above)
(Clorox, from Part B)
Approx. 0.10M NaOH 250 mL in one or two squirt bottles by the sinks.
Part E. Styrofoam and Starch peanuts
polystyrene "peanuts" broken into pieces, enough to fill a 100 mL beaker
starch "peanuts" broken into pieces, enough to fill a 100 mL beaker
(acetone, from Part C)

Part F. Foil and Base
aluminum foil in 1x1" squares, one per student pair, (12)
(6M NaOH, from parts above)
I. Introduction: Chemistry is an experimental science. Its development and application depends upon the measurement of physical properties such as mass, volume, temperature, time, heat transferred, electrical current, and so on. The metric system is usually used in chemical measurements although other systems may be used in certain areas of applied chemistry.

Precision is a term used to describe the agreement among repetitive measurements of the same quantity. If the agreement is good the precision is high. In large part, precision depends upon the instrument used. For example, in measuring mass, a typical analytical balance will give differences in repetitive measurements of about 0.0001 g (0.1 mg). A top loading balance will give differences in mass of about 0.001 g (1 mg). Hence, the analytical balance is capable of higher precision. In this lab we will look at the reproducibility of measuring volumes.

The precision of measurements depends also on the size or magnitude of the measured quantity. For example, the measurement of a 1 gram sample to the nearest 0.0001 g and a 100 g sample to the nearest 0.01 g both give precision of one part in ten thousand or 0.01% variation among measurements.

The precision that one strives for varies. At times, comparatively imprecise measurements are adequate.

Accuracy is the agreement of a measured value with an accepted value. Precise measurements may or may not be accurate. Commonly, accuracy is measured as percentage error, that is, the absolute difference between measured (M) and accepted (A) values divided by the accepted value and then multiplied by 100 or

$$\frac{|M-A|}{A} \times 100 = \% \text{ error}$$

The accuracy of a measurement is always limited by the degree of refinement of the apparatus used, and by the skill of the observer. Most measurements involve the reading of some scale, like on a balance or a graduated cylinder. Thus, the accuracy of the measurement depends on the fineness of the graduations, as well as the width of the lines marking the boundaries on a scale. In every measurement the last digit must be estimated and therefore has some uncertainty associated with it. However, this doubtful digit carries some meaningful information about the quantity measured, and is reasonably trustworthy. This last digit therefore determines the number of significant figures, and hence the accuracy of the measurement. For example, consider the following:

```
   __________ |
   _________  |__________|__________|        .________|________|__________|__________|__________|__________|__________|

    5    6    7        5    6    7
value = 6.4    value = 6.39
```

* soda pop = soda = pop  II-1
Archimedes' Principle. In this experiment you will be taking advantage of Archimedes' Principle. When an object is totally submerged in a liquid it displaces its own volume of the liquid. The relative masses of the object and the displaced liquid determine whether the object will float or sink.

Sinking: If the mass of the liquid displaced is LESS than the mass of the object the object will sink. For example, if a decimeter cubic block of oak wood displaces 1000 mL of water, the water's mass is 1 kg. But the mass of the oak wood is greater than 1 kg and will therefore sink.

Floating: If the mass of the liquid displaced is EQUAL to the mass of the object then the object will float such that it just displaces its own mass of liquid (it cannot displace more than its own mass). For example, if a decimeter cubic block of balsa wood is physically forced to submerge, it will displace 1000 mL of water, the water's mass is 1 kg. But the mass of the balsa wood is less than 1 kg and will therefore float.

The property that describes this behavior is DENSITY or mass per unit volume:

\[
\text{Density} = \frac{\text{mass}}{\text{volume}}
\]

In the metric system, the ratio is expressed as grams per centimeter cubed (g/cm³) [or grams per milliliter (g/mL) since 1 cm³ = 1 mL, for distilled water]. For a given substance at a particular temperature, density is an intensive property, a property which is characteristic of the nature of the substance and not dependent on the quantity present. In this experiment, the density of a liquid will be measured and the precision and accuracy of these measurements will be determined.
II. **Experimental**  
(Don't forget to show sample calculations, be careful of significant figures, and share the work load.)

**Part A. Density of Pop Cans:**

1. **Relative Densities:** Investigate the properties of the cans of soda in water using the water tanks provided and distilled water. Develop a list of the relative densities of the four types of soda pop. Postulate reasons for the differences you observe. Record your ideas before you continue.

2. **Mass:** Your group will be assigned one brand of soda. Obtain 4 cans of one kind of soda pop. Using a Denver balance (0.001g), determine the mass of each can and calculate the mean mass and experimental error (see Appendix 1) of just your brand of soda. Record only the mean mass and the experimental error of the other types of pop from the other groups in your class and compare.

<table>
<thead>
<tr>
<th>Table I possible headings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brand of pop</td>
</tr>
<tr>
<td>Mass</td>
</tr>
</tbody>
</table>

3. **Volume:** Keeping Archimedes' Principle in mind, design a simple water displacement experiment to measure the volume of your group's assigned brand of soda. Design an experiment before you come into lab so that each person contributes their ideas to the group. Available materials are listed at the end of the lab. If there is something else you need, within reason, you may ask at the stock room for it and sign it out. Some things to keep in mind: you should not open the can; try to use materials readily available in the lab; work as a TEAM! Record your group's results. Then share, record and compare the other class groups' volume results.

**Question 1.** Carefully record the details of your procedure. After you have determined the volume of one can, look at your procedure—is there a way that you can simplify it? make it more precise? Where does your procedure have possible errors?

4. **Measured Densities:** Using your results from 2. and 3. above, compute the densities of the different brands of pop.

**Question 2.** List the densities in order and compare this list to the relative densities list from number 1. above. How do they compare? How could you be more accurate and precise?

**Part B.** Now let's determine the density of the pop out of the can. First we will need to
Appendix B 120

Search for the Best Volume Measuring Device.

When determining the density of any liquid it is necessary to accurately measure its volume. You have available to you the following three devices: a beaker, a graduated cylinder, and a buret. First you need to undertake an experiment to determine which of these devices will yield the best accuracy and precision. When reading the markings on glassware, estimate to one tenth of a division on the container, for example, a beaker with graduations of 0, 10 & 20 mL would be estimated to 1 mL.

Remember to divide the work between the group members.

1. Volume: Instead of using the volume measurements that are read from the three devices, we will compute the exact volume for each device using the density equation, the masses from 3. a., b., and c. and the density of water from the CRC Handbook. \( D = \frac{M}{V} \), knowing \( D \) and \( M \) we can find \( V \). This means that we will be testing how accurately and precisely we can deliver volumes with each device.

2. Density: Record the temperature of the water in the tank with a digital centigrade/Celsius thermometer. Look up the density of water at this temperature using a suitable reference source, such as the Chemical Rubber Company (CRC) Handbook of Chemistry and Physics.

3. Mass: Take the mass of 3, 10mL portions of distilled water from your tank using the three measuring devices.
   a. Graduated cylinder. Measure, as accurately as possible, 10 mL of deionized water using a 10 or 100 mL graduated cylinder. Determine the mass of this water (and hence its volume) by pouring it into a tared (preweighed) container (or use the graduated cylinder) and obtain the mass of water plus the container. Record the massings and calculate the mass of the water. Repeat to determine the mean mass for a total of 3, 10 mL portions.
   b. Beaker. Measure 10 mL of the deionized water using a 25 or 50 mL beaker and determine the mass of the water as above. Again repeat the procedure to obtain three mass readings.
   c. 25 mL buret. Fill the buret to just below the zero mark. Read this as your initial reading. Allow, as accurately as possible, 10 mL to drain into a container of known mass and determine the mass of the transferred water as above. Repeat to obtain three mass readings.

Table II needs to include:

<table>
<thead>
<tr>
<th>Measuring device</th>
<th>Measuring Trial #</th>
<th>Mass of: Container + water</th>
<th>Density at given temperature: Mean Mass</th>
<th>Abs. Dev.</th>
<th>Exp Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>- Container</td>
<td>Water</td>
<td>II-4</td>
<td></td>
</tr>
</tbody>
</table>
4. Calculated Volumes: Calculate the exact volumes delivered by each device and calculate both the experimental error and the percent error of the calculated volumes using 10.00 mL as the acceptable value for the true volume. Rank the volume measuring devices used in order of decreasing accuracy and also decreasing precision. Based on these results, choose the best device for Part C of this experiment.

Questions 3: Which measuring device is most accurate and precise?

Part C. Density of the Liquid Pop.

In this part of the lab you will determine the density of the sodas by "measuring" the liquids directly. Choose one can of your group's assigned brand and open the can (or you may use already opened cans from previous labs.) What should be your major concern when you are taking the density of a carbonated liquid? How could you correct for this problem? (Hint:* Think about what happens to an open can of soda when it sits out overnight. You may want to compare the mass of the unopen can to the mass of the open can.) Before lab meets, design a simple procedure to measure the density of the sodas, consider using the information you learned from the volume measuring devices in section B. You may want to compare the mass of the liquid when it is carbonated and decarbonated, (see the instructor for decarbonated pop). Share the results of your group's brand with the rest of the class by placing your values in the appropriate space on the table on the black board (overhead, computer). Record and compare the other class groups' values.

*When a substance is dissolved in a liquid the resulting solution is often denser than the pure liquid since the dissolved substance generally does not have much effect on the total volume but does increase the total mass. The dissolved molecules or ions "fit" into the spaces between the solvent molecules.

