GENERAL CHEMISTRY LABORATORY FOR ENGINEERS:

A RESEARCH-BASED APPROACH

by

Timothy Lowell Sorey

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This dissertation has been read by each member of the dissertation committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

Dr. John R. Amend

Approved for the Department of Chemistry and Biochemistry

Dr. David J. Singel

Approved for the College of Graduate Studies

Dr. Joseph J. Fedock

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ABSTRACT

Changes made in requirements to the Accreditation Board for Engineering and Technology in 2000 have made it possible for several engineering curricula to take one semester of a two part general chemistry series. At Montana State University – Bozeman engineering majors constitute just over 37% of the total 850 students per year in the first term general chemistry population. The single-semester engineering curricula enroll 88% of the engineering students. These students receive an incomplete survey of general chemistry, missing important topics such as equilibrium and kinetics, acids and bases, and electrochemistry that are taught in the second semester.

In 2001, discussion was initiated between the Department of Chemistry and Biochemistry and the Dean and Department Heads of the College of Engineering to identify learning objectives and chemistry content important to engineering students. Current learning and teaching theories were used to develop an original laboratory learning approach that supported these objectives. Next, innovative measurement technology was integrated for students' use in gathering experimental data. These materials were tested, evaluated, and refined during MSU freshman labs and in-service technology training for Montana science teachers.

The development of this general chemistry lab curriculum for these engineering majors supports both national science education goals and those of the Accreditation Board for Engineering and Technology. This curriculum employs the latest in microcomputer-based technology and guided-inquiry approaches to learning. This innovative approach fosters engineering track students' development of tools and skills necessary for critical thinking and problem solving.

Engineering students collaborated as research groups to (a) design and conduct experiments, (b) discuss and evaluate data, (c) prepare and write lab reports, and (d) present an oral report to their peers. This approach creates a research environment for students to connect chemistry in the context of real-world engineering applications.

Not only did the treatment group (N=70) outperform their fellow engineering students in lecture exams and quizzes, but over a four and a half fold increase of enrollment into the second semester of general chemistry was observed. This approach shows promise as a transferable template for other interdisciplinary laboratory curriculum in general chemistry and deserves implementation and further research.

CHAPTER 1

PREFACE TO THIS RESEARCH STUDY

The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them.
Sir William Bragg

This Research Study

Changes in requirements of the Accreditation Board for Engineering and Technology (ABET) in 1998 caused several engineering curricula to reduce their general chemistry requirements to one semester. This eliminated important content areas such as redox chemistry and acid-base chemistry. 37.9% of the student population in the first term of general chemistry sequence, CHEM 131, are engineering majors. Of these, only 38.8% go on to take the following term of general chemistry, CHEM 132.

This study reports a new laboratory course design for single semester engineering students. This approach integrated important second semester chemistry content into the first semester of general chemistry and developed research skill-sets and tools important to the process of science. The laboratory curriculum used interdisciplinary applications to develop chemistry concepts, stimulating students' interest in chemistry, building lesson continuity, and encouraging lifelong learning.

The Organization of this Research Study

This dissertation consists of four parts (Figure 1).

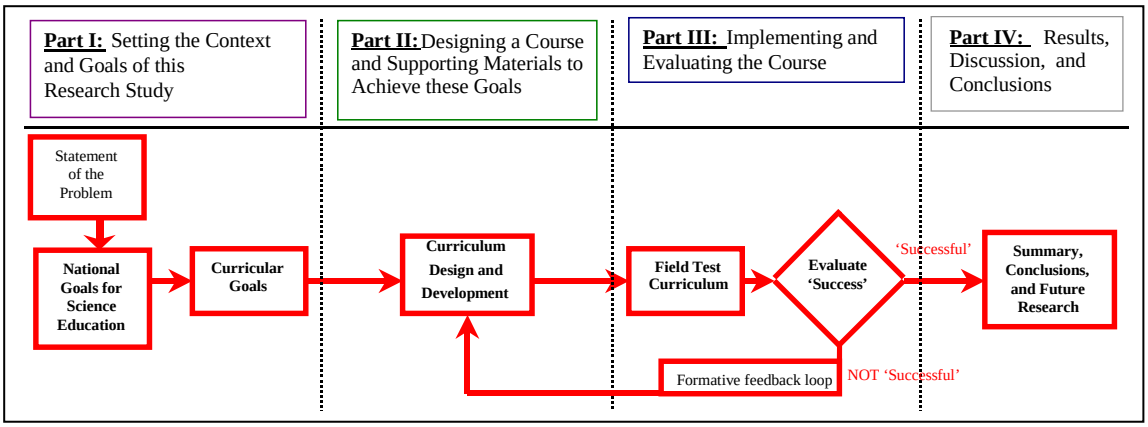

Figure 1: Dissertation Overview-This figure presents the four chronological parts of the completed dissertation.

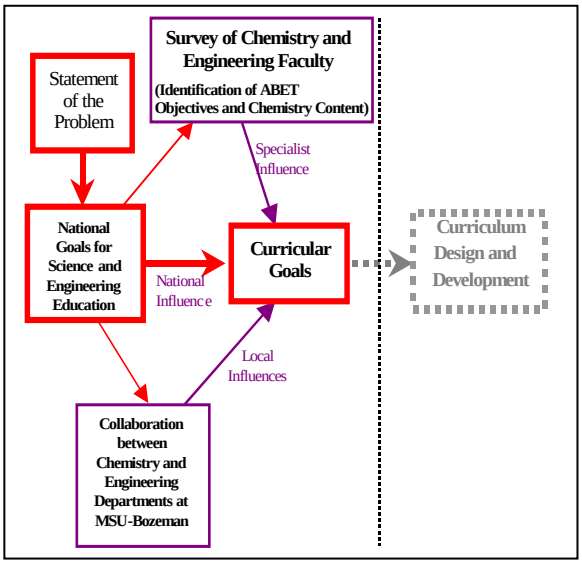

Figure 2: Part I - Chapters 1-5 set a context for this research study and the collaborative efforts with the College of Engineering and national faculty.

Goals for the laboratory program were developed from national recommendations presented in (1) ABET's guidelines for student learning objectives, (2) the National

Science Foundation's *"Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering and Technology"*, and (3) the Carnegie Foundation's Boyer Commission "*Reinventing Undergraduate Education: A Blueprint for America's Research Universities"*(Figure 2). These recommendations were integrated with results from a national and local survey of college chemistry and engineering faculty. This data was compiled with the help of Prentice Hall/Pearson Education Publishing and MSU's College of Engineering. Its goal was to identify curricular goals for engineering students in general chemistry at MSU-Bozeman.

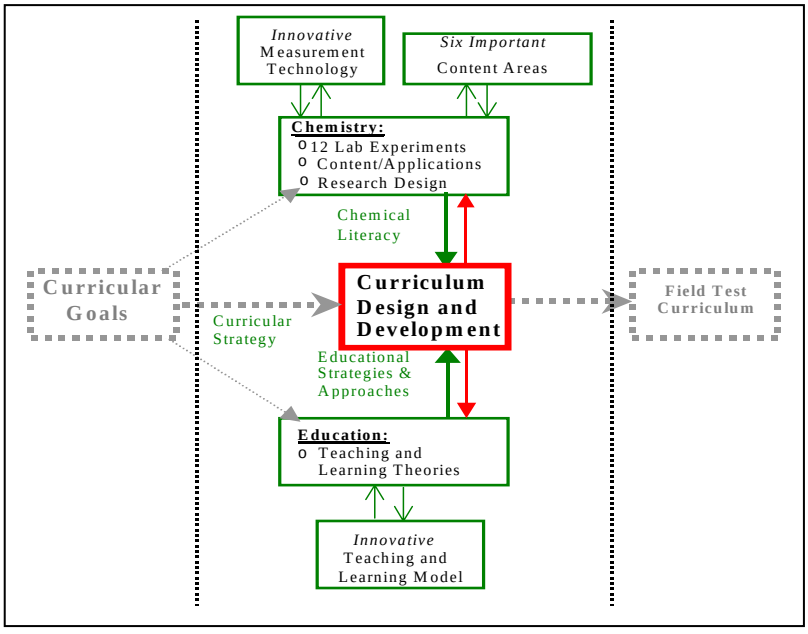

Figure 3: Part II - Chapter 6-9 describes the chemistry and educational strategies for this laboratory for engineers, along with the materials that help to achieve the curricular goals.

In Part II: *Designing a Course and Supporting Materials to achieve these Goals,* chemistry content and scientific research strategies are described that integrate with current teaching, learning, and assessment theories to develop a laboratory curriculum.

This course included use of newly developed measurement technology. Students used these tools to explore chemical principles that have, in the past, been too difficult to teach or have not been taught in a general chemistry laboratory (Figure 3).

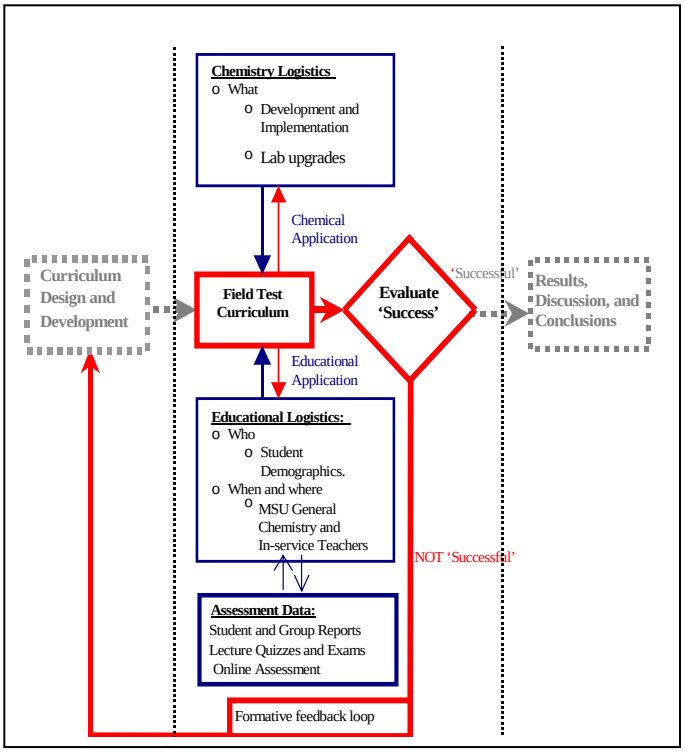

Figure 4: Part III - Chapter 10 describes the implementation and evaluation of the laboratory curriculum for engineers.

In, Part III: *Implementing and Evaluating the Course*, the field-testing, assessment, and formative evaluation components of this project are described. Chemistry and education content are described for a number of consecutive laboratory lessons within a single semester. These serve as a sample of the curriculum for the final semester that the course was offered. A feature of interest in this section is the evaluation of a problem-solving approach in the laboratory setting that models scientific laboratory research (Figure 4).

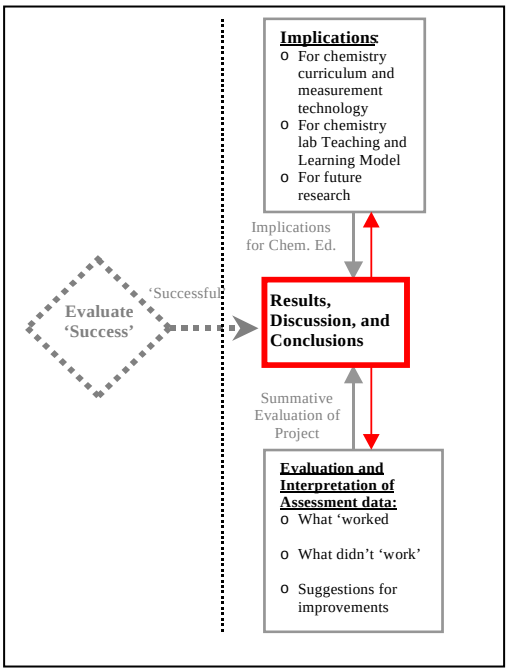

Figure 5: Part IV - Chapter 11 discusses the results, the implications, and impacts of this research study in chemistry and chemical education.

Finally, in Part IV, the assessment data are interpreted in the context of the course goals and student learning objectives. This study shows that engineering students who took this lab course outscored their counterparts on lecture exams and quizzes. In addition, these students earned half a letter grade higher overall and the enrollment of these students into the second quarter more than quadrupled (Figure 5). This research paper concludes with a discussion of an approach to problem-based laboratories in general chemistry and implications for future research.

Flow Chart of Organization for this Dissertation

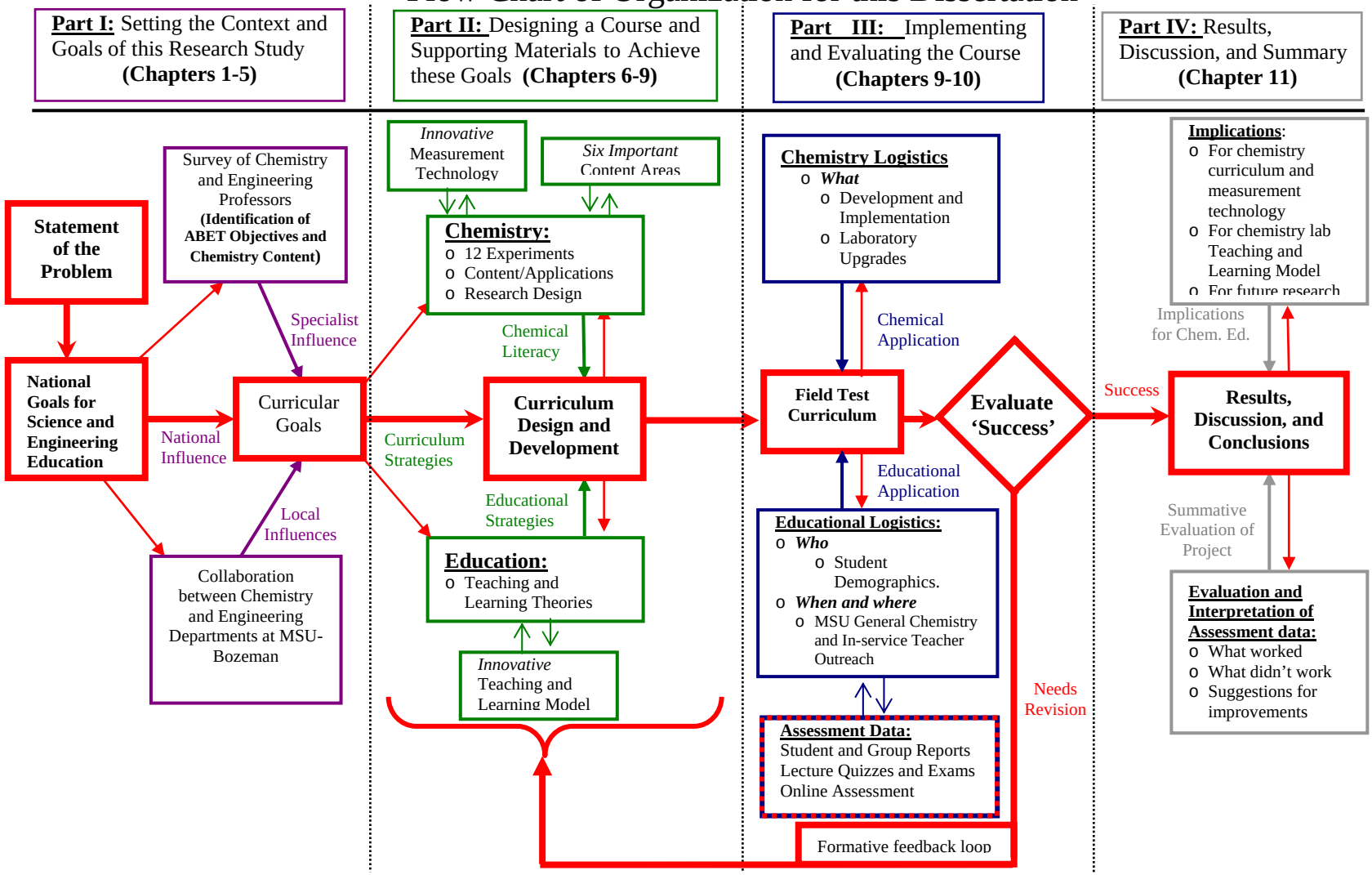

Figure 6: Comprehensive Flow-Chart of this research study.

CHAPTER 2

SETTING THE CONTEXT OF THIS DISSERTATION PROJECT

Isolation in all forms is the thing to be avoided;
connectedness is what we should strive for.
John Dewey

Identifying a Problem

A 2002 analysis of the student population of general chemistry classes showed that only 39.8% of the students in the first term of general chemistry, CHEM 131, at Montana State University-Bozeman were enrolling in the second semester of general chemistry. Many of the enrolled individuals were engineering students who, due to changes in ABET program requirements, were no longer required to take the two-semester sequence of general chemistry. These engineering students taking only one semester did gain understanding of chemistry content important to the field of engineering.

Further analysis of the engineering curriculum, outlined in ABET's National *Criteria for Engineering Programs*, showed different requirements for different engineering curricula. Some engineering curricula required two semesters, CHEM 131 and CHEM 132, while other curricula only required the first semester.

The National ABET Criteria for Accrediting Programs in Engineering (2000) for Civil Engineering graduates states that a "fundamental understanding of general

chemistry is required." The Department of Civil Engineering has made two semesters requisite. For Chemical Engineering curricula, the criteria specify that these individuals should have "a working knowledge of advanced chemistry such as organic, inorganic, physical, analytical, materials chemistry or biochemistry." Chemical Engineering students take two semesters of general chemistry.

ABET criteria for other engineering curricula are either less specific in the wording about chemistry or allow the program to choose between science disciplines altogether. For example, ABET states that students in Electrical and Computer Engineering curricula should have "…knowledge of mathematics through differential and integral calculus, basic sciences, computer science, and engineering sciences necessary to analyze and design complex electrical and electronic devices, software, and systems containing hardware and software components, as appropriate to program objectives." Basic science is not clearly defined by ABET. What is emphasized, however, is the importance of analysis and design that contribute to the process of electrical engineering.

Another example is the ABET criteria for Mechanical Engineering, which offer a choice between physics or chemistry. This program "must demonstrate that graduates have: knowledge of chemistry and calculus-based physics with depth in at least one; the ability to apply mathematics through multivariate calculus and differential equations; familiarity with statistics and linear algebra; the ability to work professionally in both

thermal and mechanical systems areas including the design and realization of such systems." Students are given the freedom to choose between physics or chemistry.

The Demographics of General Chemistry and Identifying a Target Population

The Demographics of General Chemistry, CHEM 131

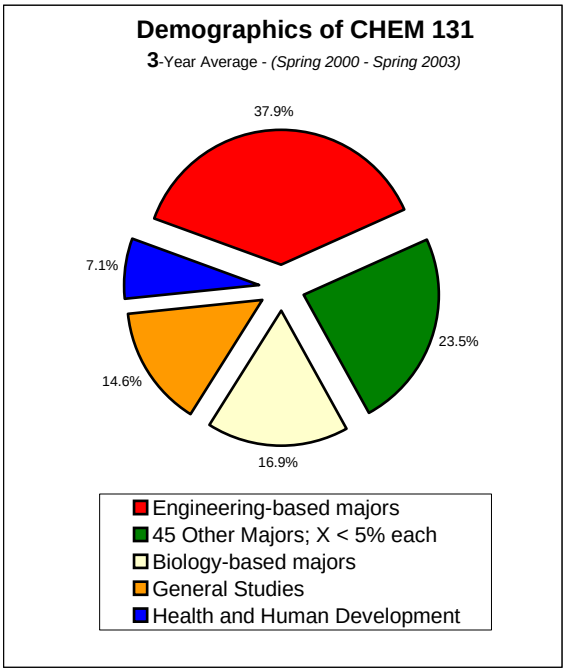

Figure 7: CHEM 131 Demographics– A Three-Year Average.

A recent three-year review of the demographics (2000-2003) of first semester general chemistry students at Montana State University - Bozeman reported more than 50 different majors. Of 2,576 students enrolled over this three-year period, 76.5% were registered as four general majors. The largest of these four groups (37.9%) were pursuing engineering-based majors (Chemical Engineering, Civil Engineering, Computer Engineering, Computer Sciences, Electrical Engineering, General Engineering, Industrial

& Management Engineering, and Mechanical Engineering). The second largest group (16.9%) was pursuing biology-based majors (Biological Sciences, Cell Biology and Neurosciences, Microbiology, and Biotechnology). The last two largest groups were undeclared majors or General Studies (14.6%) and those pursuing a Health and Human Development major (7.1%). The remainder of the population, 23.5%, was made up of over 45 majors, where no single major made up any more than 5% (Figure 7 and Appendix A: Three-year Demographics Study of CHEM 131).

The Target Population: Single Semester Engineering Students

Chemical Engineering and Industrial and Management Engineering required that their students take both semesters of general chemistry. Other engineering programs, such as General Engineering, Civil Engineering (at the time this study began), Computer Sciences, Electrical Engineering, and Mechanical Engineering, required that their students take only the first semester of the two-semester sequence.

91.3% of the Chemical Engineering students completed CHEM 131. Of these, 82.5% continued into the second semester of general chemistry. Like their Chemical Engineering counterparts, a relatively high percentage of Electrical Engineering students and Mechanical Engineering students who began the first term of general chemistry also completed it, 82.5% and 88.5%, respectively. Unlike their chemical engineering counterparts, however, second semester enrollment was 0.8% for Electrical Engineering students and 2.9% for Mechanical Engineering students.

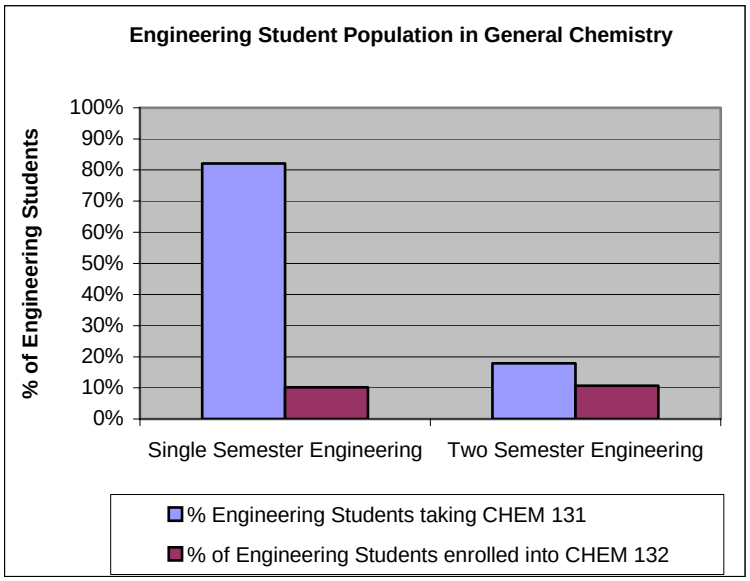

Figure 8: Retention of engineering students into CHEM 132: Single Semester Engineering Students versus Two Semester Engineering Students.

Single semester engineers made up 82.1% and *two semester engineers* made up 17.9% of the engineering population. 59.6% of all the two semester (N = 151) and 12.4% of all the single semester (N = 692) engineers who had completed CHEM 131 went on to take CHEM 132 (Figure 8). The two largest single semester engineering curricula over a three-year period, 2000-2003, were Mechanical Engineering (N= 277) and Electrical Engineering (N= 118). A decision was made to target these student populations for a research study.

CHAPTER 3

AN HISTORICAL PERSPECTIVE OF SCIENCE EDUCATION AND TODAY'S CHEMICAL EDUCATION RESEARCH

Science is a way of thinking much more than
it is a body of knowledge.
Carl Sagan

Curricular Emphases within Science Education: (1893-1957)

An Emphasis on Discipline

To better understand the current national vision of science education for undergraduate education, it is useful to examine the evolution of science education since the late 19th century. At the turn of the century, the industrial revolution determined how people lived and worked. For the U.S. to gain global and economic status in the world, developing a scientifically literate society was key.

A committee of ten college and school leaders was appointed at the annual meeting of the National Education Association (NEA) in Saratoga Springs, New York in July of 1892 (De Boer, 1991). In 1893, the NEA charged *The Committee of Ten* to hold a conference of school and college teachers of each principal subject. They asked that each conference consider:

> …the proper limits of its subject, the best methods of instruction, the most desirable allotment of time for the subject, and the best methods of testing the pupils' attainments therein…(p. 3)

Although this ruling was primarily given to move more students from high school to college, it can also be regarded as the first national movement toward a standards-based approach to assessing pre-college students. Within a short period of time, three separate conferences convened, including *The Conference on Physics, Chemistry, and Astronomy*, *The Conference on Natural History*, and *The Conference on Geography*.

While *The Conference of Physics, Chemistry, and Astronomy* members supported laboratory instruction, they felt that students should not be encouraged to "rediscover" the laws of science. They believed that "An intelligent teacher should direct the interpretation of laboratory results and show students how to properly work." The conference members objected to what they called "loose work" in the science laboratory. They asserted that much of the instruction in colleges and high schools should be more content-based and reflect key theoretical scientific processes.

Although general physics labs focused upon measurements, calculations, and verification of physical laws, the members of this conference recommended that a general chemistry laboratory should concentrate exclusively on the preparation of simple compounds and on an examination of their properties. Titles of experiments included "Preparation of oxygen," "Properties of oxygen (With iron)," "Preparation of hydrochloric acid," "Properties of hydrochloric acid," "Action of hydrogen sulfide upon salts," and so on. (National Education Association, 1893, pp. 124-137) The members of this conference shaped the teaching of laboratory chemistry well into the next century. In fact, laboratories that emphasized student inquiry would have to wait well over half a century before they would begin to emerge.

An Emphasis on Application

By the 1920's, a different teaching method evolved which surveyed chemistry in terms of practical applications problems and was designed to foster applied knowledge of chemistry. The basic argument for this approach was to understand the principles of chemistry and their relationship to the industrial and technological world. It was hoped that student enthusiasm for social relevance, also referred to as a "life adjustment education," would help students to focus on practical applications of chemistry within a *lecture* setting. The agenda of this "life adjustment approach" was described in 1920 by the National Education Association:

> In the past, chemical laws, theories and generalizations have usually been taught as such, and their applications in industry and daily life have been presented largely as illustrative material. In the reorganized course, this order should be reversed. Laws and theories should be approached through experimental data obtained in the (research) laboratory and through applications with which the pupil is already familiar and in which he has a real interest. (p. 36)

Designed to increase student interest via practical applications in the real world, an overemphasis on applications began to supplant the basic principles of the discipline. For example, copious amounts of data from research laboratories and industrial applications were placed in front of students during lecture. Although attempts were made to make these fundamental principles and theories of chemistry meaningful, the students did not physically see where these data originated.

Laboratory instructors didn't implement the life adjustment education approach, so laboratory activities continued much on the same path as before. Basic preparation of chemicals and examination of their properties was the status quo. There was, however,

recognition of the limitations of this type of laboratory experience. The NEA noted that, "too many experiments involve repetition of work described in the text or have no outcome beyond the mere doing and writing in the notebook" (1920, p. 39).

A Liberal Emphasis

Over two decades later, another teaching approach for K-12 science education emerged. The National Education Association issued a report in 1944, *Education for All American Youth*, proposing a "liberal approach" to science education. This approach introduced students to the role of science in human progress, to the scientific view of the world and of man, and to history of science. Within the report, an imaginative association with the great scientists and their major experiments was also encouraged (Hurd 1961, p. 83).

Commissioned by Harvard president James B. Conant, *The Harvard Committee on General Education*, came to similar conclusions about college level chemistry in their report, *General Education in a Free Society*. While criticizing science education practices in 1945, this committee, in the words of Conant, stated:

> From the viewpoint of general education, the principle criticism to be leveled at much of the present college instruction in science is that it consists of courses in special fields, directed toward training the future specialists and making few concessions to the general student…Comparatively, little serious attention is given to the examination of basic conceptions, the nature of scientific enterprise, the historical development of the subject, its great literature, or its interrelationships with other areas of interest and activity. (p. 220-221)

However, *The Harvard Committee* supported a liberal approach to science education:

> Science instruction in general education should be characterized mainly by broad integrative elements – the comparison of scientific with other modes of thought, the comparison and contrast of the individual sciences with one another, the relations of science

> with its own past and with general human history, and of science with problems of human society. These are areas in which science can make a lasting contribution to the general education of all students…(Conant 1945, p. 155-156)

For both secondary schools and colleges, science education was seen as a means to develop an appreciation for the way science was conducted, to view the importance of science within society, to understand the place of scientific thought within history, and to recognize the relationships between science and society. This liberal emphasis also presented science as a human activity or process, further de-emphasizing science as a structured body of knowledge (DeBoer, 1991). Critics of this liberal approach, however, like those who opposed life adjustment education, claimed that emphasis on the *who*, *where*, and *when* of science was replacing the basic discipline content of *what* was being taught.

The "Golden Age" of Science Education: (1958 – 1988)

Sputnik: an Event That Catalyzed Science Education

An economic superpower after World War II, the United States' desire to lead scientific research and technology was spurred by the cold war with the Soviet Union. However, with the launch of Sputnik in early 1957, approaches to science education fell under harsh scrutiny at a national level:

> The Soviet launch…promptly ended the debate that had raged for several years about the quality of American Education. Those who had argued since the late 1940s that American schools were not rigorous enough and that life adjustment education had cheapened intellectual values felt vindicated, and as one historian later wrote, "a shocked and humbled nation embarked on a bitter orgy of pedagogical soul-searching."
>
> (DeBoer, 1991, p 146)

Sputnik gave science education reformers a means to broadcast their arguments against a liberal emphasis, resulting in a nation-wide curriculum reform movement. As a result, the 1957 *National Defense Education Act* was passed that provided over ninety million dollars from 1958 to 1961 to reform science education and another $600 million from 1961 to 1975 (Mathews, 1994). Programs were begun that resulted in the Physical Science Study Committee (PSSC) for physics, CHEM Study and CBA for chemistry, and Biological Sciences Curriculum Study (BSCS) for Biology.

Back to Basics: Content-Based Reforms in Chemical Education

In June, 1957, the American Chemical Society (ACS) began to actively coordinate high school and introductory college chemistry coursework (DeBoer 1991, p152-153). The ACS appointed Arthur F. Scott of Reed College and Laurence E. Strong of Earlham College as directors of a program to upgrade undergraduate chemistry. Together, they oversaw nine high school chemistry teachers, nine college professors of chemistry, and the development of a new high school chemistry curriculum. This new course would be referred to as the Chemical Bond Approach (CBA).

This was the first attempt to teach chemistry that would, according to Strong (1962), "Produce a study of chemistry that will reveal the importance of theory and experiment." Strong continued:

> Chemistry, through most of its history, has been largely descriptive. In the last sixty years, however, there has been an extensive development of theory in chemistry. These two aspects of modern chemistry – the descriptive and the theoretical – provide a possibility for acquainting students with science as a process of inquiry that interrelates the mental and the experimental. (p. 44)

The CBA curriculum focused primarily on two goals. The first was "to present the basic principles of chemistry as an intellectual discipline and to achieve an appreciation of chemistry as a creative pursuit of human knowledge." The second was "to develop facility in analytical, critical thinking – especially thinking which involves logical and quantitative relationships." (Hurd, 1970, p 182)

In 1959, the ACS's *Ad Hoc Committee* and representatives of the National Science Foundation met with Glenn Seaborg, then the Chancellor of the University of California at Berkeley, to discuss an alternative approach to high school chemistry (DeBoer, 1991, p. 154-155). The intent, much like the CBA approach, was to interrelate diverse phenomena of chemistry while placing an emphasis on laboratory work so that students could understand chemical principles through personal experiences. Seaborg agreed to supervise the project, employing chemistry professor J. Arthur Campbell of Harvey Mudd College as director of the project. Campbell suggested the name *Chemical Education Material Study* or CHEM Study.

Outstanding high school teachers, university chemistry and mathematics professors, and industrial chemists began the preparation of materials for the new course in April of 1960. By the 1962-1963 school year, this aggressive plan had approximately 700 teachers in high schools and junior colleges implementing new courses to 45,000 students.

> The laboratory program was designed (1) to help students gain a better idea of the nature of scientific investigation by emphasizing the "discovery approach", and (2) to give students an opportunity to observe chemical systems and to gather data useful for the development of principles subsequently discussed in the text and class work.
>
> (Merril & Ridgway, 1969, p. 33-34).

This decision to use a discovery approach to acquire data for development of principles in a laboratory setting was a great departure from basic preparation of chemicals and examination of their properties. This was one of the first advances in laboratory learning that had been attempted since the end of the 19th century. In addition, this approach would begin the movement toward student-centered learning with use of technology for data acquisition and, ultimately, toward students thinking both scientifically and technologically within an instructional laboratory setting.

Thinking Outside the Box: Foundations of Science Education

Like the *Ad Hoc Committee*, *The Woods Hole Conference* (September, 1959) also recognized that national security hinged upon curricular reforms in science education. This committee would search for a solution to this problem from a completely different angle – a theoretical perspective of teaching and learning. The conference included 35 diverse representatives from various fields of science and mathematics. Researchers of psychology, education, and history were also included, unlike previous national projects such as CBA and CHEM Study which were staffed by chemists and chemistry teachers (DeBoer, 1991, p. 156).

Headed by Jerome S. Bruner, a psychologist from Harvard University, *The Woods Hole Conference* attempted to understand the psychology behind science education and how psychology explained student learning. Bruner would introduce the cognitive, human-centered ideas of Jean Piaget – ideas that proved to be the cornerstone of the conference. A great emphasis was given to a structure for learning that was referred to as constructivism:

> "Learning" is, most often, figuring out how to use what you already know in order to go beyond what you currently think. There are many ways of doing that. Some are more intuitive; others are formally derivative. But they all depend on knowing something "structural" about what you are contemplating – how it is put together. Knowing how something is put together is worth a thousand facts about it. It permits you to go beyond it.
> (Bruner, 1960, p. 4)

The outcome of this conference was a more complete understanding of the process of scientific inquiry and its potential impact upon the teaching of science. As chemistry educators better understood the process of learning, they could support students by offering them:

> "…more opportunities to think and learn how to think critically. As inquirers, students learn to be independent, to compare, to analyze, to synthesize knowledge, and to develop their mental and creative faculties."
> (Sund and Townbridge, 1967, p. 22)

With a better understanding of teaching and learning, chemical educators were released from structures that were imposed by classical education. James Rutherford forecast in the early 1960's:

> Science teachers must come to know just how inquiry is in fact conducted in the sciences. Until science teachers have acquired a rather thorough grounding in the history and philosophy of the sciences they teach, this kind of understanding will elude them, in which event not much progress toward the teaching of science as inquiry can be expected. (p.80-84)

Rutherford's words went largely unheard. Without appropriate training, high school teachers would lead these newly developed curricula from CBA and CHEM Study down an unsuccessful path. These approaches were deemed revolutionary due to the support from leading scientific researchers of the day and the hope was that they would pull science education into the second half of the 20th century. However, there was an inability to measure the effectiveness of these curricula in the classroom because

assessment methods had not yet been developed. The inability to assess was reflected in the Foreword section of the 1964 CHEM Study textbook, which stated:

> *"Is this course better than (or, as good as) the traditional one?"* An answer is not readily found in comparative tests…. The issue cannot be completely resolved "objectively" because value judgments are ultimately involved. Whether the CHEM Study goals are valid and the approach is reasonable must be decided with due consideration to the reported experience of teachers and to the credentials of those who developed the materials. (p. viii)

In the years that followed The Wood's Hole Conference, a few theories of learning emerged from the basis of constructivism. Some of these were R. Cagne's *Hierarchical Learning* (1977), R. Karplus' *The Learning Cycle* (1977), Novak's *Receptive Learning* (1979), and J. Clement's *Models-based Learning* (1983). These learning theories, some of which will be further explained in Chapter 7, continue to be the foundation for many successful teaching and learning practices today.

After the early sixties, the gap between chemists who developed curriculum in programs like CBA and CHEM Study and educational psychologists who developed educational theories of teaching and learning practices remained disparagingly wide. This lack of collaboration finally became an issue, as the science literacy crisis of the early 1980's came to light. Mathews (1994) summed up the crisis this way:

> Despite all the money and effort that had been expended since *Sputnik*, the bulk of American high school graduates and citizens had minimal scientific understanding. A few knew a great deal; the vast majority knew very little. (p. 29)

A Nation at Risk, a 1983 publication from The National Commission on Excellence in Education, went much further with its evaluation. "The educational foundations of our society are presently being eroded by a rising tide of mediocrity that

threatens our very future as a nation and as people." This forceful statement came in the wake of the *National Assessment of Education Program's* (NAEP) measurement of science literacy of nine-, thirteen-, and seventeen-year-olds. In 1969, Congress instituted NAEP, a mandatory nationwide assessment. Performed every four years, the assessment showed a continuous decline in the late 1970's in scientific literacy test scores and again in the early 1980's.

Once again, questions were raised about the effectiveness of science education. Was science education really no better or even worse than in the post-Sputnik 1960's? Did the NAEP assessment measure the scientific literacy appropriately and accurately? If so, what was causing this inadequacy of science education and how could it be remedied?

National Goals for Science Education

During the mid to latter 1980's, a debate over the definition of scientific literacy raged. The debate arose mainly out of competing perspectives on the level of scientific literacy an educated individual should attain. For example, this researcher opines that a high school graduate from public K-12 institutions should be able to ensure their personal safety around household chemicals and have an ability to make an educated vote on science-based legislation. By 1989, it was generally agreed that age appropriateness should be the gauge of scientific literacy with a defined minimum level for every high school graduate. The American Association for the Advancement of Science (AAAS), in their 1989 publication, *Project 2061*, stated a working definition for scientific literacy:

> The scientifically literate person is one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of

> science; is familiar with the natural world and recognizes both its diversity and unity; and uses scientific knowledge and scientific ways of thinking for individual and social purposes. (p. 8-12)

Whether affected by social, political, economical, or technological domains, it seemed that science instruction and curriculum design in the U.S. would be criticized and blamed for local and global failures. For as much money and effort that went into the curriculum reforms in the early sixties, the 1976-1977 National Survey found that only 15% of CHEM Study materials and less than 5% of CBA chemistry curriculum had been adopted and remained in use within American schools. (DeBoer, 1994, p. 166) NAEP assessments deemed high school graduates as scientifically illiterate and unskilled in inquiry-based problem solving. Therefore, efforts in CHEM Study and CBA fell short of their intended goals.

Science education is not a straightforward endeavor, it is wrought with historical, scientific, and psychological variables that, when combined, offer a complex perspective (Figure 9 – End of Chapter). The K-16 science education issue today is similar in nature to that which was presented to *The Committee of Ten*: How can we better teach the process of science? In fact, this quest for understanding the dynamic process of science education has been the Holy Grail for which science education continually searches.

Chemical Education Today

The Origin of Student Research Labs and Emergence of MBLs

Some of the earliest work in collegiate chemistry education was laboratory based and can be traced back to Justus von Liebig at Giessen, Germany in 1824. He stated,

> At that time, chemical laboratories in which instruction was given in analysis did not exist anywhere; what people called such, were rather kitchens, filled with all sorts of furnaces and utensils for carrying out metallurgical or pharmaceutical processes.
>
> Nobody understood how to teach analysis.
>
> Justus von Liebig

What Leibig discovered was a unique strategy that blended mentoring with collaborative teamwork, creating an environment where students and their scientific research flourished (Lagowski, 2002). Whether it was the science itself or Leibig's approach to research, he attracted many young talented students from all over Europe, Great Britain, and the United States. In fact, many of his students were successful in applying these strategies to their own scientific research, earning Nobel prizes in the fields of chemistry and biology (Sachtleben 1958).

Liebig has been credited by many as the pioneer of the modern research laboratory, laying much of the groundwork for the social and scientific interactions between students, their research advisors, and the scientific community (Oesper, 1927, Twigg and Twigg, 1973, and Lagowski, 2002). Although this model for research group work has been successful in upper division and graduate coursework and research, this approach has been abandoned in undergraduate labs for several reasons. One reason is that freshman and sophomore level chemistry courses grew larger and informal discussions were not logistically possible. Another reason is the limited time and allocation of resources to support student laboratory learning.

As a result, chemistry education has evolved from a lab-centered experience into a lecture-centered endeavor. This means that the laboratory, instead of being the central

focus of student inquiry, has become a validation process to support the agenda that is laid down from lecture. This translates into laboratory experiences that may be *scientist-like*, but even by Leibig's standards have become little more than watered down lock-step *recipes* that students follow in their laboratory "kitchens."

Clearly, the experiences freshman and sophomore students have in learning chemistry are primarily in a non-research environment that is more theory-based. Whether a student is or is not a chemistry major, it is arguable that this prescribed method offers students a skewed perception of chemistry and of science research. In fact, even within the community of chemists, the inherently disjointed nature between lab and lecture has led some to believe that lab instruction is an outdated artifact that should be abandoned (Toothhacker, 1983).

In the past two decades, several researchers have claimed that poorly conceived experiments are both confusing to the student and generally unproductive (Hodson 1990). Kirshner and Meester (1988) specifically condemned certain instructional approaches, such as verification labs, as a poor return on expensive investments, with students rediscovering well-known principles, thus reducing motivation and curiosity.

The difficulty, as Pienta and Amend (2005) suggest, is that students perceive some experiments as *trivial* and therefore a waste of their effort and time. The same can be said for *non-trivial* experiments that go beyond their ability to understand and end up frustrating rather than teaching them. More recent research, including this research study, demonstrates that an effective learning approach coupled with microcomputer-

based learning tools helps to make non-trivial experiments attainable by students in the general chemistry laboratory.

In recent years, science education researchers have been able to better understand educational laboratories and demonstrate positive results for this type of learning environment. (Pienta and Amend 2005). Some of these results have been a product of a better understanding of the learning that takes place in the laboratory. This includes more effective laboratory teaching and learning strategies, better visualization of experimentally acquired data, and more diverse ways of accurately assessing students as they scientifically inquire in lab.