Question 4. How do the actual liquid densities compare with each other?

Question 5. How do they compare with your first impressions of their densities in part A?

Question 6. Do you have any theories of why the pops have different densities? How could you test your theory?

Question 7. What difference did carbonation make? What difference did diet versus regular make?

Question 8. Suppose you drop a can of soda into a water tank. The can sinks to the bottom. How could you make the can float? Hint: Under what conditions does a can float? Think about a way to alter the properties of the water.
Question 9. Suppose you have a 12oz and a 6oz can of regular cola. The cans are identical except that one is about half the size of the other. You drop the 12oz can into a water tank and it sinks. What would happen to the 6oz can if you dropped it into the same tank? Explain.

Question 10. Scientists want to know the density of a moon rock. The rock massed at 2.865kg by use of a balance. Since the rock is pitted with holes (and may even have holes or hollows inside it) how would you suggest determining the volume of the rock?

III. Conclusion
Density, an intensive property, can tell you something about a substance. What did you learn from this lab? What experiments would you suggest for further research on this topic? What would you change to improve this lab?

Acknowledgment
Development of this laboratory was made possible by CURI, 1001 Connecticut Ave., N.W., Suite 901, Washington, D.C. 20036.

Student Materials List
3 - 300 mL Erlenmeyer flasks
1 - 400 mL beaker
2 - 50 mL 
1 - 150 mL 
10 mL graduated cylinder
100 mL 
plastic ice cream bucket with hole near the top
rubber tubing
10 mL volumetric pipet and bulb
thermometer
CRC Handbook
balance that masses to three decimal places
Appendix B - APPENDIX I

Procedure for Calculating Experimental Error and the Standard Deviation

| Sample Number | Measured value \((x_i)\) | Deviation, \(\delta\) | \(|\delta|\) |
|---------------|--------------------------|----------------------|--------|
| 1             | 4.28                     | -0.01                | 0.01   |
| 2             | 4.21                     | -0.08                | 0.08   |
| 3             | 4.30                     | 0.01                 | 0.01   |
| 4             | 4.36                     | 0.07                 | 0.07   |
| 5             | 4.26                     | -0.03                | 0.03   |
| 6             | 4.33                     | 0.04                 | 0.04   |

\[ \Sigma = 25.74 \quad \Sigma = 0.00 \quad \Sigma = 0.24 \]

1. To calculate the Arithmetic mean, \(\bar{x}\):

\[ \bar{x} = \frac{\Sigma x_i}{n} \]

\[ \bar{x} = \frac{25.74}{6} = 4.29 \text{g} \]

2. To calculate the Average deviation = Experimental Error,

\[ \delta = \frac{\Sigma |\delta_i|}{n} \]

\[ \delta = \frac{0.24}{6} = 0.04 \]

Therefore, our reported value would be

with Experimental Error = 4.29 ± 0.04 g

This is a sufficient estimation of experimental error when a small number of samples are used. For a large number of samples of data, a more statistically proper method is to determine the uncertainty in a measurement - called the standard deviation, where the square of the deviation is used.
Lab Prep for Experiment II
Density Lessons from a Can of Soda

Based on four groups of four to five students each (18 students total)

Part A. Four brands of soda pop, each group needs four cans of one brand and one of each of the other brands of pop. (Total of seven cans per group -- it may be possible for each group to only have the four cans of the one brand and then borrow one of each of the other brands from the other class groups)
(class of 18 students-4 or 5 groups 35 cans of pop, 7 of each brand)
5 TLC water tanks, large enough to submerge pop cans completely plus some

5 balances (Denver Balances) (presently only have three)

Four groups will need:
4 400 mL beaker (already in 109 buckets)
4 10 mL graduated cylinder (already in 109 buckets)
4 100mL graduated cylinders
8 50 mL beakers
4 25 mL beakers
4 25 mL burets
4 digital centigrade thermometers

4-8 ice cream plastic buckets with holes near the top, rubber tubing

2 Hot plates or 1 griddle

Instructor demo: For density discussion

NaCl, table salt, 50 g in demo tank, one can Hawaiian Punch
ice cube, 2 - 150 mL beakers, 50 MeOH

Place an ice cube in a beaker of water and then transfer into a beaker of MeOH. Place a can of pop in a tank of distilled water and then transfer into a tank of salt water. (Hawaiian Punch seems to work best.)

II-8
Lab Prep for Experiment II
Density Lessons from a Can of Soda

Based on six groups of four students (24 students total)

Part A. Four brands of soda pop, four cans per student
   (class of 24 students-106 cans of pop, 24 of each brand)
   6 TLC water tanks, large enough to submerge pop cans completely plus some
   (presently have 5 tanks)
   6 balances (Denver Balances) (presently only have three)

Part B. Six groups will need:
   6 400 mL beaker (in 109 buckets)
   6 10 mL graduated cylinder (in 109 buckets)
   12 50 mL beakers
   6 25 mL burets
   6 digital centigrade thermometers

Part C. 8 ice cream plastic buckets with holes near the top, rubber tubing

Part D. 2 Hot plates or 1 griddle

Instructor demo: For density discussion

   NaCl, table salt, 50 g in demo tank, one can Hawaiian Punch
   ice cube, 2 - 150 mL beakers, 50 MeOH

   Place an ice cube in a beaker of water and then transferr into a beaker of MeOH.
   Place a can of pop in a tank of distilled water and then transferr into a tank of salt water.
   (Hawaiian Punch seems to work best.)

II-9
CURI Lab VII: WHAT IS A CHEMICAL REACTION?  
A LOOK AT SOME TYPICAL EXAMPLES

I. Introduction

The purpose of this experiment is to investigate some of the reactions that chemical substances undergo. You will also practice writing formulas and balanced chemical equations for the reactions you observe.

A. Symbols: A symbol is used to represent the name and also one atom of an element. A formula is a combination of the symbols of the elements that represent one molecule or formula unit of a compound. An equation is a shortened description of a chemical reaction in which a new compound is made from other compounds (or elements). In order to correctly write formulas in an equation we need to know whether molecules or ions are present. To do this we must know which substances ionize extensively in aqueous solutions (these are called strong electrolytes) and which substances are non-ionized or only slightly ionized (non-electrolytes). You will investigate some solutions to determine whether strong or week electrolytes are present. Some of the more common anions (negative) and cations (positive) are listed in appendix B. It would be very helpful in your study of chemistry to know the name, formula, and charge of each of them.

B. Equations: Three types of chemical equations are used to communicate what is happening in a chemical reaction. Although reactants and products may be in a solid state, you know from practical experience, that mixing two liquids together is much easier than mixing two solids together (think about mixing solid sugar and solid salt, versus mixing sugar water and salt water). The water allows the dissolved species (ions or molecule) to contact one another on an ionic or molecular level, and thus provides a better medium for reaction to occur. If a solid is dissolved in water it is designated as aqueous (aq), for example, NaCl(aq) designates a water solution which contains dissolved NaCl(s). The (s) designates a solid and (g) designates a gas.

1. In a Molecular equation, molecular formulas are written as reactants and products in the chemical equation.
\[ \text{AgNO}_3(\text{aq}) + \text{NaCl}(\text{aq}) \rightarrow \text{AgCl}(\text{s}) + \text{NaNO}_3(\text{aq}) \]
Since these solutions contain essentially no molecules of AgNO₃ or NaCl, we should write the reaction as occurring between ions.

2. In an Ionic equation, all strong electrolytes are written as ions in solution and those molecules insoluble in water are still written as molecules but are underlined to denote their weak electrolyte status. The formation of insoluble AgCl is the factor driving this reaction to the right. In order to determine whether a precipitate will form in a reaction, thereby driving the reaction to the right, one must know solubility rules. Some empirical solubility rules are given in appendix A.
\[ \text{Ag}^+ + \text{NO}_3^- + \text{Na}^+ + \text{Cl}^- \rightarrow \text{AgCl} + \text{Na}^+ + \text{NO}_3^- \]

3. In the Net Ionic equation, those species that do not change during the course of the reaction are omitted.
\[ \text{Ag}^+ + \text{Cl}^- \rightarrow \text{AgCl} \]
Another example between barium nitrate and sodium sulfate may be written as:

Molecular: \( \text{Ba(NO}_3\text{)}_2 + \text{Na}_2\text{SO}_4 \rightarrow 2\text{NaNO}_3 + \text{BaSO}_4 \)

Ionic: \( \text{Ba}^{2+} + 2\text{NO}_3^- + 2\text{Na}^+ + \text{SO}_4^{2-} \rightarrow 2\text{Na}^+ + 2\text{NO}_3^- + \text{BaSO}_4 \)

Net Ionic: \( \text{Ba}^{2+} + \text{SO}_4^{2-} \rightarrow \text{BaSO}_4 \)

C. Types of Reactions

During your investigations you will learn to recognize chemical changes. Often evidence of a chemical change is obvious. For example, chemical reactions may be accompanied by:
- a change of color
- formation of a precipitate or gas
- the absorption or evolution of heat.

Sometimes, however, evidence of a chemical change may be more subtle. For example, some precipitates are milky or gelatinous and may be easily overlooked by inexperienced chemists.

Simple reactions can be categorized into several groups. We will be investigating reactions which fall into the following four categories:

1. **Single displacement reactions.** These are reactions in which an element (usually a metal) displaces another element from a compound.
2. **Double displacement reactions** (Metathesis reactions). (muh-TATH-uh-sis is Greek for "to transpose") These reactions involve the exchange of parts of the reactants. Two important types fall into this class:
   - Precipitation reactions
   - Acid-Base reactions
3. **Combination reactions.** In these reactions two substances combine to form a third compound. If one of the substances is oxygen, the reaction is also called a combustion reaction. If a change occurs when a substance is heated in air (which is 20% oxygen) a combustion reaction is indicated.
4. **Decomposition reactions.** These are reactions in which a single compound reacts or decomposes to give two or more substances. In many common examples, a gas is given off. Evidence for gas evolution includes bubbling, fizzing, and/or odor.

II. Investigation Procedure

A. Conductivity, Ionic and Covalent Compounds: First, we will investigate the nature of some solutions by determining their conductivity. We will be determining whether or not the solutions contain ions (charged particles). If a solution contains ions, it will conduct electricity and the bulb on the tester will light up. The amount of light will tell us if the solution is a very weak, weak, or strong electrolyte. Make up a table in your lab notebook similar to the one given.
Appendix B 128

<table>
<thead>
<tr>
<th>Test Solutions (Formula)</th>
<th>Type of Substance</th>
<th>Observations</th>
<th>Type of Electrolyte</th>
<th>Ions (light strength)</th>
</tr>
</thead>
<tbody>
<tr>
<td>distilled water (H₂O)</td>
<td>pure water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tap water</td>
<td>mostly water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sodium chloride</td>
<td>salt solution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>sucrose</td>
<td>dissolved organic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>copper(II) nitrate</td>
<td>salt solution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>acetone</td>
<td>pure organic liq.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dilute hydrochloric acid</td>
<td>strong acid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dilute acetic acid</td>
<td>weak acid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dilute sodium hydroxide</td>
<td>strong base</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>dilute ammonia</td>
<td>weak base</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Divide up the work and test all the substances in the table. Rinse off the electrodes carefully with distilled water between tests!

Question
1. Which of the solutions tested above contain an appreciable concentration of ions? List the Types of Substances which were present in those solutions that were good conductors.

B. Single Displacement Reactions:
Make up a table in your lab notebook similar to the one below.

<table>
<thead>
<tr>
<th>Test Mixture</th>
<th>Observations</th>
<th>Evidence of reaction</th>
<th>Final Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Zn(s) plus HCl(aq)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Zn(s) plus Cu(NO₃)₂(aq)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Cu(s) plus Zn(NO₃)₂</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VII-3
For each test, follow the specific directions below. Record your initial observations, look for all evidence of a chemical reaction. Allow the mixtures to sit for most of the lab period, and then record any additional observations.

1. \( \text{Zn} + 6 \text{M HCl} \): Place a small strip of \( \text{Zn} \) in a small test tube and cover with 6M HCl.
2. \( \text{Zn} + 0.1 \text{M Cu(NO}_3\text{)}_2 \): Place a small strip of \( \text{Zn} \) in a small test tube. Cover with 0.1 M \( \text{Cu(NO}_3\text{)}_2 \) solution.
3. \( \text{Cu} + 0.1 \text{M Zn(NO}_3\text{)}_2 \): Place a small strip of \( \text{Cu} \) in a small test tube. Cover it with 0.1M \( \text{Zn(NO}_3\text{)}_2 \) solution.

Questions
2. Record your observations for each reaction. Write out the molecular, ionic, and net ionic equations for the reactions that are taking place.
3. Was a gas given off in any of the reactions? If so, which one(s)? Can you identify the gas?
4. Looking at the last two tests, which metal is more reactive, \( \text{Zn} \) or \( \text{Cu} \)?

C. Double Displacement Reactions

C1. Precipitation Reactions
C1.a. Treat 1 mL of lead nitrate solution with a few drops of 6 M hydrochloric acid. Allow the precipitate to settle and decant (pour off) the supernatant liquid. Save the precipitate for the next step.

Question
5. Record your observations. Write out the molecular, ionic and net ionic equations for this reaction. Be sure to underline the precipitate.

To the precipitate from the previous reaction, add a few drops of potassium iodide solution. (Lead iodide is yellow and less soluble than lead chloride.)

Question
6. Record your observations. What is the new precipitate composition? Write out the molecular, ionic and net ionic equations.

C1.b. Use 2 - 4X6 cell well plates to test for precipitation reactions. Prepare a table as shown below. Place 10 drops of the nitrate solutions, listed at the top of the table, in each test well in the column below it. Add 20 drops of the solutions, listed on the left of the table, to each well in the row. Observe the plates over both a sheet of white paper and the black lab bench. Record the formula of any precipitate that forms. Be sure to consult Appendix A for solubility rules to help you determine the precipitate composition. If no precipitate forms, leave the space blank. Also, remember that salt formulas must contain equal numbers of positive and negative charges.

Note: it is not necessary to write equations for all the reactions, only the one given at the bottom of the table, Question 7. (Use Appendix D to help you balance the equation.)
Appendix B 130

<table>
<thead>
<tr>
<th></th>
<th>Barium Nitrate</th>
<th>Ferric Nitrate</th>
<th>Cupric Nitrate</th>
<th>Nickel Nitrate</th>
<th>Calcium Nitrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium Hydroxide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Chloride</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Carbonate</td>
<td></td>
<td>* Fe(OH)₃</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Phosphate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium Sulfate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Question 7.** Ferric hydroxide precipitates here as shown in the following equation, not ferric carbonate as might be expected. Balance the molecular equation for this reaction, and write out the ionic and the net ionic equations.

**Molecular:**

\[
\text{Fe(NO}_3\text{)}_3 + \text{Na}_2\text{CO}_3 + \text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3 + \text{CO}_2 + \text{NaNO}_3
\]

**Ionic:**

**Net Ionic:**

**C2. Acid-Base Reactions**

Acid base reactions are also often double displacement reactions.

Add 1 mL of 6M NaOH to 1 mL of 6M HCl in a small test tube and mix.

**Question 8.** What evidence do you have that a reaction occurred? *Hint:* touch the outside of the test tube. (The bubbles you may see are escaping dissolved air.)

**Question 9.** Write the molecular, ionic and net ionic equations for the reaction. Recall that:

\[\text{acid} + \text{base} \rightarrow \text{salt} + \text{water}\]

What is the name of the salt formed?

**D. Combination Reactions**

**Burning of S(s).**

Place a very small (*pin-head sized: we really mean it!*!!) piece of sulfur in a small test tube. Hold the test tube with a test tube holder, and heat the test tube in a Bunsen burner flame. Test the odor of the escaping gas (with the proper procedure) and test the vapors with moistened blue litmus paper as you heat the test tube. Note: base turns litmus blue, acid turns litmus red. By the time the litmus changes color, you should be able to smell the gas.

VII -5
Question
10. Record your observations. Write the balanced equations for the reaction above.
11. What does the result of the litmus test tell you about the gas?

E. Decomposition Reactions
Marble chips plus acid.
Place a few marble chips (calcium carbonate) on each of two watch glasses. To one watch glass add enough 6M HCl to cover the chips. To the other watch glass add a similar amount of 6M HCl. Make up a table and use it to record your results.

Question
12. Record your observations. Can you determine what gas is given off? Write out the molecular, ionic and net ionic equations.
13. What accounts for the different reactivities of the two acids? (Use Appendix C to help you explain.)

Waste Disposal
All solutions should be discarded in the inorganic waste pail.

Acknowledgment
Development of this laboratory was made possible by CURI, 1001 Connecticut Ave., N.W., Suite 901, Washington, D.C. 20036.
CURI Lab VII  Acids and Bases
Lab Prep

A. Baby food jars with solutes in match-head size amounts.
   1. distilled water
   2. tap water
   3. NaCl + water
   4. sucrose + water
   5. copper(II) nitrate solution
   6. acetone
   7. 0.1M HCl
   8. 0.1M acetic acid
   9. 0.1M NaOH
   10. 0.1M ammonia

B. 20 pieces of Zn strips  (approximately 0.5cm X 2 cm or smaller)
   20 pieces of Cu strips  "  
   *(6M HCl)  5mL per 2 students, approx. 100mL
   0.1M copper (II) nitrate  "  "  "  "  "
   0.1M zinc nitrate  "  "  "  "  "

C. C1. same as regular lab VII
   C2. FeS  Iron(II) sulfide - small bottle of powder
      *(3M HCl)
   C3. *

D. Sulfur  - very small bottle of powder

E. marble chips, *(6M HCl), 6M acetic acid

* Have available from CURI Lab I
CURI Lab VIII: ACIDS AND BASE: PROTON TRANSFER REACTIONS

I. Introduction

In the Bronsted concept, an acid is a proton (hydrogen ion) donor, while a base is a proton accepter. Neutralization is a proton transfer between a donor and accepter. For example, consider the reaction between gaseous HCl and NH₃:

\[ \text{HCl}_g + \text{NH}_3(g) \rightarrow \text{NH}_4^+(g) + \text{Cl}^-_g \]

HCl is a good proton donor (strong Bronsted acid) while NH₃ is a proton accepter (Bronsted base). NH₄⁺ is a weak proton donor and Cl⁻ is a very weak proton accepter.