Student interpretation of experimentally acquired data has been the common denominator of good science education practices and, since the inception of microcomputer-based laboratories (MBLs) for educational purposes, students have been able to visualize real time data that can be displayed as a read-out, in a spreadsheet, and graphically. In a 1994 literature review of over 20 papers, Nakhleh discussed the recognition by researchers that students' interpretations of real-time MBL generated graphs provided a major learning improvement. The ability for students to perform experiments while observing real-time graphs has revolutionized science education and will be discussed in more depth in the next section of this chapter (Monk and Nemirovsky 1994)

Some of the preliminary attitudinal data about using MBLs was reported by Furstenau (1990), who stated that over 75% of students felt that doing MBL experiments was an excellent or good idea and only 8% thought that it was a bad idea or very bad

idea. Of these dissenters, however, 9% strongly agreed and 67% agreed that these labs were challenging. In the same study, the value of MBLs was further supported with 49% of students finding computers to be very useful and an additional 30% finding them useful in designing experiments and acquiring and analyzing data. Since then, many efforts have been made in better quantifying student outcomes in regards to MBLs via traditional tests of conceptual learning. Researchers are beginning to agree that this information may be better gained from the affective domain, in the form of student motivation and curiosity that piques their interest throughout the course (Pienta and Amend, 2005).

As newer measurement technology is developed and its use in laboratories increases, chemical education researchers must continually devise assessment strategies to measure its educational effectiveness. Aside from a recent publication that suggests a method for measuring the "affordances" of instrumentation in student learning, by Nakhleh and Malina in 2003, the literature has been relatively silent on measuring student outcomes. More studies of computer-based measurement systems are needed so instructors of chemistry can make informed decisions when choosing laboratory technology to support their learning objectives.

Chemical Education Research and MBLs

There has been dramatic development, use, and assessment of electronic data collection devices (EDCs) and of microcomputer-based laboratories (MBLs) at the collegiate level in the past two decades. In the late 1980's, Furstenau and Amend were the first to successfully create and nationally disseminate chemistry curricular materials

for MBLs at the collegiate level. Their study demonstrated the value of reducing data acquisition time and introduced the importance of experimental design and data analysis.

This laboratory approach has impacted students' learning of science in three ways. First, Rogers and Wild (1996) have reported that students feel more motivated in laboratory if they have an opportunity to collect experimental data and experiment with scientific instrumentation. Second, students were observed to work in more independent and creative ways with measurement technology (Lapp and Cyrus 2000). Third, student interactions in the laboratory suggest that the computer is viewed as one of the group members that contribute to the support of experimental work-up and data analysis (Kelly and Crawford 2001).

Although use of technology in teaching laboratories has been common for well over a decade, many science education researchers believe its full potential will not be reached without a greater shift from "operating data-logging technology to interpreting data gathered" (Newton, 2000). A substantial body of research has been accrued that relates to connecting graphed data with events that are generated from physical/chemical phenomenon (Mokros and Tinker 1987; Nakhleh and Krajcik 1994; Barton 1997, Nemirovsky, Tierney and Wright 1998; Lapp and Cyrus 2000). Research suggests that when students are allowed to focus on the experiment while plotting data in real-time, the students can move to a more complex understanding of the underlying physical/chemical principles (Monk and Nemirovsky 1994). In addition, electronic data collection (EDC) devices that automatically acquire and plot directly into spreadsheets and graphs have offered students an opportunity to learn techniques for data analysis and presentation in a single laboratory period. Most scientists would recognize that this ability to rapidly process data is both general and exportable to other scientific-based disciplines outside of chemistry (Nakhleh, Polles, and Malina 2002).

If EDC are too complex, novice students may quickly get lost in the technological details, thus running the risk of never recognizing the underlying chemical principles or attaining student laboratory objectives. On the other hand, if EDC are too simple, more advanced students may feel limited in their experimentation. Ideally, EDC should be versatile enough to fit a broad range of student abilities so that students may explore in a laboratory setting that is comfortable, yet meaningful.

When instrumentation is versatile enough to fit a broad range of students, this is referred to as "ease of use" (Nakhleh and Malina 2003). Ease of use not only affects students' pragmatic data acquisition skills, but learning in the laboratory can be enhanced by conceptually understanding the instrument itself. Anecdotal evidence from a student's perspective of instrumentation is not always progressive, where "the student mentality [is] not always to learn the theory behind [instrumentation], it is to do the minimum you have to do to get the grade, to get it done, to get the A."

This researcher's interpretation of the previous evidence is that instrumentation has its time and place and should only be introduced and used if it improves student understanding of a phenomenon, helps to solve a problem, or is going to be used again in future laboratory experimentation. In this research study, students explored chemical principles in laboratory experiments that are designed to have recognizable patterns of research inquiry and experimental design. This curriculum was designed so that students explicitly used and reused particular skill-sets and tools in consecutive experiments. This approach helped students to become familiar with and then master the use of mathematics and instrumentation that are transferable to other scientific disciplines (Nakhleh, Polles, and Malina 2002).

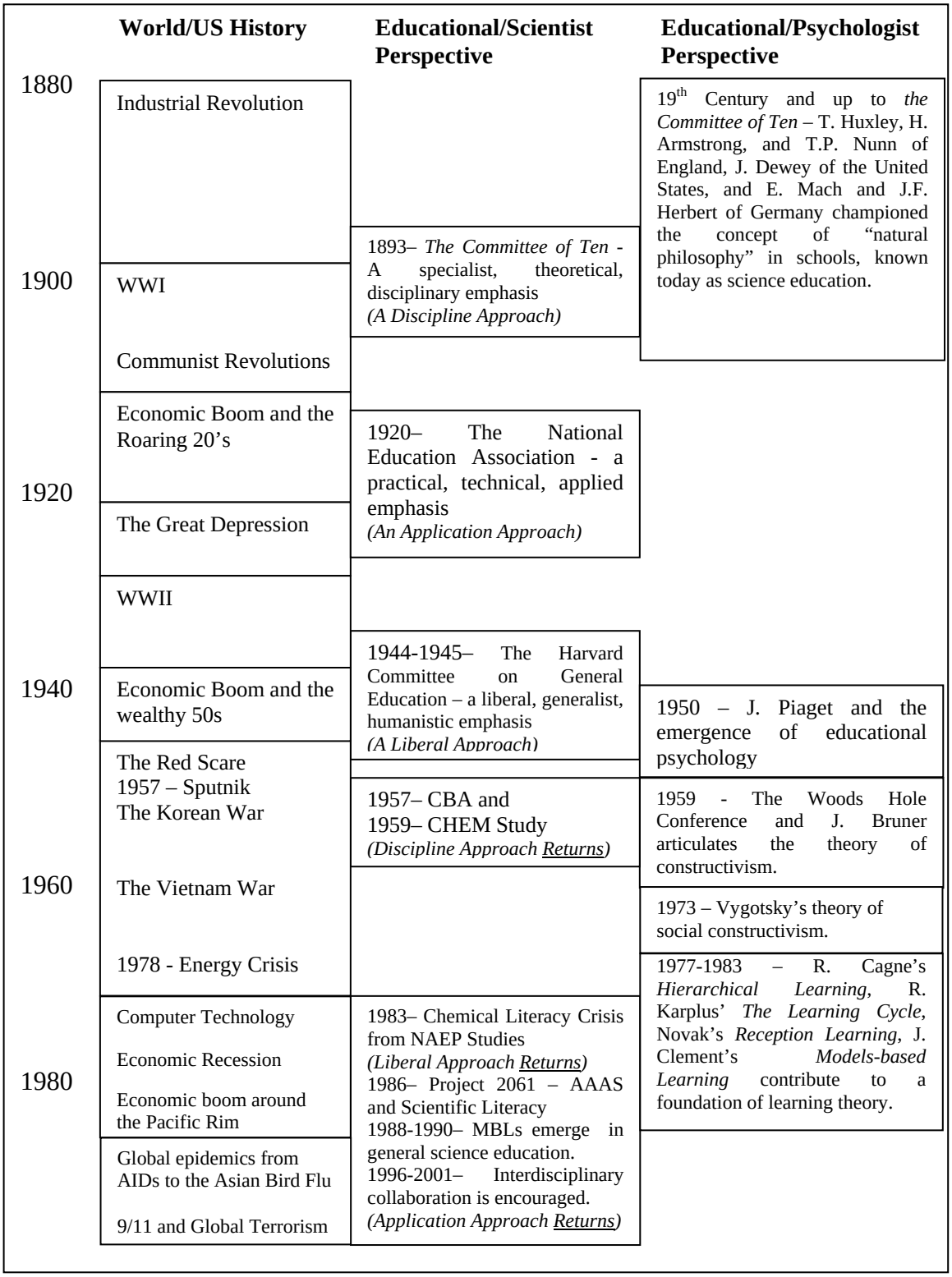

Figure 9: Science Education Timeline - A perspective of science education in the World and US history.

CHAPTER 4

ALIGNING THIS RESEARCH STUDY WITH NATIONAL AND LOCAL GOALS

There is a critical need for colleges and universities to more broadly and effectively integrate science, math, and technology into the general education curriculum.
N.S.F.'s "Shaping the Future" – 1998

From Awareness to Proactive Collaboration with The College of Engineering

Initial Meetings and Collaborations with the College of Engineering

Soon after it was discovered that low enrollment in the second term of general chemistry was due to changes in ABET Criteria for Accrediting Programs in Engineering, a meeting was schedule with the Dean of the College of Engineering, Dr. Robert Marley, and the Assistant to the Dean, Heidi Sherrick, in late November of 2001. It also became apparent that a solution to this problem would require interdepartmental cooperation and collaboration between MSU-Bozeman's College Of Engineering and The Department of Chemistry and Biochemistry.

Preliminary meetings with the Chair of the Chemistry Department's Undergraduate Curriculum Committee, Dr. Jan Sunner, soon evolved into interdepartmental collaborations with the various department heads of the College of Engineering in late March of 2002. During these meetings, data from the previous demographic study were shared and the problem, that some engineering students were receiving an incomplete survey of general chemistry, was clearly defined. To support this, the chapter headings from Brown and Lemay's 2001, 8th Edition were presented as a

guideline to show the content that students were missing by not taking the second semester of general chemistry, CHEM 132. These topics were:

Ch. 11 – Intermolecular Forces and Liquids and Solids
Ch. 12 – Physical Properties of Solutions
Ch. 13 – Chemical Kinetics
Ch. 14 – Chemical Equilibrium
Ch. 15 – Acids and Bases
Ch. 16 – Acid-Base Equilibria and Solubility Equilibria
Ch. 18 – Entropy, Free Energy, and Equilibria
Ch. 19 – Electrochemistry
Ch. 20 – Nuclear Chemistry

During this meeting, participants discussed different aspects of chemistry that they believed were important to engineering students. Some of the discussion also generated ideas that supported real-world application of chemistry and the use of technological and mathematical tools for student exploration in a laboratory environment.

Two remedies to this issue were proposed. One idea was that a single semester chemistry course for single semester engineering majors could be designed. The other idea was to reconsider having all engineering majors take both semesters of general chemistry, CHEM 131 and CHEM 132.

For the remainder of 2002, different views of the problem were shared between the College of Engineering and Undergraduate Curriculum Committee in the Department of Chemistry and Biochemistry. It was apparent that more information from a broader perspective would be required. Because of this, a survey was prepared and implemented for the purpose of identifying the needs of single semester engineering students. This survey, presented in the next section, contributed to collective viewpoints from nationally distributed general chemistry faculty and local engineering faculty at MSU-Bozeman. These results contributed to a data driven decision for an acceptable solution.

The 2002 "Chemistry for Engineers" Survey

A two-part survey was developed and distributed in mid-summer of 2002 in collaboration with the College of Engineering. With the help of Heidi Sherrick, assistant to the Dean of the College of Engineering, the surveys were distributed to twenty-eight MSU-Bozeman Engineering faculty members. At the same time, staff of John Challice, Editor in Chief with Prentice Hall, administered this survey to general chemistry professors (N=16) who were nationally distributed at ABET accredited colleges and universities. The first part of the survey, Part A, offered a list of chemical principles that were recognizable to both engineering faculty and chemistry faculty that represented the two semester sequence of general chemistry. Chemistry and engineering professors were to choose the chemical principles they thought were vital for engineering track students. In this survey, professors designated which particular chemistry content should be mastered, surveyed, or whether it was unimportant.

The second part of the survey, Part B, presented a list of ABET objectives from the *2001 Criteria for Accrediting Engineering Programs*. The same set of professors were asked to place a check mark next to those objectives they thought should be covered in a general chemistry course. By quantity of votes from the participating professors, ABET objectives were prioritized and incorporated to create student learning objectives for single semester engineering students. The results from the surveys, reported in the following chapter, yielded both national and local specialists perspective that influence curricular choices and student learning objectives (Appendix B: Survey Instruments and Outcomes).

Identification of Chemistry Content
and Student Learning Objectives

Outcomes for Part A: Chemistry Content
Important to Engineering Students

The normalized data from Part A that were collected from nationally and locally distributed surveys is presented in Figure 10. This graph reflects the relative importance

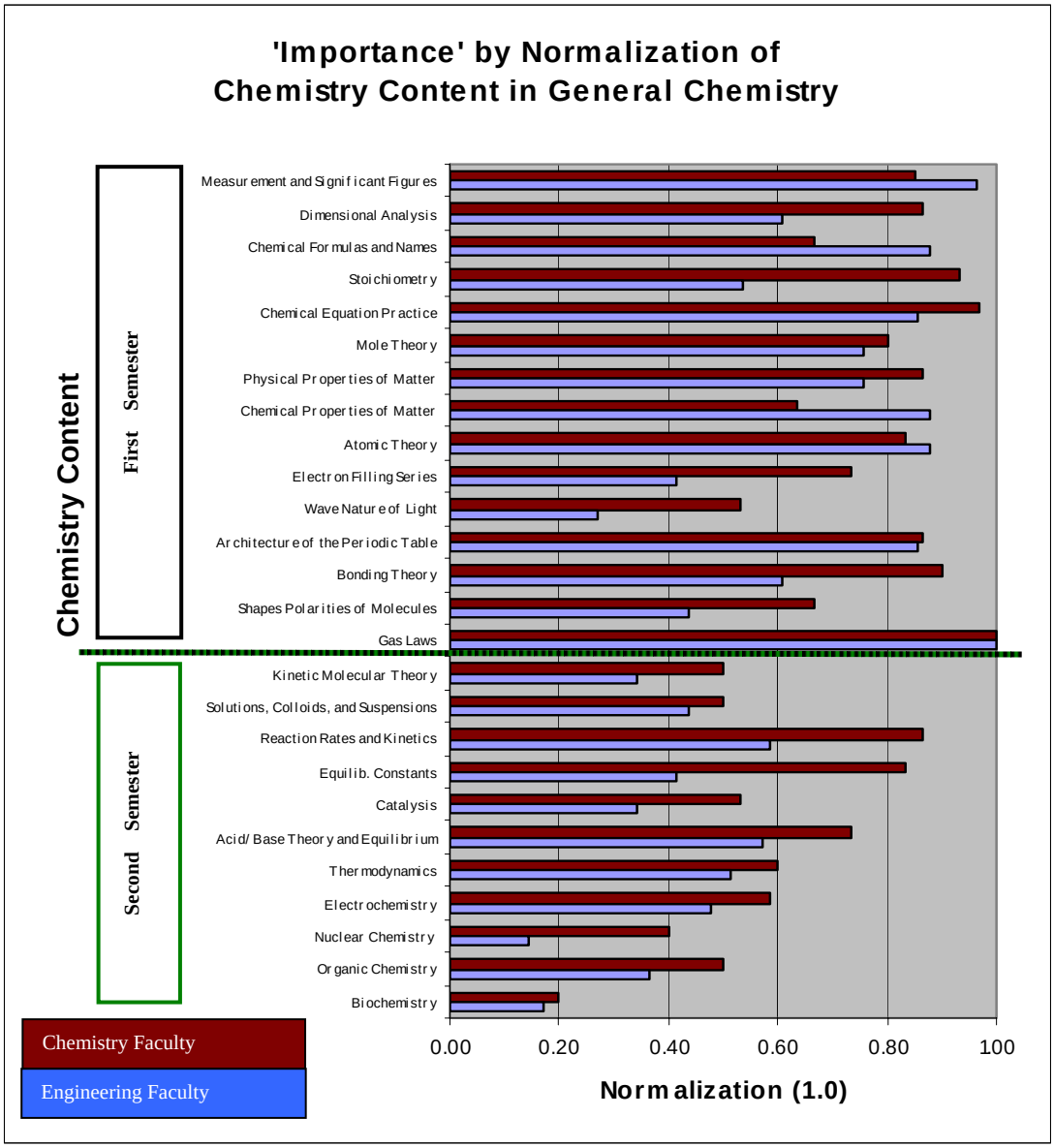

Figure 10: Faculty Survey - Part A - Importance of content from chemistry and engineering perspectives.

of chemistry content in each content area. The upper maroon histograms show the nationally distributed chemistry faculty members while the lower blue histograms show local MSU-Bozeman engineering professors. The data for the chemistry content are also grouped into first semester and second semester, using the sequence found in Brown and Lemay's 8th edition. This is indicated on the graph with a distinctive green and black line of separation. (Normalization of these data were calculated by finding the highest rated chemistry content area for each surveyed group, assigning a value of 1.0, and adjusting other chemistry content areas according to the survey results.)

These data demonstrated a difference in perspective in the importance of chemistry content between chemistry and engineering faculty. There was also a relatively high agreement, $X > 0.50$ averaged and normalized votes, for some content that is only offered in the second semester of general chemistry.

Some interesting outcomes in Part A of the survey included trends of importance that are similar, but not the same for both MSU engineering faculty and nationally distributed chemistry faculty. MSU engineering faculty rated the four most important chemistry content areas for engineering track students to be Gas Laws, Measurement and Significant Figures, Chemical Formulas, and Chemical Properties of Matter, respectively. Nationally distributed chemistry faculty, who teach at ABET accredited colleges and universities, believed that Gas Laws, Equation Theory, Stoichiometry and Bonding Theory should be of most importance to engineering-track students.

To display a better perspective of importance from both faculties, averages of the normalized survey results for engineering and chemistry faculty are plotted in descending order on the next page in Figure 11. To demonstrate the significance of the difference in importance between these two groups, a calculation of DELTA, (Normalization of

Chemistry Perspective) – (Normalization of Engineering Perspective), is plotted directly below the chemistry content of interest (Figure 11).

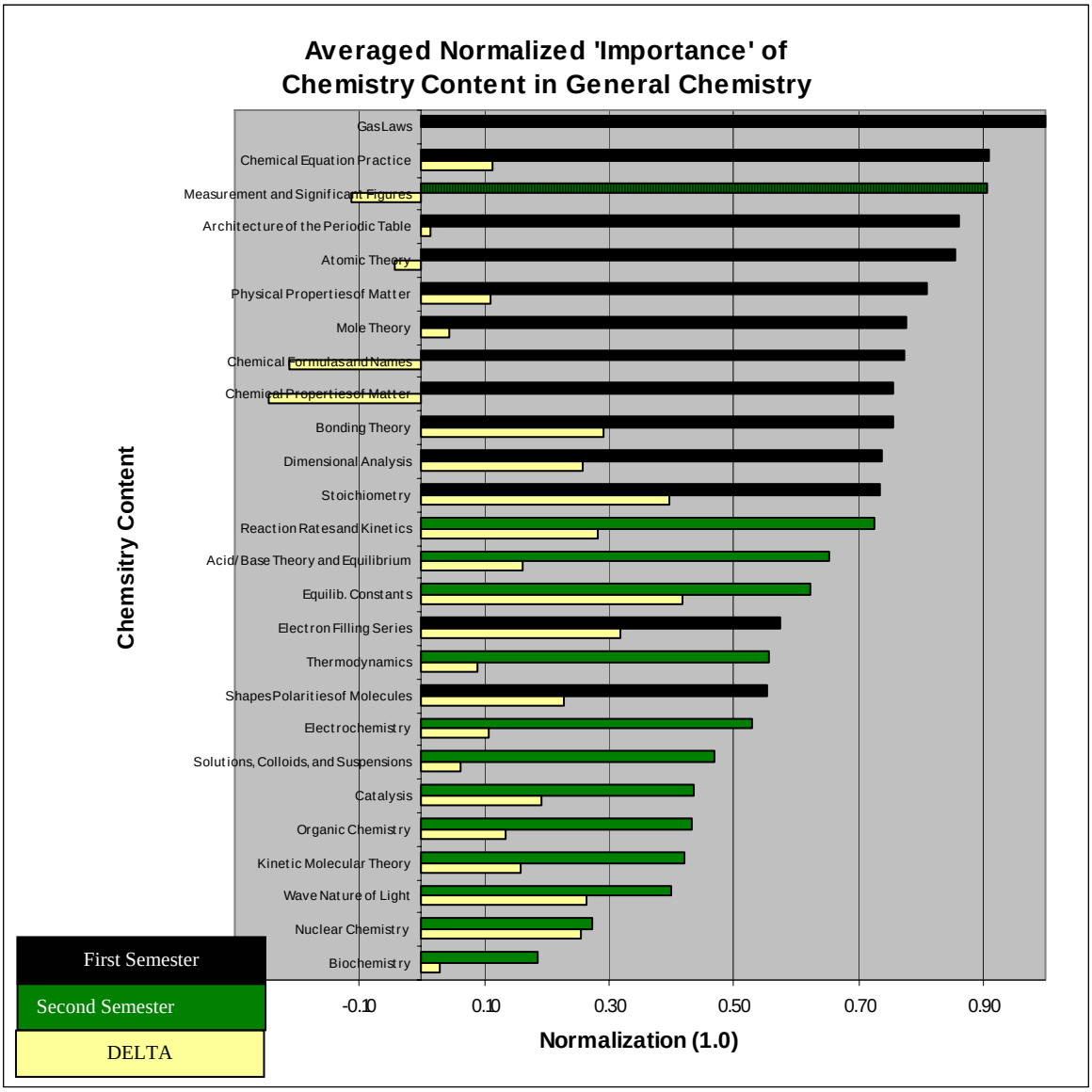

Figure 11: This is a graph of the averaged and normalized 'Importance' of chemistry content from an engineering and chemistry perspective. Difference of perspective between faculty are reflected in DELTA

These data suggest that the top nine content areas are in good agreement with chemists' priorities and are of greater importance to engineering faculty. The top four chemistry content areas that both chemists and engineers believe may be appropriately

addressed in a general chemistry include Gas Laws, Chemical Equation Practices, Measurement and Significant Figures, and Architecture of the Periodic Table.

There are five content areas from second semester that over half of both faculties, $X > 0.50$ in averaged and normalization units, believed should be mastered or surveyed in general chemistry. These five areas included Rates of Reaction and Kinetics, Acid and Base Theory and Equilibrium, Thermodynamics, Equilibrium Constants, and Electrochemistry, respectively.

Outcomes for Part B: Learning Objectives for Engineering Students

In Part B, the same 28 engineering faculty at MSU Bozeman and 16 nationally distributed chemistry faculty were surveyed on the possible application of ABET learning objectives in general chemistry. The results of this survey can be seen in Figure 12, where the survey asked participants to perform the following task:

> *Below is a list of ABET (Accreditation Board for Engineering and Technology) objectives. Please check those objectives you think should and could be specifically addressed in a freshman general chemistry course.*
>
> Engineering programs must demonstrate that their graduates have:
>
> (a) an ability to apply knowledge of mathematics, science, and engineering.
> (b) an ability to design and conduct experiments, as well as analyze and interpret data.
> (c) an ability to design a system, component, or process to meet desired needs.
> (d) an ability to function in multi-disciplinary teams.
> (e) an ability to identify, formulate, and solve engineering problems.
> (f) an understanding of professional and ethical responsibility.
> (g) an ability to communicate effectively.
> (h) the broad education necessary to understand the impact of engineering solutions in a global context.

(i) a recognition of the need for, and an ability to engage in lifelong learning.

(j) a knowledge of contemporary issues.

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

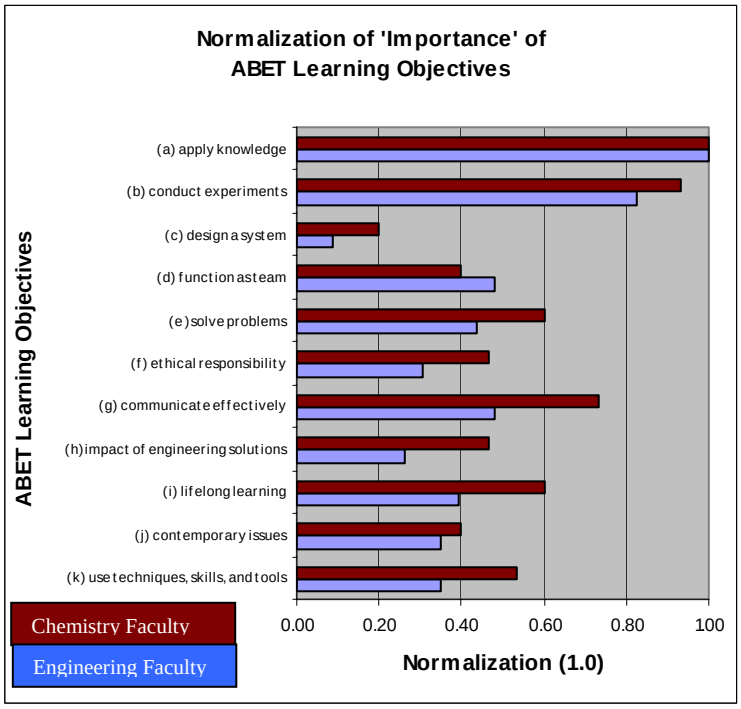

Figure 12: Faculty Survey – Part B - Normalization of ABET student learning objectives from a chemistry and engineering perspective.

The top two ABET related objectives that engineering and chemistry faculty believed could best be addressed in general chemistry were (a) *an ability to apply knowledge of mathematics, science*, and engineering and (b) *an ability to design and conduct experiments, as well as analyze and interpret data*, shown in Figure 12. Both faculty were in good agreement with ABET Student Learning Objectives, as their combined normalization and DELTA show in Figure 13. This descending order also shows the top seven objectives that have a value of 0.46 units of normalization or greater.

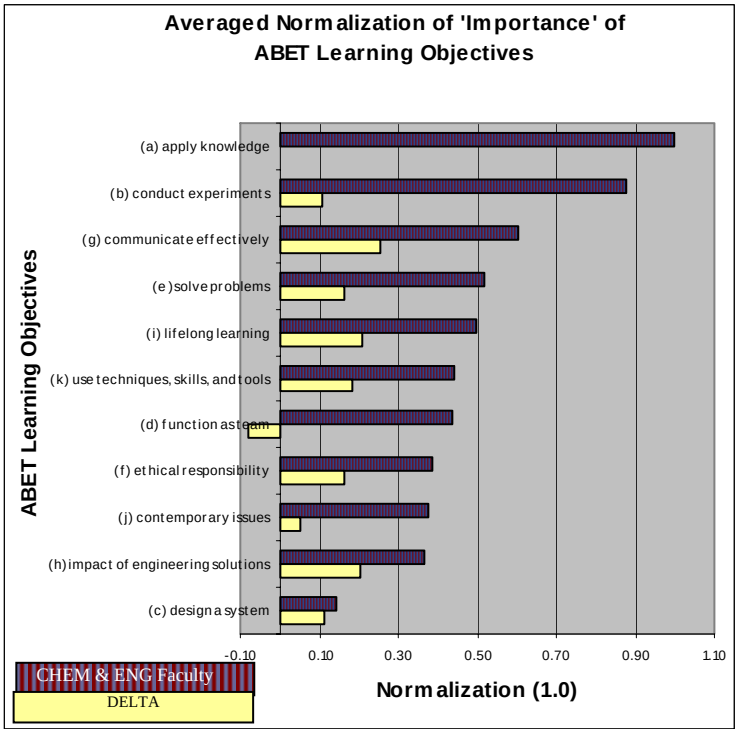

Figure 13: Hierarchy of ABET student learning objectives from an engineering and chemistry faculty perspective.

With the exception of (d) *an ability to function on multi-disciplinary teams*, more chemists believed that these ABET learning objectives should and could be specifically addressed in a freshman general chemistry. Notice that there was no DELTA value for objective (a), since both chemistry and engineering faculty agree on its importance. A negative DELTA can also be observed in the graph above for objective (d), where engineering faculty placed a higher importance on functioning in interdisciplinary teams. These data assisted the researchers in the development of specific student learning objectives for this research study.

CHAPTER 5

GOALS AND OBJECTIVES FOR THIS RESEARCH STUDY

In the absence of goals, we become strangely loyal to performing daily acts of trivia.

Unknown

Considering A National Vision for Science Education

A National Vision for Undergraduate Education in Science and Mathematics

In 1994, the National Science Foundation convened a board of thirty-one individuals that ranged in experience from industry to academics to redefine a national vision for undergraduate science education. The committee published a series of recommendations for undergraduate science education in *"Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering and Technology."* Volume I was published in 1996 and Volume II was published in 1998. One of these recommendations states that:

> All students should have access to supportive, excellent undergraduate education in science, mathematics, engineering and technology, and all students should learn these subjects by direct experience with the methods and process of inquiry.

In April of 1998, the Carnegie Foundation's Boyer Commission, an eleven member group independently funded by the Carnegie Foundation for the Advancement of Teaching, published a report, "*Reinventing Undergraduate Education: A Blueprint for America's Research Universities.*" In this report, The Boyer Commission reminded

undergraduate science educators of a point made by John Dewey almost a century ago when he stated that, "…learning is based on discovery guided by mentoring rather than on the transmission of information". The commission continued to echo Dewey's claim by recommending that:

> Undergraduates need to become an active part of the audience for research. In a setting in which inquiry is prized, every course in an undergraduate curriculum should provide an opportunity for a student to succeed through discovery-based methods.

In September, 2001, the National Research Council released, "*Investigating the Influence of Standards: A Framework for Research in Mathematics, Science, and Technology Education.*" They reported that nationally developed standards, "…intentionally do not prescribe curriculum, but provide criteria for designing a curriculum framework for selecting instructional materials." (p.8)

An Approach to the Problem and Research Study Outcomes

An Approach to the Problem

The two possible solutions, previously mentioned in Chapter 4, included (a) offering a single semester lecture and lab for engineering track students or (b) changing the requirement for all engineering track students to two semesters of general chemistry, CHEM 131 and CHEM 132. Neither of these approaches was acceptable to either the Department of Chemistry or the College of Engineering at MSU-Bozeman, so a compromise was struck in the early Spring of 2003.

A final decision was made to create a laboratory course that specifically supported single semester engineering curricula for Mechanical Engineering and

Electrical Engineering. This course would include students taking the first term of general chemistry, CHEM 131 lecture, but enrolling them into a separate laboratory section that addressed important chemistry content that was identified in the local and national survey, as discussed in Chapter 4. The following section outlines the intended outcomes of this laboratory curriculum for single semester engineering students.

Research Study Goals and Alignment with National Science Education

This research study aligns with these national efforts to improve science education in the United States. Five research study goals were formulated and show alignment with excerpts from the N.S.F.'s, *"Shaping the Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering and Technology"* and The Carnegie Foundation's Boyer Commission Report, *"Reinventing Undergraduate Education: A Blueprint for America's Research Universities."*

The research study goals were to:

1. Design laboratory curriculum for single semester engineering students that incorporate identified chemistry content of importance into a problem solving and guided-inquiry approach that models laboratory research. This goal is supported by the National Science Foundation:

   > "Build into every course inquiry, the process of science, a knowledge of what SME&T (Science Math Engineering and Technology) practitioners do, and the excitement of cutting edge research."

2. Integrate measurement technology that supports the chemistry content identified in the survey and provide an opportunity for engineering students to

build skill-sets and tools for scientific laboratory experimentation. This goal is supported by the Boyer Commission:

> "The thought processes to identify problems should be emphasized from the first year, along with the readiness to use technology to fullest advantage."

3. Develop opportunities for engineering students to work as scientific research teams so that they may collaboratively solve problems and present their findings in both oral and written formats. This goal is supported by the Boyer Commission:

> "Every freshman experience needs to include opportunities for learning through collaborative efforts, such as joint projects and mutual critiques of oral and written work."

4. Support interdepartmental collaboration with the College of Engineering toward an interdisciplinary approach for general chemistry laboratory learning. This goal is supported by the National Science Foundation:

> "Build bridges to other departments, seeking ways to reinforce and integrate learning, rather than maintaining artificial barriers."

5. Develop and implement an assessment plan that evaluates the effectiveness of this laboratory approach, its curricular materials, the supporting measurement technologies, and the teaching and learning strategies. This goal is supported by the National Science Foundation:

> "Make methods of assessing student performance consistent with the goals and content of the course
>
> "Use instructional technology effectively."

Student Learning Objectives for this Dissertation Project

Student Learning Objectives for General Chemistry Laboratory for Engineers

The learning objectives identified were actual ABET objectives that should and could be specifically addressed in a freshman general chemistry course for Engineering Track students. The results of this survey (Figure 12) showed that general chemistry faculty and engineering faculty were in relatively good agreement, with a relatively small difference, $X < 0.26$ normalization units.

The top six ABET learning objectives for engineering graduates were chosen and are listed below, ranked from highest to lowest in value.

Engineering programs must demonstrate that their graduates have:

(a) an ability to apply knowledge of mathematics, science, and engineering.

(b) an ability to design and conduct experiments, as well as analyze and interpret data.

(g) an ability to communicate effectively

(e) an ability to identify, formulate, and solve engineering problems.

(i) a recognition of the need for, and an ability to engage in lifelong learning.

(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

(d) an ability to function in multi-disciplinary teams.

From this survey, ABET learning objectives were discussed with faculty in the College of Engineering. As a result, a co-authored list of acceptable student learning objectives for this laboratory was collaboratively derived.

After completing this course, engineering students will be able to…

1) display an ability to apply their knowledge of chemical principles, mathematics, and measurement instrumentation that are important to chemists and engineers within a research laboratory setting.

2) identify, analyze, and solve application problems in the laboratory through designing and conducting experiments that build scientific research methodology and skills.

3) use modern research skills and tools of mathematics and measurement technology to effectively collect, analyze, and interpret data when solving experimental laboratory problems.

4) communicate effectively as a research group when solving problems in the laboratory and when presenting results in both written and oral formats.

5) recognize a need for chemistry and the importance of lifelong learning.

CHAPTER 6

INTEGRATING SKILL-SETS AND TOOLS OF LABORATORY RESEARCH FOR SINGLE SEMESTER ENGINEERING STUDENTS

Science may set limits to knowledge, but
should not set limits to imagination.
Bertrand Russell

Criteria for Integrating Innovative Measurement Technology and Math

Measurement Technology and Mathematics That Support Student Exploration

Since the 1980's, John Amend's research group in the Department of Chemistry and Biochemistry at Montana State University-Bozeman has successfully developed, tested, and disseminated microcomputer-based laboratories (MBLs) for general chemistry. Some of this has been accomplished during one week workshops that have involved over 275 college faculty and 800 high school faculty at Montana State University and elsewhere in the United States and Canada. Today, microcomputer-based laboratories are commonly used in science and math education at almost every level, K-16. As new measurement technology becomes more affordable, an increased level of interest has been shown by educational institutions and has resulted in the development of various electronic data collection (EDC) systems that are commercially available for students to use in analysis.

One of the first studies on the use of MBLs was by Dr. Ron Furstenau, of the Amend Group, where he concluded his study with a statement, "It almost seems that the

computer has been a solution waiting for a problem, the cart before the horse. In many instances, the computer has been used without really thinking about what it is that needs to be accomplished." This statement is still true today.

In fact, current curricular materials for MBLs may not always be clearly defined with a mission statement, program goals, or even student learning objectives. As a result, these EDC technologies can quickly become a superficial focal point instead of necessary tools that are deemed essential for and assist in student exploration of scientific principles.

To align this research study with ABET criteria for Electrical Engineering and Mechanical Engineering programs, a list of criteria (Table 1) for choosing skill-sets and tools was created in collaboration with the faculty from College of Engineering. This was done so that the identified chemistry content, presented in Chapter 4, and student learning objectives, presented in Chapter 5, could be supported with the appropriate mathematics and measurement technology for this single semester engineering laboratory curriculum.

When considering skills and tools of measurement technology in chemistry, students will:	**When considering skills and tools of mathematics in chemistry, students will:**
o Apply theoretical electronic symbols, circuit laws, and circuit diagrams in a practical laboratory setting through electronic environmental sensors.	o Apply algebraic manipulation for theoretical and experimental calculations.
o Apply hardware and software calibration to translate the weak electrical signals of environmental sensors.	o Apply theoretical calculations during hardware and software calibration of environmental sensors.
o Apply readouts and amplifiers in a laboratory setting.	o Apply and understand statistical analysis through exploration of various chemical phenomena.
o Create and apply electronic environmental sensors and control loops into their experimental design and data acquisition.	o Apply differential calculus, such as derivatives and integrals, in the study real chemical systems.

Table 1: Criteria for skill-sets and tools chosen for this program.

This research project clustered the identified lab skills-sets and tools into packages that are transferable in solving experimental problems. In today's world, these components are not relevant to a single discipline but are universally transferable, especially with the use of electronic data collection (EDC) and microcomputer-based laboratories (MBLs). This research study integrated technology so that students could build laboratory skill-sets and tools that are transferable from one lab to the next as they explore new and different chemical systems.

Along with appropriate sequencing in the laboratory curriculum, the skill-sets and tools identified in the Table 1 are built into each lesson as recurring strands of measurement technology and mathematics. The underlying idea was straight forward, to offer engineering students an opportunity to gain mastery of EDC while applying it in various chemical contexts throughout a single semester. This plan is further discussed in Chapter 7.

Choosing Microcomputer-Based Laboratory Equipment for Students

The primary choice of microcomputer-based laboratory equipment for the Department of Chemistry and Biochemistry at MSU-Bozeman was the MicroLab interface systems. This system is the most recent generation of the original MSU Laboratory Interface developed in the late eighties by Amend, Furstenau, and colleagues. Since 1999, this researcher and collaborators from other institutions have continually contributed to the development and upgrading of both hardware and software of this system and that is now in more than one hundred colleges and universities in the U.S. and

Canada. All of the individuals involved with this project have a common belief that chemistry is a laboratory-centered science, where students should be offered an opportunity to learn about research design and build skill-sets through use of versatile laboratory tools. It is this research design and use of skill-sets and tools that help students to explore interesting chemical principles. In the next chapter, this teaching and learning theory, *The Scientist's Research Cycle*, is described.

CHAPTER 7

A RESEARCH-BASED APPROACH TO GENERAL CHEMISTRY LABORATORIES

If there were only one reason for educational laboratories,
let it be to teach the process of science.
J.J. Lagowski

Identification of Teaching and Learning Theories and Laboratory Models

The Roots of Research Science: Deductive and Inductive Experimentation

Scientific research begins either deductively or inductively (Abraham 1997). The deductive method, also known as a top-down approach, begins with an abstract theory and designs an experimental protocol that either confirms or disproves it. This protocol includes designing a focused experiment, collecting data and observations, and then analyzing the observations to test the theory. In most all real-world scenarios, first attempts at experimentation and data analysis are seldom successful in either confirming or disputing the proposed theory. Instead, there is usually refinement of experimental parameters and further analysis of data (Figure 14).

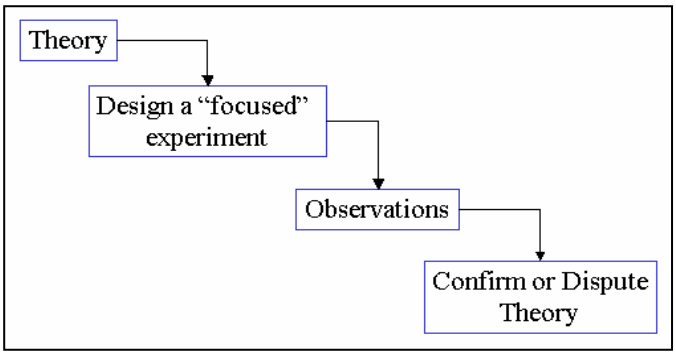

Figure 14: A deductive research approach. – A Top-down Design.

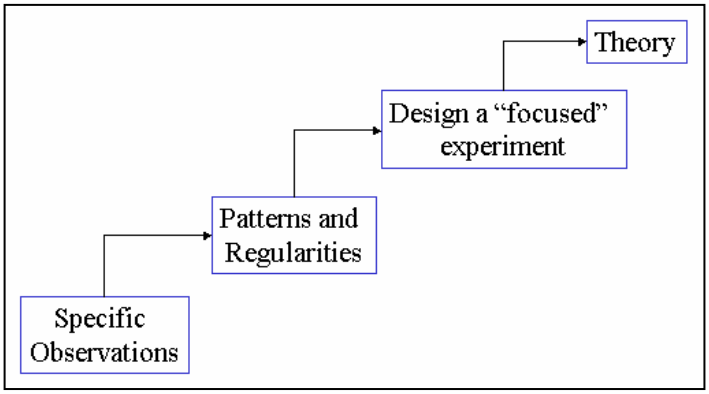

Figure 15: An inductive research approach. – A Bottom-up Design

The inductive approach to experimentation is referred to as a bottom-up design and begins with a specific observation (Figure 15). The researcher analyzes these observations, looking for patterns of regularity. These initial data are used to design a more focused experiment that, in an ideal situation, produces experimental data supporting the underlying scientific theory. As seen in the deductively "focused" experimentation, the results do not always yield evidence that justifiably supports a given theory. More often, a researcher revisits the original phenomenon, looks for other patterns and regularities, and designs a better experiment that offers data, which can elucidate an acceptable theory.

These two methods offer two ways that scientists inquire in the laboratory. Deductive experimentation is *narrow* in scope to begin with, when compared with inductive experimentation, and once the appropriate data are compiled and analyzed, it potentially offers resolution to the original theory in question. Inductive experimentation is considered *open-ended* and exploratory from the start, where the initial search for an

underlying theory or explanation of the observed phenomenon is either completely unknown or at least conceptually broad.

In both cases, experimentation is required. Rarely do scientists move directly from theory to confirmation or from specific observations to theory during the first attempts. In fact, most inductive and deductive experiments are likely to have iterative loops of refinement that are cyclic in nature.

Currently Accepted Teaching and Learning Theories for Laboratory Instruction

When a good theory for laboratory instruction is developed, it assists science educators in structuring how students learn and construct understanding about the world around them. If appropriate, this theory can help educators to create an environment that supports student inquiry and the process of science.