Using Appendix C, we can look at this reaction in another way. Note that the acids are strong (good proton donors) at the top of the chart and get weaker towards the bottom, and the bases start out weak at the top of the chart and get stronger (good proton accepter) towards the bottom. We could consider the reaction above as a competition for H⁺ between Cl⁻ (a very weak base, near the top of the base chart) and NH₃ (a stronger weak base, more than half way down the base chart.)

An acid will donate a proton to any base beneath it in the chart. Thus perchloric acid, HClO₄ or other strong acids (SA), will transfer their proton nearly quantitatively to H₂O, a weak base (WB), to form H₃O⁺ (hydronium ion) and ClO₄⁻ or the corresponding anion of the acid. For example:

\[ \text{HNO}_3 + \text{H}_2\text{O} \rightarrow H_3O^+ + \text{NO}_3^- \]

SA  WB  SA  WB

for simplicity, this is often written:

\[ \text{HNO}_3 \rightarrow H^+ + \text{NO}_3^- \]

Notice that the strong acid, H₃O⁺, is a 'weaker' strong acid, because it is below HNO₃, a 'stronger' strong acid; the weak base, NO₃⁻, is a weaker weak base than the weak base, H₂O. This trend, of going from a stronger acid or base to a weaker acid or base, means the reaction will happen spontaneously. Other examples of acids donating a proton to any base beneath it, and moving the reaction to weaker acids and bases follow in net ionic form:

\[ \text{HF} + \text{C}_2\text{H}_5\text{O}_2^- \rightarrow \text{HC}_2\text{H}_5\text{O}_2 + \text{F}^- \]

\[ \text{HF} + \text{SH}^- \rightarrow \text{H}_2\text{S} + \text{F}^- \]

\[ \text{HF} + \text{OH}^- \rightarrow \text{H}_2\text{O} + \text{F}^- \]

Insoluble salts involving anions derived from weak acids will usually dissolve in a solution of a strong acid (H+). Example:

\[ \text{CaCO}_3 + 2 \text{H}^+ \rightarrow \text{Ca}^{2+} + \text{H}_2\text{CO}_3 \]

Carbonic acid decomposes to -

\[ \rightarrow \text{H}_2\text{O} + \text{CO}_2 (g) \]
II. Experimental Procedure:

For each reaction, 1. through 7.

a. record your observations
b. write molecular, (ionic if helpful to you), and net ionic equations
c. answer any questions

1. To 2 mL of 1M NH₄Cl add 2 mL of 1M NaOH. To another 2 mL sample of 1M NH₄Cl, add 2 mL of saturated NaHCO₃. Hold a piece of moist red litmus paper over the top of each test tube. (If litmus turns red, it indicates acid; if litmus turns blue, it indicates a base is present.)
   How can the difference in behavior be explained? (Hint: compare the base strength of OH⁻ and HCO₃⁻ toward NH₄⁺.)

2. Add 1 mL of 6M NaOH to 1 mL of 6M HCl.
   What evidence is there that a reaction occurred?

3. Add 1 mL 6M NaOH to 1 mL of 6M HC₂H₃O₂.

4. Add 1mL 6M HCl to 0.5 mL NaHCO₃ solution in a large test tube.

5. Add 1 mL of 6M HC₂H₃O₂ to 0.5 mL NaHCO₃ solution in a large test tube.
   Which acid is stronger, H₂CO₃ or HC₂H₃O₂?
   Which base is stronger, C₂H₃O₂⁻ or HCO₃⁻?

6. a. Prepare a small amount of Ba₃(PO₄)₂ precipitate from the solutions on the reagent shelf.
   b. Allow the precipitate to settle and decant the supernatant liquid. Test the solubility of Ba₃(PO₄)₂ in 1M HNO₃ by adding 1 mL of the acid to the precipitate.

7. a. Prepare a small amount of BaSO₄ precipitate from the solutions on the reagent shelf.
   b. Test the solubility of BaSO₄ in 1 mL of 1M HNO₃
   Why does Ba₃(PO₄)₂ behave differently than BaSO₄ toward 1M HNO₃?

All solutions should be discarded in the inorganic waste pail.

Acknowledgment

Development of this laboratory was made possible by CURI, 1001 Connecticut Ave., N.W., Suite 901, Washington, D.C. 20036.
Appendix B 135

CURI Lab XIV: SOLUBILITY PRODUCT CONSTANS
and ACID-BASE EQUILIBRIA

I. Introduction

The carbonates of magnesium and calcium are compounds we often encounter in
our everyday lives. Calcium carbonate and magnesium carbonate are components of
several minerals including limestone, marble (partly crystallized limestone) and dolomite:
these substances are used for building purposes and to make several useful products
including chalk, paints, paper fillers and furnace linings. Calcium carbonate is a
component of coral and pearls. Limestone (CaCO$_3$), dolomite (CaCO$_3$MgCO$_3$) and other
basic substances in the soil are also acted upon by nitric acid (from acid rain) and are
converted to the corresponding nitrates.

Surface rocks composed of these carbonate salts are subject to chemical
weathering by the action of acids. Due to the increase in industrial and urban air pollution,
the air contains increasing amounts of carbonic, nitric and sulfuric acids, which cause
severe damage to carbonate stones. In the following reaction, the calcium carbonate
(insoluble) is attacked by sulfuric acid and is converted to calcium ion. Solubility is
limited because calcium sulfate is only sparingly soluble

\[
CaCO_3(s) + 2H^+ \rightarrow Ca^{2+}(aq) + CO_2 + H_2O
\]

This kind of acid attack due to major air pollution is what causes the extensive
deterioration of stone buildings and carvings that have existed for centuries.

The presence of magnesium and calcium ions in water causes hardness which
prevents ready lathering of soap, thus interfering with cleansing and causing waste of
cleaning material. The scale (deposit) that forms in boilers is the result of hard water
reaction with soap. Hard water can be softened by depositing the calcium and magnesium
ions in the form of the carbonates, which
have a low solubility in water.

\[
Ca^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CaCO_3
\]

This experiment explores the concepts of solubility, solubility product constants
and reaction equilibria in aqueous salt solutions. Precipitating calcium and magnesium
carbonates in aqueous solutions and studying the results of acid attack on these compounds
allows us to explain and study real life situations by applying the logic of chemistry. This
experiment combines the study of two kinds of equilibria that are discussed prominently in
general chemistry, reinforcing the concept that several equilibria can be operating at the
same time. This experiment is not simply about precipitation, or about acids and bases,
but about both topics simultaneously. The fact that the carbonate ion is a strong base
implies that its concentration depends on pH, requiring close attention to acid-base
dissociation.
Calcium carbonate and magnesium carbonate are white solids that have a low solubility in water. An equilibrium is established between the undissolved solid and the small amount of solute that actually dissolves in water; this equilibrium is characterized by an equilibrium constant, Keq. The general formula for Keq for a reaction type

\[ jA + kB \rightleftharpoons lC + mD \]

where A, B, C, and D are chemical species and j, k, l, and m are their coefficients in the balanced equation.

\[ Keq = \frac{[C]^l[D]^m}{[A]^j[B]^k} \]

One specific case of Keq is the solubility equilibria. This equilibrium constant is given a specific name: solubility product constant, Ksp. For example, in the case of calcium carbonate

\[ \text{CaCO}_3(s) \rightleftharpoons \text{Ca}^{2+}(aq) + \text{CO}_3^{2-}(aq) \]

\[ K_{sp} = [\text{Ca}^{2+}] [\text{CO}_3^{2-}] \]

where the square brackets denote concentration in moles per liter and the concentrations are equilibrium concentrations. Since CaCO₃ is a solid, it does not affect the Ksp. A similar expression can be written for situations where the concentrations are not necessarily equilibrium concentrations: \( IP = [\text{Ca}^{2+}] [\text{CO}_3^{2-}] \). The quantity IP is known as the ion product.

If the ion product of calcium ion and carbonate ion (and likewise with magnesium ion and carbonate ion) exceeds or equals the solubility product constant, a precipitate will form. If the IP is smaller than the Ksp, no precipitate will form. For both the IP and Ksp units are customarily omitted. (IP > Ksp, ppt; IP < Ksp, no ppt.)

II. Experimental

Part A. Estimating an Approximate Value of the Ksp of CaCO₃

Mix equal volumes of different concentrations of calcium chloride solution with sodium carbonate solution. From observing whether a precipitate was formed or not predict the Ksp of CaCO₃.

1. Mix equal volumes (approximately 4 mL) of 0.04M calcium chloride solution and 0.01M sodium carbonate solution. Record your results in the table given below. The IP constant was calculated as follows: Equal volumes of 0.04M CaCl₂ and 0.01M Na₂CO₃ result in 0.02M [Ca²⁺] and 0.005M[CO₃²⁻]. Therefore the IP is \( 1 \times 10^{-4} \).

Question 1. From your observation of the results, what can you decide about the relative magnitudes of the ion product constant of calcium carbonate?

2. Mix equal volumes using 0.0002M calcium chloride solution and 0.0001M sodium carbonate solution.

VII - 5
Question 2. Based on these results, what conclusions can be drawn about the value of the solubility product constant of calcium carbonate?

Question 3. Predict what would happen if equal volumes of 0.4M calcium chloride solution were mixed with 0.1M sodium carbonate solution.

3. Now test your prediction experimentally.

<table>
<thead>
<tr>
<th>K_{sp} of CaCO_{3} (Table 1)</th>
<th>pH of each soln</th>
</tr>
</thead>
<tbody>
<tr>
<td>CaCl_{2}</td>
<td>Na_{2}CO_{3}</td>
</tr>
<tr>
<td>0.04M</td>
<td>0.01M</td>
</tr>
<tr>
<td>0.0002M</td>
<td>0.001M</td>
</tr>
<tr>
<td>0.4M</td>
<td>0.1M</td>
</tr>
</tbody>
</table>

Part B. Estimating an approximate value of the K_{sp} of MgCO_{3}
1. Mix equal volumes (approximately 4 mL) of 0.02M magnesium chloride solution and 0.01M sodium carbonate solution and heat. Record your results in the table 2 given below.

Question 4. From your observation of the results, what can you decide about the relative magnitudes of the ion product constant of magnesium carbonate?

2. Mix equal volumes using 0.02M magnesium chloride solution and 0.001M sodium carbonate solution and heat.

Question 5. Based on these results, what conclusions can be drawn about the value of the solubility product constant of calcium carbonate?

Question 6. Predict what would happen if equal volumes of 0.2M magnesium chloride solution were mixed with 0.1M sodium carbonate solution and heated.
3. Now test your prediction experimentally.

Question 7. Why did the solution have to be heated to precipitate MgCO_{3}, while no heat was required to precipitate CaCO_{3}? What difference does the pH make? What happens to the pH when the solution is heated? Use the following equation to help you answer this question.

$$\text{Mg}^{2+} + 2\text{HCO}_3^- \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{MgCO}_3(\text{ppt})$$
K\textsubscript{sp} of MgCO\textsubscript{3} (Table 2)  | pH of each soln before and after heat

<table>
<thead>
<tr>
<th>MgCl\textsubscript{2}</th>
<th>Na\textsubscript{2}CO\textsubscript{3}</th>
<th>I.P.</th>
<th>Exp ppt</th>
<th>act ppt</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02M</td>
<td>0.01M</td>
<td>5x10\textsuperscript{-3}</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.02M</td>
<td>0.001M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2M</td>
<td>0.1M</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Part C. Acid Weathering of Rocks**

The oxides of sulfur and nitrogen present in the atmosphere as a result of industrial pollution react with the moisture also present in the atmosphere to form sulfuric and nitric acids respectively. The presence of these acids is what causes "acid rain" - a major environmental issue today. Besides causing considerable damage to animal and plant life, the acids in the atmosphere also attack rocks like limestone and marble and lead to chemical wearing away of the same. The effect on carbonate rocks of sulfuric and nitric acids in acid rain can be modeled by observing the effect of several concentrations of these acids on a calcium carbonate precipitate.

1. Prepare six test tubes containing freshly precipitated calcium carbonate by mixing equal volumes (approximately 2mL) of 0.01M sodium carbonate solution with 0.04M calcium chloride solution. Determine the pH of your starting mixture.

From the 0.01M sulfuric acid solution available in the lab, prepare 10 mL each of the following solutions: .001M, .0001M, 1x10\textsuperscript{-4}M, 1x10\textsuperscript{-5}M, 1x10\textsuperscript{-6}M. The .001 M H\text sub{2}SO\text sub{4} is made by carefully diluting 1.0 ML of the .01M H\text sub{2}SO\text sub{4} with 9mL of water and mixing thoroughly. In a similar way, the .0001M H\text sub{2}SO\text sub{4} can be made from the .001M H\text sub{2}SO\text sub{4}. This is known as a serial dilution. Each solution should be thoroughly mixed before a portion of it is diluted further. **Save these serial dilutions for Part D.** Determine the pH of the six sulfuric acid solutions. To each of the six test tubes containing freshly prepared calcium carbonate precipitates, add 2 mL of the six different sulfuric acid solutions. Stir the mixture with a glass rod and record your observations. Did the precipitate dissolve? Was there any evolution of a gas? Measure the pH of the contents of each test tube after the addition of acid. Fill in the table provided.
Results of $H_2SO_4$ attack on $CaCO_3$ (Table 3)

<table>
<thead>
<tr>
<th>Tube #</th>
<th>$H_2SO_4$ M</th>
<th>Vol of acid</th>
<th>$pH H_2SO_4$</th>
<th>dissolves $CaCO_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$1x10^{-2}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>$1x10^{-3}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$1x10^{-4}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$1x10^{-5}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$1x10^{-6}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>$1x10^{-7}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Repeat the above procedures using nitric acid instead of sulfuric acid.

Results of $HNO_3$ attack on $CaCO_3$ (Table 4)

<table>
<thead>
<tr>
<th>Tube #</th>
<th>$HNO_3$ M</th>
<th>Vol of acid</th>
<th>$pH HNO_3$</th>
<th>dissolves $CaCO_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$1x10^{-2}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>$1x10^{-3}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$1x10^{-4}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$1x10^{-5}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$1x10^{-6}$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>$1x10^{-7}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Question 7. Below what pH level do strong acid solutions cause major weathering of $CaCO_3$?

Question 8. Write the net ionic equation for each acid when they attack $CaCO_3$.

Question 9. What salts are used in water softeners, or in industry to keep pipes clean or water soft?
Part D. Estimate an Approximate $K_a$ for Acetic Acid

To each of the serial dilutions from Part C add 2 drops of thymol blue indicator solution and mix well. Since the $[H^+]$ and pH of these solutions are known, the colors of these solutions will be used as standards for comparison. $\text{pH} = -\log [H^+]$

To another test tube of the same size, add 5.0 mL of 1.0M acetic acid and 2 drops of the indicator solution. By comparison of the color of this solution with the colors of the $H_2SO_4$ solutions, estimate the pH of the solution and calculate the $[H^+]$. (The comparison is best made by looking down from the top of the test tubes against a white background.)

The extent of ionization of a weak acid, HA

$$\text{HA} \rightleftharpoons H^+ + A^- \quad \text{(e.g. acetic acid)}$$

is determined by an equilibrium expression:

$$K_a = \frac{[H^+][A^-]}{[HA]}$$

Question 10. Calculate the $K_a$ for acetic acid.

Acknowledgment: Development of this laboratory was made possible by CURI, 1001 Connecticut Ave., N.W., Suite 901, Washington, D.C. 20036.
### CURI LAB PREP XIV

1 L each soln, divided into two bottles

**pH meters**

<table>
<thead>
<tr>
<th>Part A.</th>
<th>CaCl₂</th>
<th>.4M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>.04M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.0002M</td>
</tr>
<tr>
<td>Na₂CO₃</td>
<td></td>
<td>(.1M available from reg lab 12)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.01M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.001M</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.0001M</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part B.</th>
<th>MgCl₂</th>
<th>.2M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>.02M</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part C.</th>
<th>H₂SO₄</th>
<th>.1M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>.01M</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Part D.</th>
<th>HNO₃</th>
<th>.1M</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>.01M</td>
</tr>
</tbody>
</table>

**Part D. (Acetic acid 1.0M from reg lab 12)**

---

**XIV - 7**
Appendix C

Workshop for Facilitation of Inquiry-Based Laboratories

00. What is inquiry-based learning?

0. What do you want to get out of this workshop?

I. Rational and Vision for change
   A. Student demographics
      women 60%, minorities 10%, low SES increasing %
   B. Types of Students
      less well prepared, less writing, more people oriented, informal environment

II. Goals of Chemistry Laboratory
   A. Group work to define goals
      actual experiments-- hypo., exp. design, data, interpretation
      learn standard lab techniques
      in-depth coverage of some topic(s)
      redesign lab with respect to pedagogy, curriculum, and environment
   B. What you want your students to be--outcomes
      have learning that is relevant to them
      increase abstract thinking ability
      cooperative learners, team oriented
      self-directed

III. Skills needed
   A. First day
      1. Establishing a warm supportive environment
      2. Establishing cohesion
      3. Establishing rules
      4. Setting expectations
         a. Example lab write-ups
         b. Rubrics
   B. Needs of the students
      1. Learning styles
      2. Learning cycles
      3. Environment
      4. Relevancy
      5. Technology
6. Self-interest and self-directing — control
7. Cognition time — time to manipulate data and seek trends

C. Instructional methods
1. Cohesive classroom
2. Cooperative learning
   a. Grouping
   b. Monitoring
   c. Reporting
3. Guided and open inquiry learning vs. Verification
4. Individualization of learning
5. Teaching in learning cycles — to utilize many different learning styles
   4MAT: concrete experiences, reflective observation, abstract concepts, experimentation
6. Scientific method — process learning
7. Assessment methods
   Holistic
   Rubrics
   Performance assessment, self and group

III. Resources
A. Technology
B. Materials
C. Time
D. Curriculum
  1. Review types of curricula
     a. Lab-oriented class — Ditzler & Ricci, *Discovery Chemistry*
     b. Inquiry-based — Abraham & Pavelich, *Inquiries into Chemistry*
     c. Emphasize relevancy— Ellis, *Materials Science*, and CURI
  Or
  2. Review of particular labs
     a. performance of labs
     b. critique of pedagogy, and curriculum

IV. Summation
A. Review of material presented
B. Conclusions of participants
C. Suggestions
Managing Complex Change
Curricular Change and Rationale

Vision (rationale for change)
Increase interest and enthusiasm for chemistry
Change in student demographics
Employ improved educational methods

+ Goals
Better meet the needs of all students

+ Skills
Pedagogy
  Supportive environment
  Cohesive classroom
  Cooperative learning
  Inquiry-based learning
  Teach to meet learning styles
Scientific method
Assessment methods