The Learning Cycle (J. Atkin and R. Karplus – 1962, Abrahams 1996) is a three-step inquiry-based laboratory teaching approach. This includes an exploration phase, (E), an intervention phase, (I), and an application phase, (A), shown in Figure 16.

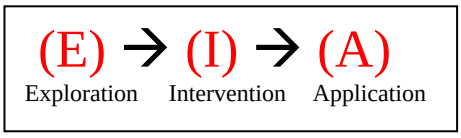

Figure 16: *The Learning Cycle* is an inductive laboratory approach to experimentation.

In the exploration phase, the students explore and observe an unknown scientific phenomenon. This observation is meant to build student experiences that are associated with a target concept or theory that will be developed in the following phase. Next, in the intervention phase, the instructor initiates a classroom discussion about the collected data

and derives the underlying theory. Finally, in the application phase, students evaluate this concept by reapplying it to another experiment, thereby validating the underlying theory.

Since The Learning Cycle always begins with the student making some initial observations, it can be considered an inductive-based laboratory-learning model. Mary Nakleh, of Purdue University, describes The Learning Cycle, as follows:

> Learners selectively attend to the flow of information presented, and their preconceptions determine the information to which they pay attention. The brain actively interprets this selected information and draws inferences based on its stored information. The newly generated meanings are then actively linked to the learner's prior knowledge...
>
> Thus the learning is viewed as a cyclical process. First, the new information is compared to prior knowledge. Then it is fed back into the same knowledge base. (p. 191-196)

This approach relies heavily upon clarity of explanation from the lab instructor and assumes that the student's application goes smoothly enough to support their explanation. Because teachers interpret data for the students in the intervention phase, this is a teacher-centered approach. As good as the designed curricula may be, this three step *Learning Cycle* is too linear and does not offer students enough cycles of discovery to reflect the true nature of science. Finally, this teaching approach models experimentation that always begins inductively, thereby neglecting the possibility of experimentation that can begin from a theoretical basis or in a deductive manner.

Model-Based Learning (J. Clement – 2000), much like the *Learning Cycle*, recognizes the importance of students' prior knowledge. This approach expects students to call upon their prior knowledge and natural reasoning skills to perform the laboratory

experiment. The instructor begins lab with a formal discussion that offers students an *initial model of understanding*, (M1), about what they will be doing in lab. This is followed by experimental laboratory exercises (Figure 17).

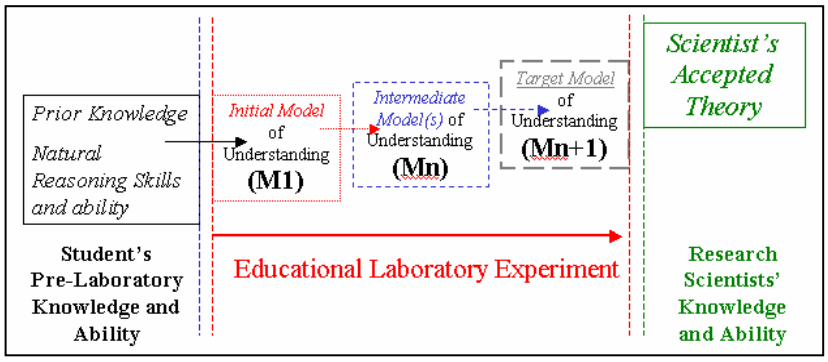

Figure 17: *Model Based Learning* approach is a deductive approach to experimentation.

Throughout the laboratory experiment, the cyclic nature of this approach is implied as students continually refine their understanding to a higher level or levels of *intermediate models of understanding*, (Mn). Students may evolve multiple intermediate models of understanding until they reach a *target model of understanding*, (Mn +1), that this laboratory was designed to develop.

Although the expected target model is meant to provide a higher level of understanding, it is not expected that students fully comprehend the scientist's accepted theory. This is thought to be an acceptable outcome for most students in general college science courses since scientific theories imply a comprehensive network of complex and interrelated concepts and principles. This delineation between the *scientific theory* and *scientific model* demonstrates an important aspect of learning about unknown systems. A scientific theory implies that there is enough knowledge about a set of systems to accurately predict and explain the nature or behavior of a set of phenomena. A scientific model, on the other hand, is a tentative description of a single system that may or may not

accurately predict and explain a limited number of phenomena and their properties. A model of understanding should be considered a starting point or even a *theory in progress* that will be quickly replaced through continued experimentation and data analyses.

Both students and research scientists explore unknown systems of interest with a model-based approach. The main difference between research scientists and students, however, is what they explore and their relative knowledge bases. Scientists build from a broad infrastructure of practical and theoretical knowledge to explore the frontiers of science. Students build from a less structured set of foundational knowledge. In both cases, this approach offers an opportunity for students to test ideas and recognize that, just like real research scientists, they must always think critically about and scrutinize the world around them.

Like the Learning Cycle, this laboratory approach can be contested in its validity in regards to real science. This approach relies heavily upon the evolution from the initial model of understanding to the next and remains ambiguous on what exactly this process entails. Finally, this learning approach models laboratory experimentation that begins deductively and, as though it were the antithesis of the three-step Learning Cycle, neglects the possibility of an experiment beginning inductively.

Developing and Implicating an Original Learning Theory and Laboratory Approach

A Learning Theory: The Scientist's Thought Process

This section introduces a learning theory that builds from the previous foundations of inductive experimentation, deductive experimentation, The Learning

Cycle, and Model-Based Learning. Proposed below is the process of science from a scientist's perspective.

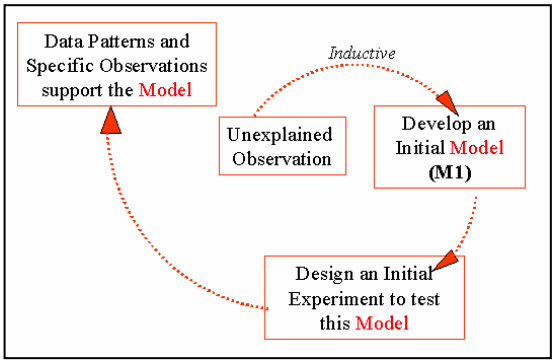

Figure 18: Inductive experimentation begins with an unexplained observation of interest.

An experiment may begin inductively with unexplained observations, where a scientist attempts to derive an initial, yet simplistic, model of understanding about a system of interest, (M1). A laboratory experiment is designed to test this model and data are collected to see if they create patterns that match this model's predictions. If these predictions match this initial model of understanding, then it can be deemed successful. (Figure 18)

Alternatively, a scientist may have an abstract idea of what they plan to test by creating a preliminary, yet simplistic, model of understanding (M1). From this, they devise an experiment and look for patterns in their analyses that either confirm or dispute their model's predictions (Figure 19). Since this experimentation began with an initial model of understanding, this experimental approach is deductive in nature.

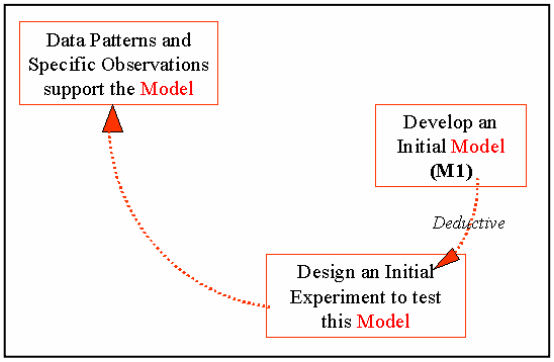

Figure 19: Deductive experimentation begins with the development of initial model of understanding.

If researchers do not observe patterns in these data, then it is possible that either their initial model was flawed, they did not perform an experiment that rendered these patterns visible, the data that were acquired are flawed due to experimental error or technology malfunction, or they have a basic misconception of the underlying chemical phenomenon. Regardless of the cause, if these acquired data and observations do not support the model of understanding, (M1), they can be regarded as unexplained observations, **(???)**. (Figure 20)

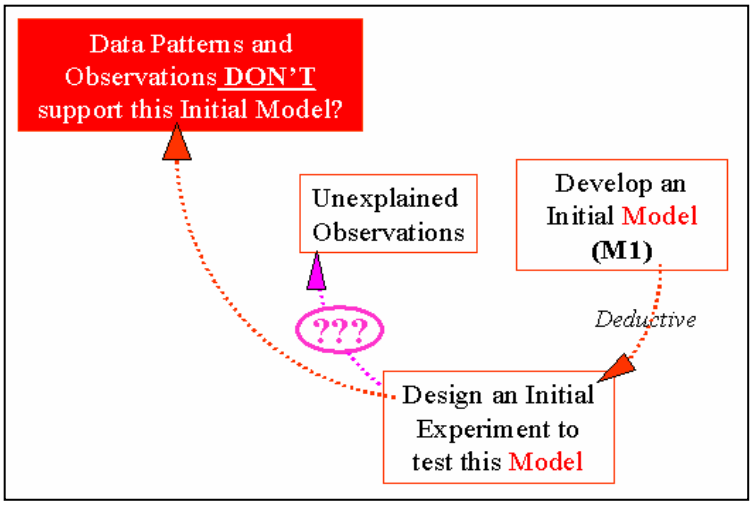

Figure 20: Unexplained observations sometimes result from an experiment when a crude model or experimental design are inadequate.

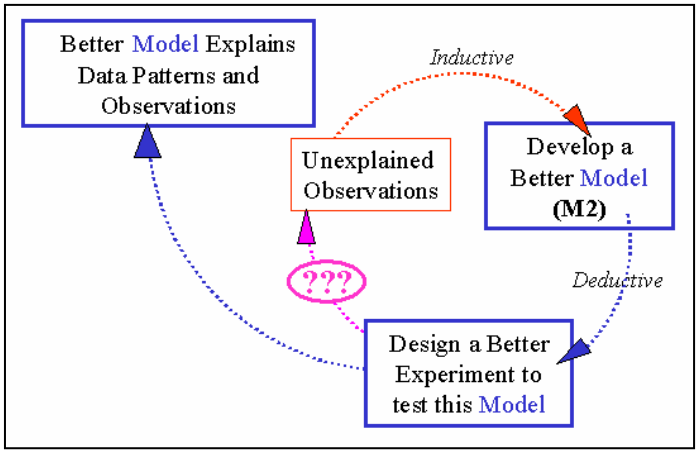

Figure 21: *The Scientist's Thought Process* accounts for the inductive and deductive nature of scientific experimentation.

These unexplained observations ultimately assist scientists in inductively constructing a better model of understanding (Mn**)**, as shown in Figure 21. Once again, this better model is then tested with an improved experimental design. If expected patterns are not observed in these new data, then the scientist continues in this refinement loop until an acceptable model of understanding is found. An acceptable model emerges when data patterns and observations match predicted outcomes of the experiment.

Whether scientific experimentation begins inductively *or* deductively, scientists rely heavily on their ability to use both approaches, even during a single laboratory experiment.

A Framework for Laboratory Learning: Applying The Scientist's Research Cycle

The cyclic process described in the previous section, *The Scientist's Thought Process*, supports the functional framework that was applied in this research study. A laboratory begins with a statement of a problem that students need to solve. At this point, the students perform some initial lab activities to characterize the chemical problem of

interest. Alternatively, an initial discussion of the chemical content deductively presents a preliminary model of understanding.

Once the problem is clearly understood, students can begin their cyclical scientific learning process. First, students ask some preliminary testable questions, also known as hypotheses, and design experiments that potentially yield useful information about the larger lab problem. Second, microcomputer-based measurement technologies are used to expedite student acquisition of experimental data. Third, students organize and process experimental data. Finally, students analyze and evaluate their data, considering the validity of their current understanding to decide whether or not it offers some resolution to the laboratory problem. If not, students continue to the fifth step, where they discuss and revise their experimental designs and try again. This process continues until the laboratory problem is successfully solved (Sorey and Amend 2005).

Each time step four is reached in this process, a question is asked, “Do these data help to synthesize a plausible solution to the proposed laboratory problem?” Students need to take time to reflect upon their data and evaluate their current understanding to reach a definitive “yes” or “no.” If yes, then the problem is considered solved and the experiment should be tested for confirmation to verify reproducibility. If the initial answer is no, which is most likely the case in performing scientific research, then students either need to reevaluate their data or revise their experimental research design (Figure 22).

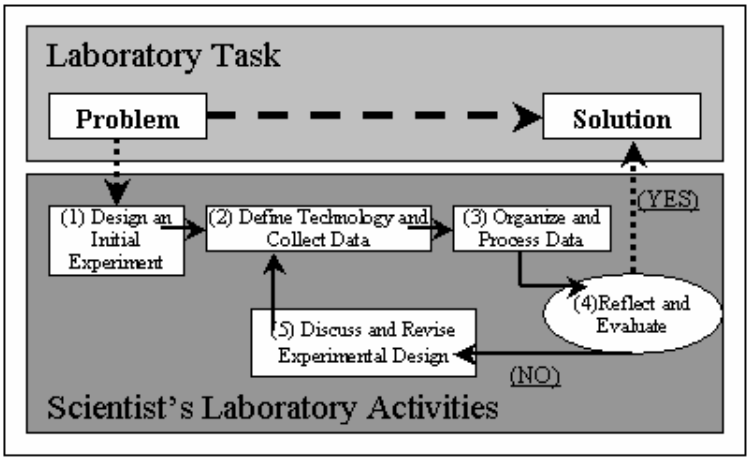

Figure 22: The *Scientist's Research Cycle* approach emphasizes solving practical problems in a laboratory setting.

In all cases, informational resources are available so that students make an informed decision. These resources may include classroom textbooks, student lecture notes, the World Wide Web, a fellow lab mate, and even the laboratory instructor. The strength of this student-centered approach includes exposure to the true cyclic nature of scientific research, affording them multiple opportunities to ask "What if…?" in a single laboratory period.

The Teaching Model: A Research-Based Approach for Engineers

In the *Scientist's Research Cycle* lab instructors guide their students to solve their laboratory problems much like research groups. The laboratory problem, which is clearly presented at the beginning of each experiment, is meant to pique student curiosity and offer a practical real-world engineering application. This real-world engineering application is referred to as the "application problem".

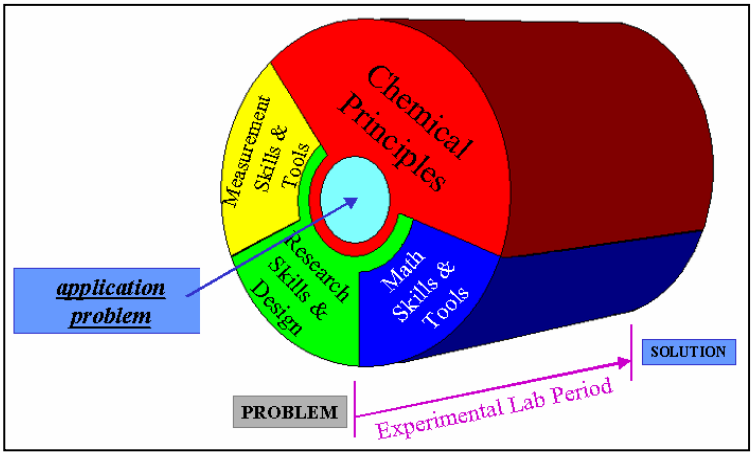

Figure 23: An *Application Problem* is the core of a single laboratory period.

As Figure 23 illustrates, the application problem is the core of all laboratory activities. To solve a problem, students needed to develop an understanding of the underlying chemistry principles and apply the appropriate research skills and design. In each lab, data was acquired and analyzed using skill-sets and tools of measurement technology and mathematics.

The Research Extension Application Problem:
A Research-Based Approach

Microcomputer-based labs alleviate time constraints for data acquisition, organization, and analyses, as previously discussed in Chapters Four and Five of this paper. These technological tools also give students enough time to solve more than one engineering application problem in a single experimental lab period.

General chemistry students have traditionally worked in pairs at MSU-Bozeman. This is also the case in this experimental laboratory course, where student pairs solved a single application problem, described in the previous section. On designated weeks, however, two of the ten laboratory partners operated as a 'Research Group' to solve both

the ‘Class Application Problem’ and an additional ‘Research Extension Application Problem’ (Figure 24). Even though this research extension may have introduced additional skill-sets and tools or experimental design, it was always designed around the underlying chemistry content and chemical principles that were presented earlier in the class application problem.

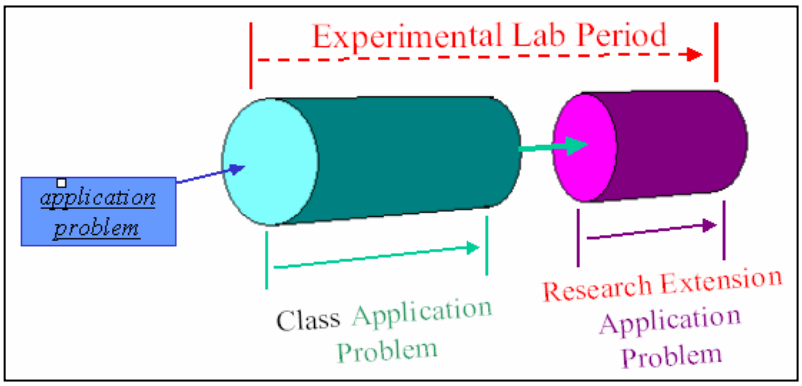

Figure 24: A *Research Group* solves both application problems in a single lab period.

After the Research Group solved both of the application problems in the laboratory, they scheduled a “Research Group Meeting” with the lab instructor after the experimental lab period and before the next lab period. During this informal ‘Research Group Meeting’, students presented and discussed their experimental data. With guidance from the instructor, students interpreted their results to arrive at acceptable solutions to the problem.

At the beginning of the next laboratory session, the Research Group provided an explanation of the research extension in an oral report, including safety, experimental research design, their data, and the results of their experiment. The oral report concluded with a solution to the problem and at least one real-world example that supported the underlying chemistry principle. Upon completion of the oral report, the research group

fielded questions from the other laboratory students and a final written report was handed to the instructor.

The Intended Outcome: Designing Continuity in The Laboratory Curriculum

From the beginning of the semester to the end, each Research Group solved two unique, research extension application problems. Each research extension incorporated the skill-sets and tools that were necessary to solve the following week's Class Application Problem.

Since each research group offered their oral presentation at the onset of the following week's lab, they not only introduced their solution to the research extension problem, but also the transferable skill-sets, tools, and experimental designs that are pertinent to solving that day's class application problem. This helped to build an important thread of continuity across the entire semester timeline (Figure 25).

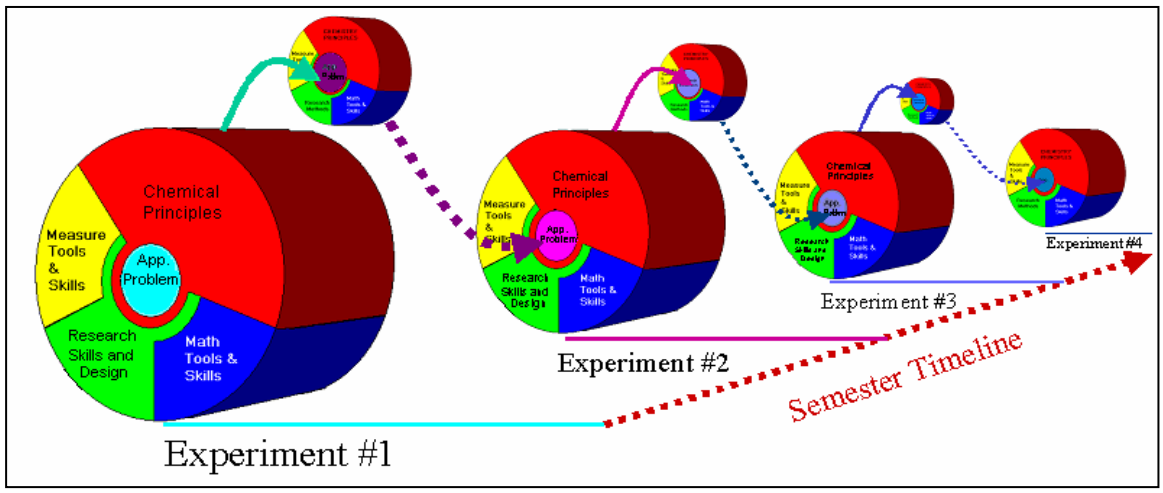

Figure 25: Research Extensions offer skill-sets, tools, and experimental research design from one student to the next in oral reports, creating continuity throughout the entire semester

There were two criteria for choosing Research Extension Application Problems. The first criterion was that chemistry content important to single semester engineering curricula would have to be integrated. Second, research extension problems needed to introduce skill-sets, tools, and experimental designs that could be transferable from one laboratory experiment to the next. This is referred to as clustering.

The Scientist's Research Cycle coupled with this Research Extensions were designed to support student exploration of chemistry content and the processes of experimentation, including research group interactions and formal/informal discussion and reporting of experimental data. This student problem-solving approach is a directed approach that asks students to apply their knowledge of chemistry content and processes of laboratory experimentation in a way that helps them to achieve their final goal, a solution to the problem.

CHAPTER 8

INTEGRATING CHEMISTRY AND EDUCATION: PLANNING THE SEQUENCE OF LABORATORY EXPERIMENTS

The best way to create interest in a subject is to render it worth knowing, which means to make the knowledge gained usable in one's thinking beyond the situation in which the learning has occurred.

Jerome Bruner

Chemistry Content in General Chemistry

Content Sequence

In general chemistry, instructors use textbooks as a tool to define the content and the sequencing of content areas throughout the term. For this study, the first semester of general chemistry, CHEM 131, followed the sequence of the Brown, Lemay, and Bursten Textbook- Chemistry: The Central Science, Edition 8. CHEM 131 covered the first ten chapters in a fifteen-week period:

Ch. 1 – Measurement
Ch. 2 – Atoms, Molecules, and Ions
Ch. 3 – Mass Relationship in Chemical Reactions
Ch. 4 – Reactions in Aqueous Solution
Ch. 5 – Gases
Ch. 6 – Thermochemistry
Ch. 7 – Quantum Theory and Electronic Structure of Atoms
Ch. 8 – Periodic Relationships Among the Elements
Ch. 9 – Chemical Bonding I : Basic Concepts
Ch. 10 – Chemical Bonding II : Molecular Geometry and Hybridization of Atomic Orbitals

The second semester of general chemistry, CHEM 132, continued with Chapters Eleven through Twenty of the same text:

Ch. 11 – Intermolecular Forces and Liquids and Solids
Ch. 12 – Physical Properties of Solutions
Ch. 13 – Chemical Kinetics
Ch. 14 – Chemical Equilibrium
Ch. 15 – Acids and Bases
Ch. 16 – Acid-Base Equilibria and Solubility Equilibria
Ch. 18 – Entropy, Free Energy, and Equilibria
Ch. 19 – Electrochemistry
Ch. 20 – Nuclear Chemistry

One of the difficulties of creating this laboratory curriculum was to align with the chemistry content presented in CHEM 131 lecture while incorporating second semester content. Following is a suggestion for this alignment and how it was performed so that student learning of content knowledge would be supported in both lecture and lab.

Chemistry Content Sequence for this Laboratory

Building from the Basics of Measurement

For more than fifteen years, chemical education research performed in the general chemistry program at MSU-Bozeman has developed and studied the use of microcomputer-based laboratory technology. These tools of discovery have been developed to support student inquiry through experimental design and quantitative measurement of chemical phenomenon. Students require some preliminary training with laboratory measurement and use of technology so that their laboratory experience is beneficial to their learning. This researcher continued this type of preliminary training so that students could assimilate these tools of discovery into their experimentation and research designs.

The importance of training students to use microcomputer-based technology has been well documented since the late 1980's (Furstenau 1990; Morgan 1997; and Nakleah and Malina, 2003). This was the first time, however, that curriculum was designed to support engineering students' exploration of general chemistry content in tandem with an emphasis on skill-sets and tools of measurement technology. For this reason, the first three weeks of this experimental general chemistry laboratory course focused upon experiments that would build a foundation for the fundamental principles of research design, environmental measurement, and mathematical analysis (Table 2).

Week	Chapter	Chapter Title
Week #1	1	Measurement Technology in Chemistry
	2	Understanding and Applying Some Basic Principles of Sensors and Electronics
	3	Getting Started I: MicroLab Software and Hardware
Week #2	4	Organizing and Analyzing Experimental Data
	5	Getting Started II: Designing Experiments and Collecting Data
	6	Getting Started III: Drawing Information from Graphs
Week #3	7	Physical Properties of Matter: Identification of and unknown Organic Compound

Table 2: Measurement Manual Chapter titles from "Measurement: The Basic Science", a study booklet that supports students' inquiry of microcomputer-based measurement technology.

Using a lab manual, "Measurement: The Basic Science – Special Edition for Engineers," the students first read about chemistry history and the *Scientist's Research Cycle* (Sorey, Amend, Furstenau, and Hammond 2004). Then they performed laboratory experiments that introduced the principles of Measurement, Significant Figures, and Statistical Analysis. These experiments involved a number of experiments with environmental transducers that monitored pH buffers and household solutions, light intensities within the laboratory, Pressure vs. Temperature, Celsius vs. Fahrenheit,

Density, Pressure vs. Depth, Pressure vs. Volume, %T vs. Absorbers, and Radioactivity. As in regular sections of lab, this two-week experience ended with students experimentally determining the identity of an unknown organic liquid by measuring the boiling point, freezing point, density, solubility, and evaporation rate (Furstenau, 1990).

After completing their laboratory research training, students were prepared to solve research extension application problems, based upon three basic criteria (Appendix C: Lab Syllabus and Grading Criteria). First, research extensions were designed to support students' prior knowledge and skill-sets that were presented in previous labs or lectures. Second, these research extensions offered an opportunity for students to develop new knowledge and skill-sets in a laboratory setting. Finally, the new chemistry knowledge and research skill-sets would be used again in future laboratory experiments.

After completing the research extension application problems, it was expected that research extension students would be able to:

1) Develop additional or related content knowledge and laboratory skills, thus building continuity from one laboratory exercise to the next.
2) Gain ownership of their unique work done separately from their lab mates.
3) Gain proficiency in oral communication through informal group research meetings and formal weekly laboratory oral presentations.

From Start to Finish: the Sequence of Laboratory Experiments

Each of the *Class Laboratory Experiments* was chosen to support the order of chemistry content presented in lecture. The corresponding *Research Extension Experiments* were designed to follow the criteria described in the previous section, creating continuity from one lab experiment to the next. In Table 3, the entire lab sequence is generically described. Labs that existed before this study are shown in black.

Some of these pre-existing labs were updated, however, and integrated the use of current technology or different teaching methods and are displayed in blue.

	Class Experiment	Research Extension Experiments
Week 1-3	Measurement: The Basic Science	No Research Extensions
Week 4	Gravimetry: Quantitative Analysis: Finding % Nickel in an Unknown Solid	Quantitative Analysis of Phosphorous Plant Food
Week 5	Spectroscopy: Qualitative Analysis and Identification of Unknown Gases	Quantitative analysis of Fluorescein Sodium Salt in an Aqueous Solution
Week 6	Quantitative Analysis of Aqueous Solutions: Colorimetry, Turbidimetry, Nephalometry, and Fluorometry	Quantitative and Qualitative Analysis of an Ion Pair in an Aqueous Solution.
Week 7	Qualitative and Quantitative Analysis of Water: Solving for Unknown Ion Pairs and Solving for their Quantity	Using Conductivity to Quantitatively analyze Dissolved Solids in a Solution
Week 8	An Introduction to Thermodynamics: Flames, Heat, and Calories	Determination of salt via high resolution thermometry and 'Heat of Solutions'
Week 9	SPRING BREAK	SPRING BREAK
Week 10	Molecular Geometry, Bonding, Isomers, Polarity, and of Organic Compounds	Proof of Molecular Configuration and Quantitative Analysis of Sugars in Solution
Week 11	FOOD CHEMISTRY AND COUNTING CALORIES	Snackfood Analysis Lab - Quality Control and Data Asymilation – Acme Analytical Labs
Week 12	The Behavior of Ideal Gases: Applications of Boyle's and Charles Law	Determination of Acetic Acid in Vinegar via pressure and ideal gas laws
Week 13	Electrochemistry: Spontaneous Corrosion and Voltaic Cells	Electroplating and Quantitative Determination of Copper Plating
Week 14	Acid and Base Solutions: understanding pH via pH electrodes, and performing a pH titration.	Titration of an Ant-acid Tablet and Observations of a *Buffer Region*
Week 15	Kinetics – Crystal Violet Experiment	No Research Extensions

Table 3: Laboratory Experiments - Previously designed labs (black), improved labs (blue), or new labs (red) were implemented throughout the fifteen week Spring semester of 2004 for CHEM 131 engineering sections.

Weeks four through twelve of the semester paralleled the content of the regularly scheduled labs in CHEM 131. By week thirteen, students in regularly scheduled labs, referred to as the "Non-Treatment Group", used the last three weeks to perform individual projects and present an oral report. Instead, students in the engineering laboratory sections, referred to as the "Treatment Group", are able to include three additional chemistry experiments from the second semester of general chemistry, Electrochemistry, Acid/Base chemistry, and Kinetics (Table 3).

Supporting Laboratories with Application Problems

To support student learning from objective two, *Students will be able to identify, analyze, and solve application problems in the laboratory through designing and conducting experiments that build scientific research methodology and skills,* each of these previously described labs began with discussion of a problem that needed to be solved (Table 4).

	Class Application Problem	Research Extension Application Problem
Week 1-3	Measurement: The Basic Science	N/A
Week 4	Gravimetry: What is the % Nickel in an Unknown Solid?	What is the % Phosphorous in a particular plant food?
Week 5	Spectroscopy: What is the unknown element in the gas discharge tube?	What is the concentration of aqueous Sodium Fluorescein solution?
Week 6	Colorimetry, Turbidimetry, Nephelometry and Fluorescence: What are the concentrations of colored, turbid, and fluorescent solution?	What ion pair exists in an aqueous solution and what are their respective concentrations?
Week 7	Qualitative and Quantitative Water Quality Analysis: What ion pairs exist in an aqueous solution and what are their concentrations?	How can conductivity of a fluid help us to quantitatively analyze dissolved solids in a solution?
Week 8	An Introduction to Thermodynamics: How many calories are in the snack foods that I eat?	How can a water soluble solid be identified through its 'The Heat of Solution'?
Week 9	SPRING BREAK	SPRING BREAK
Week 10	Molecular Geometry and Bonding of Organic Compounds: How do atoms bond and what are their shapes and geometries when they do?	What effects do some sugars have on light and how can we use this to quantify its concentration?
Week 11	FOOD CHEMISTRY AND COUNTING CALORIES	Snack food Analysis Lab - Quality Control and Data Asymilation – Acme Analytical Labs
Week 12	Gas Laws: What are the dependencies of P vs. V, T vs. V, and P vs. T and how does this help us to solve for absolute zero?	What % of Acetic Acid is in Vinegar via pressure and ideal gas laws?
Week 13	Electrochemistry: What voltaic cells can we make to run an electric car motor?	How can we plate out copper onto another metal surface?
Week 14	Acid and Base Solutions: How do pH electrodes function and what does this tell us about the concentration of the hydrogen ion?	What is the % by mass of base or acid in an aqueous household solution?
Week 15	Kinetics:– What is the order of Crystal Violet Experiment	N/A

Table 4: Application Problems - This table frames each of the previously described experiments in Table 4 into a single question that students need to solve in a laboratory setting.

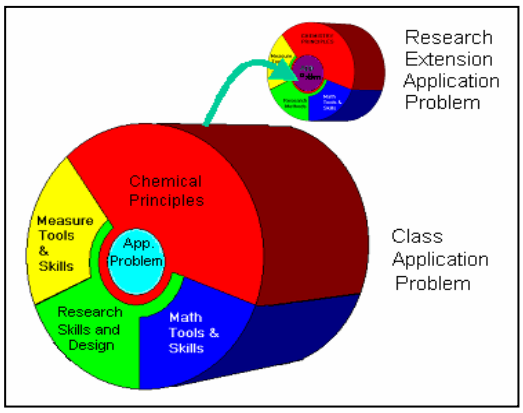

Figure 26: Students solve their laboratory problems by applying chemical principles and research design and skills.

Class Application and Research Extension Application problems were the core of lab experiments (Figure 26). Each experiment was outlined to identify all of the necessary components of content and process that students needed to solve their problems; Chemical Principles, Research Methods, and Tools and Skills of Math and Measurement. Once outlined, students were offered enough information so that they could either discover these underlying principles or learn them from supplementary post lab materials (Appendix E: Lab Experiments, Research Extension Lab Experiments, and Student Reports).

Supporting Application Problems with Chemistry
Content and Experimental Process

To support students in their laboratory problem solving, an inventory of chemistry content and chemical principles was identified. This list served two functions. First, it helped to outline target concepts necessary for students to successfully perform a single laboratory experiment. Second, this list was used to coordinate the sequencing of chemistry concepts throughout the semester to maintain a logical progression from one lab to the next. For example, students qualitatively and quantitatively explored properties

of aqueous ions during Weeks Five through Seven. An inventory of chemical principles was listed to identify the conceptual knowledge students developed in solving the application problems throughout this timeline (Table 5).

Week and Class Topic	Chemistry Content From National and Local Survey	Chemical Principles	
		Class Experiment	Research Extension Topic and Experiment
Week 5: Spectroscopy:	Measurement, Atomic Theory, Mole Theory, and Solution Chemistry.	Wave nature, wavelength, frequency, speed, and energy of light, the Bohr Model of the Atom with respect to line spectra, and radiant blackbody heat with respect to band spectrum.	Fluorometry: Excitation wavelength and emission wavelength of aqueous fluorescent molecules and the use of mole theory to create calibration curves for the quantitative analysis of these compounds in aqueous solutions.
Week 6: Colorimetry, Fluorimetry, Turbidimetry, & Nephelometry	Measurement, Significant Figures, Chem. Properties, Bonding Theory, Mole Theory, and Solution Chemistry & Equilibrium.	% T and A of Light through colored and turbid aqueous solutions, Fluorescence and Stokes Shift, Beer-Lambert Law, The Tyndall Effect, Equilibrium, K_{sp}, and Mole Theory & Standard Dilutions to create calibration curves. Solve for unknown concentration of Fluorescent sample from pre-made calibration concentrations.	Quantitative and *Qualitative* Analysis of an Ion Pair in an Aqueous Solution. Qualitative analysis of ions in solution with a test reagents and building an observations spot matrix to identify unknown ions. Measuring turbidimetrically and colorimetrically the insoluble and colored solutions from this analysis.
Week 7: Qualitative & Quantitative Analysis of H_2O:	Measurement, Significant Figures, Chem. Properties, Bonding Theory, Mole Theory, Solution Chemistry, Chemical Formulas, Reactions, Stoichiometry, and Solution Chemistry.	Beer-Lambert Law and the Tyndall effect, coupled with qualitative spot test matrices to determine the concentration of two unknown salts dissolved in an aqueous solution, along with their corresponding molecular formulas.	Using Conductivity to Quantify Dissolved Solids in a Solution: Measuring electrolytes in aqueous solutions that are a function of conductivity, building a calibration curve, and solving for concentration of solutes.

Table 5: Chemical Principles are identified and mapped out to create a logical flow of experimentation.

To support student experimentation of these chemical principles in the laboratory, identifiable research design and techniques, measurement technology skills and tools, and

mathematical skills and tools were also carefully inventoried. This assisted the researcher in identifying students' experimental needs in the process of qualitatively and quantitatively exploring behavior of aqueous solutions (Table 6).

	Research Design and Techniques	Measurement Technology Skills & Tools	Math Skills & Tools
Spectroscopy: Week 5: *Class Application Problem*	-Create wave-nature interference with springs. -Observe emission spectra of various gas discharge tubes.	-Use a hand-held spectroscope -Use Energy of Light Hardware and Software -Atomic Spectrum Software	- Use Cartesian coordinate and draw wavelength and frequency -Use equations: $c=\lambda\upsilon$ and $\lambda T=hc/4.965kB$ - Graph frequency vs. Energy
Week 5: *R.E. Application Problem*	-Create standard solutions for calibration curves. -Determine analytical wavelength of Fluorescence versus concentrations.	-Use five LED's to observe excitation of fluorescein - Use glassware to make calibration solutions. - Use MicroLab 10-color Colorimeter to measure fluorescence vs. concentration	-Find best-fit software function for fluorescence vs. concentration -Graph calibration curve to solve for concentration of unknown sodium fluorescein.
Colorimetry, Fluorimetry, Nephelometry & Turbidimetry: Week 6 *Class Application Problem*	-Create standard solutions for calibration curves. -Determine analytical wavelength for colorimetric, turbidimetric, and fluorimetric analysis.	- Use glassware to make calibration solutions. - Use 10-Color Colorimeter to for colorimetric, fluorometric, turbidimetric determinations of unknown aqueous solutions.	- Use equations: $A=\varepsilon_\lambda l[C]$, Turbidity=$\varepsilon_\lambda l[C]$, and $K_{sp}=[X^-][Y^+]$ - Graph and curve-fit of phenomenon versus vs. known concentrations to solve for unknowns.
Week 6 *R.E. Application Problem*	-Analyze ions in solution via spot plate/Test Matrix. -Choose the best spectroscopic approach for determination of unknown ion in solution.	- Use 10-color Colorimeter in any one of its modes, colorimetric, flourometric, or trubidimetric, to determine concentration of a single unknown ion.	- Calibration curve assist in solving for the concentration of ions in solution. This helps to solve for the stoichiometric balancing of the molecular formula.
Week 7: Qualitative & Quantitative Analysis of H_2O:	-Create standard solutions for calibration curves. -Analyze ions in solution via spot plate/Test Matrix.	- Use glassware to make calibration solutions. - Use 10-Color Colorimeter to for colorimetric, fluorometric, turbidimetric determinations of unknown aqueous solutions.	- $A=\varepsilon_\lambda l[C]$, Turbidity vs. [C], $K_{sp}=[X-][Y+]$, and solving for Balanced Molecular formulas from concentration of ions in solution. Double checking this result w/ conductivity vs. concentration of ions.
Week 7: *R.E. Application Problem*	-Analyze ions in solution via spot plate/Test Matrix. -Create calibration curve of conductivity versus concentration of ions in solution.	- Use a conductivity probe to calibrate and collect in units of *Semens* for determination of quantity of dissolved ions in an aqueous solution	-Use equations: Conductivity versus concentration of ions in solutions

Table 6: Supporting Experimental Process - Research design and techniques and math and measurement skills & tools are mapped out so that instructor can supply materials for students to solve problems.

These inventories in Tables Five and Six are an example of how the entire semester of experiments were coordinated into a logical sequence. This organizational strategy was the key to combining both chemical content and experimental laboratory processes so that logical concepts could evolve over a series of consecutive laboratories.

The Importance of Laboratory Sequencing – An Example

Laboratory experiments were sequenced to help students recognize and transfer knowledge, skills, and tools from one laboratory experiment to the next. To explain the structure of Research Extensions, three consecutive weeks of laboratories will be presented with actual student data (Figure 27 and following text).

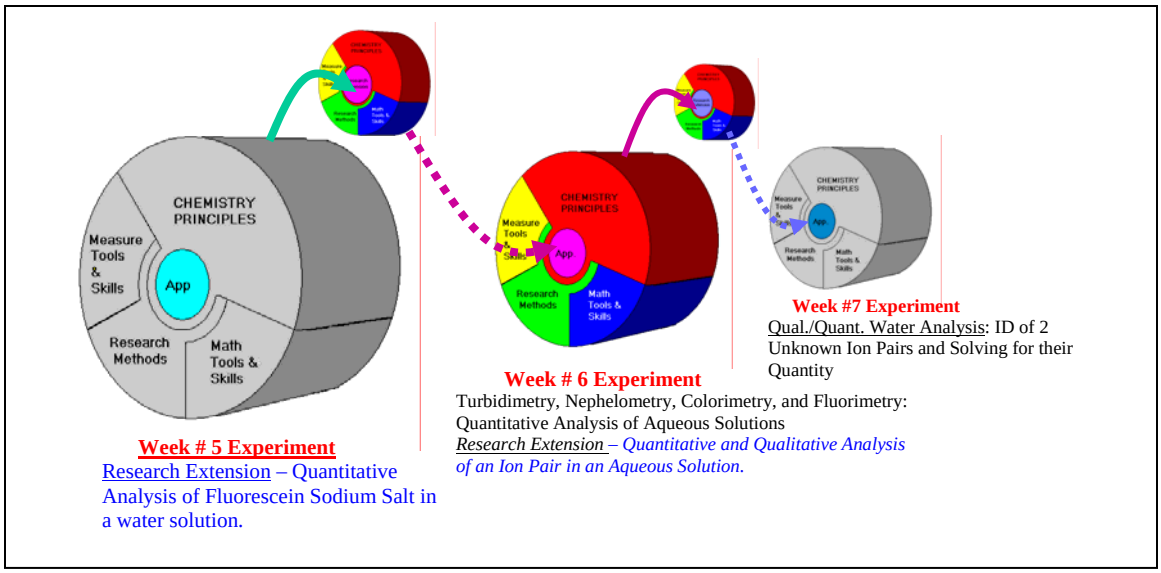

Figure 27: Sequencing Example - Three consecutive weeks of planned laboratory experiment, week five through week seven, are explained to show the impact of sequencing in this laboratory approach.

After completing the class application problem, Week-Five Research Extension Group, a group of four students, were asked, "What is the concentration of an unknown aqueous sodium fluorescein solution?" In this experiment, students first used light emitting diodes to determine the best excitation wavelength for analysis of the unknown

solution (Figure 28). This qualitative determination was validated with a spectral scan of the solution with MicroLab's 10-color colorimeter (Figure 29).

Figure 28: Excitation of aqueous sodium fluorescein with a 472nm LED.

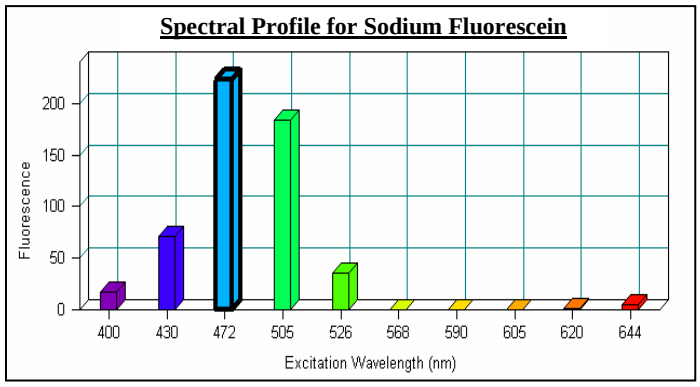

Figure 29: Excitation Spectra of Sodium Fluorescein with MicroLab's 10-color colorimeter.