+ Incentives

+ Resources
  Curriculum
  Technology
  Pedagogy
  Time
  Materials

+ Action Plan

Change

Knoster, (1991)
### Historical Perspective of Why Students Don’t Learn

<table>
<thead>
<tr>
<th>Time</th>
<th>Reasons Given</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early first half of century</td>
<td>Didn’t pay attention or didn’t try</td>
</tr>
<tr>
<td></td>
<td>Crowded homes</td>
</tr>
<tr>
<td></td>
<td>Hunger, Illness, Family chores</td>
</tr>
<tr>
<td></td>
<td>National origin, Religious background</td>
</tr>
<tr>
<td></td>
<td>*Poor background was considered a motivator for achievement</td>
</tr>
<tr>
<td>Later</td>
<td>IQ, Socioeconomic status</td>
</tr>
<tr>
<td></td>
<td>Insufficient environmental stimulation</td>
</tr>
<tr>
<td>1950s - 1960s</td>
<td>Rapid growth</td>
</tr>
<tr>
<td></td>
<td>Family mobility</td>
</tr>
<tr>
<td></td>
<td>Belligerent student attitudes</td>
</tr>
<tr>
<td>1970s - 1980s</td>
<td>Divorce rate, One-parent families</td>
</tr>
<tr>
<td></td>
<td>Teen pregnancies</td>
</tr>
<tr>
<td></td>
<td>Bilingualism</td>
</tr>
<tr>
<td></td>
<td>Drug culture</td>
</tr>
<tr>
<td>Late 1980s</td>
<td>Complete reversal -- low achievement is due to schools, teachers and instructional programs</td>
</tr>
</tbody>
</table>

*Dunn, Beaudry, & Klavas, (1988)*
Student Demographics
At GVSU

Women 60%

Men 40%

Minorities 11%
(minorities in chemistry 1-3%)

Students with financial aide 68%
(excludes non-degree, foreign, and those with less than 6 credits)

In-state students 97%

Out-of-state students 3%

Part-time students 35%

Graduate students 19%

GVSU Admissions Office Fall 1995
Factors for decreased number of women, minorities and all students in sciences

Ability
- Schaff, Languis, & Russell (1989) studied brainwave topography and found a difference in the brainwave patterns of males and females, especially prominent in spatial concepts.
- Equal preparation yields equal achievement
- Lack of motivation and relevancy often reason for women and minorities lower achievement
- Lack of understanding of learning style (cognitive style) and lack of learning strategies (how to learn)

Affective Domain
- For women, there is no divorcing of emotions from knowledge
- Women integrate everything, including relationships, men compartmentalize (separate work from home, emotions from learning, etc.)
- Women need to see the goal of "helping others" to take science

Anxiety (Math and science phobia) is related to:
- Self-efficacy
- Past successes
- Imagination
- Academic and general self-concept
- Lack of knowledge on which to build new knowledge
Understanding the Needs of the Students

Students’ needs are to:

1. Understand and value the learning goals
2. Understand the learning process
3. Be actively involved in the learning process
4. Relate subject matter to their own lives
5. Control the learning environment by setting goals or following their own interests
6. Experience success
7. Receive realistic and immediate feedback that enhances self-efficacy
8. Receive rewards for performance gains
9. See learning modeled by adults as an exciting and rewarding activity
10. Experience an appropriate amount of structure
11. Have time to integrate learning
12. Have positive contact with peers
13. Receive instruction matched to their cognitive and skill level and learning style.

Overview of the Recommended Goals for Science Education in the United States Today

1. Increase the scientific literacy and critical thinking ability for all students.

2. Increase the number and diversity of students graduating from sciences through increased recruitment and graduation goals.

3. Improve retention with increased support services.

4. Generate an academic atmosphere in which women and minorities are expected to succeed and which sufficient numbers of successful women and minorities are visible at all levels.

5. Redesign courses to provide an interesting and challenging curriculum taught with greater skill and with more awareness for the environmental factors that affect women and minorities' learning.

6. Increase in-depth coverage of topics and concepts.

7. Increase linkage of scientific knowledge with societal issues.
Goals of Chemistry Laboratories

Goals of chemistry labs since the early 1900s have been, in order of priorities:

1. To verify principals.
2. To reinforce facts to learn and remember.
3. To learn standard methods of analysis.
4. To learn to use simple apparatus and instruments.
5. To learn how to keep records.
6. To develop habits of honesty, accuracy, self-reliance, cleanliness and orderliness.
7. To satisfy curiosity and develop interest in chemistry.

New goals necessary to accommodate appropriate curricular changes for chemistry laboratory education in the 1990s, in order of priorities, are:

1. To excite interest in chemistry and methods of scientific investigation.
2. To appreciate measurement methods.
3. To become familiar with instrumentation and apparatus techniques.
4. To become aware of practical methods for real systems, as opposed to theoretical ideals.
5. To develop skill in the design of experiments.
6. To interpret instructions, analyze data, and write reports.
7. To obtain and interpret data to answer questions.
8. To learn safety in handling and disposing of chemicals.

Lloyd, (1992b)
Pavelich and Abraham (1977) Simplified Goals

1. Acquaint the student with the fundamental laboratory techniques and procedures.

2. Enhance the student’s thinking ability, i.e., toward more abstract thinking processes. (In Piagetian terms, help move the concrete operational student into the stage of formal operations and the formal operations student to deepen his abstract thinking ability.)

3. Give the student experience with some aspects of scientific inquiry, especially data interpretation, hypothesis formation and experimental testing of hypotheses.

McNeal’s goals (1989) as stated in Real Science in the Introductory Course

Students should be able to:

1. Analyze problems.

2. Ask testable questions.

3. Distinguish among data, assumptions and hypotheses.

4. Develop expository writing, data analysis, oral presentation and discussion.

5. Search and retrieve bibliographic information.
Science Education Outcomes for Students

For Scientific Investigations

Students will be able to do the following:

1. Demonstrate the use of science process skills
   - classify
   - develop a research question
   - making predictions
   - collect, analyze, and interpret data

2. Demonstrate the use of laboratory skills

3. Generate a hypothesis and design an experiment to test that hypothesis

4. Determine if measurements are reliable and valid

5. Make judgments about the adequacy of evidence supporting a hypothesis

6. Develop alternative interpretations and look at data in more than one way

For Practical Reasoning

Students will be able to do the following:

1. Work successfully through a complex problem with a group of other students.

McColskey, & O'Sullivan, 1993
Important First Day

1. In the right place?
   Have students put information from the board on the front cover of their lab manual.

   On board: Class, section
   Instructor name
   Phone Number(s) (include home, and chemistry office if wanted)
   Office and office hours, times available by appointment

2. Fill out forms
   (have manuals, and all necessary forms at each lab station)
   Have students fill out the prerequisite sheet (review them after class to insure all have the proper prerequisites)
   Have students fill out a 3x5 card with:
   - Name
   - Address
   - Phone number
   - Major
   - Preferred learning style
     (if they don’t know it, strongly suggest they utilize the MS3 services)
   - Any health concerns that would influence laboratory work
     (diabetic, epileptic, pregnant, etc.)
   - Back side: put down something unique about themselves
     (sky-diver, in the military, musician, from far away, hobby, sport, etc.)

3. Get Acquainted Methods (establishing cohesion and supportive environment)
   Determining the needs of the students
   learning styles
   relevency - interests - career goals
   1. Partner introductions
   Have partners and/or groups introduce themselves to each other with the idea that they will introduce their partner to the class.
   Instructor introduces self first and then walks around the class as each person introduces their partner. If the student is shy, you can repeat the name loudly enough for everyone to hear. Be sure to get the correct pronunciation of the name. Do whatever it takes to learn the names (repeat it to yourself 6 times, rhyme the name with something you will remember the person with, etc.) After several students have introduced themselves, have the last one repeat the names of those previous. Don’t make it a memory test, if they forget either help them out or have the person repeat their name.
   Have each person share the same information. like; name, hometown, major or career goals, favorite sport, etc., plus something unique about them
that will help everyone remember them. It often works to allow the students to decide what they want to know about each other, sometimes they chose to know where they will be going after class (helpful for those walking to cars and dorms in the dark especially) or if they would be interested in forming a study group.

2. Ball of string: getting connected

You take a general census of students by a show of hands. Start out with very general questions like: how many in the class are freshmen, sophomores, juniors and seniors; how many commute; how many are in sports or in a campus group; how many are in health sciences, etc. Then introduce yourself and explain how the introduction process of 'connectedness' works.

One person holds the ball of string. As that person introduces themselves, giving the same two or three items of information, or whatever the students want to know, and lastly something they think they have in common with others in the class. If someone else has the same thing in common with the person introducing themselves then they raise their hand and the person with the ball of string throws it to one of them, holding onto the end of the string. The next person introduces themselves and so on until everyone is connected. The ball of string is wound up in reverse and each person tells one thing unique about themselves as they are winding up their section.

(Names of other acquaintance activities are The Name Chain, What's in a Name, Know Your Classmates, Guess Who?, and Dyads. These and many more ideas like these are available from many different sources; one source is Jones, V., & Jones, L. (1990).)

Review laboratory and safety rules

Explain how lab time is typically spent. Explain how reports are to be written and either give or post an example lab or important parts. Explain where and when to hand in reports and attendance requirements.