Next, the Research Extension group made three standard calibration concentrations from the stock solution of Sodium Fluorescein (CAS # 518-47-8) and created a calibration curve with the MicroLab ten-color colorimeter and used the 472nm LED as the analytical wavelength for fluorometric determination. After performing a linear curve-fit of fluorescence versus concentration, students solved mathematically for the unknown concentration, finding that they were within 6.2% of the actual value, 1.0 X 10^{-6}M Sodium Fluorescein (Figure 30).

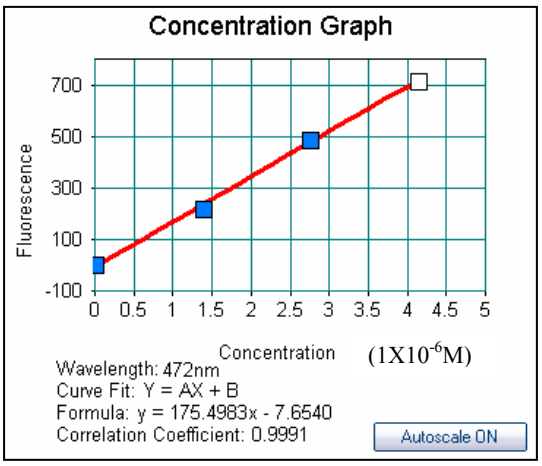

Figure 30: Fluorometric Calibration curve using 472nm LED as the analytical wavelength.

In the beginning of the following lab period, the Week-Five Research Extension Group explained their experiment and results. This presentation helped the rest of the class to develop ideas for solving the week-six class application problem, "What are the concentrations of unknown colored, turbid, and fluorescent solutions?" Afterwards, students fluorimetrically determined the unknown concentration of quinine in club soda and then made similar calibration curves based upon the chemical phenomena of absorbance and scatter in aqueous solutions (Appendix E: Lab Experiments, Research Extension Lab Experiments, and Student Reports).

After completing these three experiments in lab, the Week-Six Research Extension Group solved their Research Extension Application Problem, "What ion pair exists in an aqueous solution and what are their respective concentrations?" In this experiment, the Research Group qualitatively identified an unknown salt solution via spot-test matrix method. After students identified the salt solution, they quantified its concentration with one of the previously learned approaches. These methods included colorimetry, turbidimetry, nephelometry, or fluorimetry. For example, one Research

Group qualitatively determined that the aqueous solution of Unknown W was $Fe(NO_3)_3(aq)$ (Figure 31). They decided that a colorimetric analysis would be most appropriate in determining its concentration. After students made dilutions from a stock solution of known $Fe(NO_3)_3(aq)$, they chose the best wavelength, a 400nm LED, for analysis with data from the MicroLab 10-color Colorimeter (Upper absorbance "Spectrum Profile" in Figure 32).

SPOT TEST

W		clear no PCT	clear no PCT	red PCT	yellow (aq)	orange hue no PCT
	$HCl_{(aq)}$	$HNO_{3\,(aq)}$	$H_2SO_{4\,(aq)}$	$KSCN_{(aq)}$	$K_2CrO_{4\,(aq)}$	$NH_4OH_{(aq)}$
$Fe(NO_3)_{3\,(aq)}$	slightly yellow no PCT	clear no PCT	clear no PCT	red PCT	yellow (no PCT)	orange hue no PCT
$Ba(NO_3)_{2\,(aq)}$	clear no PCT	clear no PCT	white no PCT	clear no PCT	yellow PCT	clear no PCT
$AgNO_{3\,(aq)}$	white PCT	clear no PCT	clear no PCT	white PCT	red PCT	clear no PCT
$Ni(NO_3)_{2\,(aq)}$	clear no PCT	clear no PCT	clear no PCT	clear no PCT	clear no PCT	clear no PCT
$Pb(NO_3)_{2\,(aq)}$	white PCT	clear no PCT	white no PCT	clear no PCT	yellow PCT	white PCT
$CuSO_{4\,(aq)}$	slightly yellow no PCT	clear no PCT	clear no PCT	yellow no PCT	yellow PCT	blue no PCT

Figure 31: Spot Test - Research Extension Group's spot-test matrix determination of $Fe(NO_3)_3$.

Once the students scanned their unknown with the 10-Color Colorimeter (described in the next chapter) they found that it was out of range of the calibration curve. After a group discussion, students recognized the analytical inappropriateness of extrapolating so far outside of the calibration curve. To solve this problem, the Research Group diluted their unknown to one-half of its original concentration and scanned it again. The unknown concentration fell outside of the calibration curve again, so students

diluted the unknown to one-half of this value and scanned once again ("Concentration Graph" of Figure 32).

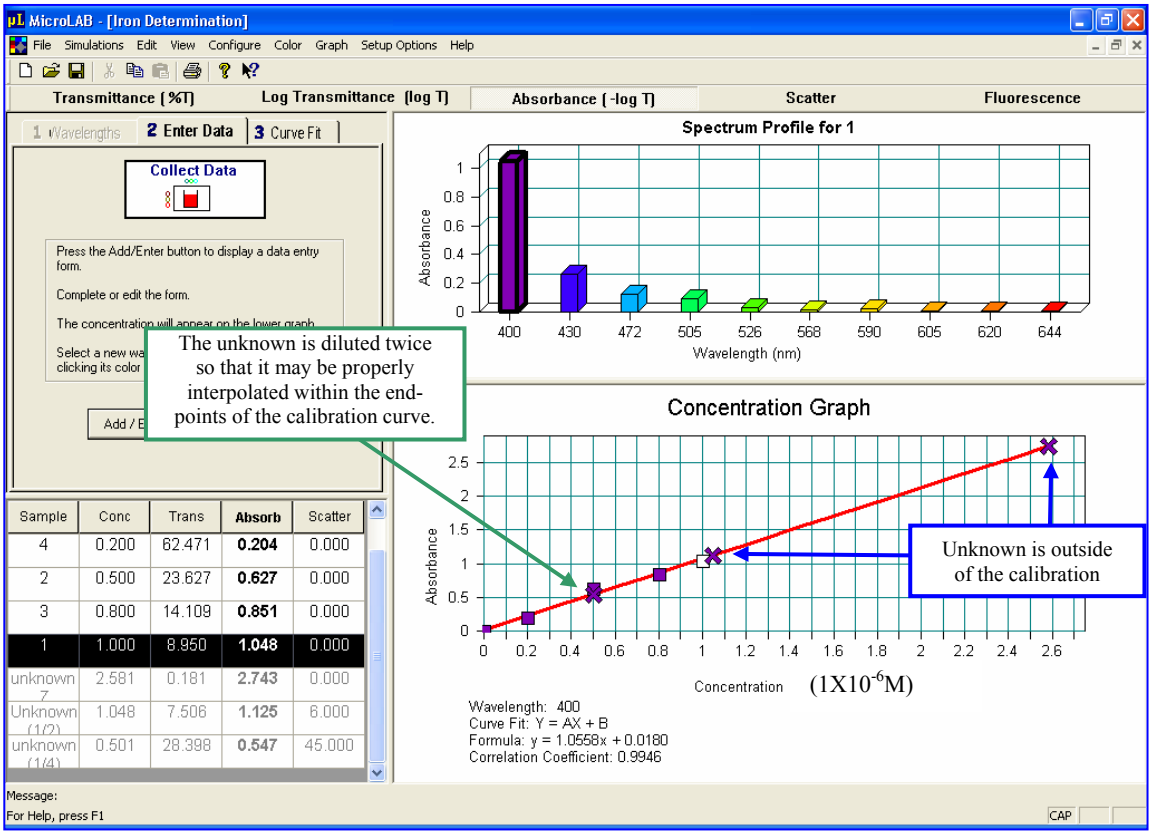

Figure 32: Colorimetric Calibration Curve - 400nm LED is used as the analytical wavelength to solve for the unknown concentration of $Fe(NO_3)_3$. To properly interpolate this value, the original unknown must be diluted twice.

During the research group meeting, students presented the calculated concentration of the final dilution of $Fe(NO_3)_3$ to be $0.501X10^{-2}M$. During this meeting, students recognized that this value was 25% of the actual unknown value. This was due to two consecutive dilutions to one-half the original concentration.

In week seven, the Week-Six Research Extension Group presented their research methods for using a spot test to qualitatively identify unknown ions. They also described their colorimetric analysis of aqueous Iron (III) Nitrate that determined its concentration

to be 2.004 X10^{-2}M. Since the actual concentration was 2.000 X10^{-2}M $Fe(NO_3)_3$*(aq)*, students were pleased to demonstrate their results of 0.200% experimental error.

After the Week-Six Research Group's oral presentation, the entire class pursued the week seven class application problem, "What two ion pairs exist in an aqueous solution and what are their concentrations?" Similar to the Week-Six Research Extension Application Problem, students qualitatively identified the mixture of two different salts that were dissolved into water via spot-test matrix. Afterwards, students measured a volume of the unknown solution and separated out the metal cations with the help of a solubility table, K_{sp}, and a centrifuge. Once separated, the analyte was re-dissolved into solution and its concentration determined via previously learned spectroanalysis.

One of the most important aspects of sequencing the labs was that students shared their experiences with each other, passing on knowledge and techniques that would help their lab mates to explore future lab problems. At times, laboratory materials would limit students' imaginations, but they were able to access the lab instructor, the worldwide web, the CRC handbook of constants and multiple textbooks for ideas and support. One intended outcome for doing this was to help students become more self-reliant in the lab.

CHAPTER 9

IDENTIFYING AND INTEGRATING SECOND SEMESTER CHEMISTRY CONTENT THAT IS IMPORTANT FOR ENGINEERING STUDENTS

The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them.
Sir William Bragg

Identifying and Supporting Second Semester Chemistry Content

Chemistry Content of Importance to Single Semester Engineering Curricula

This research study included a number of new laboratory experiments for both first and second semester general chemistry. This dissertation, however, focuses mainly upon new experiments that support chemistry content from the second semester. In Figure 10, the combined "Importance" of chemistry content from survey data of Engineering and Chemistry faculty is graphed to show the six top rated areas from the second semester of chemistry general chemistry (Figure 33). The rating of each of these content areas was a combined average of chemistry and engineering faculty and was standardized so that the highest rated topic was assigned a value of 1.0. Therefore a rating of 0.50 standardized units or greater meant that at least half of the combined engineering and chemistry professors deemed these content areas important to engineering students.

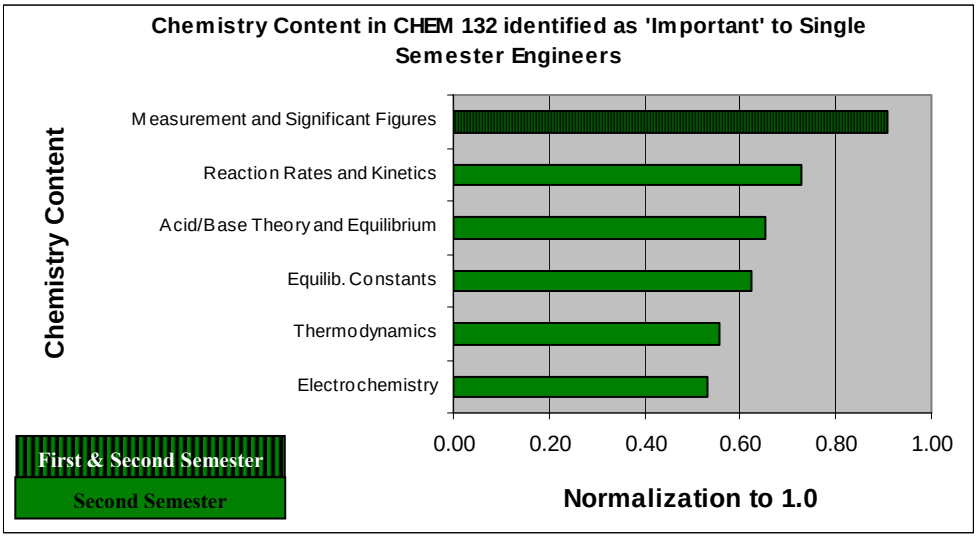

Figure 33: Second Semester Chemistry Content - The top rated chemistry content from second semester general chemistry were identified as important to single semester engineering students. Measurement and Significant Figures are carried over from the first semester.

These identified chemical content topics from second semester were then integrated into this single semester laboratory curriculum (Table 7).

Order of presentation (Week #)	Identified Chemistry Content from Second Semester of General Chemistry
Week # 1	1. Measurement and Significant Figures (BOTH SEMESTERS)
Week # 8	2. Thermodynamics
Week # 13	3. Electrochemistry
Week #14	4. Acid-Base Theory, Equilibrium, and Equilibrium Constants
Week #15	5. Reaction Rates and Kinetics

Table 7: Chronology of second semester chemistry content.

Supporting Chemistry Content for Single Semester Engineering Curricula

This chapter describes key experiments developed for the single semester engineering laboratory. Each of the experimental descriptions in this chapter begin with a

flow chart that describes specific student learning objectives in each area of *Application Problem*, *Chemical Principles*, *Experimental Research Skills and Design*, *Measurement Skills and Tools*, and *Math Skills and Tools* (Figure 34). Following the flow chart, a brief narrative explains the student's experimentation, the required laboratory materials and experimental set-up, and typical student data. (Note: Expanded flow charts are found in Appendix D: Laboratory Outlines)

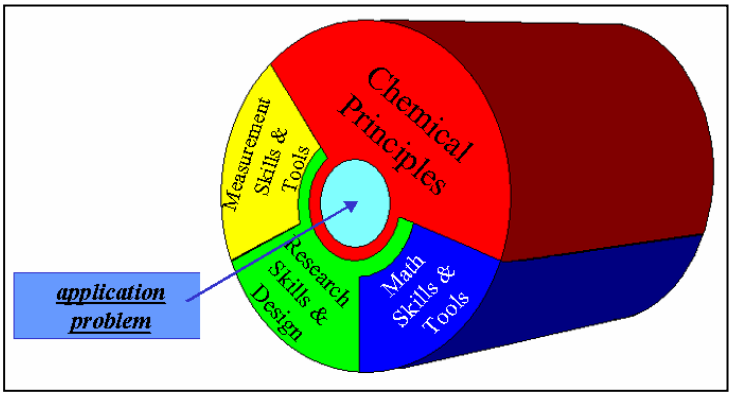

Figure 34: Conceptual elements of each experiment was built around an application problem.

Measurement, Significant Figures, and Statistical Variation of Data

Measurement and Significant Figures was rated as the most important content area of interest to both chemistry and engineering faculty (Figure 33). To address this, a concurrent thread that emphasizes measurement was integrated into the entire semester of this laboratory curriculum. Students began the first day of labs with an experiment involving measurement and significant figures.

During the first three weeks of lab, engineering students were introduced to some of the tools and skill-sets of modern measurement technology. This included the

collection of data with several easy-to–use instruments, such as a DVM, a handheld Fluke Thermocouple device, and a computer interface. Two short experiments were designed to help students determine significant figures and the statistical variations that are found when collecting large data sets (Figure 35).

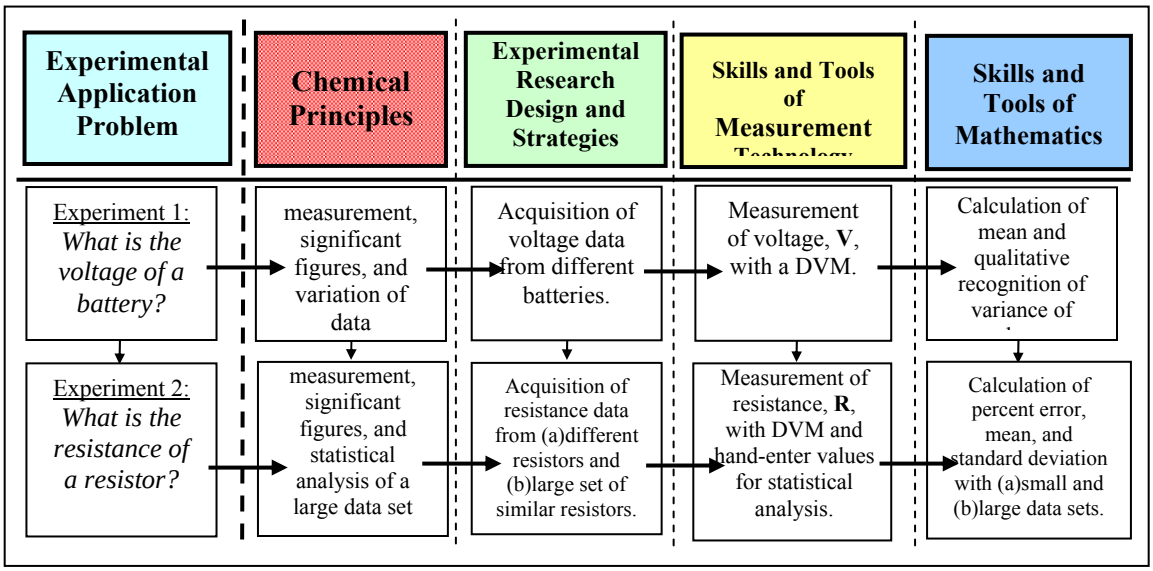

Figure 35: Measurement - A flow chart for students to solve experimental application problems about the identified Chemistry Content area of Measurement, Significant Figures, and Statistical Variation.

Experiment 1: Significant Figures Through Use
of DVM and Measuring Voltage

Student Objectives:

- Students will learn to measure voltage with a Digital Voltmeter (DVM).
- Students will observe that significant figures are a function of read-out device limitations.
- Students will observe variation of measurement from similar populations of batteries.

The experiment began with asking students, "What is the voltage of a battery?"

The first experimental read-out tool that students experimented with was a DVM. They

learned that voltage was a measurement of electromotive force. Students measured the voltage of an AA battery with their DVM (Figure 36).

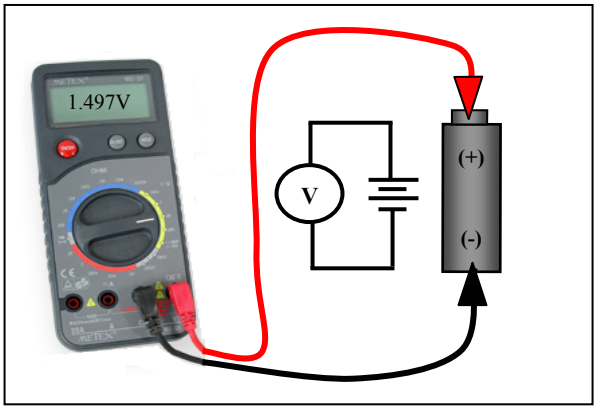

Figure 36: Battery Measurement - This is a physical drawing of how to measure the voltage of a 1.6V battery and the circuit diagram of this in the upper left-hand corner.

The DVM that students used, the Metex ™ ME-31, has a 3-3/4 digit display. The first three digits from the right are integer values that range from zero to nine while the fourth digit, furthest to the left, displays integer values between zero and three. Thus the read-out has a maximum and minimum range of +/- 3.999.

When measuring a 9-V alkaline battery, the students found that only three digits from the right displayed the appropriate values, 9.34V. As a result, only three significant figures were measured, instead of four, thus a loss of one significant figure, as compared to the 1.5-volt battery, was due to the limitations of the DVM display.

Finally, students passed their AA and 9V batteries around the lab and recorded each of the individual values. After calculating an average from the ten batteries of each type, students observed that, despite similar packaging, these batteries have variations in cell voltage (Table 8).

Battery Type	Measured Voltages	Average Voltage
AA/1.6V	1.601V, 1.582V, 1.509V, 1.564V, 1.566V, 1.601V, 1.530V, 1.524V, 1.536V, 1.497V	1.551V
9V	9.04V, 8.95V, 9.35V, 9.34V, 8.94V, 9.37V, 9.38V, 8.96V, 9.10V, 9,16V	9.16V

Table 8: Battery Data - A population of similar batteries vary in voltage.

Experiment 2: Statistical Variation in Data Using a DVM and Measuring Resistance

Student Objectives:

- Students will learn to measure resistance with a DVM.
- Students will observe significant figures are a function of read-out device limitations.
- Students will observe variation of measurement from similar populations of resistors and will apply statistics for analysis.

In this experiment, students used the DVM to measure the resistance of several different resistors. Students learned how to read each resistor's color code and corresponding accuracy (Figure 37).

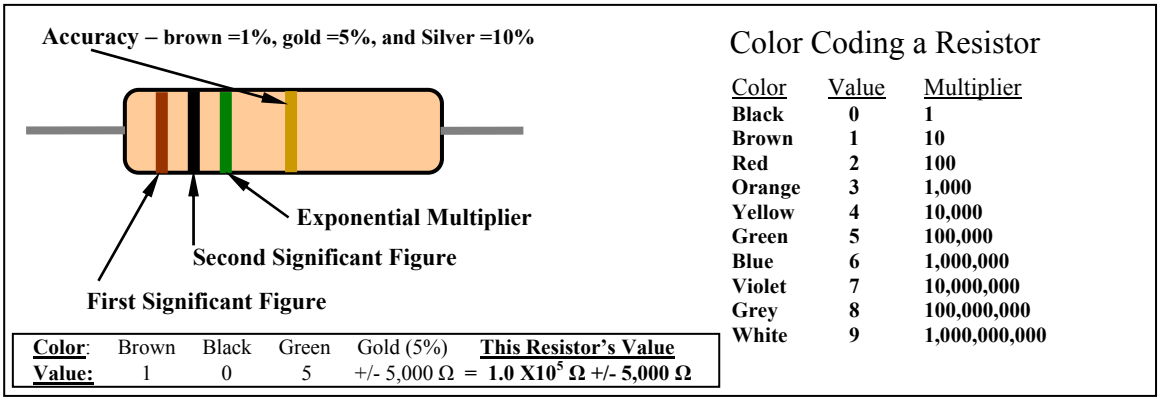

Figure 37: Resistor Color-Code – Five and ten percent resistors use four color-coded bands to indicate resistance values. The first two bands from the left are the first and second significant figure. The third band is the decimal multiplier. A fourth band indicates the accuracy of the resistor – a Silver band indicates 10% accuracy, while a gold band indicates 5% accuracy.

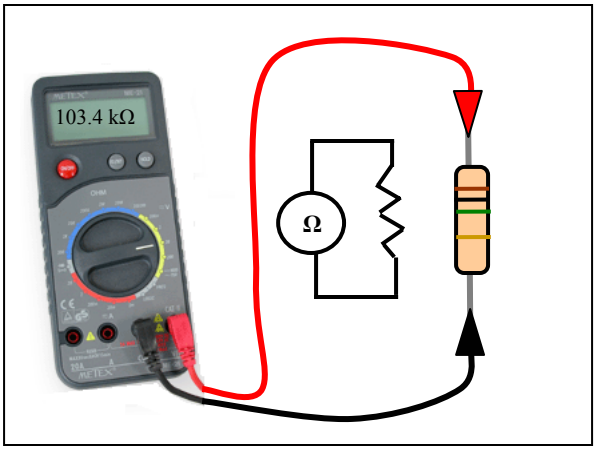

Figure 38: Resistor Measurement – The DVM need only be dialed to 'Ω' to read out the resistor values in ohms.

Physically arranging these five resistors from least to greatest, students measured their values with a DVM (Figure 38). As before, students observed that the actual measured value may be displayed with up to four significant figures, such as 103.4kΩ. When the largest digit had a value greater than 3, for example 676Ω, a significant figure was dropped due to limitations of the DVM's digital display.

Resistors	Color Code	Predicted Resistance Value (Ω)	Measured Resistance Value (Ω)	Measured Significant Figures	Calculated % error (within +/-5%)
1	Brown, Green, Yellow, & Gold	$15X10^4$	148,700	4	-0.87%
2	Orange, Orange, Orange, & Gold	$33X10^3$	32,550	4	-1.4%
3	Brown, Black, Red, & Gold	$10X10^2$	1,005	4	+0.50%
4	Blue, Grey, Brown, & Gold	$68X10^1$	676	3	-0.59%
5	Brown Black, Brown, & Gold	$10X10^1$	99.2	3	-0.80%

Table 9: Resistor Data - Data acquired from the five resistors.

Next, students calculated error to validate the fourth colored band, where:

[Measured Value – Nominal Value]/ [Nominal Value] X 100% = % Error (1)

These data, the color-coding, the predicted resistance values, the measured resistance values, the significant figures, and the calculated percent error, were collected and entered into a data table (Table 9).

This experiment was practical, quick, and easy. Students collected data that demonstrated how well each resistor matched its color-coded value, but most importantly it introduced them to the idea that significant figures are dictated by limitations of the laboratory instrumentation.

Finally, students explored the concept of variation in experimental data by collecting values from a larger data set. Working in groups of four, students measured fifty or more resistors with the same color-coded value and hand-entered them into MicroLab's data acquisition software. Plotting the measured resistance versus resistor number, students created and printed out a graph.

Using the MicroLab software, students calculated the mean and standard deviation of the resistor values. In one example, students found that seventy-two resistors color-coded as 150kΩ had a calculated mean and standard deviation of 149.8Kohm and 0.7053Kohm, respectively. Next, students used a ruler and pen to draw lines on the graph that represented the mean and resistances that are one standard deviation, $\pm\sigma$, and two standard deviations, $\pm 2\sigma$, away from the mean, respectively (Figure 39). Finally, students counted the number of data points within plus or minus one standard deviation of the mean and again for two standard deviations from the mean. In this example 63.9% of the resistors were within $\pm 1\sigma$ and 94.4% were within $\pm 2\sigma$. A theory of statistics was presented that explained that these values would tend to 68% and 95% as the population went to infinity (Christian 2004). From these data, students calculated the percent error of this population of resistors to be 0.47% within $\pm 1\sigma$ and 0.94% within $\pm 2\sigma$ of the calculated mean. Other groups of students used different sets of resistors that had different variances.

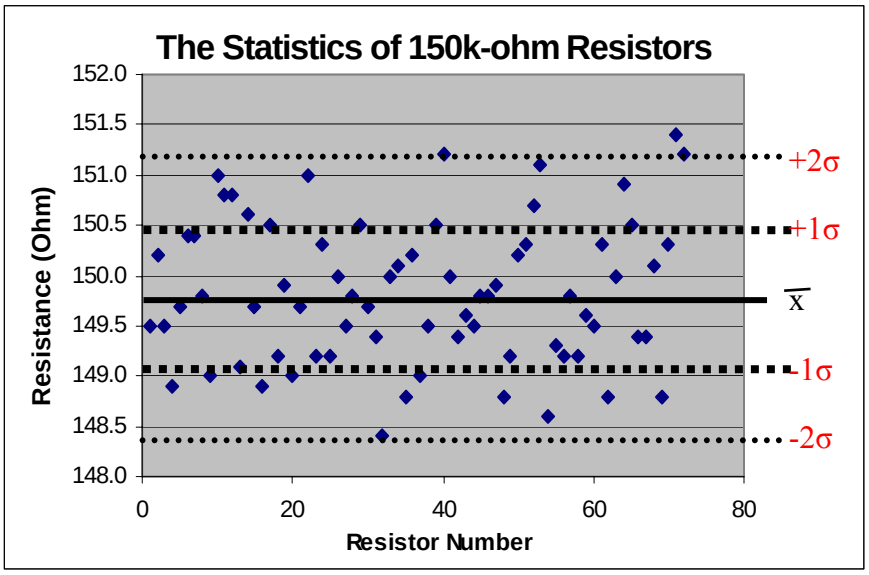

Figure 39: Resistor Statistics – The values of seventy-two 150 K-ohm resistors and the corresponding statistical values.

These experiments demonstrate how measurement technology gives students the ability to easily and quickly collect experimental data. Not only do students encounter the importance of significant figures as a function of instrumental limitation, but they are also able to observe that large data sets have randomized scatter that are best analyzed and explained through statistical analysis.

Thermodynamics and High Resolution Thermometry

Many types of thermal transducers are commercially available. In the next three experiments, students explored the output of two different linear IC temperature transducers (Figure 40). From this, they learned how to calibrate sensor output with software so they could accurately determine small changes in temperature, 0.01^{o}C. Finally, the high-resolution thermometer was used to collect data to identify an unknown solid by calorimetric determination of Enthalpy of Solution.

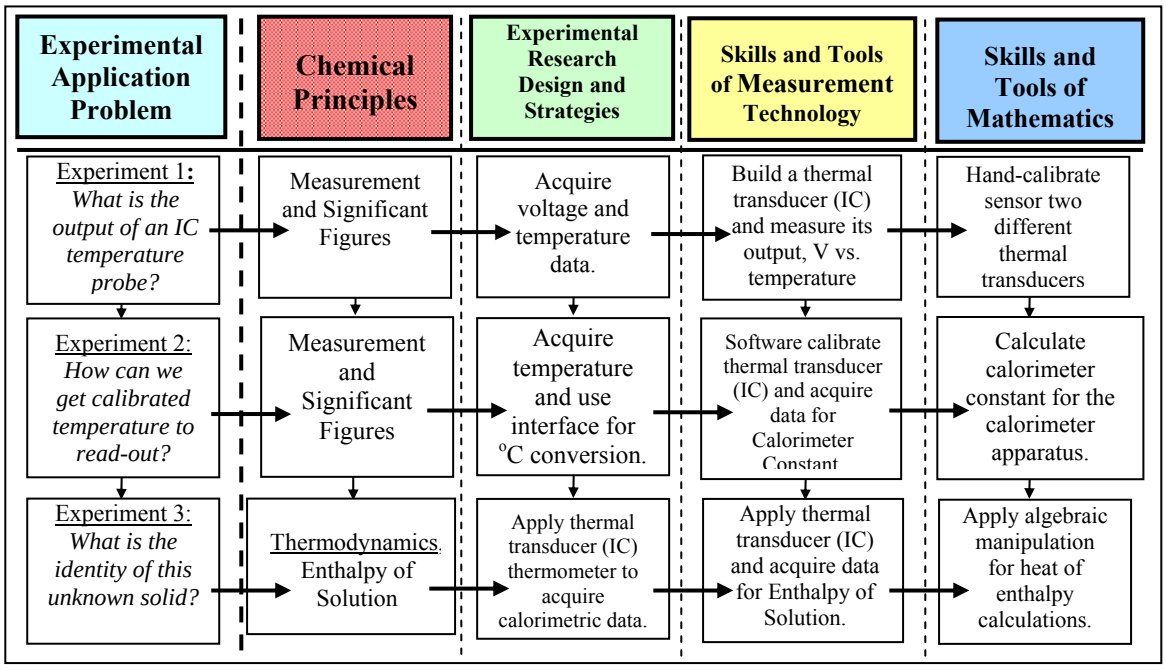

Figure 40: Thermodynamics – A flow chart of components for students to solve experimental application problems about the identified Chemistry Content of Measurement, Significant Figures, and Thermodynamics through high resolution thermometry.

Experiment 1: Understanding IC Sensors a
nd Measuring Temperature

Student Objectives:

- Students will measure the output of two different IC temperature sensors.
- Students will use IC output data to derive a linear calibration curve.
- Students will use software to validate their linear hand-calibration and use it to easily translate voltage output values to ^{o}C values.

Students worked with two integrated circuit (IC) thermal transducers, National Semiconductor's LM35 and LM34. Powered by a 9-volt battery, these ICs produced weak voltage outputs calibrated to Celsius and Fahrenheit temperature scales. The sensor output was connected to a DVM (Figure 41).

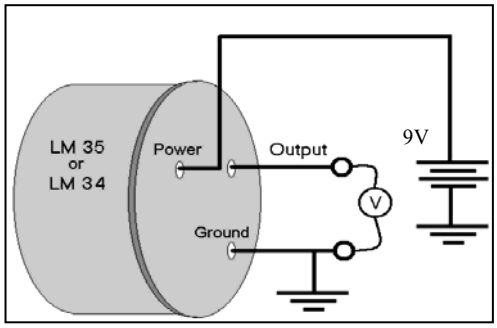

Figure 41: Linear Temperature IC - Configuration of the 3-pin IC temperature transducers.

Next, students collected two sets of data from each of the IC sensors with a DVM. This included placing a thumb and then an ice cube in thermal contact with the IC's metal surface. Students first observed a voltage increase and then a decrease, with both the LM35 or LM34 thermal transducer.

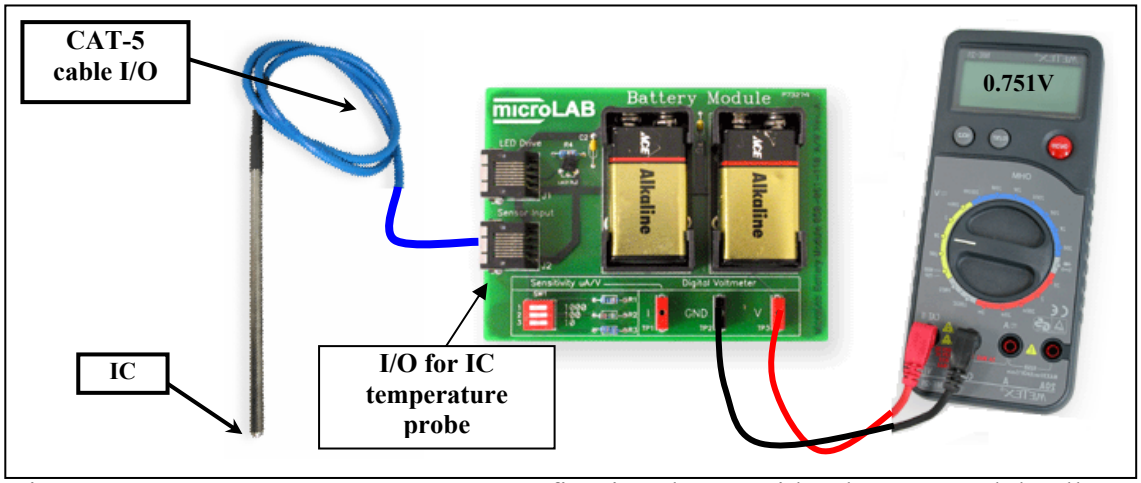

Figure 42: IC Temperature Sensor – Configuring the IC with a battery module allows for quick read-out of sensor voltage output with a DVM.

To safeguard against corrosive or conductive effects of a solution, students used LM34 and LM35's that were securely silver-soldered into the end of a stainless steel tube. One of the mounted "IC probes" was then connected to a Battery Board Module and DVM for read-out (Figure 42).

Students collected output values for these ICs in water baths of various temperatures and recorded the corresponding temperature values to the nearest 0.10°C with a temperature meter (Table 10). Students hand-plotted and then hand-calculated the slope intercept formula to calibrate each sensor (Equation 2 and 3 and Figure 43).

Temperature Sample	DVM Reading from LM-34 (V)	DVM Reading from LM-35 (V)	Measured Temperature with a FLUKE Thermocouple
Your Thumb	0.965	0.3471	----------
A) Ice-water slush	0.3390	0.01282	0.0°C
B) Water (room temp.)	0.704	0.2047	20.0°C
C) Water (above room temp.)	0.892	0.3042	30.0°C
D) Water (below room temp.)	0.531	0.1120	10.0°C

Table 10: IC Temperature Probe data were acquired from water baths, Fluke thermocouple (°C), and IC sensor output (V).

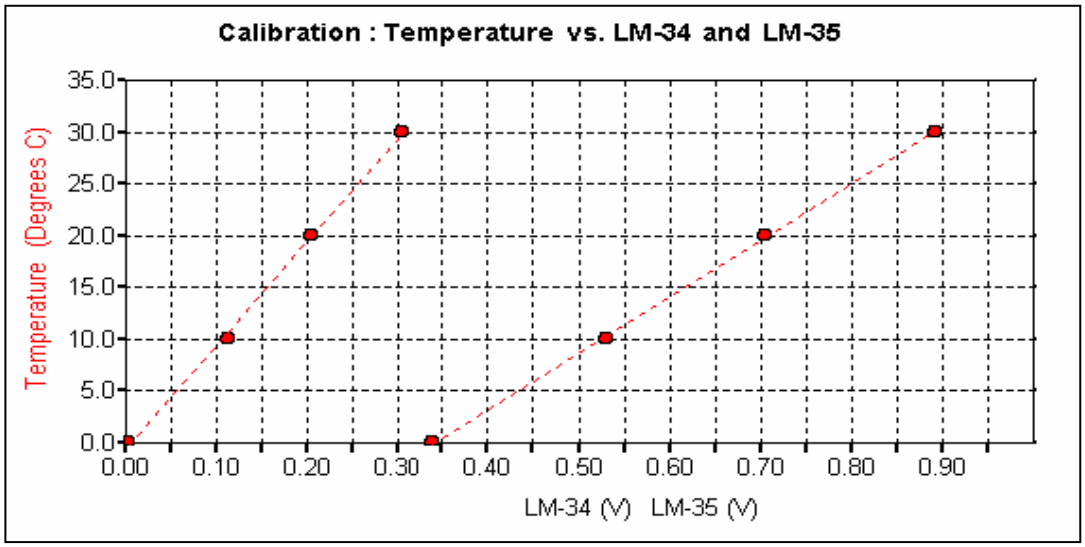

Figure 43: Hand-Calibration - Students hand-plot temperature vs. LM34 and LM35 output on graph paper to see that these are linear temperature sensors are different.

This part of the experiment provided students with experience in graphing and point-slope calculation of data to derive the equations:

$$Y_{LM34} = (54.5^{o}C/V)\ XV - 18.6^{o}C \qquad (2)$$

$$Y_{LM35} = (99.8^{o}C/V)\ XV - 0.517^{o}C \qquad (3)$$

With these equations, students converted the previously measured thumb temperature values from the LM34 and LM35, 0.965V and 0.347V, into degrees Celsius, 34.0°C and 34.1°C, respectively. With an observed difference of 0.1°C between the two different sensors, students recognized that the sensor output could be translated into a common measurement of temperature, °C. This hand-derived calibration curve was the first of many different types of calibrations that were performed throughout the semester. By convention, temperature should be plotted on the x-axis and voltage on the y-axis, however, students place temperature on the y-axis so that students get an equation that directly translates the output value of the sensor. This change in convention should be mentioned to students and is seen throughout this laboratory approach.

Finally, students hand-entered these data into MicroLab software, created a Voltage versus Temperature calibration graph, and performed a first order curve fit. In Figure 44, it can be seen that these data matched the student's hand-calculated calibration curve for the LM34 (Equation 2). The corresponding Pearson Correlation Coefficient demonstrated the linearity of these IC's, $R^2 = 0.9998$.

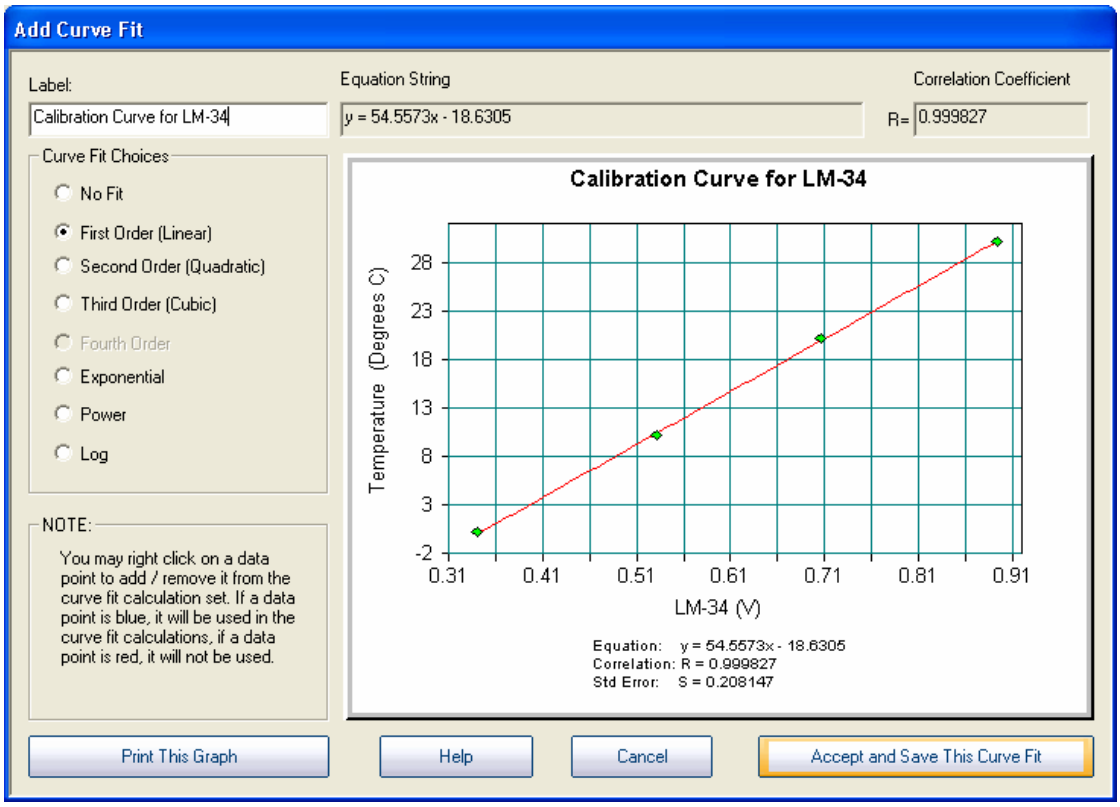

Figure 44: Software Calibration of Temperature IC –Students perform a linear curve-fit or first order function on these data to see if it matches their hand-calculated equation.

Not only is the linearity for the LM35 acceptable, but its equation, y = 99.7887x-0.5166, was used in software to convert the voltage (x-axis) into degrees Celsius (y-axis), and vice versa (Figure 45). For example, after the LM35 and LM34 have software generated calibration curves that converted thumb temperature output values, 0.347V for the LM35 and 0.965V or the LM34, into degrees Celsius. Students observed that the calibrated values had a common temperature of 34.1^{o}C. Also, if the LM35 temperature sensor output remained below a value of 399.9mV (approximately 40^{o}C), students would have four significant figures for read-out on their DVM, and can read to 0.01^{o}C.

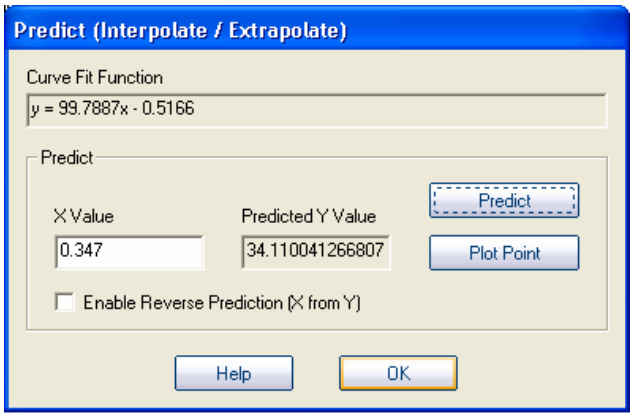

Figure 45: Software Predict Function – The linear calibration function of an LM35 is used to solve for values of ^{o}C.

Although students continued to use software for most of their mathematical computations and curve-fits, the efforts of hand calculating at least one calibration curve helped students to appreciate the benefits of computer-based measurement technology. (Note: This researcher was part of the team that developed, tested, and refined this software and hardware approach.)

Experiment 2: More Accurate Temperature Readings

Student Objectives:

- Students will learn how to calibrate with software and a high resolution Fluke thermocouple meter standard.
- Students will learn that multiple point calibration of an IC temperature sensor with microcomputer-based technology creates an accurate temperature measurement tool.

Like the DVM, the MicroLab interface can measure the voltages and currents from sensor outputs. The software used this input to create calibration equations for real-time data display of temperature, pH, or any other probe that students have previously calibrated. An onboard sixteen-bit analog to digital converter measured the output of a

sensor to one part in about 65,000. If calibrated with an appropriate standard, it would be possible for students to observe temperature changes to better than 0.003°C with this IC temperature sensor.

It was pointed out to the students, however, that the accuracy of a calibrated sensor was only as good as the calibration standard, where the typical alcohol glass thermometer is estimated by eye to only about 0.2°C and is certified to ±1°C (Fischer *Ever Safe* Thermometers, 2005). Instead, these four sections of laboratory for engineering students used a National Institute of Standard Technology (NIST) traceable Model #51 FLUKE thermocouple meters for calibration of their temperature sensors, whose certified accuracy was ±0.3°C and resolution of 0.1°C (Fluke Model 51, 2005).

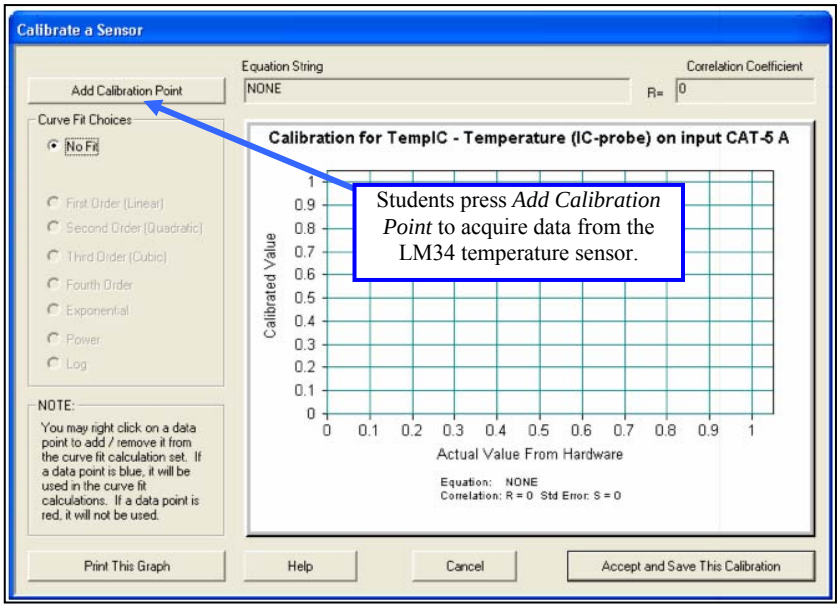

Figure 46: The Calibrate a Sensor screen is an interactive place where students can acquire data and perform a mathematical curve-fit for software calibration.

A LM34 IC temperature probe was connected to the MicroLab interface and calibrated (Figure 46). Students pressed *Add Calibration Point* to collect raw output from the LM34 IC temperature sensor.

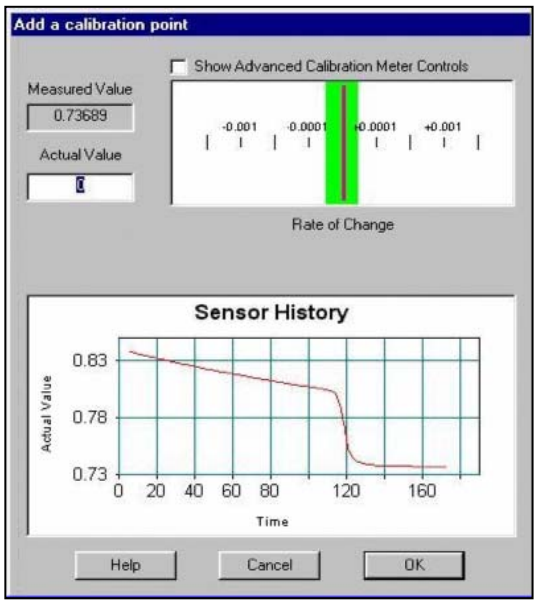

Figure 47: The *Add a Calibration Point* screen helps the student to accurately calibrate their IC temperature sensor.

The *Add a Calibration Point* screen has two unique and extremely useful displays. One critical aspect of the calibration procedure that students needed to be aware of was the time it took for a sensor to equilibrate or stabilize in its output readings. The lower portion of the screen displays a *Sensor History* that showed the sensor output versus time in seconds (Figure 47). Students were able to see that when they changed the temperature of a solution around a temperature sensor, it took several seconds for the sensor to warm up or cool to the new solution temperature, producing an output that accurately reflected the sensor's surroundings. Students could observe sensor output signals, displayed in the *Measured Value* box, just like the data that were collected with the DVM read-out, battery board, and IC temperature sensors in the previous section.

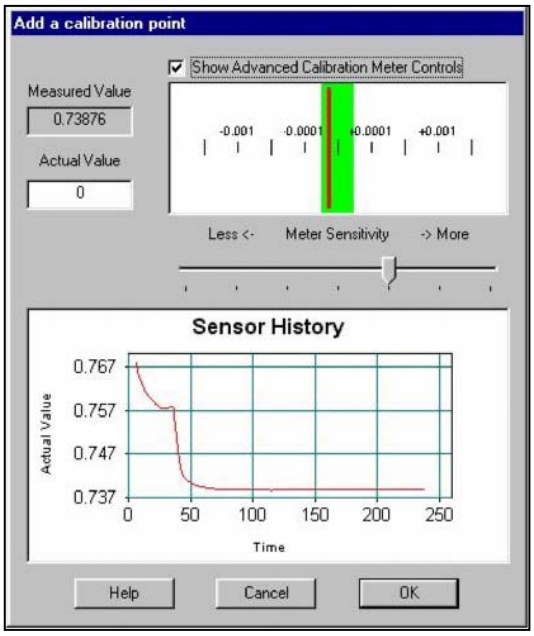

Figure 48: Clicking on the *Show Advance Calibration Meter Controls* helps students to adjust the displayed resolution of the rate of change of a sensor.

The other aspect of calibration, shown in the upper display with a green bar in the center and a moving red line was a *Rate of Change* meter, which displayed the direction and the rate that the temperature sensor output was moving (Figure 48). If the sensor output was moving up, the meter would read in the positive (+) part of the scale. If the sensor was output is moving down, the meter would read in the negative (-) part of the scale. Students learned that stirring the sensor in its standard solution helped the sensor to reach equilibrium more quickly. When the sensor finally stabilized, the red line was displayed within the boundaries of the green central band. If students clicked in the *Show Advanced Calibration Meter Controls* box, a meter sensitivity control would appear. There, students increased or decreased the sensitivity of the read-out so that they were able to measure an acceptable rate of change for each sensor that they used throughout the semester. In general, this control was run with as much sensitivity as could be maintained by the calibration method available.

As in the previous section, students used a zero degree Celsius temperature standard by making a slush of ice and water in a Styrofoam cup, placed the IC temperature probe and Fluke Thermocouple into the mixture, and hand-entered the thermocouple's read-out into the *Actual Value* box. When the sensor stabilized, students left-hand clicked on OK and the data point was recorded. Students prepared several additional standards by mixing hot and cold water, with one standard near the boiling point of water.

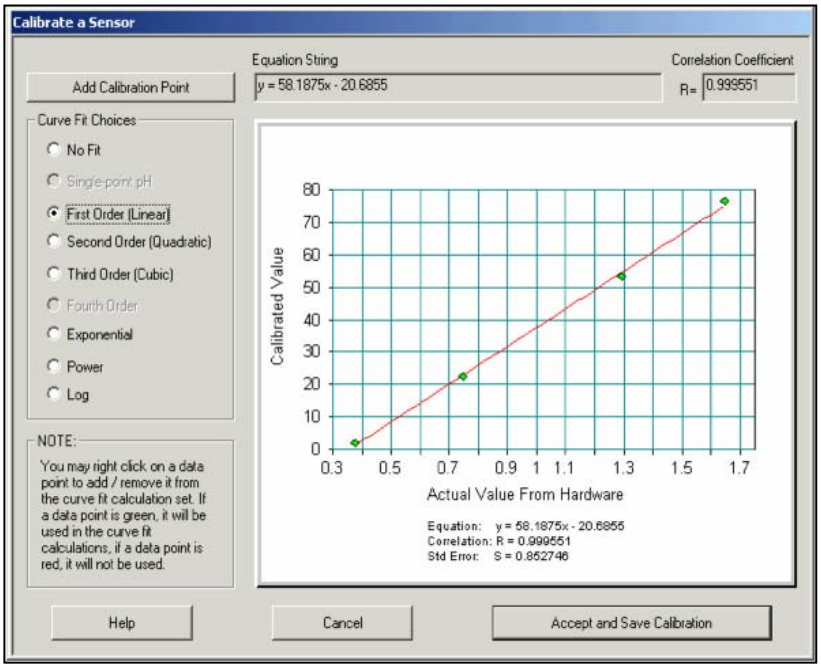

Figure 49: A linear regression curve-fit is plotted to fit the LM34 data acquired through the MicroLab interface. The point highest and to the right, however, has been collected in error.

Each time students recorded a data point; it was plotted on the calibration graph (Figure 49). When students had several points plotted, they performed a curve fit, just as they had previously done in the hand-entered data. Selecting the *First Order (Linear)* curve fit, students observed that the LM-34 IC temperature sensor had the same linear response as before, with the same equation for the linear regression.

If one of the student data points was recorded in error, they put their mouse over it and right clicked. The dialog box appeared and permitted them to remove this data point from the calibration curve data. The point turns red and remained on the graph, but was not used in the calculation (Figure 50). The rationale behind this feature was to let the students know that making mistakes are a part of experimentation, but that they are also ethically obligated to report and explain all of the data that are collected.

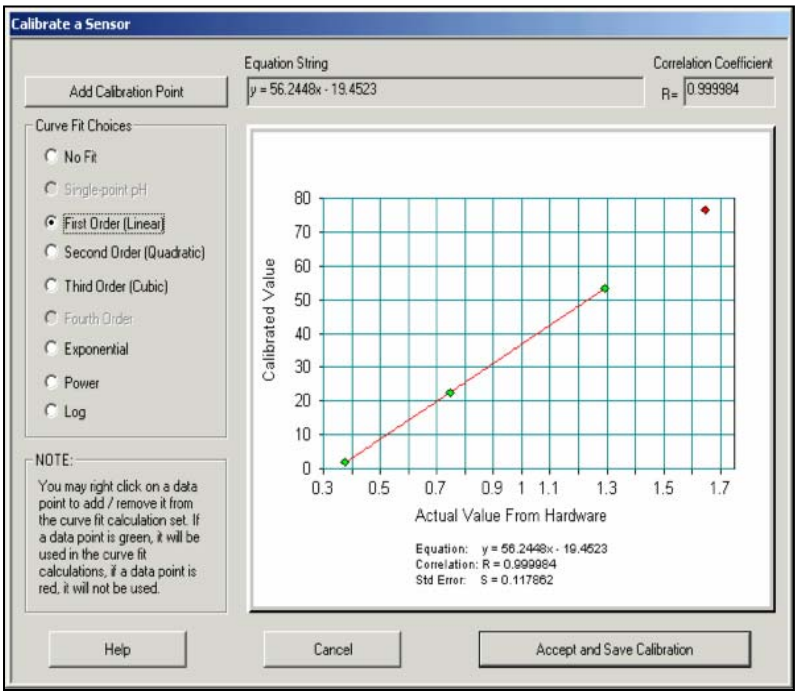

Figure 50: A data point that has been collected in error may be excluded from a linear regression curve-fit, but remains displayed on the graph. Students must justify any data point exclusion when presenting these data in the written or oral report.

Upon completion of the calibration routine, students repeated this process for any sensor and its corresponding standards that would be used throughout the semester. Logistically, a Fluke Thermocouple meter was shared at one laboratory table of four students who used it to calibrate their IC temperature sensors. The MicroLAB software

calculated the standard error and presented it along with the correlation coefficient, offering added information about the data points in regards to chosen curve-fit function. (Note: This researcher was part of the team that developed, tested, and refined this software and hardware approach.)

Experiment 3: Identifying a Solid by
Determining Enthalpy of Solution

Student Objectives:

- Students will apply the IC temperature sensor that they callibrated to a laboratory experiment.
- Students will apply their knowledge of the first law of thermodynamics in the transfer of heat between liquids and the Enthalpy of Solution of a solid.
- Students will solve for the identity of an unknown via heat of solutions.

Students used this software calibrated IC thermometer to determine the enthalpy of solution and solve for the identity of an unknown salt.

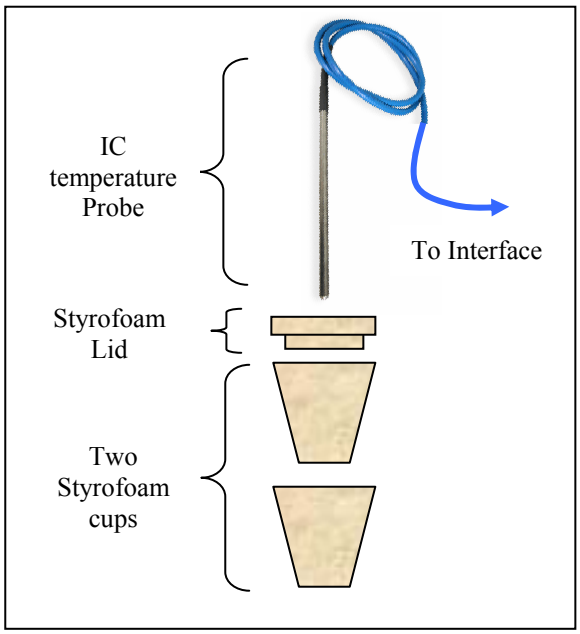

Figure 51: The calorimeter apparatus consists of double nested Styrofoam cups with lid and the IC temperature probe.

First, students applied their knowledge of conservation of energy to find a calorimeter constant for their reaction chamber, which consisted of a double nested Styrofoam cup with lid and their stainless steel temperature sensor (Figure 51). In a sample experiment, students obtained approximately 50g of hot water with approximately 50g of room temperature water, massing to the nearest $1/100^{th}$, and calculated the amount of heat that was transferred from the hot to the cold water. For example, when 47.60g of water at 22.50°C was placed in the double nested Styrofoam cup and then 53.00g of water at 38.50°C was added, an experimental equilibrium temperature of 30.57°C was observed. From this, students calculated the heat exchanged between the hot and cold water, where *q* is heat, m is mass of water, ΔT is the final temperature minus the initial temperature, and S.H. is the specific heat constant of water, 1.000cal/g°C (Brown, Lemay, and Bursten 2000):

$$q = (m \times S.H._w \times \Delta T) \qquad (4)$$

Theoretically, students expected that the heat of the hot water should have been completely absorbed by the cold water:

$$q_{hot} = -q_{cold} \qquad (5)$$

Instead, students found that the heat gained by the cold water, 381.8cal, was not equal to the heat lost by the hot water, -422.4cal. After performing this experiment, students deduced that the calorimeter apparatus was absorbing heat.

Adjustments were made to equation 7, accounting for the calorimeter, q_{cal}:

$$q_{hot} = -(q_{cold} + q_{cal}) \qquad (6)$$

Students then solved for the calorimeter constant, which was 5.17cal/°C, for this example.

Now that the calorimeter apparatus and set-up was understood, students massed approximately 50g of deionized water and placed it in the calorimeter, measuring the initial temperature of the water. Next, students massed an unknown solid, placed it into the calorimeter apparatus, and stirred until the solid completely dissolved and the solution came to a thermal equilibrium.

In this example, room temperature water at 22.55^{o}C was massed, 50.30g, and three pellets of unknown solid, 0.7716g, were placed into the calorimeter. The final temperature was 26.14^{o}C, where the ΔT was calculated at 3.59^{o}C. These values were used to calculate the heat of the reaction, q_{rxn}, attributed to the dissolution of the unknown solid into H_2O *(l)*:

$$q_{rxn} = -(q_c + q_{cal}) = [(m_c \times S.H._w \times \Delta T_c)+(C_{cal} \times \Delta T_{cal})] = 1.99X10^2 \text{ cal} \quad (7)$$

After dividing the experimental heat value by the mass of the solid, an average of three experimental test trials yielded a value of -258 cal/g. The reproducibility of this experiment was quite good, where the average percent error difference from the experimental mean was calculated at 0.200%.

Finally, students found values for heat of solutions for different solids in a CRC handbook. They discovered that values were listed in SI units of kJ/mol. Students either converted their experimental values into kJ/mol or the CRC catalog values into cal/g (CRC 74th Edition, p. **5**-101). Choosing the latter option, the value for NaOH*(s)*, - 44.5 kJ/mol, was converted into cal/g:

$$(-44.5 \text{ kJ/mol})(1.000\text{cal}/0.004184\text{kJ})(1 \text{ mol}/40.00\text{g NaOH}) = -266 \text{ cal/g} \quad (8)$$

and an experimental error was calculated at -2.65%.

In post lab discussions, students recalled observations of the hygroscopic nature of solid NaOH and recognized two potential errors. One error was a mass increase of NaOH due to water's adsorption onto the surface of the solid and the second was the reaction of the adsorped water with the solid NaOH. In both instances, this contributed to an overall lower enthalpy of solution or an observed negative percent error.

From these three experiments, students applied their prior knowledge of measurement and significant figures from previous experiments in the context of the interesting chemical phenomenon of enthalpy of solutions. Students were also able to achieve the first three learning objectives by creating a temperature sensor from scratch and applying it to solve a laboratory problem.

Electrochemistry and Electrogravimetric Analysis

The branch of chemistry that studies the exchange of electrons between atoms and molecules, electrochemistry, is in many ways a natural fit for understanding the basics of measurement technologies. In this series of laboratory exercises, students learned about measuring the difference in potential between two dissimilar elements and deriving the electrochemical series from a lemon battery and five different metals. Next, students performed a series of experiments to find the reduction potential of various metals. Finally, students used this information to electroplate a specified amount of Copper. An alternative laboratory experiment was also presented that asked students to experimentally determine the charge of a cation in solution (Figure 52).

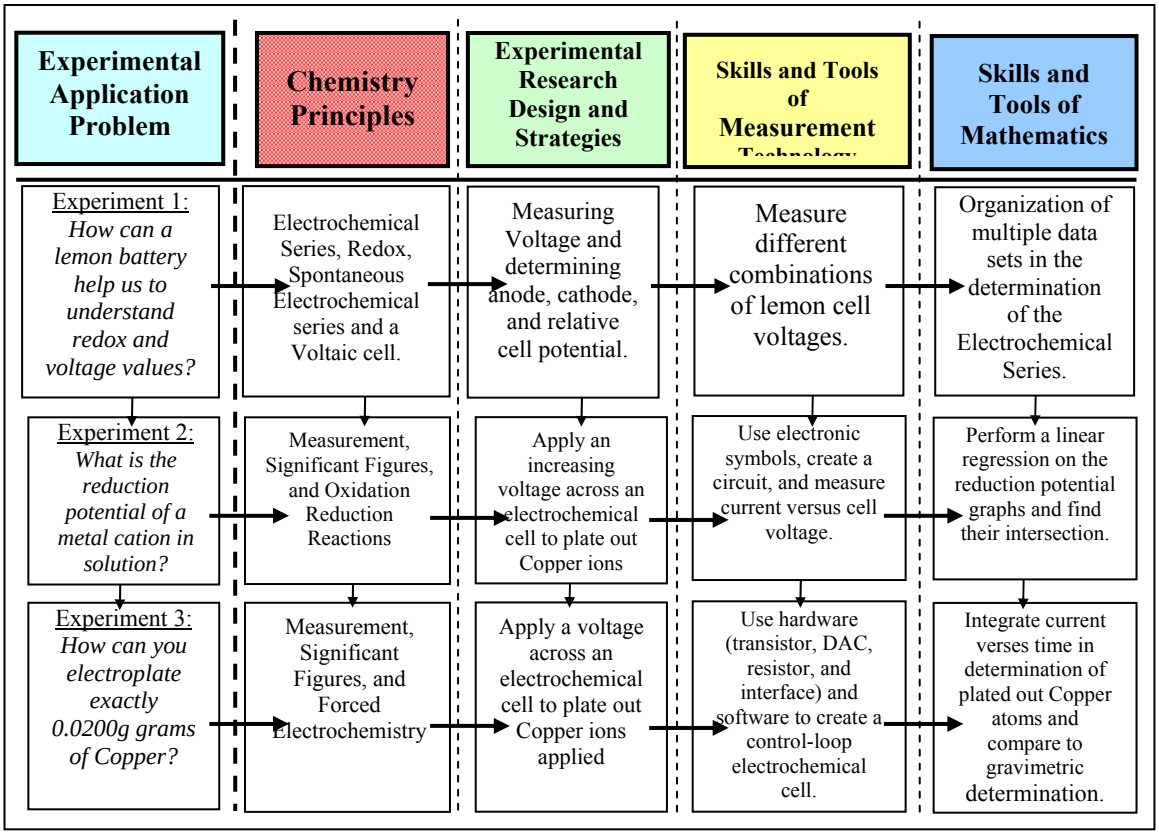

Figure 52: Electrochemistry - A flow chart of the necessary components for students to solve electrochemistry application problems.

Experiment 1: Constructing the Electrochemical Series via Lemon Battery

Student Objective:

- Students will derive the Electrochemical series through experimentation and measurement.
- Students will recognize repeating patterns from acquired data.

To pique the students' interest, a spontaneous electrochemical reaction was performed by placing a Copper wire in a solution of aqueous Silver sulfate. A theory is presented that explained that the Copper wire reduced the aqueous Silver (I) ion, becoming aqueous Copper (II) ion:

$$Cu^{o}(s) + Ag_2SO_4(aq) \leftrightarrows CuSO_4(aq) + 2Ag^{o}(s) \qquad (9)$$

This chemical equation was then presented as two half reactions, where students determined that for every Cu*(s)* metal atom oxidized, two $Ag^{+}(aq)$ were plated out:

$$Cu^{0}(s) \rightarrow Cu^{2+}(aq) + 2e^{-} \quad (10) \quad \text{and} \quad 2\,e^{-} + 2Ag^{+}(aq) \rightarrow 2Ag^{0}(s) \quad (11)$$

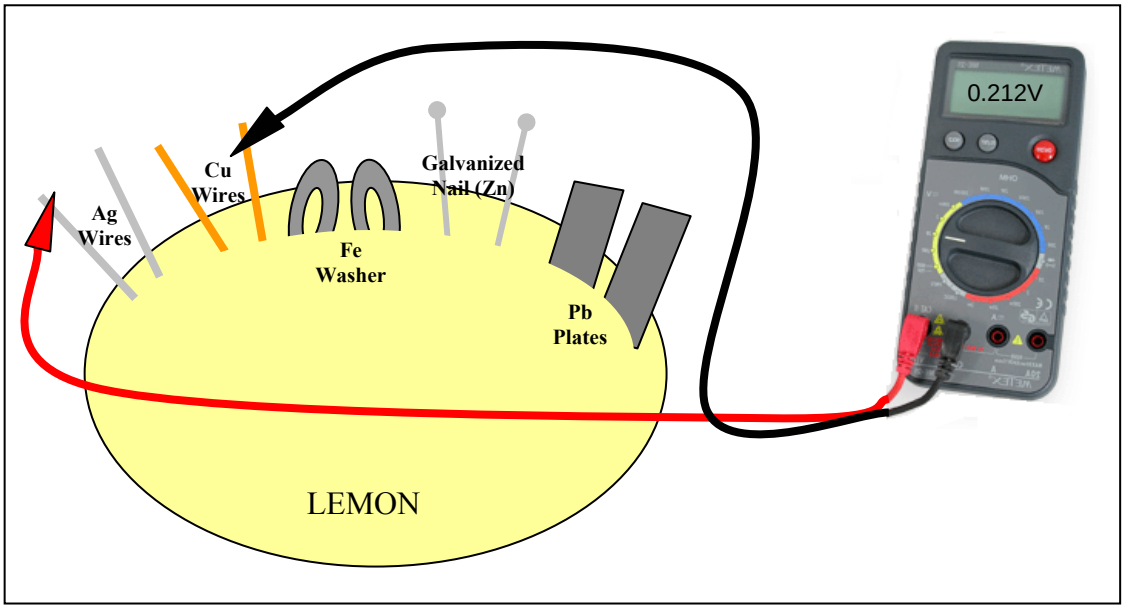

Figure 53: This simple lemon battery is an affordable and simple way for students to derive the electrochemical series without using a Standard Hydrogen Electrode.

Next students inserted five pairs of dissimilar metals into the top of a single lemon (Figure 53). The metals include two galvanized nails, two iron washers, two Copper wires, two Silver wires, and two lead plates. Students first connected the negative lead of the DVM to the Lead plate and touched the red test lead to each of the other metals. Students observed the resultant voltage from each of the different combinations and record their observations in a data table (Table 11).

Voltage of Pb with Pb = 0.000V
Voltage of Pb with Cu = +0.298V
Voltage of Pb with Fe = -0.173V
Voltage of Pb with Ag = +0.423V
Voltage of Pb with Zn = -0.596V

Table 11: Voltages of a lemon battery with Lead as the reference.

Next, students were asked to arrange these values from the most positive voltage to the least positive voltage. Using the previously discussed spontaneous electrochemical reaction and the sign of the voltage students decided which metal gained electrons and which metal lost electrons.

	Metal	Voltage	GAINS e^-	LOSES e^-	Neither
Most (+) Voltage	Ag	+0.423	X		
	Cu	+0.298	X		
	Pb	0.000			X
	Fe	-0.173		X	
Least (+) Voltage	Zn	-0.596		X	

Table 12: The data recorded displays the Electrochemical series and which metal would gain or lose electron.

Using data from Table 12, students were asked to predict the voltages that would be observed with at least two other dissimilar metals used as a reference. After checking their predictions experimentally, this hierarchical phenomenon was described as the Electrochemical Series, where their data and observations showed a repeated pattern of descending order from Ag, Cu, Pb, Fe, and Zn (Data Table 13). In this experiment, Silver (I) ion took electrons from all of the other metals.

Test Lead	**Zn** (reference)	**Pb** (reference)	**Ag** (reference)
Ag	+1.015V	+0.423 V	**0.000V**
Cu	+0.893V	+0.298V	-0.110 V
Pb	+0.592V	**0.000V**	-0.422 V
Fe	+0.420V	-0.173 V	-0.597 V
Zn	**0.000V**	-0.596 V	-1.018 V

Table 13: Experimental data show the Electrochemical Series.

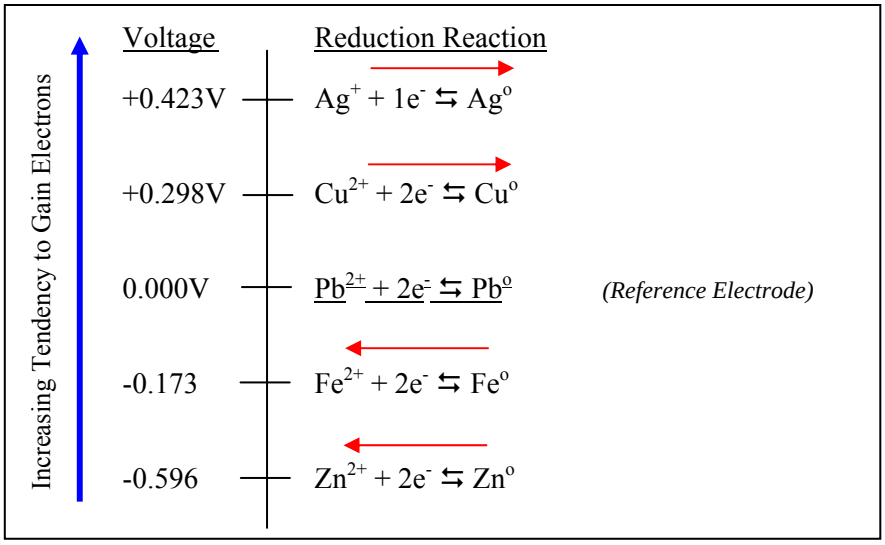

Figure 54: Electrochemical series based upon a Lead reference electrode in a lemon battery.

In this portion of the experiment, students learned that cations could be reduced spontaneously, but follow an order that was based upon the elements' tendency to gain electrons, the Electrochemical Series (Figure 54) and in their textbooks. Once ordered, students were able to predict the potential between any two sets of metals and ions. It should noted that although the pattern for the Electrochemical Series is observed, the numeric values for the reduction potentials of this lemon battery will not match values of a Standard Hydrogen Electrode. This may be due, in part, to temperature effects, but mostly due to the difference in cationic concentrations of metals at the electrodes.

Experiment 2: Redox Potentials in Metal Cationic Solutions

Student Objectives:

- Students will experimentally determine reduction potentials for various elements by constructing an electrolytic cell and software control loop.
- Students will apply their knowledge of the electrochemical series.

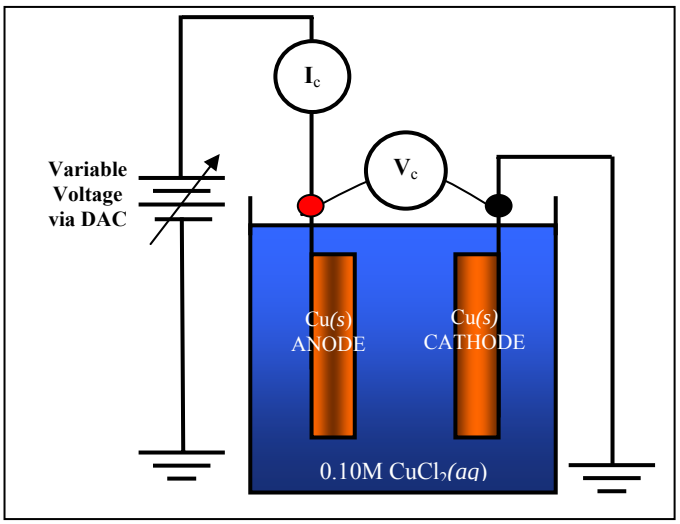

Figure 55: Student Perspective of the experimental set-up for the study of Electrochemistry.

In this part of the experiment, students constructed an electrolytic cell to study the reduction potential of several metals. A potential difference was applied to two Copper plates that were positioned into a solution of 0.1M $CuCl_2(aq)$. The voltage over the electrochemical cell began at 0.00V and was slowly increased in a positive direction, resulting in the electro-deposition of Copper ion from solution. The current supplied to the electrochemical cell, I_c, was also measured so that students could see what reduction potential was ideal for electroplating Copper (II) cation (Figure 55 and 58).

Plotting current versus voltage over the electrochemical cell, students should observe an increase of slope near the reduction potential (Figure 56). Plotting two linear regressions, one for the data before the observed change in slope and one for the data after, the intersection of these two lines showed a value of 0.3495V, which is 2.2% from the expected reduction potential for Copper (II), 0.342V. Since this potentiometric scan of solution only took a few minutes to set-up and acquire data, students then measured and observed the reduction potential of a Silver/Silver (I) cation solution. For instance

when this same experimental set-up was applied to a system of Silver metal electrodes and aqueous 1.0M Silver Nitrate, it resulted in an observed reduction potential of 0.796V (Figure 57). The expected reduction potential for Silver (I) is a value of 0.7996V, which is 0.45% error.

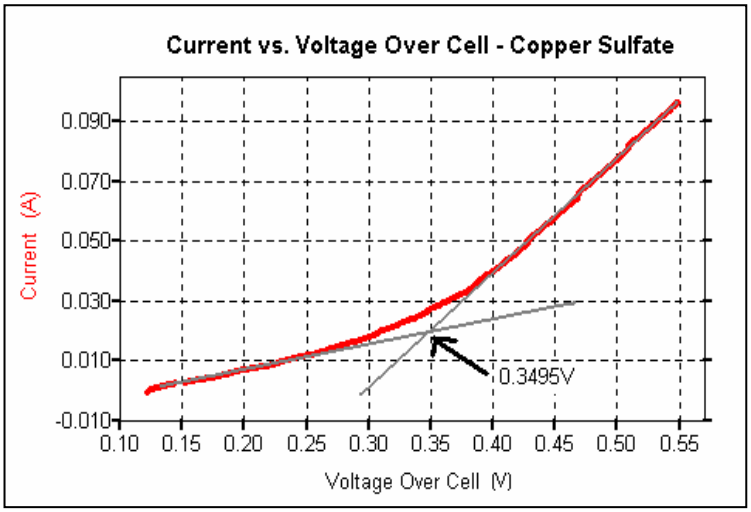

Figure 56: Copper II Reduction - Ramping the cell voltage, a change of current is observed at the standard reduction potential for Cu^{2+}*(aq)*.

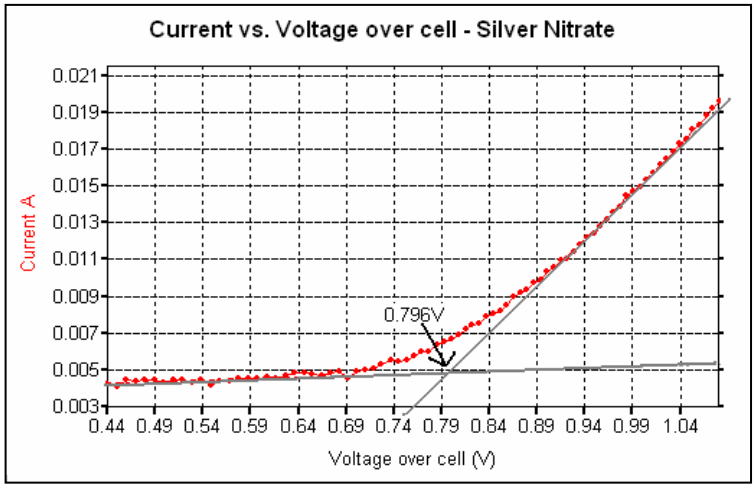

Figure 57: Silver Reduction –Ramping the cell voltage, a change of current is observed at the standard reduction potential for Ag^{+}*(aq)*.

In this experiment, students observed that Silver required a larger difference in potential for the reduction to drive the reaction than did the Copper system, thus the Electrochemical Series was validated. Students also learned that the voltage over an electrochemical cell must be adjusted to slightly above the reduction potential to maximize electroplating at the cathode and oxidation at the anode. Upon review of the standard electrochemical series in their textbook students find that the reduction of Copper (II) ion requires an E^{o}_{cell} voltage of 0.342V.

Finally, it was explained to students that care must be taken when increasing the cell potential to values greater than the reduction potential of interest, where electrons may be donated to undesired redox reactions. For example, raising the cell voltage above +0.401V may cause a side reduction reaction of dissolved oxygen in an aqueous solution or the electrolysis of water at a cell potential of +0.828V (74^{th} Edition CRC, **8**-23and 24).

Experiment 3: Electroplating Copper and
Electrogravimetric Analysis

- Students will apply their knowledge of redox potential to select a voltage to deposit a predetermined amount of Copper onto a cathode, 0.0200g.
- Students will use coulometry and electrogravimetric analysis to determine the amount of Copper plated out onto the cathode.

Now that students have experimentally determined the optimum voltage across the electrochemical cell for plating out Copper (II) ions, the same physical apparatus may

be used to electroplate 0.0200g of Copper potentiostatically to the cathode. The rationale behind this particular experiment is its broad practical application in industry, from printed circuit boards to the electrodeposition of chrome on the bumper of a car.

Only two experimental parameters from the previous experiment needed to be changed to perform this experiment. First, an increase in Copper ions was required, 1.00M $CuSO_4$*(aq)*, to overcome the electrochemical bilayer that forms during the direct current electrolysis. Second, students created a software control loop with guidance from the instructor so that the voltage over the cell remains constant to make facilitate the reduction of Copper (II) ion. From the previous experiment, students found that the minimum voltage for oxidation at the anode and reduction at the cathode was 0.3495V.

The physical apparatus, a MicroLab Sensor Amplifier Module, was used in this electrochemical process due to the ease of access to a +5V regulated power NPN transistor, and a current sensing amplifier (Figure 58). In the future, an electronic module that contains only the regulated transistor and the current sensing amplifier will be used to decrease component complexity so that students may focus upon the chemistry involved.

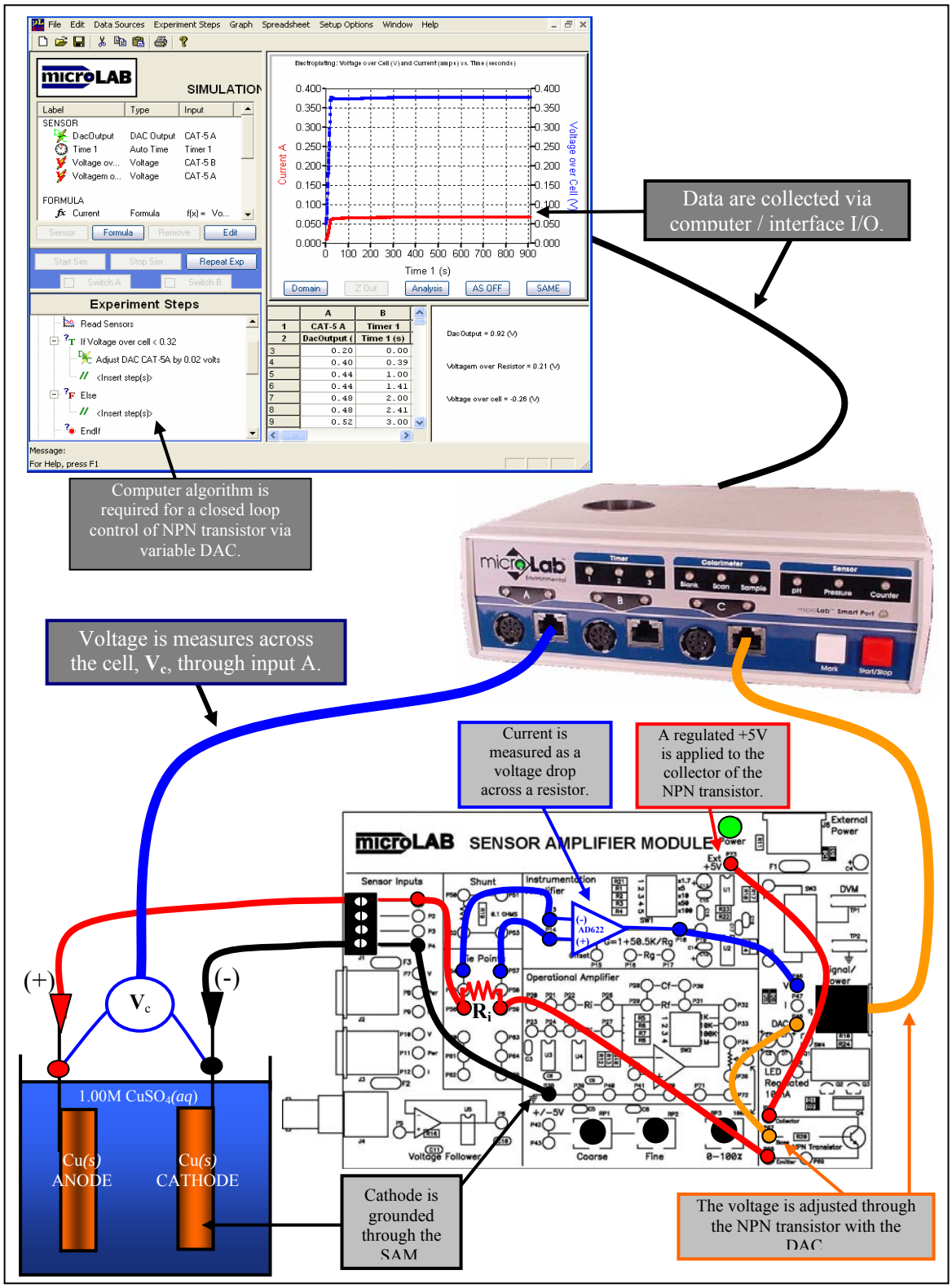

Figure 58: This pilot electrochemical cell set-up utilizes MicroLab's Sensor Amplifier Module and interface. Controlling an NPN transistor with the interface DAC, the voltage across the cell can be adjusted in software.

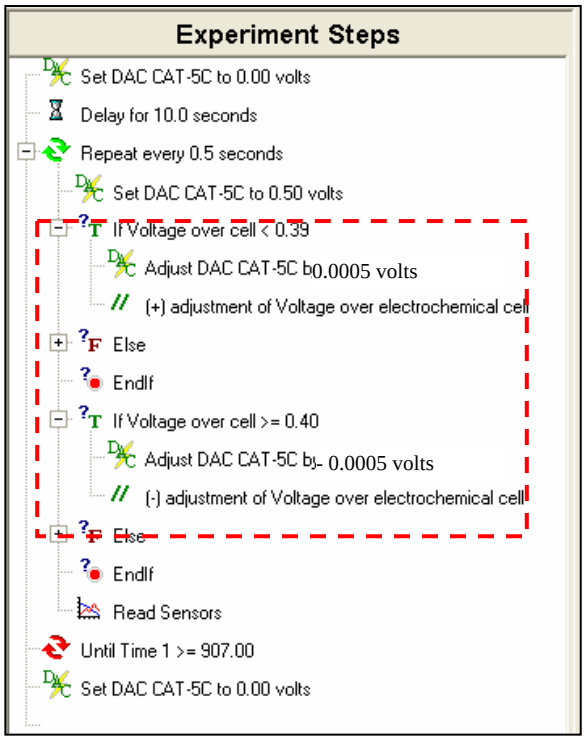

Figure 59: Electrochemical cell experimental program steps to control this electrochemical experiment.