Explain how labs will be graded, post a typical laboratory correction rubric or post the rubric for each lab.
Instructional Methods

Cohesive Classroom

Have students assist you in determining the type of classroom they want.

Utilize their ideas for:
  grading rubrics,
  cooperative and partner groupings. Allow them to switch partners the first few weeks to find out with whom they work best.
Or assign groups the first day and encourage team work and study group formations.

Solicit student opinions daily about how their lecture and discussion sections are going.

Determine if they need extra help,
  know and suggest appropriate support services, and study methods.
Be willing to answer questions.

Bring in new discoveries and talk about them with the students.

Relate the topic to relevant chemistry whenever possible (e.g. everyday life, cooking, manufacturing, weather, environment, etc.)
Cooperative Learning
Grouping methods

Student Team Learning (Slavin)
Competitive teams attempt to improve over their previous scores

Think-Pair-Share (Kagan)
Partners talk together and come to a consensus, then meet with the other pair in the group and then the group comes to a consensus.

Jigsaw (Aronson)
One person from each “home” group meets to become an “expert” about a separate topic. The “experts” return “home” and teach the information from each different topic to the students at “home”, and complete an assignment utilizing information from each topic.

Learning Together (Johnson & Johnson)

Group Investigation (Sharan & Sharan)
Groups of four chose a sub-topic to investigate

Talk Aloud Pair Solving (Pinkerton)
One student is the “problem solver”, talking their way through as they do the problem. The partner asks questions to keep the “solver” verbalizing.

Roundtable (Davidson)
For an assignment having multiple answers, or as a basis for brainstorming.
Use one sheet of paper. In turn, each person in the group writes down their idea, verbalizes it, and passes the paper to the next person. You may skip your turn on one round. Continue to pass the paper until time is up.

Numbered Heads Together (Davidson)
The instructor assigns a number to each person, 1-4, in the group. Work on solving the assigned problem together in your group. Make sure everyone understands the problem, process, and solution. You will be called on, by number, to represent your group.
Aids to Cooperative Learning

The environment needs to be safe: students must be able to make mistakes and take risks.

The instructor needs to model the techniques, social skills, and learning strategies and encourage the students to practice often.

Academic levels need to be mixed in the groups.
Combinations of high and medium, and medium and low level students work best. If a group contains high, medium and low levels, the high will tend to teach the low and the medium will tend to watch.

Roles in the class need to change: the authority needs to shift to the students; they ask the questions, plan the work, organize the information, and share their findings.

Wiske & Levinson, 1993

Plan instructional materials to promote interdependence. Give only one copy of the materials to the group.

Assign roles to assure interdependence. Give job titles such as researcher/reader, summerizer/recorder, materials supplier/labeler, lab assistant/performer of the activities.

Structure individual accountability, as well as a group assessment, in which individual’s rewards are based both on their own scores and on the average for the group as a whole.

Mary & Rillero, 1994
Cooperative Learning Ground Rules

1. Work together in groups of 4.

2. Cooperate with everyone in your group.
   a. Praise liberally, no put-downs, encourage each other
   b. Use personal names

3. Achieve a group solution for any problem.

4. Make sure that everyone understands the solution before the group goes on.

5. Listen carefully to others.
   a. Try, whenever possible, to build upon each other’s ideas.
   b. It’s important to get all ideas out in the open. (There is no such thing as a bad idea!)

6. Share the leadership and other jobs in the group.

7. Make sure that everyone participates and no one dominates.

8. Proceed at a pace that is comfortable for your group.

Davidson, 1990
Cooperative Learning Self Evaluation

I participated in each activity.  
Always  Occasionally  Never

I critically listened to others.  
Always  Occasionally  Never

I respected others' viewpoints.  
Always  Occasionally  Never

I came to class prepared.  
Always  Occasionally  Never

I helped others when needed.  
Always  Occasionally  Never

I remained open-minded.  
Always  Occasionally  Never

I took my turn and didn't dominate the discussion.  
Always  Occasionally  Never

Parma City, 1993
Cooperative Learning Group Evaluation

We understood the task objectives and procedures.  
Always  Occasionally  Never

We assigned tasks to group members.  
Always  Occasionally  Never

We practiced cooperative social skills.  
Always  Occasionally  Never

We reflected and discussed group behaviors.  
Always  Occasionally  Never

We checked to make sure everyone understood the material and the project.  
Always  Occasionally  Never

We had confidence in our ability to complete the task.  
Always  Occasionally  Never

Parma City, 1993
Inquiry Learning

Characteristics of Lab Types

<table>
<thead>
<tr>
<th></th>
<th>Verification</th>
<th>Guided-Inquiry</th>
<th>Open-Inquiry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Order</strong></td>
<td>C $\rightarrow$ D</td>
<td>D $\rightarrow$ C</td>
<td>D $\rightarrow$ C</td>
</tr>
<tr>
<td><strong>Choice of Problem</strong></td>
<td>T</td>
<td>T</td>
<td>S</td>
</tr>
<tr>
<td><strong>Experiment Design</strong></td>
<td>T</td>
<td>T</td>
<td>S</td>
</tr>
<tr>
<td><strong>Data Analysis</strong></td>
<td>T</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td><strong>Data Explanation</strong></td>
<td>T</td>
<td>S</td>
<td>S</td>
</tr>
</tbody>
</table>

* C: Concepts  D: Data  T: Teacher  S: Student

Pavelich & Abraham, 1979
Verification Laboratory:

The teacher (or lab manual) chooses the problem, the experimental design, the method of data analysis, and (through the introductory theoretical discussion) suggests an explanation for the data.

Guided-Inquiry Laboratory:

No theoretical introduction of methods of data analysis are given, only explicit experimental instructions. Students are told what problem to investigate and what experiment to do but they must generate their own analysis and explanation of the data.

Open-Inquiry Laboratory:

Students first collect data and then draw concepts from these data. They are allowed to choose the problem they want to investigate, design their own experiment, and formulate an analysis of and an explanation for their data; a mini-research experience. Suggested systems for investigation are given and utilize concepts practiced in the guided-inquiry segment of the laboratory.

Pavelich & Abraham, 1979
Learning Styles

Pg. 192*, Dunn and Dunn Learning Styles; types of learners, Innovative, Analytic, Common-Sense, and Dynamic.

MS3- learning styles survey from The Teaching Professor, 1993.

Hemisphericity

Pg. 220*, Learning Activities of the Right and Left Hemispheres of the Brain.


Learning Cycles

Pg. 223*, The 4-Mat System, McCarthy, 1980

(* as cited in Jones & Jones)
How Do I Learn Best?

This test is to find out something about your preferred learning method. Research on left brain/right brain differences and also on learning and personality differences suggests that each person has preferred ways to receive and communicate information.

Choose the answer that best explains your preference and put the key letter in the box. If a single answer does not match your perception, please enter two or more choices in the box. Leave blank any question that does not apply.

1. You are about to give directions to a person. She is staying in a hotel in town and wants it visit your house. She has a rental car. Would you:
   V) draw a map on paper? R) write down the directions (without a map)?
   A) tell her the directions? K) collect her from the hotel in your car?

2. You are staying in a hotel and have a rental car. You would like to visit a friend whose address/location you do not know. Would you like them to:
   V) draw you a map on paper? R) write down the directions (without a map)?
   A) tell you the directions by phone? K) collect you from the hotel with their car?

3. You have just received a copy of your itinerary for a world trip. This is of interest to a friend. Would you:
   A) call her immediately and tell her about it?
   R) send her a copy of the printed itinerary?
   V) show her on a map of the world?

4. You are going to cook a dessert as a special treat for your family. Do you:
   K) cook something familiar without need for instructions?
   V) thumb through the cookbook looking for ideas from the pictures?
   R) refer to a specific cookbook where there is a good recipe?
   A) ask for advise from others?

5. A group of tourists has been assigned to you to find out about national parks. Would you:
   K) drive them to a national park? R) give them a book on national parks?
   V) show them slides and photographs? A) give them a talk on national parks?

6. You are about to purchase a new stereo. Other than price, what would most influence your decision?
   A) A friend talking about it?
   R) Reading the details about it?
   K) Listening to it?
   V) Its distinctive, upscale appearance?

7. Recall a time in your life when you learned how to do something like playing a new board game. Try to avoid choosing a very physical skill, e.g., riding a bike. How did you learn best? By:
   V) visual clues-pictures, diagrams, charts?
   R) written instructions?
   A) listening to someone explaining it?
   K) doing it?

8. Which of these games do you prefer?
   V) Pictionary
   R) Scrabble
   K) Charades

9. You are about to learn to use a new program on a computer. Would you:
   K) ask a friend to show you?
   R) read the manual which comes with the program?
   A) telephone a friend and ask questions about it?
10. You are not sure whether a word should be spelled 'dependent' or 'dependant'. Do you:
   R) look it up in the dictionary?
   V) see the word in your mind and choose the best way it looks?
   A) sound it out in your mind?
   K) write both versions down?

11. Apart from price, what would most influence your decision to buy a particular textbook?
   K) Using a friend's copy    R) Skimming part of it
   A) A friend talking about it    V) it looks OK

12. A new movie has arrived in town. What would most influence your decision to go or not go?
   A) friends talking about it.    R) you read a review about it.
   V) you saw a preview of it.

13. Do you prefer a lecturer/teacher who likes to use:
   R) handouts and/or a textbook?    V) flow diagrams, charts, slides?
   K) field trips, labs practical sessions?    A) discussion, guest speakers?

Test Results:

<table>
<thead>
<tr>
<th></th>
<th>Visual</th>
<th>Auditory</th>
<th>Reading/Writing</th>
<th>Kinesthetic</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Items</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

How did you learn best?

Taken from: The Teaching Professor, April 1993
Diagnosing Learning Styles

**STIMULI**
- SOUND
- LIGHT
- TEMPERATURE
- DESIGN

**ENVIRONMENTAL**
- MOTIVATION
- PERSISTENCE
- RESPONSIBILITY
- STRUCTURE

**EMOTIONAL**
- COLLEAGUES
- SELF
- PAIR
- TEAM
- AUTHORITY
- VARIED

**SOCIOLOGICAL**
- PERCEPTUAL
- INTAKE
- TIME
- MOBILITY

**PHYSICAL**
- ANALYTIC
- GLOBAL
- CEREBRAL PREFERENCE
- REFLECTIVE
- IMPULSIVE

**PSYCHOLOGICAL**

Simultaneous and successive processing

Learning Activities Related to the Right and Left Hemispheres of the Brain

<table>
<thead>
<tr>
<th>LEFT</th>
<th>RIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>workbooks, worksheets</td>
<td>creative art activities</td>
</tr>
<tr>
<td>drill and repetition</td>
<td>boundary breakers</td>
</tr>
<tr>
<td>repetitive learning games</td>
<td>guided imagery</td>
</tr>
<tr>
<td>demonstrations</td>
<td>creative writing</td>
</tr>
<tr>
<td>copying</td>
<td>values clarification</td>
</tr>
<tr>
<td>following directions</td>
<td>use of metaphors</td>
</tr>
<tr>
<td>collecting facts</td>
<td>designing</td>
</tr>
<tr>
<td>computations</td>
<td>solving old problems new ways</td>
</tr>
<tr>
<td>record keeping</td>
<td>mythology</td>
</tr>
<tr>
<td>making displays</td>
<td>open-ended discussions</td>
</tr>
<tr>
<td>making scrapbooks</td>
<td>self-expressive activities</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>INTEGRATIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>problems of logic</td>
</tr>
<tr>
<td>acting</td>
</tr>
<tr>
<td>interpreting data</td>
</tr>
<tr>
<td>hypothesizing</td>
</tr>
<tr>
<td>simulation games</td>
</tr>
<tr>
<td>dramatic presentations</td>
</tr>
<tr>
<td>Innovative Learner</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td><strong>The Learner:</strong></td>
</tr>
<tr>
<td>Seeks meaning</td>
</tr>
<tr>
<td>Wants reasons for learning new material</td>
</tr>
<tr>
<td>Needs to be personally involved in the learning process</td>
</tr>
<tr>
<td>Desires to work with people</td>
</tr>
<tr>
<td>Is highly imaginative</td>
</tr>
<tr>
<td>Has good divergent thinking skills</td>
</tr>
<tr>
<td>Perceives information concretely, processes it reflectively</td>
</tr>
<tr>
<td>The Teacher:</td>
</tr>
<tr>
<td>Is a motivator</td>
</tr>
<tr>
<td>Uses the discussion approach</td>
</tr>
<tr>
<td>Incorporates a great deal of teacher-student interaction</td>
</tr>
<tr>
<td><strong>The Teacher:</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
Sample Activities for a Unit on Water Supply

**Dynamic Learners**
learn through self-discovery
work through trial & error approach
bring action to concepts—carry through favorite question: "What can this become?"

**Common Sense Learners**
want to know how things work
need hands on experience
enjoy problem solving practical application of ideas
favorite question: "How does this work?"

**Innovative Learners**
need to be personally involved
learn through listening and sharing ideas
idea people—innovative and imaginative
favorite question: "Why or why not?"

**Analytic Learners**
need to have the facts
want to know what the experts think
create concepts & models
favorite question: "What?"

---

Assessment Methods  

(Give examples of each)

**Rubrics**

1. Point system -- best for essays, conclusions, and summaries

2. Checklists -- use to check off steps or key words in answers, or for students to check their own work before turning it in.

3. Analytical Rating Scales -- Dimensions or criteria of a task are rated on a continuum. Example scales: acceptable, not acceptable; inadequate, partially satisfactory, exemplary; exceeds goals, meets goals, approaches goals, goal not yet met. (example pg. 43)

4. Focused Holistic Rating Scale
   The student must demonstrate the following to receive and “A”:

5. Holistic
   Model responses are selected that represent numbers on the scale to be used. Student responses are compared to the models.

McCloskey & O'Sullivan, 1993
## Sample Holistic Rubric

| Task Criteria | Ratings | | | | |
|---------------|---------|---------|---------|---------|
|               | Exceeds | Meets   | Approaches | Goal Not Yet Met |
| 1. Correctly state the problem and identify the information needed to solve it and the steps needed to arrive at a solution. | | | | |
| 2. Produce reasonable data values needed for the solution. | | | | |
| 3. Apply concepts, equations, and formulas related to the problem | | | | |
| 4. Make accurate conversions as needed to solve the problem | | | | |
| 5. Make clear tables, graphs | | | | |
| 6. Communicate conclusions clearly, using examples as needed | | | | |
August 17, 1995

Dr. Sandra Bacon
Grand Valley State University
Loutit Hall, Chemistry Department
Allendale, MI 49401--9403

Dear Dr. Bacon:

Please be advised that CURI, owner of the copyright for the Women in Chemistry Laboratory modules waives the copyright for use of the modules at Grand Valley State University for the Masters Journal and for one year of classroom use. When we have permission from our agent, we will renew this waiver.

Sincerely yours,

Julia M. Jacobsen
Chairman, Board of Directors
Dr. Michael J. Pavelich  
Department of Chemistry and Geochemistry  
Colorado School of Mines  
Golden, CO 80401

Dear Dr. Pavelich:

I am writing my masters of education thesis on the implementation of inquiry-based chemistry laboratories and would like permission to utilize figures and quotes from page 100 of your article, An Inquiry Format Laboratory Program for General Chemistry, printed in the Journal of Chemical Education, February, 1979, for use in the pedagogical workshop to accompany the curriculum implementation. We are purchasing your text Inquiries Into Chemistry and would be interested in any other helps you can give us.

If you could either send me a letter, or sign for your permission below I would appreciate it. My manuscript is due on April 16th, 1996, so I would appreciate your immediate attention.

Thank you,
Sincerely,

Elizabeth Maschewske

Elizabeth Maschewske has my permission to utilize the above mentioned quotes and figures.

Signature: __________________________

Date: 4/9/96

cc: Michael R. Abraham
Dear Dr. Abraham:

I am writing my masters of education thesis on the implementation of inquiry-based chemistry laboratories and would like permission to utilize figures and quotes from page 100 of your article, An Inquiry Format Laboratory Program for General Chemistry, printed in the Journal of Chemical Education, February 1979, for use in the pedagogical workshop to accompany the curriculum implementation. We are purchasing your text Inquiries Into Chemistry and would be interested in any other helps you can give us.

If you could either send me a letter, or sign for your permission below I would appreciate it. My manuscript is due on April 16th, 1996, so I would appreciate your immediate attention.

Thank you,
Sincerely,

Elizabeth Maschewske

Elizabeth Maschewske has my permission to utilize the above mentioned quotes and figures.

[Signature]

April 3, 1996
Dear Drs. McCloskey and O'Sullivan:

I am writing my masters of education thesis on the implementation of inquiry-based chemistry laboratories and would like permission to utilize figures and quotes from chapter 4, Rubrics and Grading, pages 41-44, contained in, How to Assess Student Performance in Science: Going Beyond Multiple-Choice Tests. A Resource Manual for Teachers. 1993, for use in the pedagogical workshop to accompany the curriculum implementation.

If you could either send me a letter, or sign for your permission below, I would appreciate it. My manuscript is due on April 16th, 1996, so I would appreciate your immediate attention.

Thank you,
Sincerely,

Elizabeth Maschewske

Elizabeth Maschewske has my permission to utilize the above mentioned quotes and figures.  

Signature  

Date
NAME: Elizabeth Ann Maschewske

MAJOR: (Choose only 1)

_____ Ed Tech  _____ Ed Leadership  x Sec/Adult
_____ Elem Ed  _____ G/T Ed  _____ Early Child
_____ Elem LD  _____ Sec LD  _____ SpEd PPI
_____ Read/Lang Arts

TITLE: Implementation of Inquiry-based Freshman Chemistry Laboratories

PAPER TYPE: (Choose only 1)  SEM/YR COMPLETED: Winter, 1996

_____ Project  x Thesis

SUPERVISOR'S SIGNATURE OF APPROVAL  4/6/96

Using the ERIC thesaurus, choose as many descriptors (5 - 7 minimum) to describe the contents of your paper.

1. Inquiry  6. Curriculum Development
2. Chemistry  7. Scientific Attitudes
5. Program Implementation  10. Learning Processes

ABSTRACT: Two to three sentences that describe the contents of your paper.

College freshmen chemistry laboratory courses need to be updated to better meet the needs of all students, and in particular, the needs of women and minorities. Changes in curricula and pedagogy are recommended to facilitate implementation of the latest research concerning science education, inquiry-based curricula, and meeting students' needs.

** Note: This page must be included as the last page in your master's paper.

9 - 12/19/95