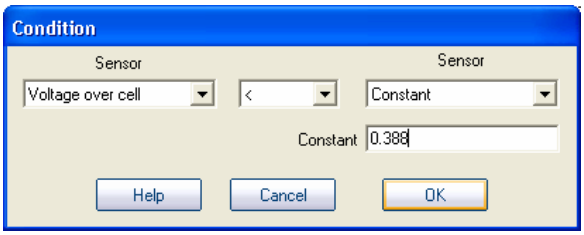

Figure 60: Conditional statements set the upper and lower limit of V_{cell}.

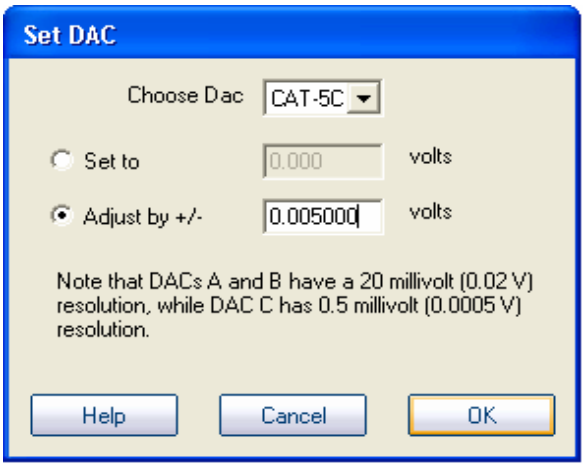

Figure 61: DAC is adjusted by software by plus or minus five millivolts.

With guidance from the instructor, students used the same experimental set-up as before, but created *Experimental Steps* in a software program that set an acceptable potentiostatic voltage across the electrochemical cell, V_c (Figure 59). The algorithm began with setting the digital to analog converter (DAC) to 0.00V, allowing time for students to place the pre-massed electrodes into the aqueous solution of Copper (II) Sulfate. After ten seconds, the DAC was adjusted to place a difference of potential over the cell to the specified experimental range between $0.388V<V_c<0.400V$, as discussed in the previous section. To maintain the prescribed voltage over the cell, two conditional statements were created: an upper and lower limit to the voltage over the cell. If the voltage over the cell was measured outside these upper and lower limits, the DAC output automatically increased or decreased (Figures 60 and 61).

Students made a few trial runs that optimize this program and then determined the amount of current that was being supplied to the electrochemical cell. In this example, the power supply provided 0.0670amperes, and students calculated the amount of time required to theoretically plate out 0.0200g of Copper.

$$(0.0200g\ Cu)(1\ mole\ Cu/63.5g)(2\ mol\ e^-/1\ mol\ Cu^{2+}(aq)) = 6.299X10^{-4}\ mol\ e^- \quad (12)$$

$$(6.299X10^{-4}\ mol\ e^-)(96{,}485\ Coulombs/1mol\ e^-) = 60.78\ Coulombs \quad (13)$$

$$(60.78\ Coulombs)/(X\ seconds) = (0.0670Current)\ or\ Time = 907.16\ seconds \quad (14)$$

Wearing plastic gloves, students cleaned the Copper cathode and anode with sandpaper and rinsed with acetone to remove any contaminants, massed the electrodes, and then ran an experiment for approximately 910 seconds. After these data were collected and plotted as Current versus time and Voltage over Cell versus time, students

used the analytical software to calculate the integral of Current versus time. In this example, 59.50 Coulombs are delivered to the electrochemical cell (Figure 62).

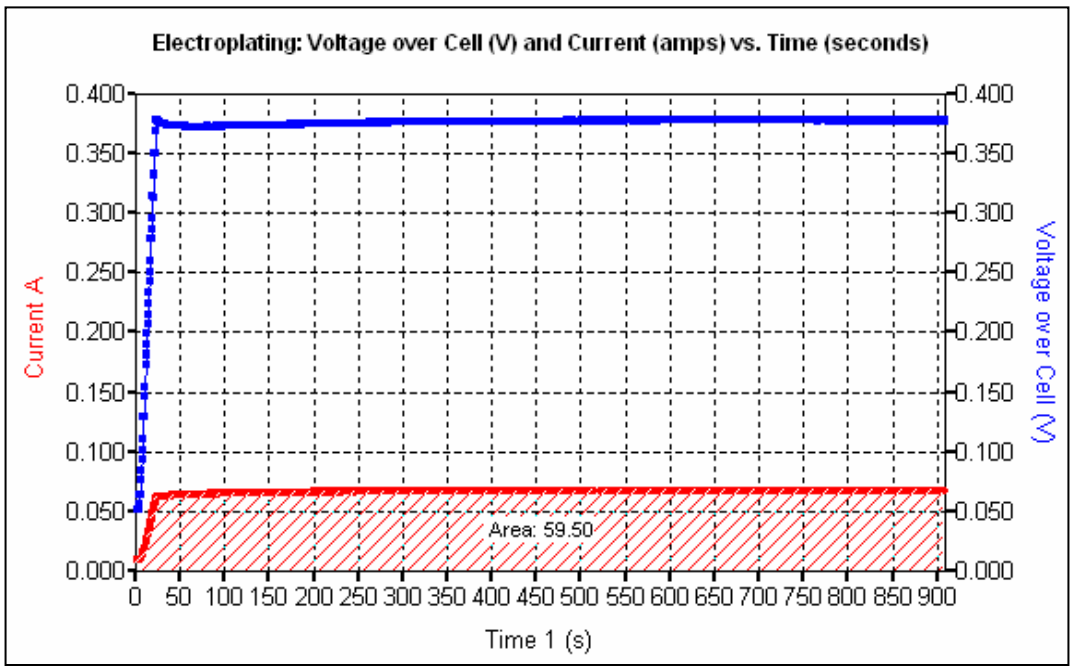

Figure 62: Electrochemical Cell Data – This graphed output of the forced electrochemical cell displays voltage over the cell (V) versus time (seconds) and current (amps) vs. time (seconds). The integral of current versus time shows that 59.50 Coulombs have been delivered the electrochemical cell.

From these data, students made a coulometric prediction of the amount of Copper that should have been plated out onto the cathode and ionized from the Copper anode.

(59.50 C)(1 mol e^-/96,485 C)(1 mol Cu^{2+}*(aq)*/2 mol e^-)(63.5g Cu/1mol)=0.0196g Cu (15)

The final mass of each electrode is measured for a gravimetric determination of Copper (II) cation ion that was reduced at the cathode or oxidized at the anode, where:

$$\Delta m_{electrode} = m_{final} - m_{initial} \quad (16)$$

Δm of Cathode $_{trial\ 1}$ = (1.2693g – 1.2492g) = + 0.0201g % $Error_{trial\ 1}$ = +2.7% (17)

Δm of Anode $_{trial\ 1}$ = (1.2252g – 1.2437) = - 0.0185g % $Error_{trial\ 1}$ = -5.5% (18)

After performing three trials, the average of experimental error was:

Average % error for Cathode = +4.1% (19)

Average % error for Anode = -3.0% (20)

Expecting near 100% efficiency, students are asked what were some possible experimental errors. One of the major reasons, they postulated, was the possibility of a side reaction with the Copper (II) ion in solution, where:

$$Cu^{2+}(aq) + 1e^- \leftrightarrows Cu^+(aq) \qquad E^o = 0.137V \qquad (21)$$

Another error that students needed to be aware of was an observed increase of mass in both cathode and anode after electroplating. This was due, in part, to the handling of the electrodes and the reaction of Copper metal with atmospheric oxygen:

$$2Cu^o(s) + O_2(g) \leftrightarrows 2CuO(s) \qquad (22)$$

To minimize the oxidation of Copper, students immediately washed the electrodes with acetone. If this is done, then results of less than ±5% error can be achieved, as shown in the example above.

<u>An Alternative Experiment: Calculating the Cationic Charge or Molecular Mass:</u>

Alternatively, students can either solve for the cationic charge of a metal species in solution or the molecular mass of the plated out solid. For example, students may acquire data in the same manner as previously described, but are instead asked, "What is the cationic charge of Copper ion in solution?" To solve this problem, students would need to be provided with the molecular mass of Copper in order to solve for the ratio of the moles of electrons to the moles of Copper deposited. Calculating with $\Delta m_{cathode}$:

$$0.0201g\ Cu_{cathode} = (59.50\ C)(1mol\ e^-/96{,}485\ C)(1molCu)/X\ mol\ e^-)(63.5g/1mol\ Cu) \qquad (23)$$

(X mol e^-)/1 mol Cu =[(59.50 C)(1 mol e^-/96,485 C) (63.5g/1molCu)]/0.0201g $Cu_{cathode}$ (24)

X mol e^-/(1 mol Cu)= 1.95 (25)

The same calculations can be performed for the change of mass calculated for the anode of this chemical reaction, where :

X mol e^-/(1 mol Cu)= 2.11 (26)

From these calculations, the data suggested that two electrons are required to plate out one Copper, therefore it must be a (2+) cation. With access to many different metal solutions, students should be able to perform this experiment for a number of systems.

These electrochemistry experiments met the student learning objectives and the criteria for choosing appropriate mathematics and measurement technologies for engineering students. Electronic symbols are used to describe experimental set-up and control loops. Also, theoretical calculations are compared to measured experimental values, including the use of calculus for integration under the curve.

Electrochemistry and Acid/Base Chemistry

In this series of experiments, students utilized the fundamentals of electrochemistry that were learned in the previous laboratory. This included students experimenting with electrochemical half-cell concentrations, its effects on the cell voltage, and using the Nernst Equation as a mathematical model and the Electrochemical Series as a conceptual model in explaining their data. Finally, the electrochemical

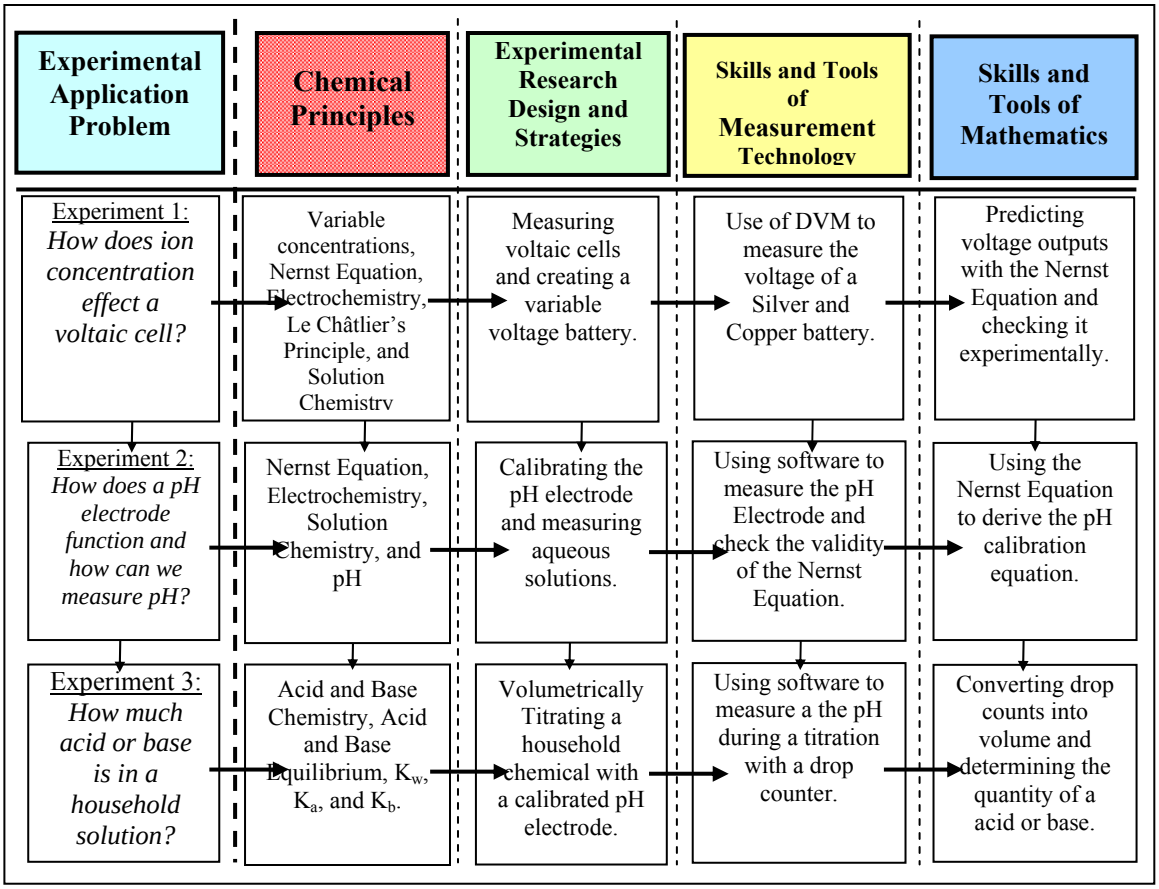

Figure 63: Acid and Base - A flow chart of components for students to solve experimental application problems about acid and base chemistry.

Experiment 1: Constructing a Copper and Silver Voltaic Cell
and Understanding the Nernst Equation

Student Objectives:

- Students will observe a variation of voltage due to a change in concentrations of half-cells.
- Students will experimentally derive the charge transfer and validate it through the Electrochemical Series and the Nernst Equation.

Students learned about oxidation and reduction in the previous session, where a battery can be created by two dissimilar half-cells that contain metal, their corresponding cation, such as $Cu^{o}(s)$ in $Cu(NO_3)_2(aq)$ or $Ag^{o}(s)$ in $AgNO_3(aq)$ (Figure 53). Students

were asked a question, "Based upon the previous data and your knowledge of the electrochemical series, which direction would you predict the electrons to flow in a Silver and Copper battery?" Students recalled that Silver was above Copper on the electrochemical series and has a greater ability to gain electrons and predict that the electrons should flow from the Copper anode to the Silver cathode over a wire. The lab instructor took time to support this prediction with a conceptual model, including a brief explanation of the salt bridge (Figure 64). Then, from the electrochemical series, students predicted that a positive voltage should be produced by the difference of the observed values (Figure 65).

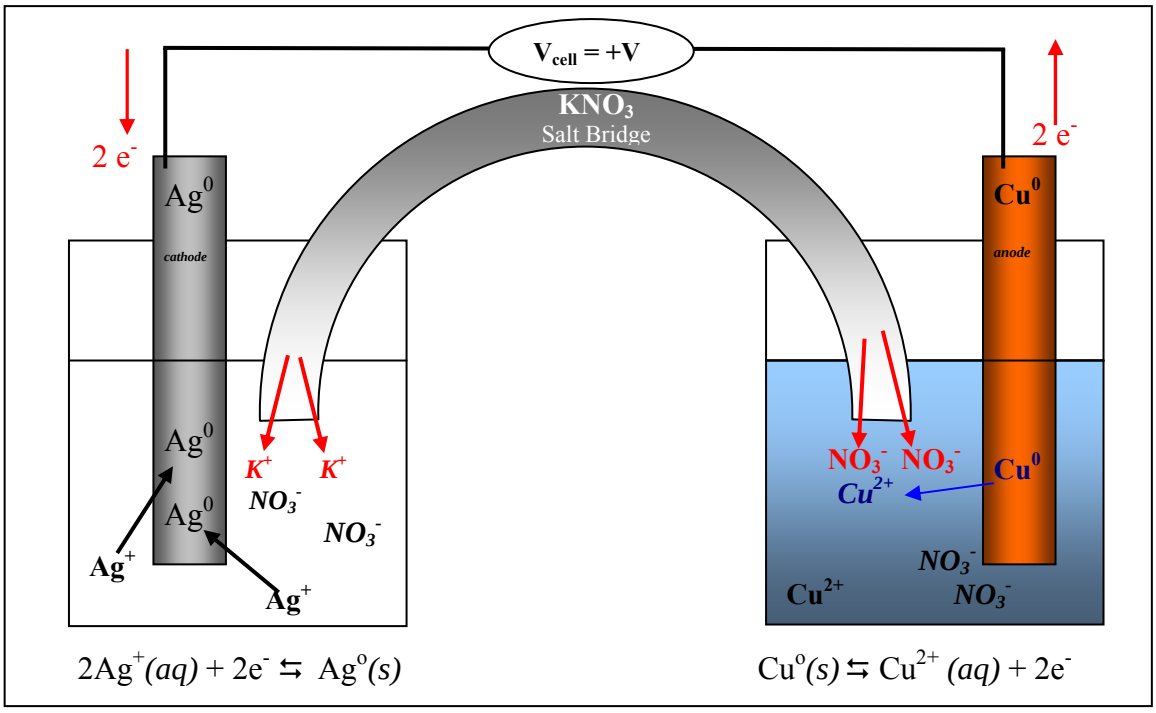

Figure 64: Students learn that a KNO_3 salt bridge allows for counter-balancing of ions in solution. It is explained that the potassium cations, $K^+(aq)$, from the salt bridge substitute for the reduced Copper ion, $Cu^{2+}(aq)$, in the Copper half-cell and the nitrate anions, $NO_3^-(aq)$, partner with the oxidized zinc solid, $Zn^o(s)$ in the zinc half-cell.

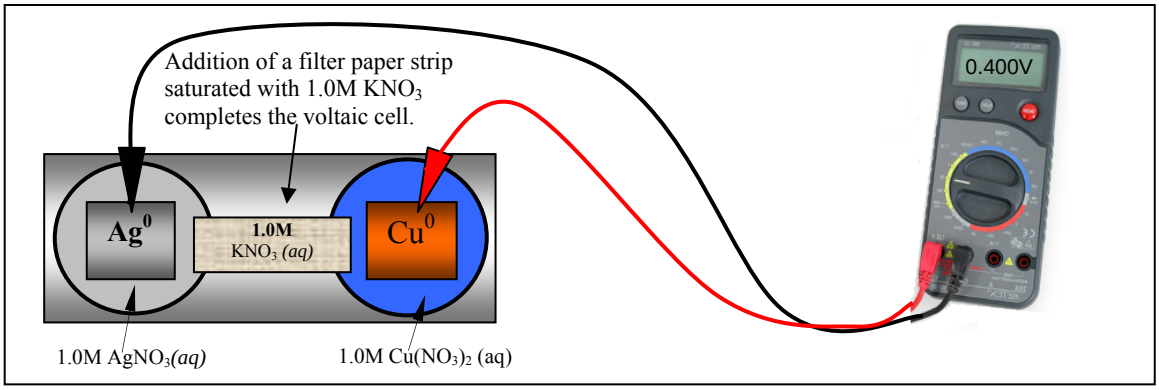

Figure 65: To complete the demonstration, a wetted filter paper of 1.0M KNO_3*(aq)* is placed in between two half cells of Silver metal/1.0M Silver(I) Nitrate and Copper metal/Copper(II) Nitrate. After this, a positive voltage was observed on the DVM, 0.400V.

To test their prediction, students experimented with half-cells that were created by placing approximately 1.5mL of 1.0M $AgNO_3$*(aq)* into one well of a spot plate and 1.5mL of 1.0M $Cu(NO_3)_2$*(aq)* into an adjacent well. The solid metals were placed into their respective solutions, Ag^o*(s)* into $AgNO_3$*(aq)* and Cu^o*(s)* into $Cu(NO_3)_2$*(aq)*. Using a DVM, students connected the black lead to the Copper and the red test lead to the Silver metal. The DVM displayed a voltage of 0.000V until the salt bridge, a filter paper strip saturated with 1.0M KNO_3*(aq)*, chemically connected the two half-cells on the spot plate. For this example, a voltage of 0.400V was observed.

Students were presented with the Nernst Equation (Harris, 1995, p. 354):

$$E_{cell} = E^o_{cell} - (2.3)RT/nF \; LOG_{10} \; [OX]/[RED] \qquad (27)$$

The cell voltage, E_{cell}, at standard pressure and temperature is dependent upon the two half cells involved, E^o_{cell}, and incorporates the ratio of the gas constant, R, and Temperature, T, to that of the number of electrons that pass from the oxidized metal to the reduced metal in a voltaic cell, n, and the Faraday constant. The next focus of this

experiment was the logarithmic function of the ratio of Oxidizing Species and Reducing Species. When comparing half-cells, the students were taught the correct notation for this set of half-cells; $Cu(s) \mid Cu(NO_3)_2(aq) \parallel AgNO_3(aq) \mid Ag(s)$.

Students recognized that the Nernst Equation, in the context of this type of battery, was a function of the Copper (II) cation concentration, $[Cu^{2+}]$, and the Silver (I) cation concentration, $[Ag^{+}]$, for the oxidized and reduced species, respectively. Assuming standard temperature, this equation simplifies to:

$$E_{cell} = E^{o} - (0.05916V/n)\ LOG_{10}\ [OX]/[RED] \qquad (28)$$

Experimental conditions for this two electron transfer system of Copper (II) and Silver (I) was next considered by:

$$E_{Cu/Ag\ cell} = E^{o}_{Cu/Ag} - (0.05916V/2e^{-})\ LOG_{10}\ [Cu^{2+}]/[Ag^{+}]^2 \qquad (29)$$

Students then recognized that when the concentrations of the $AgNO_3$*(aq)* and $Cu(NO_3)_2$*(aq)* solutions were the same, for example both cells having 1.0M metal solutions, then the logarithmic portion of the Nernst equation was zero and the cell potential, $E_{Cu/Ag\ cell}$, was equal to the standard potential, $E^{o}_{Cu/Ag}$:

$$E_{Cu/Ag\ cell} = E^{o}_{Cu/Ag} - C\ LOG_{10}\ [1.0M]/[1.0M] \rightarrow \mathbf{0} \quad \text{or} \quad E_{Cu/Ag\ cell} = E^{o}_{Cu/Ag} \qquad (30)$$

Next, students used the Nernst Equation to consider how changing the concentrations of $[Ag^{+}]$ and $[Cu^{2+}]$ effects the cell voltage, E_{cell}. Students tested their predictions by creating several voltaic cells that keep one half-cell constant, for example, keeping a Copper/Copper (II) Nitrate at 1.0M while changing the concentration of the Silver/Silver Nitrate half-cell 0.10M, 0.010M, and 0.0010M concentrations (Figure 66).

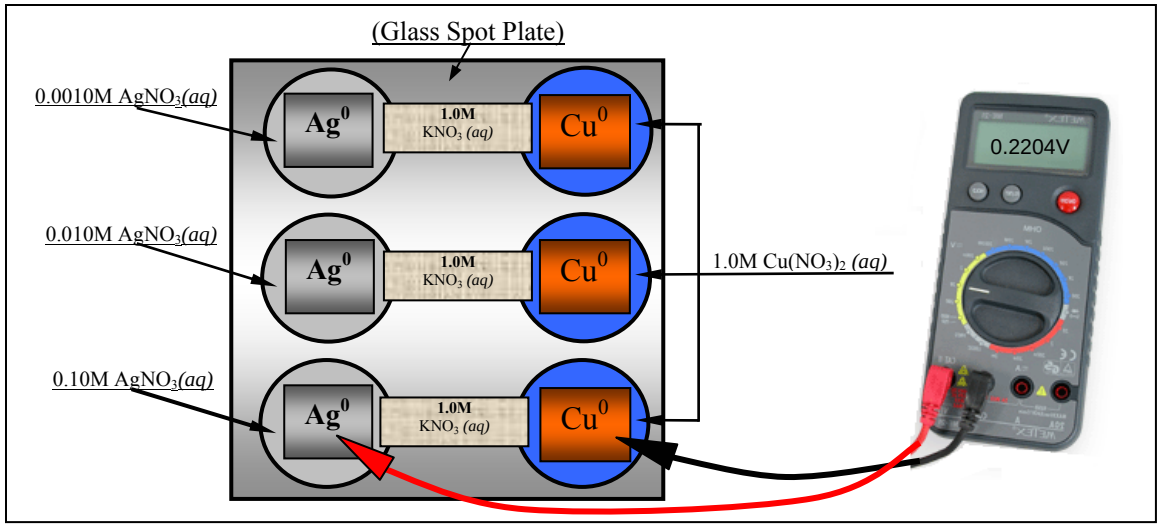

Figure 66: Students create and test half-cell combinations, using a $Cu(s)/Cu(NO_3)_2(aq)$ 1.0M half-cell as the reference and three different $Ag(s)/AgNO_3(aq)$ half-cells with 0.10M, 0.010M, and 0.0010M concentrations.

the Silver cathodes with the test leads and recorded their data in a table as shown below.

$Cu(s)/Cu(NO_3)_2(aq)$ Concentration (M)	$Ag(s)/AgNO_3(aq)$ Concentration (M)	Measured Value (**V**)
1.0M	0.0010M	0.2204V
1.0M	0.010M	0.2838V
1.0M	0.10M	0.3430V
1.0M	1.0M	0.404V

Table 14: Data acquired from the variable concentrations of the half-cell experiment.

Students observed that as the concentration of the reducing species increased, the cell voltage also increased (Table 14). When students revisited the half-cell reactions, they recognized that if Silver (I) ion concentration increased, then the chemical reaction would then be driven toward the products, as Le Châtlier's Principle would predict:

$$Ag^{+}(aq) + e^{-} \rightleftarrows Ag^{o}(s)$$

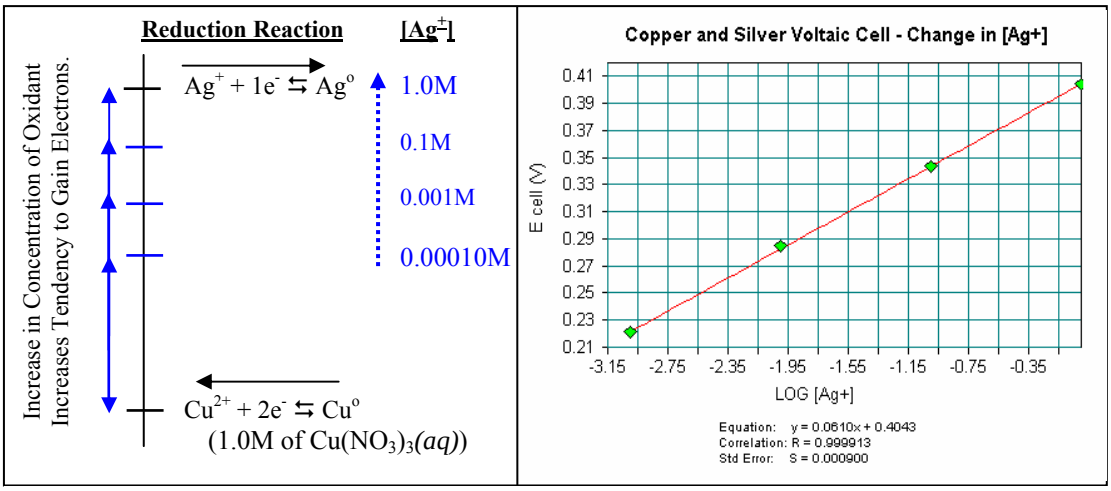

Figure 67: Increasing the Silver (I) ion concentration in an electrochemical Silver and Copper voltaic cell shows an increase of voltage. The slope shows that Silver (I) ion gains a single electron.

Graphing these data, students observed linearity and, when compared to the Electrochemical Series, showed that an increase in oxidizing agent, the Silver (I) cation, increased the difference between the silver cell and the constant Copper half-cell (Figure 67). Also, the slope of the line, 0.0601V, was close to the theoretical 0.05916V for a single-electron transfer to a single Silver (I) cation.

Revisiting Equation 29 and mathematically separating the LOG function, students created a mathematical model that further assists in explaining this system:

$$E_{Cu/Ag\ cell} = E^{o}_{Cu/Ag} - (0.05916V/2e^{-})\ LOG_{10}\ [Cu^{2+}] + (0.05916V/2e^{-})\ LOG\ [Ag^{+}]^{2}) \quad (31)$$

Reducing constant terms, multiplying the negative sign through the separated LOG terms, and placing the exponent from the Silver (I) concentration in front of its LOG function, the mathematical equation is reduced:

$$E_{Cu/Ag\ cell} = E^{o}_{Cu/Ag} - 0.02958V\ LOG_{10}\ [Cu^{2+}] + 0.05916V\ LOG\ [Ag^{+}] \quad (32)$$

This mathematical relationship offers students an equation that relates the measured voltage, $E_{Cu/Ag\ cell}$, to the change in the LOG of the Silver (I) ion concentration.

Students are now asked, "What do you predict will happen if we perform the same experiment, but keep the Silver (I) ion at the same concentration while changing the Copper (II) ion concentration?" Students then performed this experiment, using a 1.0M solution Silver (I) Nitrate concentration as a constant and changing the concentration of the aqueous Copper (II) ions from 0.00010M to 1.0M (Figure 68).

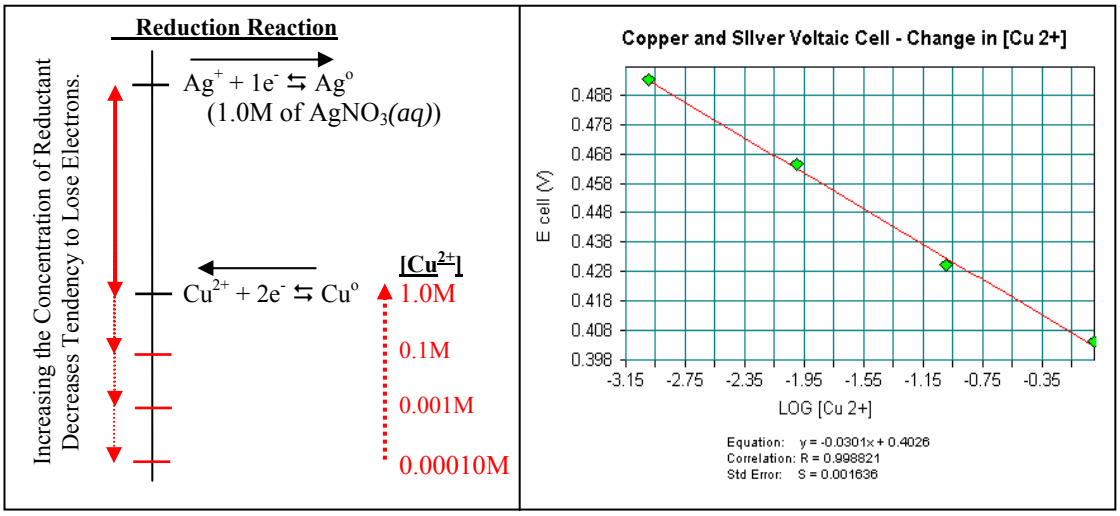

Figure 68: Overall, increasing the Copper (II) ion concentration in an electrochemical Silver and Copper voltaic cell decreases the cell voltage. The redox potential of the Cu^{2+} cell moves toward the Ag^{+} cell; the difference is less. Also, the slope of the line shows that Copper metal loses a pair of electrons upon oxidation.

In this instance, the cell voltage, E_{cell}, was observed to decrease with increasing concentrations of Cu^{2+} *(aq)*. Students apply the same logic as before, where Le Châtlier's principle assists students in understanding that an increase in reducing agent decreases the tendency for the Copper metal to lose electrons. This forces the reduction reaction of Copper toward reactants and the redox potential moves toward the Ag^{+} cell:

$$Cu^{2+}(aq) + 2e^- \leftrightarrows Cu^o(s) \qquad (33)$$

The slope of the line, 0.0301, was close to the theoretical value, 0.02958V, for a two-electron transfer from a single Copper metal, as shown in Equation 32.

In this experiment, students discovered that keeping one half-cell concentration constant and decreasing the concentration of the other half-cell showed changes in the cell voltage and the charges transferred at each respective half-cell. Students were supported in their prior understanding that the flow of electrons was based upon the electrochemical series, but they gain an experimental perspective that the relative concentrations of Copper (II) and Silver (I) also effect the cell voltage. What's more, the Nernst Equation is shown to be a powerful math model that accurately predicts the expected cell voltage and the number of electrons transferred in the process. It is this variability of voltage due to ionic concentration that was used as a premise for the next experiment, understanding and using the pH electrode.

Experiment 2: Understanding the Output of a pH Electrode

Student Objectives:

- Students will apply their knowledge of the Nernst Equation to a pH electrode and mathematically model its output for calibration.
- Students will measure the outputs of a pH electrode with a software calibration and compare it to the Nernst constant.

In this experiment, students were asked, "What does an electrochemical and a pH electrode have in common?" The instructor explained that the pH electrode was a system of two electrochemical half-cells that are chemically similar. Therefore, the fundamentals of the Nernst equation still apply. To complete this experiment, the

students needed to know that one of the half-cells remained constant, much like the previous experiment, while the other half-cell changed with the hydrogen ion concentration. This constant cell is called the reference electrode.

The pH electrode is more complex than the previous examples:

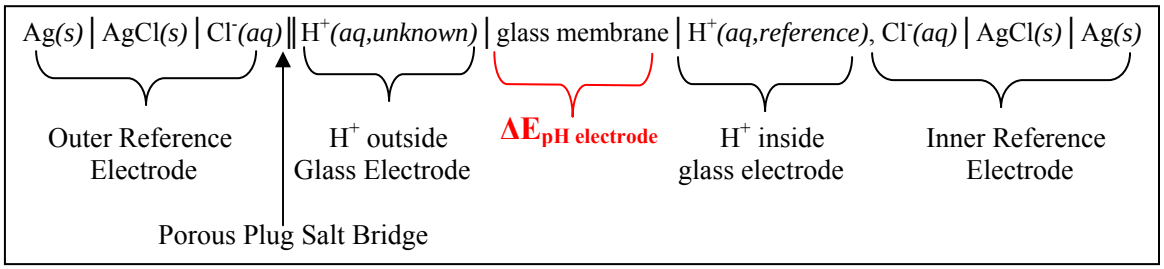

Figure 69: The pH electrode is comprised of two identical half-cells, with the exception that one of these half-cells changes with changes in external hydrogen ion concentration across a glass membrane. (Harris, 1995)

Students needed only to learn that the cell potential of the pH electrode, $E_{pH\ electrode}$, is based upon the difference of potential, or voltage, across the glass membrane that is due to the transport of single cationic charges rather than electrochemical reduction (Harris 1995). The observed voltage is determined by the ratio of the hydrogen ion reference, $H^+_{reference}$, inside the electrode as compared to that of the unknown hydrogen ion, $H^+_{unknown}$ in the external aqueous environment "comes close to obeying the Nernst Equation," Equation 28 (Harris 1995):

$$E_{pH\ electrode} = \text{constant} + (0.05916V)\ \log_{10}\ [H^+_{unknown}]/[H^+_{reference}] \qquad (34)$$

Next, students were asked to make an assumption that the hydrogen ion reference concentration, $H^+_{reference}$, was $1.0X10^{-7}M$. This assumption helped students to more easily predict the performance of a pH electrode when the external hydrogen ion concentration, $H^+_{unknown}$, was greater than, equal to, and less than $1.0X10^{-7}M$ (Table 15).

$[H^+_{reference}]$ Concentration (**M**)	$[H^+_{unknown}]$ Concentration (**M**)	Sign of Ratio $\log_{10} [H^+_{unknown}]/[H^+_{reference}]$	Prediction
$1.0X10^{-7}M$	$1.0X10^{-4}M$	(+)	$E_{pH\ electrode\ 1} <$ constant
$1.0X10^{-7}M$	$1.0X10^{-7}M$	0	$E_{pH\ electrode} =$ constant
$1.0X10^{-7}M$	$1.0X10^{-10}M$	(-)	$E_{pH\ electrode} >$ constant

Table 15: Students predicted the sign of the log based function.

Students recognized that an increasing concentration of Hydrogen ion shows a theoretical decrease in cell voltage, $E_{pH\ electrode}$. Next, an explanation of the autoionization of water shows a dynamic equilibrium relationship for water, hydroxide, and hydrogen ions, K_w. From this, students are taught how to calculate pH of an aqueous solution:

$$pH = -\log [H^+]f_{H+} \qquad (35)$$

Since students were learning the abstract concept of pH for the first time in this chemistry course, the activity coefficient, f_{H+}, was assumed to be unity and omitted from the student explanation. From Equation 35, students solved for the concentration of hydrogen ion, $H^+_{unknown}$, and transformed Equation 34 to express it in terms of pH:

$$pH = -[(E_{pH\ electrode})/(0.05916V/n\ pH)] + \mathbf{C} \qquad (36)$$

or

$$pH = -(16.90\ pH/V)E_{pH\ electrode} + \mathbf{C} \qquad (37)$$

The students predicted a linear relationship with a negative slope. If this was a single electron system, a predicted slope of –16.90 pH units per volt should be observed

To test this prediction, students connected the pH electrode to the interface and calibrated it with software and three buffered solutions of pH 4, 7, and 10. For example, a three-point calibration showed a linear response with a negative slope. In fact, students recognized that this as a single electron system, where the predicted slope matches the experimental slope value within 0.06% of the theoretical Nernst constant (Figure 70).

The pH electrode, when looking at the voltage on the y-axis and the pH on the x-axis, showed an internal reference of nearly 0.0V when the external pH was seven (Figure 71).

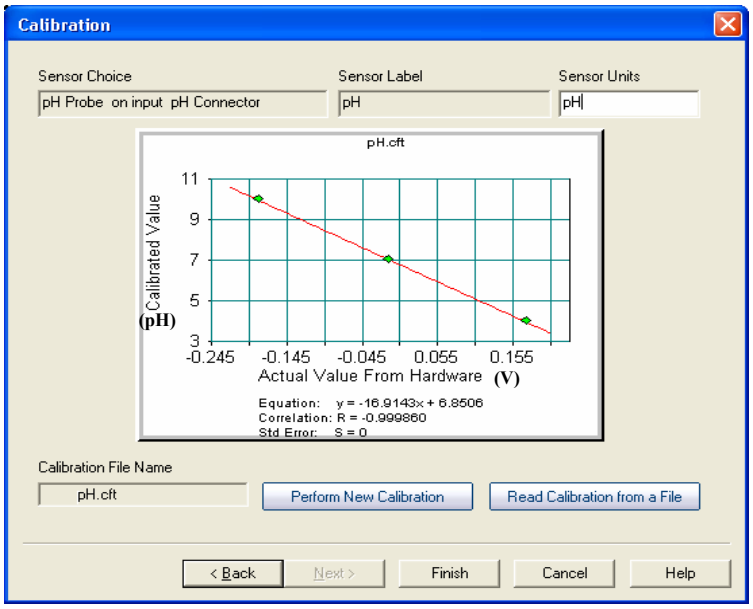

Figure 70: The output of the pH electrode versus the corresponding pH buffers shows a linear relationship that matches the predicted negative slope value, -16.9pH units per Volt.

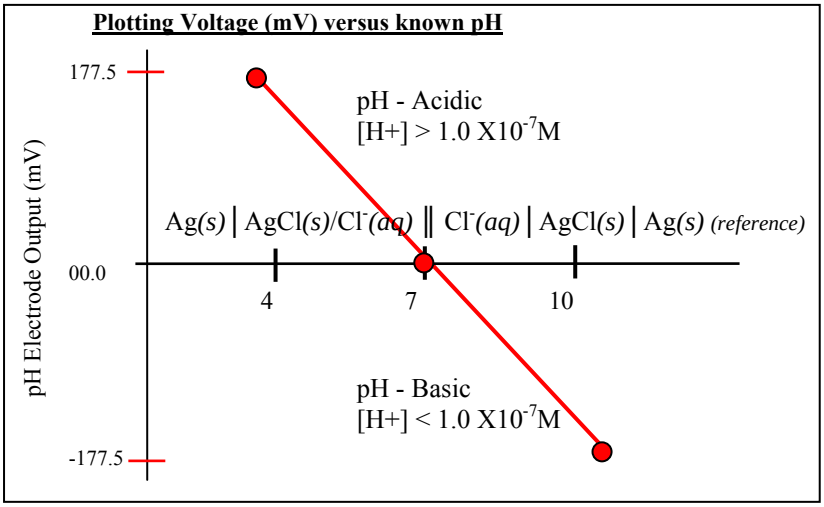

Figure 71: Output of the pH sensitive cell drops with a decrease in Hydrogen ion and crosses the reference at pH 7.0.

Finally, students used this calibrated pH electrode to test the pH of household chemicals and performed a titration of either the % by mass of acetic acid in vinegar, citric acid in lemon juice, or ammonia in glass cleaner. In this process, students used a burette, a drop counter, a pH electrode, and the appropriate titre and concentration of titre for the titration experiment.

Experiment 3: Titration of a Household Chemical
with a pH Electrode

Student Objectives:

- Students will apply their knowledge of dimensional analysis to convert drops into volumetric values.
- Students will perform a titration to determine the number of moles of acid or base exists in a household chemical.
- Students will solve for the acid constant, Ka, by finding it on a titration curve.

Students diluted 10.0mL of store bought white vinegar to 50.0mL and titrated it with 1.00M NaOH. Instead of introducing an aliquot of titre and hand-writing the pH electrode output into a lab notebook, a MicroLAB reflective drop counter was set at the tip of a burette to record drops of 1.00M NaOH at approximately 1 drop per second (Figure 72). To ensure homogeneity of the mixture and that the pH electrode reached equilibrium, the titrant was placed on a stir plate and a stir bar was used. The program was designed to read the pH at the instant a drop was detected, assigning this pH value to the previous drop. This allows for the maximum amount of time for mixing for the standard solution and for the pH electrode to equilibrate.

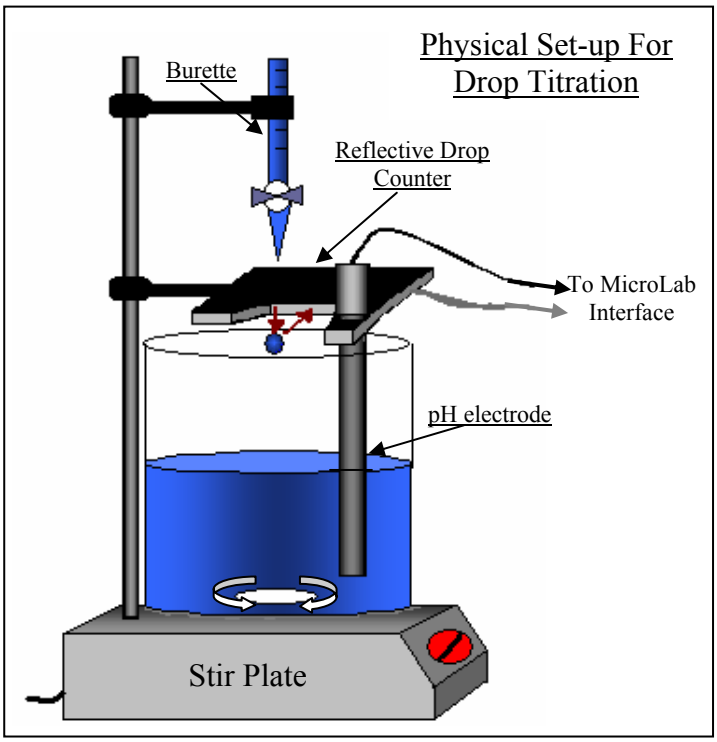

Figure 72: The pH titration set-up includes a reflective drop counter that drips at the rate of approximately 1 drop per second. The titrant is thoroughly mixed with a stir bar and stir-plat apparatus.

As the titration begins the initial volume was recorded on the buret and students plot pH versus number of drops. Once the titration went past completion, the final volume was recorded. Students created a simple conversion from drops to volume by subtracting the final and initial volumes and dividing it by the total number of drops observed. Once this conversion was used to convert number of drops to volume, pH versus volume of 1.0M NaOH can be plotted (Figure 73).

For example, the end-point was found by performing a first derivative on the data, finding that 7.50mL of 1.00M NaOH was needed to neutralize 10.0mL of white vinegar. This value was used in a sodium hydroxide to acetic acid molar conversion and then a

mass conversion to grams to solve for 0.450 grams of Acetic Acid. With a density of 1.01g/mL, the percent by mass of vinegar was experimentally determined to be 4.45%.

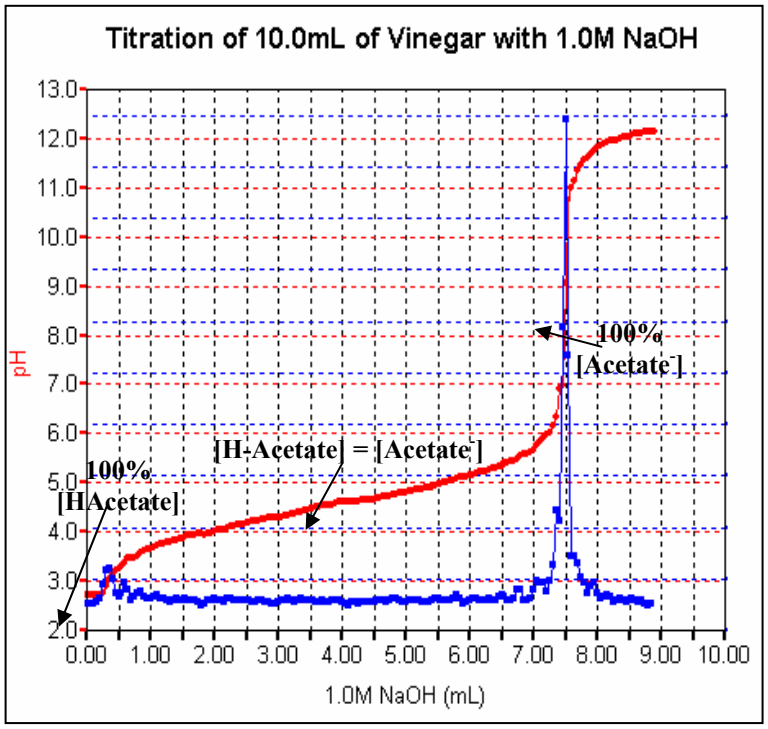

Figure 73: Titration Curve for Acetic acid (RED) and the first derivative (BLUE) that assists in finding the end-point of the titration.

Finally, students are taught about weak acids:

$$HA \leftrightarrows H^+ + A^- \qquad (38)$$

and the dissociation constant, K_a:

$$K_a = [H^+]\,[A^-] / [HA] \qquad (39)$$

Students learned that the end-point was where the conjugate base, [A-], was completely dissociated from the hydrogen ion. Therefore, halving the volume of the standard would show students where the concentrations of acid and its conjugate base

were equal, $[HA] = [A^-]$. At this point in the titration, students learned that Equation 39 could be transformed to solve for K_a by finding the pH at this half-equivalency point:

$$K_a = 10^{-pH} \qquad (40)$$

For this example, the typical student data seen in Figure 73, a pH of 4.7 was found at a volume of 3.75mL. The experimentally derived K_a is 1.88 $X10^{-5}$, which is within 7.4% of the expected value of 1.75 $X10^{-5}$, an acceptable answer for general chemistry.

In these series of experiment, students were able to better understand the power of the electrochemical series by applying it in voltaic cells, observing the effects of change in concentration, calibrating a pH electrode, and applying it to solve for the moles of acid in a solution. Beginning with a same concentration half-cell and comparing it with a concentration that is varied, students were able to observe a change in voltage that assisted them in better understanding the electrochemical series, Le Châtlier's Principle, and the underlying principles of the pH probe. Finally, students applied this knowledge in a practical application of titrating an acid or base solution, completing the lesson by solving for the K_a or K_b of a weak acid or weak base system.

Spectroscopy and Kinetics

Using the fundamental principles of spectroscopy and mathematical relationships to explore the Beer-Lambert's Law, students developed an understanding of the kinetics of a chemical reaction. In these three experiments, students experimentally derived a Beer-Lambert's Law relationship. This mathematical relationship was observed in the phenomenon of transmittance and absorbance with the assistance of MicroLab's 10-Color Colorimeter while students solved for the concentration of an unknown colored solution

of Red #2 food coloring. Finally, students used their knowledge of absorbance spectroscopy to monitor colorimetric changes in chemical compositions over time to study the kinetics of a system (Figure 74).

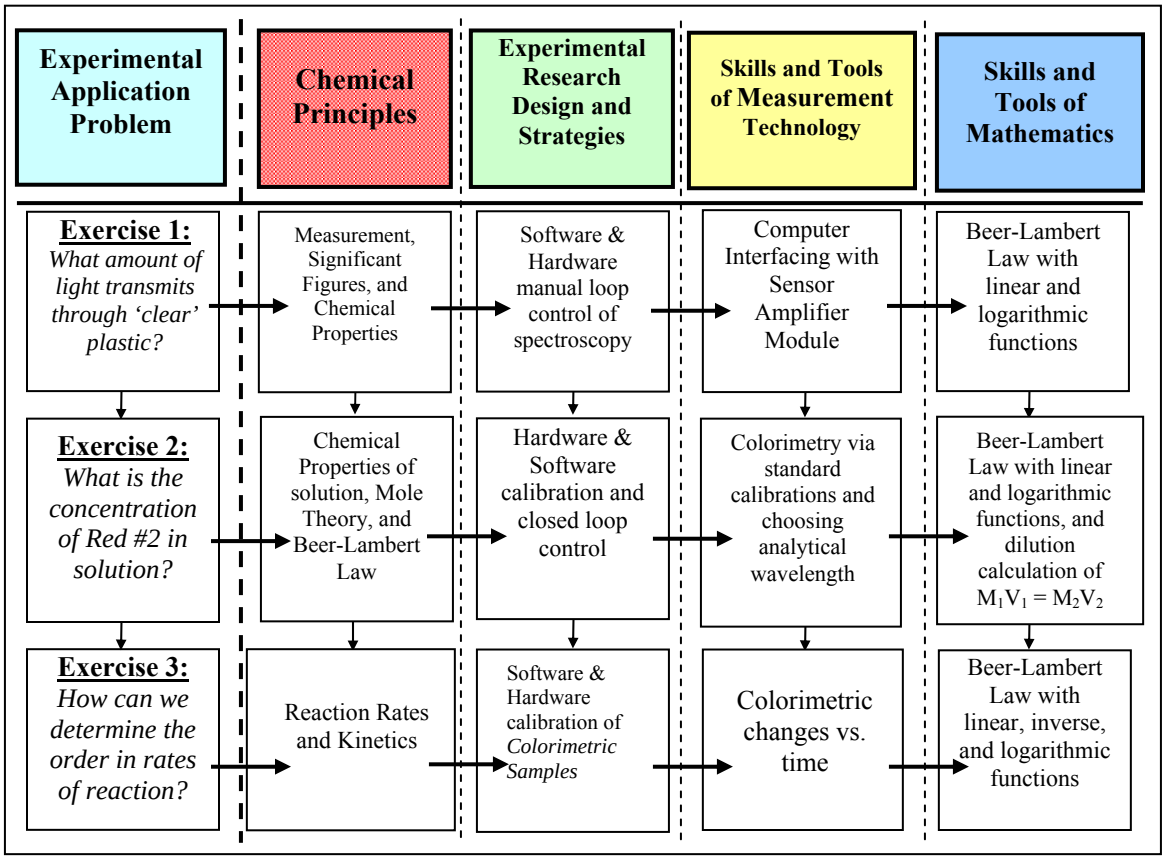

Figure 74: Spectroscopy – A flow chart of components for students to learn fundamentals about spectroscopy and Beer-Lambert Law when solving experimental application problems about the rate of chemical reactions.

Experiment 1: Fundamentals of Beer-Lambert's Law

Student Objectives:

- Students will calibrate a phototransistor and use it to collect percent transmittance with software.
- Students will acquire data and transform it with a logarithmic function that results in a linear relationship, the Beer-Lambert Law.

In this experiment, students used a red 620nm light emitting diode, LED, a phototransistor light sensor, PT, and 2" X 2" overhead transparencies. Students first plugged the phototransistor into the MicroLab interface, placed it into a clamp, and mounted it on a ring stand. The same was done with the LED, energizing it with the MicroLab interface and carefully directing its light at the phototransistor (Figure 75). Students then calibrated the phototransistor in software by assigning its output value to 100.0% when the LED was turned on and to 0.0% when the LED was turned off.

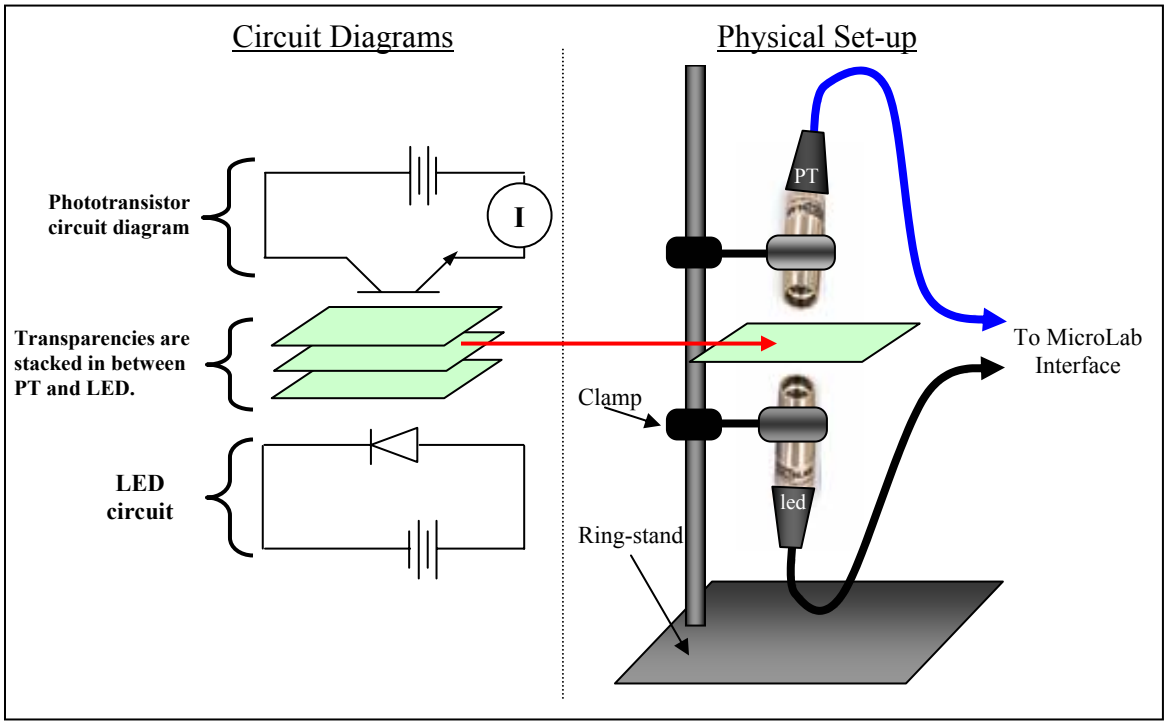

Figure 75: Beer-Lambert Law – Transparencies are placed in between a phototransistor (PT) and a light emitting diode (LED) to acquire data that models the Beer-Lambert Law. (Skoog, Holler,and Nieman, 1998, p.138)

With a calibrated phototransistor, students stacked 2" X 2" squares of overhead transparencies between the LED and phototransistor system and observed a change in the phototransistor output that was displayed on the computer monitor. To measure the

phototransistor current, students wrote a simple program. Using the keyboard for a manual input, students hand-entered the number of transparency slides placed into the optical path and, upon pressing enter, calibrated phototransistor's output was recorded. Students observed data on a graph of %Transmittance versus number of Transparencies (Figure 76). Next, students performed a mathematical function on the phototransistor data:

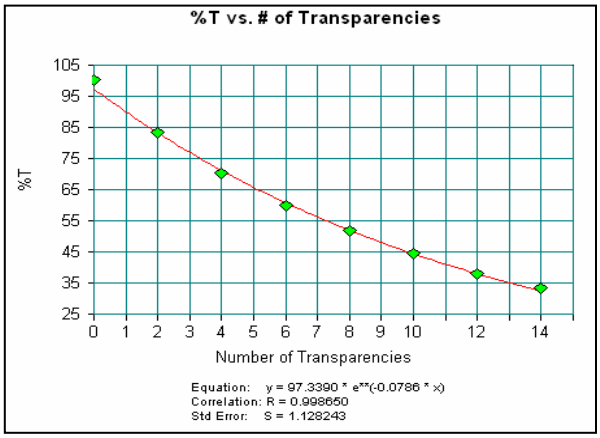

Figure 76: %T versus Transparencies – Students' data result an observed decrease in %Transmittance that displays a logarithmic relationship.

$$-\log_{10}(\%T/100) \quad (41)$$

After students plotted these transformed data versus number of transparences, it resulted in the mathematical relationship analogous to the Beer-Lambert Law (Figure 77).

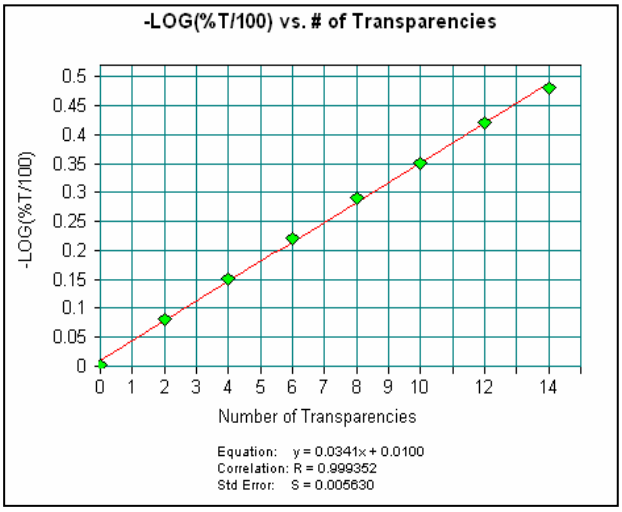

Figure 77: Student performed a mathematical function on the % Transmittance that transformed these data into a linear relationship.

Experiment 2: Colorimetry and the Determination of Concentration of Red#2

Student Objectives:

- Students will observe the phenomenon of transmittance and absorbance of light with Red # 2 Amaranth.
- Students will explore the relationship of absorbance versus concentration and the effects of different analytical wavelengths to better understand the Beer-Lambert Law.
- Students will create a calibration curve with the optimum analytical wavelength to solve for the concentration of an unknown Red #2 solution.

In this experiment, students explored the phenomenon of transmittance and absorbance of FDA approved Red #2, Amaranth, molecule (Figure 78). Students utilized the MicroLab 10-Color Colorimeter, which operated with the same basic principles as the previous experiment but with ten LED's, five phototransistors, and software control.

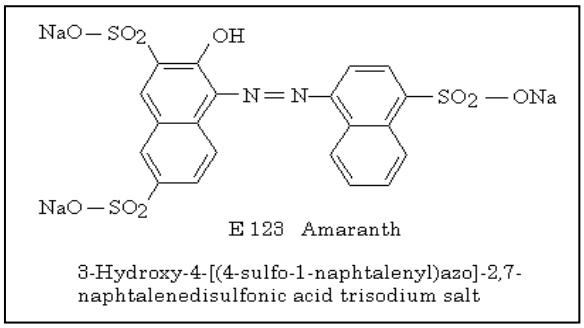

Figure 78: Molecular Structure of Red #2, amaranth.

The colorimeter was set up with LEDs and phototransistor light sensors diametrically opposed across a cylindrical sample chamber (Figure 79). A vertical cross section also shows that the LED's are vertically aligned so that a single phototransistor, sensor D, detects light from two separate LEDs across the same path lengths distances (Figure 80).

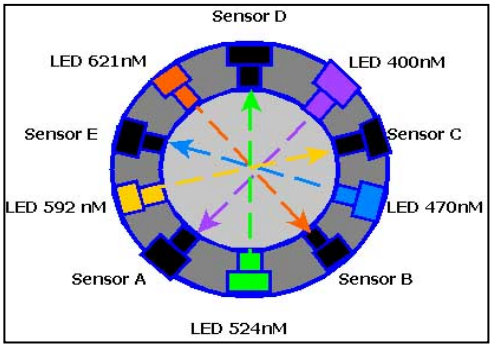

Figure 79: Top view of MicroLab's 10-color Colorimeter.

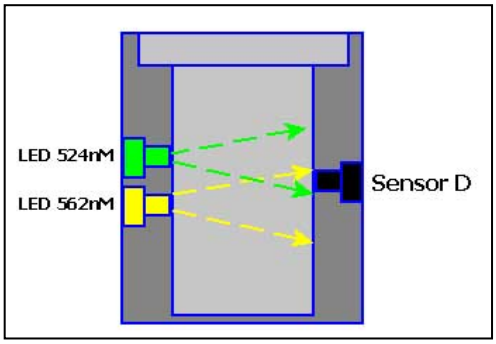

Figure 80: A cross-section of MicroLab's 10-color Colorimeter.

The MicroLab 10-color Colorimeter was calibrated by filling a glass cuvette with deionized water, wiping it free of fingerprints, placing it into the sample chamber, and pressing a calibration button. This resulted in the calibration of each LED and phototransistor pair. Students observe a plot of 100% Transmittance versus Wavelength for each LED (Figure 81).

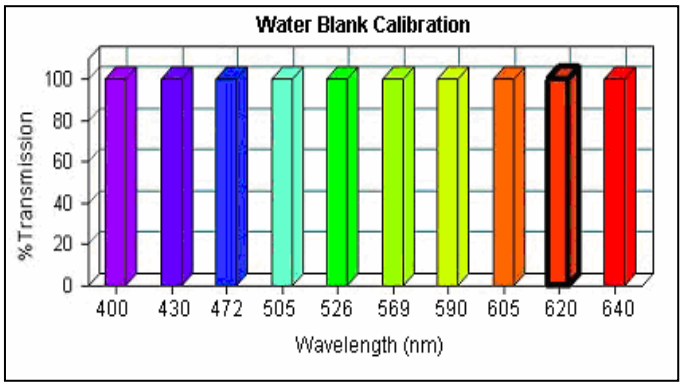

Figure 81: The % Transmittance spectrum of water, as displayed by MicroLab's 10-color Colorimeter.

Next, students scanned a solution of Red #2, revealing that red wavelengths were transmitted and green wavelengths were absorbed (Figure 82).

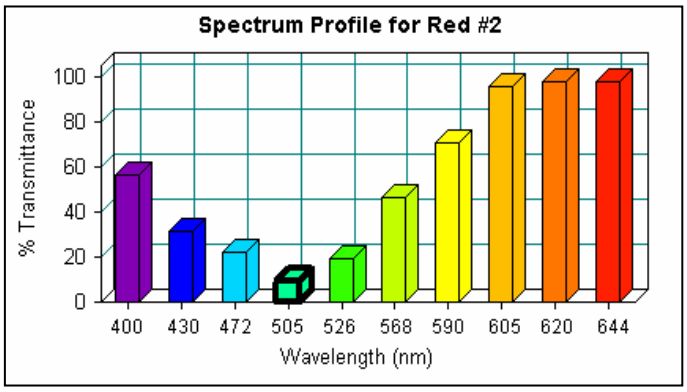

Figure 82: %Transmittance spectrum of Red #2 stock solution, as displayed by MicroLab's 10-color Colorimeter.

Students then chose a software function that automatically transformed Transmittance, %T, with a mathematical function, –log (%T/100). Students learned that this function resulted in the calculation of Absorbance (Figure 83 and equation 42).

$$A = -\log(\%T/100) \qquad (42)$$

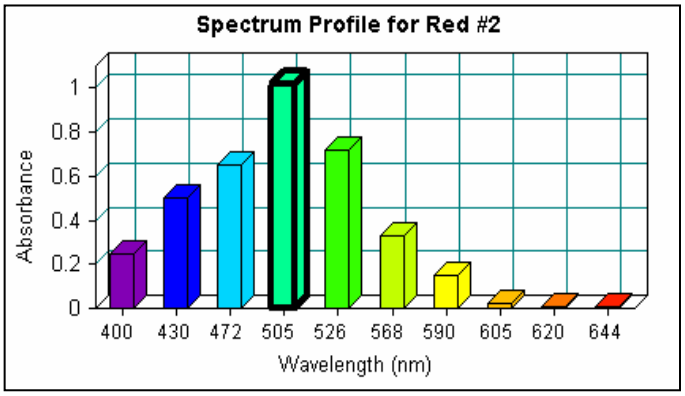

Figure 83: Absorbance spectrum of Red #2 stock solution, as calculated and displayed by MicroLab's 10-color Colorimeter.

At this point, students diluted a stock solution of Red #2, 2.47 $X10^{-5}$M, to create four different 20.0mL concentrations. Given a worksheet of predetermined

concentrations, students calculated the required amounts of Red #2 stock solution and deionized water and recorded it in a data table (Table 16).

Dilution #	[Red #2 X10^{-5}M]	Volume of Red #2 Stock Solution (mL)	Volume of Deionized Water (mL)	Total Volume
1	2.47	20.0	0.0	20.0
2	1.24	10.0	10.0	20.0
3	0.620	5.0	15.0	20.0
4	0.310	2.5	17.5	20.0

Table 16: Students calculated the amount of Red #2 stock solution and deionized water that are required to create the predetermined dilutions.

Students used these calculations to mix the four different solutions and scanned them into the 10-Color Colorimeter as standard solutions. Once these data were collected, students chose a wavelength by left clicking on the desired wavelength in the histogram of the absorbance spectrum (Left in Figure 84). For example, choosing a wavelength of 605nm created a calibration curve that showed small changes in absorbance versus concentration (Right in Figure 84). Although these data show good linearity this choice of wavelength is not the best when creating a colorimetric calibration curve. Choosing a wavelength that had a larger absorbance, 568nm, students observe that there was an observable increase of slope in the calibration curve when comparing it to that of the 605nm calibration curve (Figure 85).

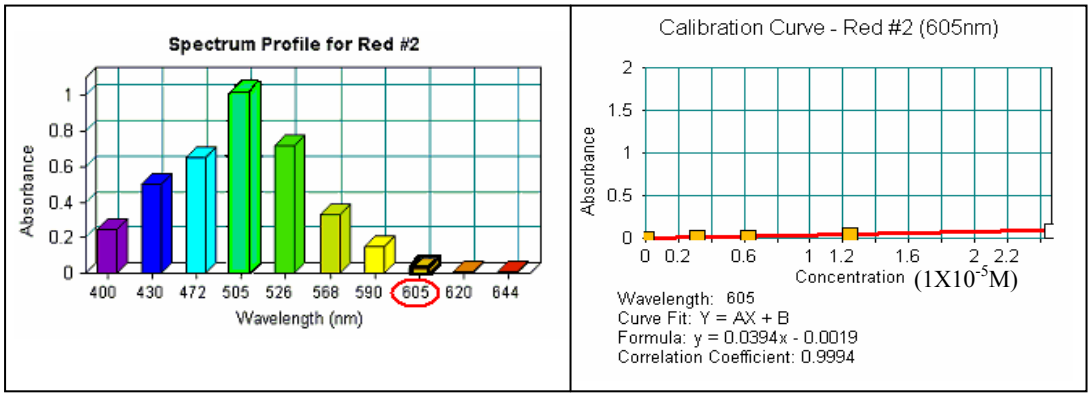

Figure 84: Students' observed a small change of absorbance versus concentration when choosing 605nm LED.

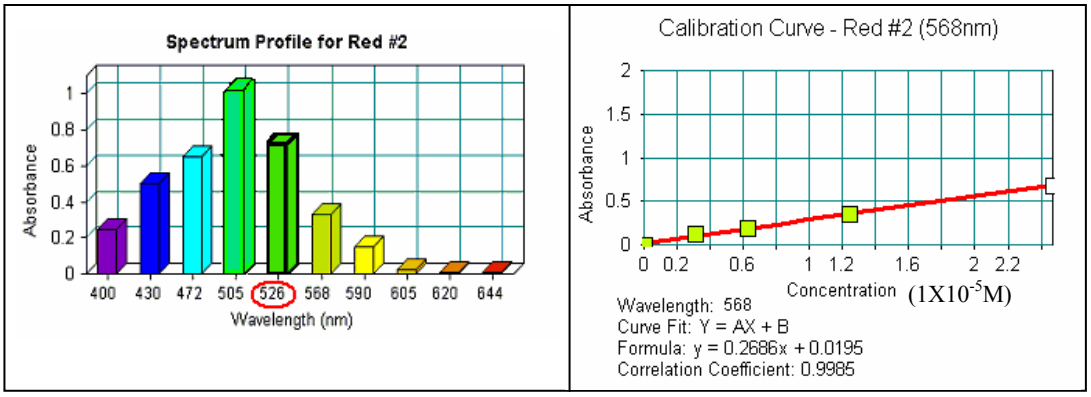

Figure 85: Students' observed a larger change of absorbance versus concentration when choosing 526nm LED.

In this part of the experiment, students explored all ten data sets of Absorbance versus concentration, choosing different wavelengths and observing the resulting effects on the slope of the absorbance versus concentration curve-fits. Students ultimately deduced that the more light of a given wavelength was absorbed, the larger the changes in concentration versus Absorbance. Students learned that this phenomenon was wavelength dependent and was expressed as the Beer-Lambert Law:

$$\text{Absorbance} = \epsilon_{\lambda} * l * [C] \qquad (43)$$

In equation 43, Absorbance depends upon the choice of wavelength in the molar absorbtivity constant, ϵ_{λ}, the path length of the cell, l, and concentrations of the analyte, [C]. With this simple linear equation, students saw that a change in molar absorbtivity changes the slope of an Absorbance versus concentration calibration curve of Red #2.

In this step, students chose the wavelength that showed a maximum absorbance. Looking at the absorbance spectrum and deciding upon the wavelength of 505nm, students found that this wavelength offers the greatest slope when compared with other wavelengths (Figure 86). This, students learned, was referred to as the analytical

wavelength, or lamda max, λ_{max}, where a maximum change in Absorbance versus concentration results in the best possible resolution for solving an unknown.

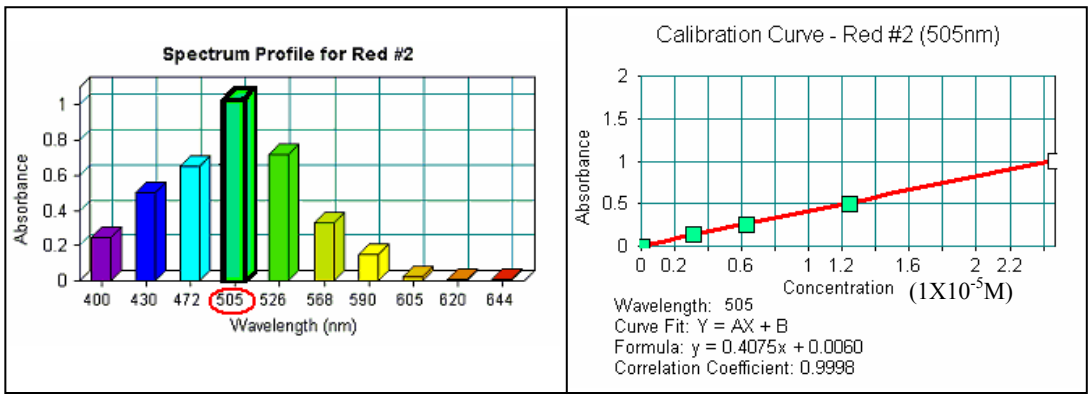

Figure 86: Analytical Wavelength – Students' observe the largest change of absorbance versus concentration when choosing 505nm LED. Because of this, 505nm is referred to as the analytical wavelength.

In the last step, students scanned an unknown Red #2 solution and collected its absorbance values at the analytical wavelength. Using the linear calibration curve, the software automatically plotted the unknown with an "X" and solved its concentration. For example, students solved for the unknown Red #2 solution to be a concentration of 0.583 X 10^{-5}M, which is 2.83% within the actual 0.600 X10^{-5}M value (Figure 87).

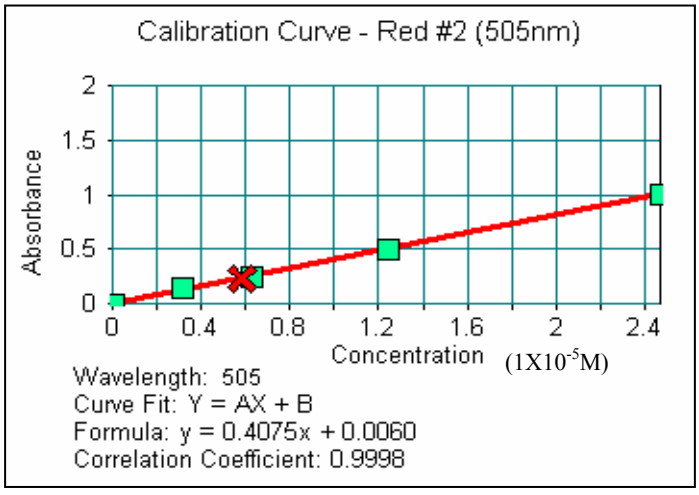

Figure 87: Colorimetric Calibration Curve Students' observe a small change of absorbance versus concentration when choosing 605nm LED.

This colorimetric data required only one second to scan each of the five standards with MicroLab's 10-color colorimeter, thus time is limited to the efficiency of the students' preparation of the standard, itself. When comparing this approach to the collection of five different standards at ten different wavelengths with the Spectronic 20, the process of calibration at each wavelength, the hand-collection of % Transmittance and Absorbance, and the hand-entering of these data into a computer graphing program takes much more effort and time. This approach allows for ease-of-use by handling these 100 data points in such a way that students easily navigate in software. As a result, students have more time to explore multiple chemical systems in one lab period and/or other important aspects of colorimetric analysis. One of these, as discussed above, is to explore the choice of an appropriate analytical wavelength by using different wavelengths and the slope of the calibration curve.

Experiment 3: Chemical Kinetics and
Determination of Reaction Orders

Student Objectives:

- Students will use calculus to theoretically derive rate laws for reactants in a dynamic chemical reaction.
- Students will acquire colorimetric data over time through experimentally monitoring changes in colored reactant.
- Students will choose the analytical wavelength and apply the Beer-Lambert Law to solve for the order of colored and non-colored reactants.

In this final experiment, students were asked, "Why is it important to know the rate at which a chemical reaction reacts?" Students explored the kinetics of crystal violets' reaction with hydroxide. Although the dynamics of this system have been known

and used in chemical education since 1964, it was a chemical system that was an ideal match for MicroLab's 10-color colorimeter hardware and kinetics software (Gorsara, 1964 and Caurie, 1964). Students quickly and efficiently determine the order of the crystal violet and hydroxide reaction (Figure88).

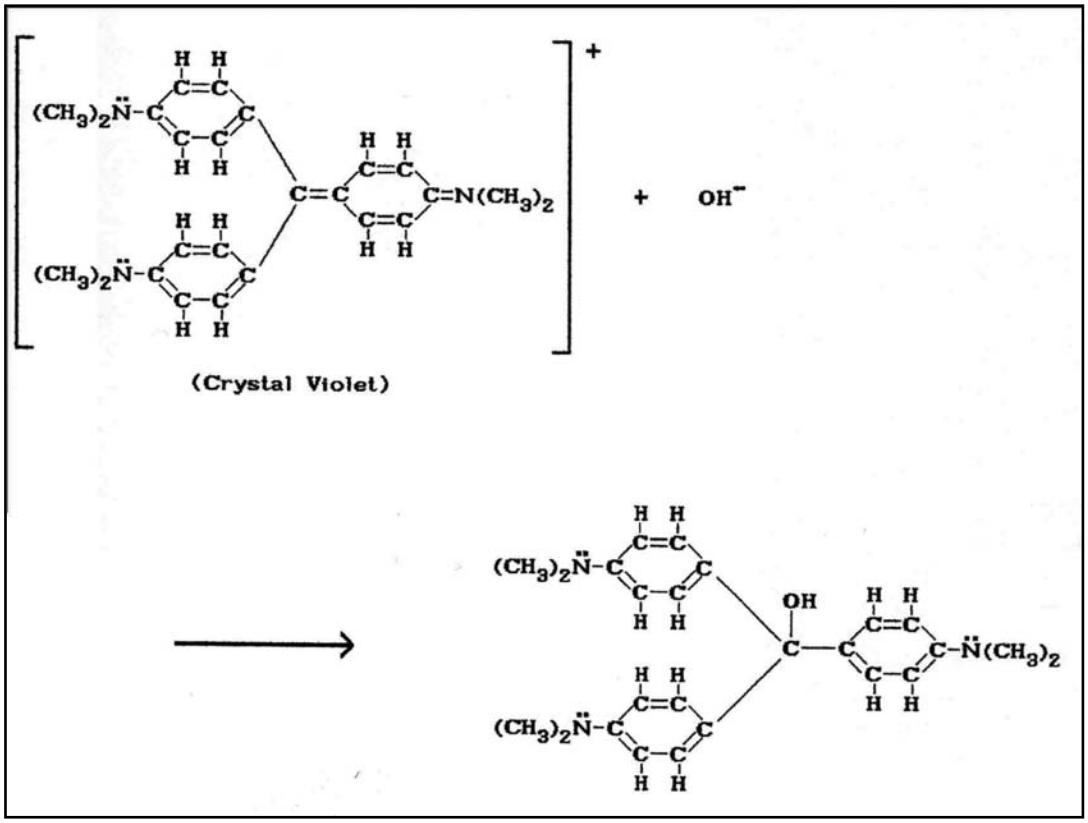

Figure 88: The Crystal Violet Reaction with Hydroxide - The reaction of a clear and purple solution of crystal violet reacts with the hydroxide ion in to form a clear and colorless solution.

Students learned that as the hydroxide ion bonds to the crystal violet molecule, it disrupted the conjugated pi bonds, rendering the resultant molecule transparent to visible light. At a macroscopic level, the solution changes over time from a deep purple to a clear colorless solution that was easily monitored by eyesight or MicroLab's 10-color

Colorimeter. As a side note, students could also be asked to incorporate the pH electrode as a possible sensor to monitor the change in pH, also.

Students were given the following forward rate equation for this reaction:

$$Rate_f = k\,[OH^-]^x\,[CV]^y \qquad (44)$$

The students were asked to experimentally determine the values of orders y and x.

Since hydroxide is clear and colorless, it is not monitored spectroscopically in solution. Initially, Hydroxide ion concentration is held constant and incorporated into a pseudo-rate constant, k', and will be tested for its reaction order later in the experiment:

$$k' = k\,[OH^-]^x \qquad (45)$$

where:

$$Rate = k'\,[CV]^y \qquad (46)$$

And:

$$-d[CV]/dt = k'[CV]^y \qquad (47)$$

The lab instructor and the students then used integral calculus to derive some of the possible rate equations for zero, first and second order equations:

$$[CV]_t = -k't + [CV]_0 \qquad (48)$$

$$\ln[CV]_t = -k't + \ln[CV]_0 \qquad (49)$$

$$1/[CV]_t = k't + 1/[CV]_0 \qquad (50)$$

After calibrating the 10-color colorimeter, students scanned a cuvette of stock crystal violet solution to view its absorbance spectrum (Figure 89). Students determined that analytical wavelength, λ_{max}, should be 592nm.

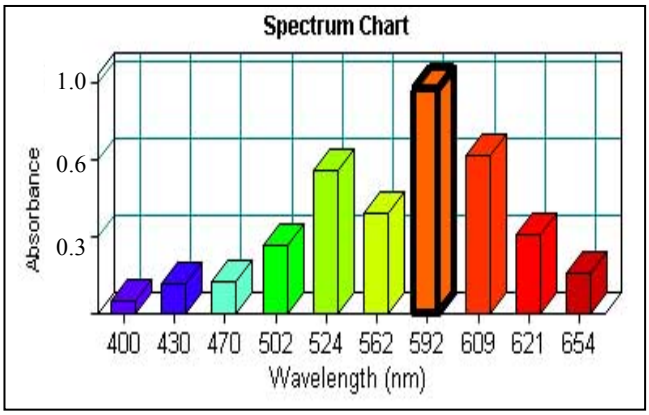

Figure 89: The absorbance spectrum of crystal violet.

Assuming a linear Beer-Lambert Law relationship, Absorbance, A, was substituted for the concentration of crystal violet, [CV], in the previous Equations 51, 52, and 53, yielding:

$$[A]_t = -k't + [A]_0 \quad (51)$$

$$\ln[A]_t = -k't + \ln[A]_0 \quad (52)$$

$$1/[A]_t = k't + 1/[A]_0 \quad (53)$$

Students performed experiments by mixing 13.5mL of $7.5X10^{-6}$ M of crystal violet with 1.5mL of 1.0M sodium hydroxide. After calibrating with a water blank, students used MicroLab's kinetics software to display real-time data in three different graphical modes during or after the experiment. One view displayed data as zeroth order or Absorbance versus Time (Figure 90). Another data view was that of first order, the natural log of Absorbance versus time (Figure 91). The last view displayed the data as second order, inverse Absorbance versus time (Figure 92). From these data, students easily observed that these data suggested a first order fit for crystal violet, therefore y = 1.

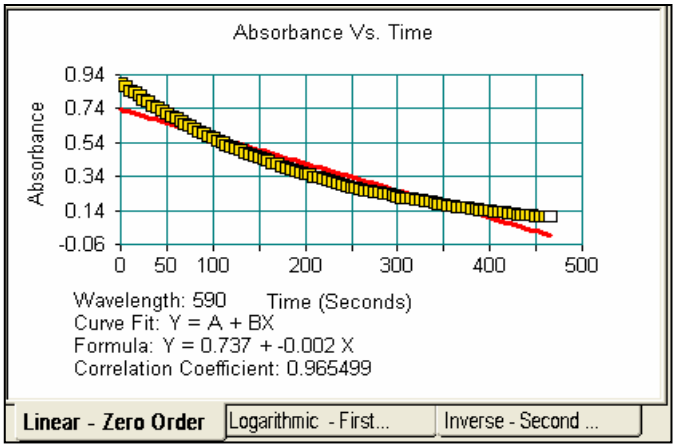

Figure 90: Zeroth Order - Experimental data of Absorbance versus time is not a good fit with the crystal violet reaction.

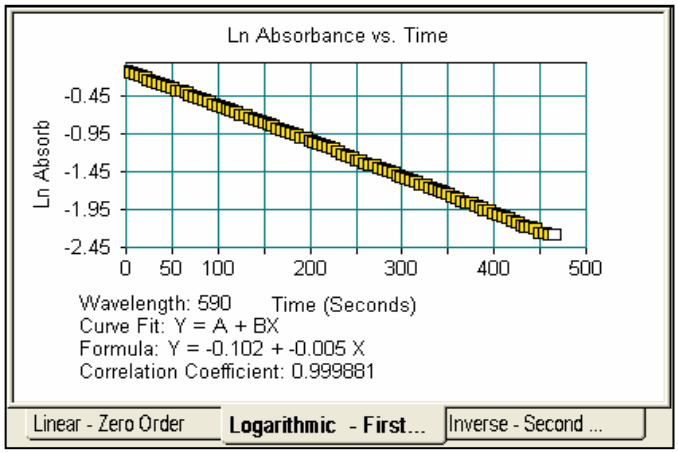

Figure 91: First Order – Experimental data of ln(Absorbance) versus time is a good fit with the crystal violet reaction.

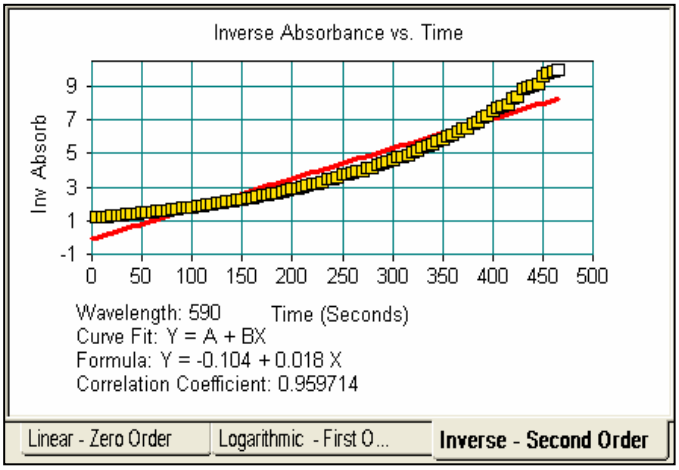

Figure 92: Second Order – Experimental data of (1/Absorbance) versus time is not a good fit with the crystal violet reaction.

Now that students have solved for the reaction order of crystal violet, students run two more reactions of this experiment. This included keeping the concentration and volume of crystal violet the same but changing the sodium hydroxide solution to higher concentrations, 2.0M, and 3.0M NaOH, respectively. For these experiments, the rate of reaction was significantly faster. Students acquired quantitative information about the pseudo-rate constants for the three different experiments, k'_1, k'_2, and k'_3, respectively.

By recording the different slopes of the first order curve-fit data for each of the reactions, students gathered information about the colorless hydroxide's order, equation 54. Students calculated a ratio of rate constants and solved for the order of hydroxide, x. For example, the ratio of first and second pseudo-rate constants was:

$$k'_1/k'_2 = (k_f[OH^-]^x_1)/(k_f[OH^-]^x_2) \qquad (54)$$

Rate constants, k, cancelled out, leaving the ratio of hydroxide and its order:

$$k'_1/k'_2 = [OH^-]^x_1/[OH^-]_2^x \qquad (55)$$

As students compared the theoretical ratios with the experimental values, they realized that the best fit for hydroxide's order, x, was the first order data (Table 17).

Ratio of Pseudo-Rate Constants	Theoretical Ratio	Zeroth Order *(theoretical)*	First Order *(theoretical)*	Second Order *(theoretical)*	Typical Student Experimental Value
k'_1/k'_2	$[OH^-]_1x/[OH^-]_2x$	$[1.0]^0/[2.0]^0$ or 1.000	$[1.0]^1/[2.0]^1$ or **0.500**	$[1.0]^2/[2.0]^2$ or 0.250	***0.597***
k'_1/k'_3	$[OH^-]_1x/[OH^-]_3x$	$[1.0]^0/[3.0]^0$ or 1.000	$[1.0]^1/[3.0]^1$ or **0.333**	$[1.0]^2/[3.0]^2$ or 0.111	***0.414***
k'_2/k'_3	$[OH^-]_2x/[OH^-]_3x$	$[2.0]^0/[3.0]^0$ or 1.000	$[2.0]^1/[3.0]^1$ or **0.667**	$[2.0]^2/[3.0]^2$ or 0.444	***0.690***

Table 17: Hydroxide Order Calculations - This is the table of data that students used to calculate the order of hydroxide in the Crystal Violet reaction. (Note that theoretical and experimental values align best with First Order.)

This study of kinetics and determination of rate order gives students content knowledge about dynamic principles of chemical reactions. The use of software and hardware systems, such as MicroLab's 10-color Colorimeter, gives students another view of the power of integrated instrumentation and control loops. Also, the theoretical derivation of rate order highlights the importance of integral calculus in the real world.

This chapter focused upon the three major outcomes of this dissertation. Experiments were developed that were identified as important to single semester engineering students. These experiments modeled the Scientist's Research Cycle and used a problem-based research approach previously described in Chapter Seven. Laboratory skill-sets and tools were developed to increase student concept synthesis and were built around applications that supported problem solving.

Experiments were developed, tested, and refined in general chemistry labs at MSU for the six top rated subject areas from second semester, including Measurement, Significant Figures, Acid-Base Theory and Equilibrium, Equilibrium Constants, Thermodynamics, and Reaction Rates and Kinetics. These experimental laboratory lessons continue to evolve and improve. The sequencing of these experiments, coupled with this learning approach, assists students in developing important skill-sets and tools so that they could better understand chemical principles and concepts through hands-on laboratory experimentation.

CHAPTER 10

CURRICULUM DEVELOPMENT, IMPLEMENTATION, AND ASSESSMENT

Those who become enamored of practices without science are like sailors who go aboard a ship without rudder and compass, for they are never certain where they will land.
Leonardo Da Vinci

Development and Implementation of the Laboratory Curriculum

The Three Phases of Curriculum Development for this Research Study

There were several phases of development for this single semester engineering curriculum. The first phase included recognition of the problem by Fall Semester, 2002, followed by the testing of experimental measurement technology and lab lessons in general chemistrylaboratory. The second phase began when laboratory curriculum and materials were developed and implemented in two sections of laboratory CHEM 131 in Fall Semester, 2003. The third phase of this research study implemented and assessed the designed laboratory curriculum in four laboratory sections of Mechanical and Electrical Engineering students.

Phase I: Initial Development and Testing: As the problem was being formalized and discussions began with the College of Engineering at MSU, the 2002 to 2003 academic year was used to evolve and test preliminary ideas for this engineering course

during general chemistry labs at MSU and in professional development workshops. In particular, some professional development outreach piloted on dissemination of measurement technology for eighth to fourteenth grade rural science teachers from the Northern Cheyenne and Crow reservations in south central Montana (Sorey, Amend, and Briggs, 2004).

Phase II: Implementation and Development in a General Chemistry Laboratory: Formal testing of curriculum began with two sections of a general chemistry laboratory. The sections in which this curriculum was implemented were randomly chosen in Fall Semester, 2003. With one section on Tuesday and one on Friday, enough time was available between lab meetings to refine experimental laboratory parameters or teaching approaches between sections.

These two sections, total enrollment of thirty-six students, used initial drafts of the class application problems and research extension application problems described in Chapters 8 and 9. Weekly research group meetings were held during the instructor's scheduled office hours. During these meetings, students presented their experimental results to the instructor, formalized their thoughts through informal discussions, and worked together in preparing their oral and written report for the beginning of the following laboratory session. Some of these student discussions were also held in a web-based online forum, where students could post their laboratory experiences for each other to read, WebCT.

Phase III: Implementation of Curriculum with Engineering Students: During Spring Semester, 2004, the refined laboratory curriculum was implemented with a population of Mechanical and Electrical Engineering students, N = 72. These engineering students were randomly assigned into four sections of CHEM 131 laboratory by their academic advisors. With two sections on Tuesday, one section on Wednesday, and one section on Thursday time was provided to make adjustments and refinements between labs.

To reduce bias, a second instructor taught half of these laboratory sections but applied the same grading structure and approaches (APPENDIX C: Lab Syllabus and Grading Criteria). This instructor was trained by shadowing the main instructor during the first laboratory section on Tuesday. The main instructor observed and, in rare instances, helped the secondary instructor on the second laboratory section on Tuesday.

An Assessment Plan for This Research Study

Choosing an Appropriate Educational Data Set

The student learning objectives, presented in Chapter 5, were used both to develop curriculum and to create an assessment plan. The assessment plan was designed to acquire data to measure the outcomes of this study. Assessment consisted of student laboratory reports, formal lecture quizzes and exams, student perception surveys, and rate of transfer into second term of the course (Table 18).

Student Learning Objectives:	Collected Educational Assessment Data				
After completing this course, students will…	Lecture Quizzes and Exams *(Collected throughout the term.)*	Individual & Research Extension Lab Reports *(Collected throughout the term.)*	Online Support: -Discussion -Pre/post lab Quizzes *(Collected throughout the term.)*	Student Self Perception Survey *(Collected at middle, and end of term.)*	Student Enrollment Study *(Collected from Spring 2000 to Spring 2005.)*
1) display an ability to apply their knowledge of chemical principles, mathematics, and measurement instrumentation that are important to chemists and engineers within a research laboratory setting.	X	X	X	X	
2) identify, analyze, and solve application problems in the laboratory through designing and conducting experiments that build scientific research methodology and skills.	X	X	X	X	
3) use modern research skills and tools of mathematics and measurement technology to effectively collect, analyze, and interpret data when solving experimental laboratory problems.		X	X	X	
4) communicate effectively as a research group when solving problems in the laboratory and when presenting results in both written and oral formats.		X	X		
5) recognize a need for chemistry and the importance of lifelong learning.	X	X		X	X

Table 18: Assessment Plan - This is a table of Student learning Objectives and the assessment data that were collected.

A Description of Assessment Data

Quantitative and qualitative types of assessment data were collected throughout Spring Semester, 2004 (Table 18). Quantitative data included students' performances in both lecture and laboratory exams and quizzes, and experimental data that was acquired

in lab and presented written and oral lab reports. Qualitative data included students' explanations of these experimental data in written and oral reports and recorded asynchronous online dialogue between students regarding experiments that were performed in lab. In both instances, currently accepted educational statistical analysis techniques were used in the assessment of this laboratory approach.

Student performance in lecture was evaluated by quizzes and exams. Data were collected that compared the performance of the Treatment Group (N=63) and Non-treatment Group (N = 40) of Mechanical and Electrical Engineering students in CHEM 131 of Spring Semester, 2004. A large enough population was used to provide statistical significance, N > 30 (Christian 2004).

Individual and Research Extension Group Laboratory reports were the primary source of feedback for monitoring agreement with the five student learning objectives (Table 13). Throughout the semester, this graded lab work was evaluated quantitatively through precision and accuracy of acquired data and qualitatively through written introductions, research designs, and explanation of acquired data. To illustrate this, a sample of A grade level and B grade level student reports is presented in Appendix E: Lab Experiments, Research Extension Lab Experiments, and Student Reports.

A second set of assessment data was collected online via WebCT. These data included pre-lab and post-lab quizzes and online post-lab student discussions. The pre-lab quizzes were designed to measure the students' pre-lab knowledge and to prepare them for the upcoming chemistry content and laboratory materials that they would be using. Upon completion of each lab, students took a post-lab quiz. To discourage memorization of quizzes and cheating between sections, the scores and answers for

quizzes were posted after the post-lab quiz was due (Hake 1998). Finally, students chose from a list of three post-lab discussion questions every week and posted an original reply or answer to the assigned question. Students were given points for posting an original quality message and interacting with other students by replying to at least two other students (Gunawardena, C., Plass, J, and Salisbury, M., 2001).

As in previous work completed in the Amend Research Group, students' perception of the effectiveness of this course was used to help evaluate approach, methods, and materials (Furstenau 1990 and Morgan 1997). In this study, an effort was made to measure a change in perception over time. Midterm and exit surveys were administered to the target students to measure their perceptions on topics that ranged from understanding of measurement technology, attitudes toward performing research group work in the lab, and the value of oral reports.

The fifth student learning objective, lifelong learning, was assessed with three sets of quantitative data. The first set of data tracked the three-year average of mechanical and electrical engineering students' enrollment in freshman general chemistry. A second set of data is from the exit survey that measured the personal interest for students to enroll into the second semester of chemistry, CHEM 132. The last set of data collected tracked the students from the study for the 2004-2005 academic year to determine how many actually enrolled into the second semester of general chemistry, CHEM 132.

CHAPTER 11

RESULTS, DISCUSSION, AND CONCLUSIONS

Not everything that can be counted counts, and not everything that counts can be counted.
Albert Einstein

Research Study Results and Discussion

A laboratory curriculum for single semester engineering students was developed, implemented, and assessed. The results of this research study are presented in this chapter. Both quantitative and qualitative assessment data were collected and used to assess this approach and its achievement of the designed student learning objectives.

Student Performance in CHEM 131: Lecture and Lab

Examination of Mechanical and Electrical Engineering student performance during the three academic years of 2000-2001 to 2000-2003 showed that 48.0% of this population, N = 493, earned a B- or greater in the first semester of general chemistry, CHEM 131. At the end of Spring Semester, 2004, 57.0% of the total population of Mechanical and Electrical Engineering students, N = 103, earned a B- or greater. Further investigation was needed to determine why these academic gains were observed.

In Spring Semester, 2004, sixty-three Mechanical and Electrical Engineering students were randomly assigned to one of the four sections of this experimental

laboratory course by their academic advisors. These students will be referred to as the Treatment Group. The remaining Mechanical and Electrical Engineering students, N = 40, were randomly placed in regularly scheduled labs by their academic advisors. These students will be referred to as the Non-treatment Group. Analyzing these two groups separately at the end of the semester, 67.1% of the Treatment Group and 40.9% of the Non-treatment Group earned a letter grade of B- or better. In fact, it was found that 45.7% of the Treatment group and 18.2% of the Non-treatment Group earned a letter grade of B or greater, as compared with the three and a half year average of 39.55%.

The Treatment Group outscored the Non-Treatment Group in all areas in this general chemistry course (Table 19). The two greatest differences between these two groups were found in lecture tests and quizzes. The Treatment Group outscored the Non-treatment Group by an average of 4.5% (tests) and 7.6% (quizzes), respectively. An Independent Samples t-test showed that the Treatment Group outperformed the Non-treatment Group on these lecture quizzes and tests to over a 95% confidence level (Appendix G: Lecture Test and Quiz Statistical Analysis).

Lecture Performance of ME and EE's in Spring of 2004	N	Lecture Tests (mean)	Lecture Quizzes (mean)	Laboratory Grade (mean)	Lecture Final Test (mean)	Overall GPA points (mean)	Final Letter Grade (mean)
Treatment	63	78.5%	88.6%	85.1%	79.5%	2.72	B-
No Treatment	40	74.0%	81.2%	83.6%	76.8%	2.36	C+
Delta	/	+4.5%	+7.6%	+1.5%	+2.7%	+ 0.36	+ 1/3 letter

Table 19: The treatment group outscored the non-treatment group consistently throughout the semester.

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Delta	/	+4.5%	+7.6%	+1.5%	+2.7%	+ 0.36	+ 1/3 letter

Table 19: The treatment group outscored the non-treatment group consistently throughout the semester.

Research Extension Application Problem Written and Oral Reports

In lab, students earned points from individual written reports and collectively as a research group from both written and oral reports. Points were assigned to individual and research group reports according to a carefully designed grading rubric (APPENDIX C: Lab Syllabus and Grading Criteria).

All students in the engineering laboratory sections solved weekly class application problems and wrote reports. Students who worked in pairs were required to write up an individual report. Students who worked as a Research Extension Group performed both the class application and research extension application problems, turning in a collective report that required all of the same components as an individual report, but also included three addendums. First, research extension students were to include a Material Safety Data Section, MSDS, at the beginning of their report that listed all of the chemicals they used and their potential hazards. Second, students were required to include a materials and instrumentation section that listed and explained any technical materials or measurement technology that were used in data acquisition. Third, students were required to present at least one real-world application that used the content knowledge that was presented and where it could be found in practical use.

The Treatment Groups' overall lab performance was exceptional. Compared with their Non-treatment Group average grade of 83.6%, the Treatment Group's average grade was 85.1% (Table 19). An Independent Samples t-test was performed on this set of data and it was found that the lab grades for the Treatment and Non-treatment Group were not significantly different from the Non-treatment Group. This was an indicator that the

Treatment and Non-treatment Groups were not graded significantly different from one another in laboratory performance.

For all four sections of single semester engineering labs, student performance was qualitatively acceptable in their written introductions, description of experimental procedures, and conclusion. Quantitatively, students' experimental results in lab were fair to good. Although no formal educational analysis was performed on these reports, the researcher noted that students showed improvements in their written and oral laboratory reports over the semester.

An example of an A grade-level and a B grade-level Research Extension Group written and oral reports can be found in Appendix E, *Lab Experiments, Research Extension Lab Experiments, and Student Reports*.

Online Assessment with WebCT

Online Pre-Lab and Post-Lab Quizzes: To analyze the impact of Research Extensions on student comprehension of chemistry content knowledge presented in lab, a methodology for averaged normalized gains on pre and post lab quizzes, referred to as the Hake Factor, *h*, was implemented (Hake 1998). These online quizzes were analyzed for two different groups of students within the Treatment Group labs, where the calculation for gain was:

$$h = (\text{post-lab quiz} - \text{pre-lab quiz})/(1\text{-pre-lab quiz}) \quad (35)$$

The two different groups within a single treatment lab included the Research Extension Group, approximately four students who worked as a team to solve both a

class application problem and a research extension application problem, and the Regular Treatment Group, the remainder of the lab students who solved a class application problem with a partner. The Hake Factor was calculated for the Research Extension Group, $N_{average} = 16$ students, and the Regular Treatment Group, $N_{average} = 56$ students, (Table 20).

Treatment Group:	Regular Treatment Group		$N_{average}=56$	Research Extension Group		$N_{average}=16$
Quiz #	Pre-lab	Post-lab	h_R (gain)	Pre-lab	Post-lab	h_{RE} (gain)
1	89.5%	90.0%	0.047	93.9%	96.3%	0.389
2	73.3%	76.7%	0.127	73.6%	88.9%	0.579
3	76.3%	81.1%	0.204	*82.7%*	*78.3%*	*-0.043*
4	88.5%	92.4%	0.340	83.1%	91.7%	0.506
5	80.2%	88.1%	0.400	84.8%	92.6%	0.511
6	52.4%	85.1%	0.687	36.7%	75.0%	0.605
8	74.5%	76.3%	0.072	81.0%	91.7%	0.563
9	76.1%	87.1%	0.461	77.9%	90.9%	0.588
Averages	76.4%	84.6%	0.292	76.7%	88.2%	0.462

Table 20: Online Pre-lab and Post-lab Quizzes - calculated averaged normalized gains or Hake Factors, *h*.
(note: Quiz # 7 is missing due to technical errors on WebCT.)

The pre-lab quiz averages for both groups are nearly identical, with difference of only 0.3%. The Research Extension Group outperformed the Regular Treatment Group on post-lab quizzes, with an increase of 3.6% (Table 21). Finally, the calculated average hake factor for the Research Extension Group was 0.462 as compared with 0.292 for the Regular Treatment Group. In both cases, students showed gain, where 0.300 is considered a low to medium gain and 0.600 is considered medium to high gain (Hake 1998).

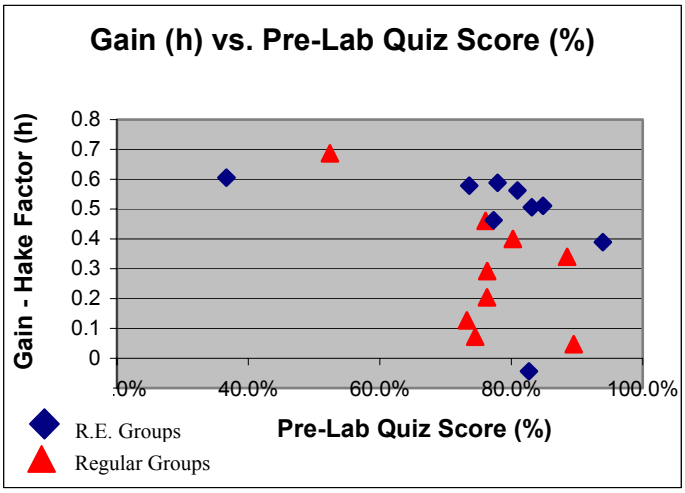


Figure 93: Research Extension (R.E.) Groups showed more consistent and higher gains on lab quizzes than the Regular Groups.

A plot of the average hake factors of the Regular Treatment Group (Regular Group) and Research Extension Group (R.E. Group) versus the corresponding average pre-lab quiz score shows a positive trend for both groups (Figure93).

This type of analysis is particularly helpful in pinpointing ineffective labs. For example, one of the quizzes for the Research Extension Group in Figure 93, quiz three in week five, showed a slightly negative average gain, -0.043. Although there could be a number of factors that could be explained why the Research Extension Groups had low performance on this post-lab quiz, it is a quantitative indicator that assisted the researcher in identifying potential problems in the design of that particular lab.

Overall, the Research Extension Group students who solved both the class application and research extension application problems showed a 1.6 times greater gain on quiz scores than the regular group students. Since the weekly number of Research Extension Group students taking weekly online quizzes was less than sixteen, the researcher did not calculate a standard deviation or solve for a statistically significant

difference between these two groups. In summary, both groups showed gains in content knowledge, but Research Extension Group students showed an overall higher average gain. (Appendix F: Online Quizzes and Discussions)

Online Essay Questions and Student Dialogue: Throughout the semester, students answered essay questions via WebCT, an online web-based tool. Students would choose from two or three possible topics and then post an answer (Appendix F: Online Quizzes and Discussions). To gain full credit, however, students needed to reply to at least two other students' postings.

In most instances a thoughtful discussion of chemistry content was observed. Much of this content required little or no prompting from the instructor. This discussion of fluorescence and Stoke's Shift illustrates the richness of the discussions:

SAMPLE DISCUSSION #1: Fluorometry - (Student Interaction)

> Topic #3: From the lab this week, what is STOKES SHIFT and where did you see evidence of this phenomenon?
> Student #(01123598) / Date: February 27, 2004 3:56pm
> Stokes Shift is the difference in wavelength/energy between light absorbed by a molecule and that emitted. In our lab we saw this effect when the aqueous fluorescent salt absorbed light of around the blue wavelength and emitted light of green, which is lower energy…A possible reason for the drop in light energy is that while the molecule was in an excited state, it lost some energy, lowering the amount of energy available to be re-emitted.
>
> Student #(01298635) / Date: Monday, March 1, 2004 12:39pm
> Good analyses of Stoke's Shift, (01123598). To further elaborate, the energy loss you talk about could be caused by the multiple bonds the molecule may have vibrating among each other, which could create heat that would dissipate throughout.

This conversation shows a good working knowledge of Stoke's Shift in solution chemistry, where excited vibronic states last approximately 10^{-15}seconds and excited

electronic states last approximately 10^{-8}s (Skoog, Holler, and Nieman 1998, p. 137). Online conversations such as this were an important part of learning. The conversions offered students the opportunity to explain themselves thoroughly and co-construct knowledge that was not restricted by time (Garrison, Anderson, and Archer 2001 and Limon 2001). This is shown by the quality of postings and replies as seen above.

Other conversations occurred that were less about chemistry content and more about student perceptions of materials presented in lab. For instance, students had a mixed reaction to the pH lab and learning about the pH electrode. The following conversation took place after the pH lab:

SAMPLE DISCUSSION #3: Electrochemistry and pH – (Student Interaction)

> Topic #3: Does understanding HOW an electrochemical sensor, like the pH probe, help you to understand pH OR does this type of information get in the way? (Please be honest.)
>
> Student#(00209359) / Date: Friday, April 23, 2004 2:15pm
> YES! Understanding how this measurement device works is essentially to understanding pH. As engineering students, we should be able to understand a given concept (pH) and be able to understand and explain how this concept is measured or detected. We don't need to know all the finer details, like how my computer works, but just the idea behind it is function.
>
> Student # (01325116) / Date: Sunday, April 25, 2004 9:25pm
> While I agree that an understanding of pH is necessary for engineers, I am not so sure that an understanding of how a pH sensor works is as relevant. I think I have a pretty good grasp on pH in general, but I haven't the slightest clue how a pH sensor works, although I might have right after the explanation of it.
>
> Student # (01258516) / Date: Monday, April 26, 2004 4:03pm
> I agree. I don't even remember the explanation of the pH probe. Too much information in at one time is not always the best.
>
> Student # (01311045) / Date: Sunday, April 25, 2004 9:25pm
> Nice, its good to see someone is being honest. I would have to agree with what (01258516) said about the pH probe being hard to understand. I also

> think though that there is always a place for that information... It might be nice to know.

Online conversations such as this were observed to take place in all four separate sections directly after the pH lab. In some instances, students supported each other's perspectives about the difficulty and/or importance of understanding of how pH sensors function and why it may be important to know. These types of online conversations, when guided by the instructor, served as a forum to continue learning outside of the laboratory, where students could freely voice their opinions and recognize that others may also have had difficulty in dealing with abstract concepts. In another round of discussions, some students recognized the importance of knowing the fundamentals of environmental sensors like the pH electrode.

SAMPLE DISCUSSION #2: Electrochemistry and pH – (Sensor Functionality)

> Student # (01316576) / Date: Saturday, April 24, 2004 10:41am
> I don't believe it is crucial to understand the mechanics of the pH sensor but it's the kind of thing that would bother me. In addition to satisfying my curiosity, it is also useful to know how all the sensors used in a lab work. If you don't know how your instrumentation works then it becomes difficult to tell if it is broken. It is also useful to know how something works because it makes it more intuitive to use.
>
> Tim Sorey / Date: Monday, April 26, 2004 11:09am
> (01316576),
> I couldn't agree more when you say, "...it is also useful to know how all the sensors used in a lab work. If you don't know how your instrumentation works then it becomes difficult to tell if it is broken." This is a big issue when you are out in the field and an instrument goes down. It is very difficult to trouble shoot when you don't know the 'native language' of the instrument. For instance, if you didn't know that an output of -voltage, 0 voltage, and + voltage corresponded to pH 10, pH 7, and pH 4, respectively...you wouldn't know if your pH probe was functioning properly or not. Thanks for this posting, Tim
>
> Student # (01328336) / Date: Monday, April 26, 2004 1:25pm
> I have to agree with Tim and (01316576). Knowing how the

> instrumentation works would definitely help in knowing whether or not the sensor is working correctly. If you thought it was working fine and were taking measurements that were completely wrong you would be working completely in vain.

Online discussions such as this have been proven to be an effective mode of students helping each other to learn content (Gunwardena, Plass, Salisbury 2001). They also help instructors to recognize possible pitfalls of specific lessons, incorporating student insight that helps to make improvements to the curriculum. With some intervention from the instructor, as seen above, students can come to a better understanding of not just chemistry content, but also the laboratory materials and how they are used. It is this, the opportunity for students to discuss content coupled with process, which helps students to move beyond the realm of abstract and into the real world of application.

Student Survey Data – Student Perceptions
of Approach, Methods, and Materials

Two surveys were administered during Spring Semester, 2004, to the four sections of engineering students. The first survey was a mid-term survey that was administered during the week of March 22, 2004, after all students had performed in a Research Group in solving a research extension application problem. The second was an exit survey that was administered during the last week of lab, April 26, 2004. The topics of the survey included chemistry content knowledge, use of WebCT, use of Measurement Technology, and Research Extensions. Research has shown that greater student attitude and student learning are directly related (P. Germann, 1998).

Chemistry Content Knowledge: In question number two of the survey, students showed an increase in belief that this laboratory section had significant impact on their knowledge of chemistry.

2. On scale of 1-5 (1 no impact and 5 large impact), what has been the impact of this laboratory section on your knowledge of chemistry?

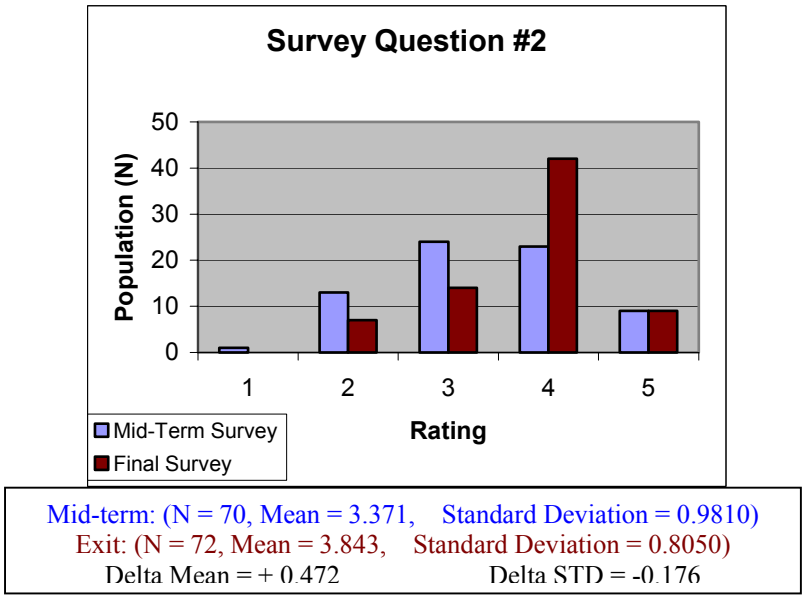


Figure 94: Students showed an increase of perceived that this course made a high impact on their chemistry content knowledge from mid-term to exit survey.

Students also reported that this lab section had significant impact on their ability to solve problems.

3. On scale of 1-5 (1 no impact and 5 large impact), what has been the impact of this lab section on your ability to solve experimental problems?

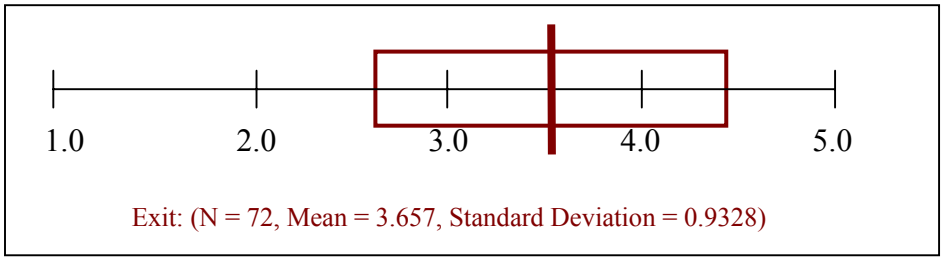
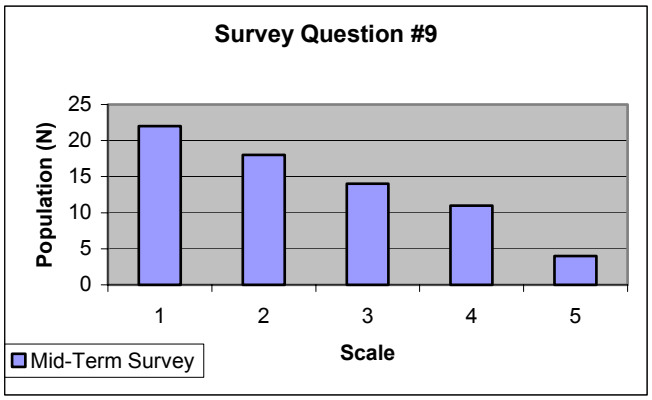


Figure 95: Student perception of impact of lab solving experimental problems.

WebCT: Students' perception of the effectiveness of WebCT had a negative student perception, with more than half of the students exhibiting no to very low interest in continuing its use (Figure 96).

9. On scale of 1-5 (1 no interest and 5 high interest), how interested are you in continuing the use of WebCT for the rest of the semester?



(Mid-term: (N = 69, Mean = 2.343, Standard Deviation = 1.250)

Figure 96: Students showed a lack of interest in using WebCT at the mid-term?

At the mid-term, less than half of the students believed that WebCT was being used effectively. By the end of the semester, however, nearly sixty percent of the class said that WebCT was being used effectively (Figure 97). This positive trend in student perception of WebCT was encouraging, since this tool was an appropriate measure of

7. Do you believe WebCT is being used effectively? (Yes, No; Undecided.)

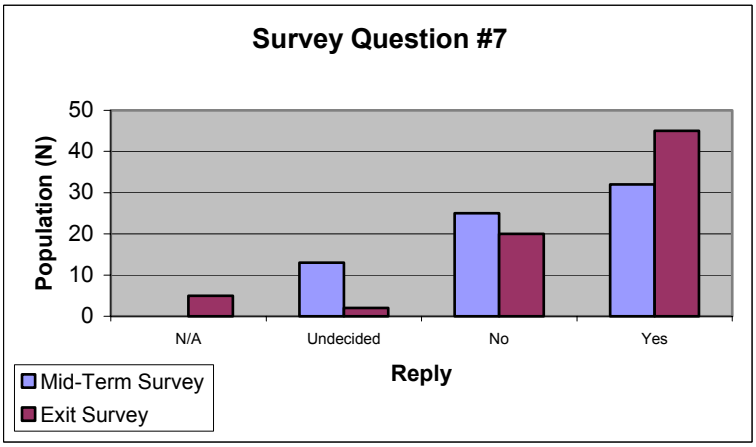


Figure 97: Student perception of the effectiveness use of WebCT over the semester.

students' understanding of chemical principles presented in lab by their performance in online quizzes and posted discussions of laboratory experimentation, as the previous section discussed. Interestingly, students reported about the same amount of time investment on WebCT upon exiting the course when compared with the mid-term. A majority of students spent less than thirty minutes per week (Figure 98).

10. Reflecting back on you use of WebCT this semester, what is the average number of minutes per week that you we logged in?

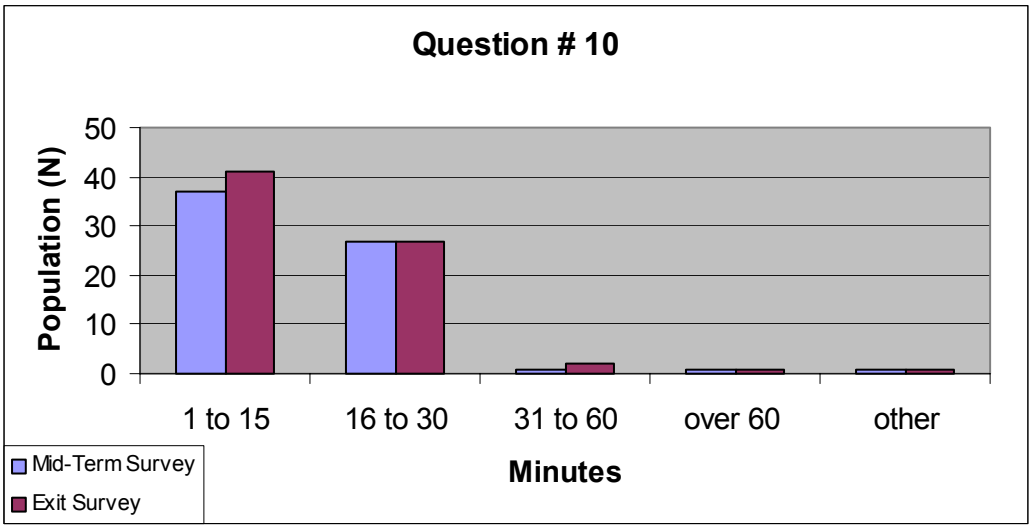


Figure 98: The amount of time students reported using WebCT per week.

Measurement Technology: At the midterm, the Treatment Group already showed a good level of understanding and comfortability with environmental sensors and computer interfaces. This is due, in part, to a population of engineering majors who more than likely have a natural affinity for technology. Nevertheless, a student reported increase in understanding and comfort in using the tools of electronic data collection was reported by the end of the semester. (Figures 99 – 102).

11. On a scale from 1 to 5 (1 having small understanding and 5 having complete understanding), please circle your current understanding of the environmental sensors you have used in lab. (Electronic sensors including pH probe, temperature sensors, light sensors…etc.)

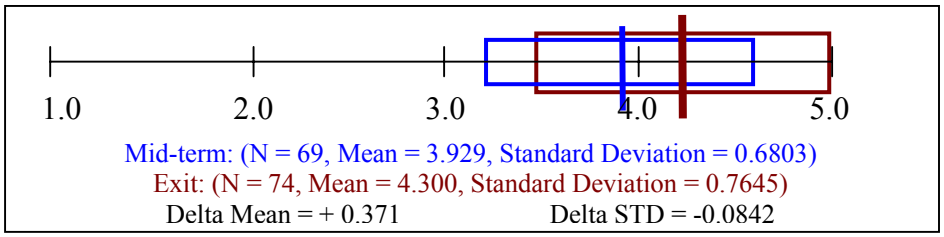


Figure 99: Students' understanding of environmental sensors.

12. On a scale from 1 to 5 (1 having no comfort and 5 for being at ease), please circle your comfortability level in using these environmental sensors for collecting data in lab.

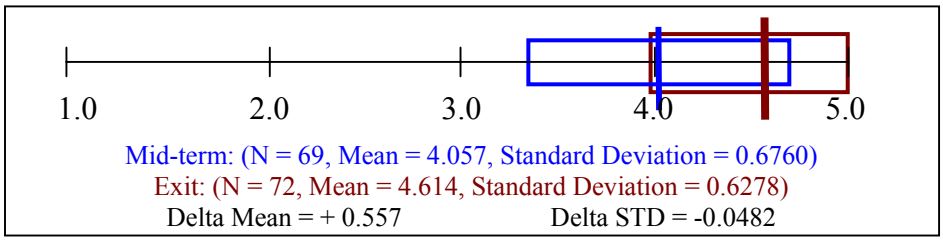


Figure 100: Students' comfortability level with using environmental sensors.

13. On a scale from 1 to 5 (1 having small understanding and 5 having complete understanding), please circle your current understanding with using the MicroLAB interface and its software for data acquisition.

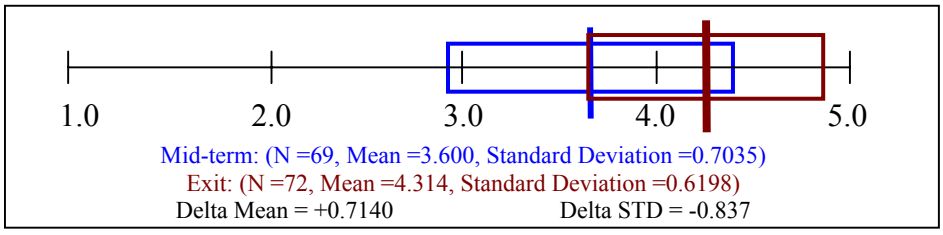


Figure 101: Students' understanding of interface and software use.

14. On a scale from 1 to 5 (1 having no comfort and 5 for being at ease), please circle your comfortability level in using the MicroLAB interface for data acquisition.

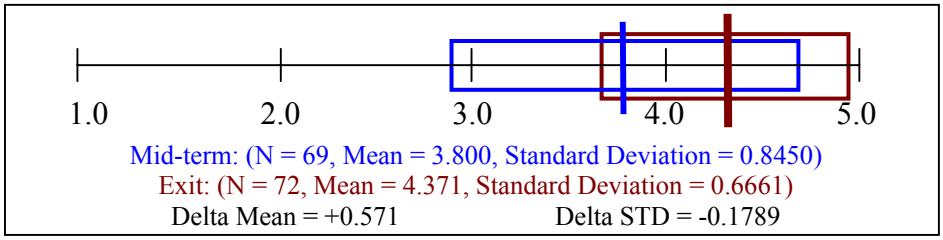


Figure 102: Students' comfortability with interface and software.

At the midterm of the semester, students believed that electronic instrumentation was effective in helping solve problems in the laboratory. By the end of the semester, this belief in effectiveness had increased (Figure 103).

15. On scale from 1 to 5 (1 not effective and 5 for most effective), please circle how effective you believe the use of electronic instrumentation is in solving problems within this laboratory.

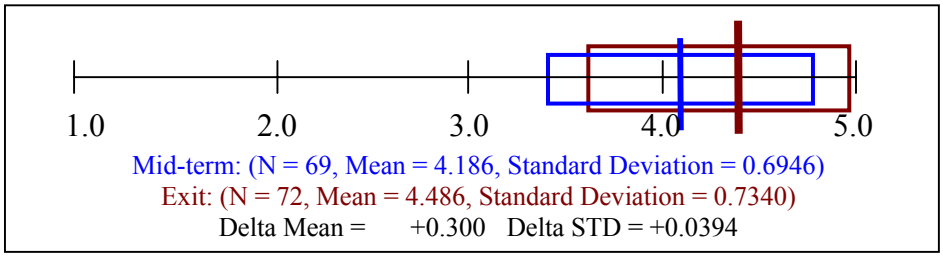


Figure 103: Students believe that electronic instrumentation is effective in problem solving.

Although students believed that electronic data collection is effective in solving problems, more students preferred having information about the instrumentation as a supplement or "other" (Figure 104). This was interpreted by the researcher to mean that students preferred having a direct purpose for the instrumentation if it was to be presented in the laboratory.

17. About the previous question; would you prefer to have more information about instrumentation as part of the laboratory OR as supplemental materials.

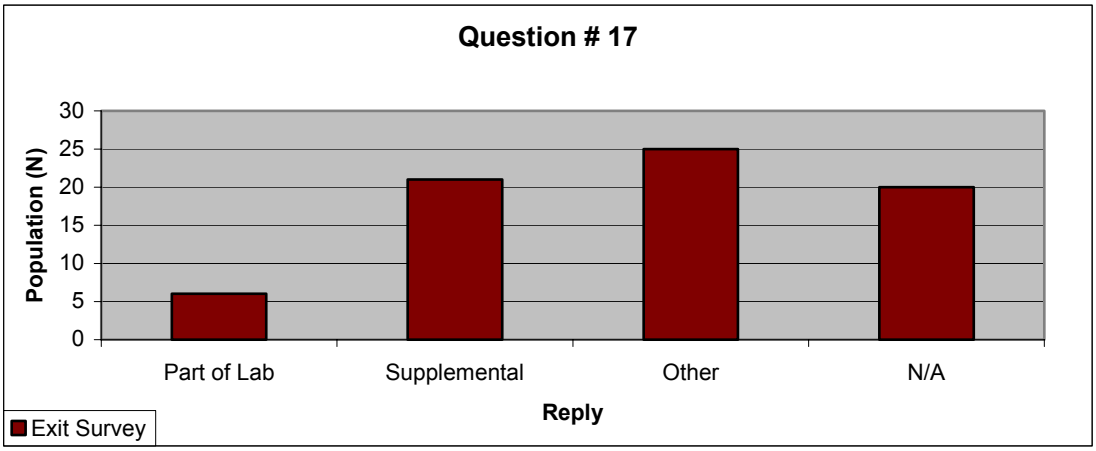


Figure 104: Although students displayed a preference for information about instrumentation as part of a supplement for laboratory, they had "other" alternative ideas, also. (See Appendix A).

Research Extensions: At midterm, students reported a low to minimum level of liking the Research Extension (Figure 106). By the end of the term, student perceptions had vastly changed. The level of liking the Research Extension increased nearly 170%. Similar positive trends were observed when students considered their level of interest as a listener during oral reports and their level of enjoyment when working as a Research Group (Figure 105-107).

23. On scale of 1-5 (1 minimum and 5 maximum), how well did you like the Research Extension part of the lab?

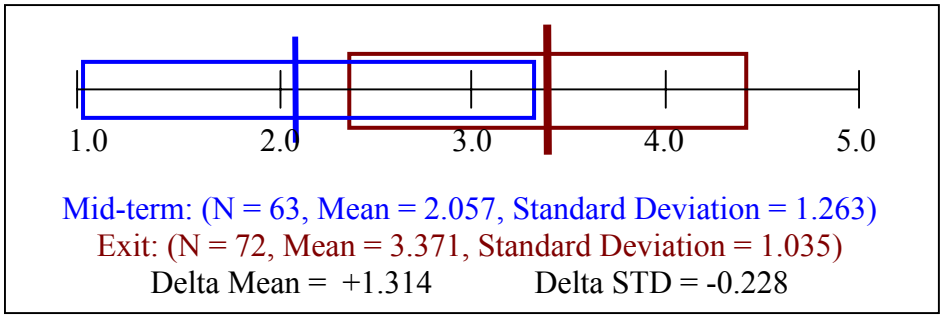


Figure 105: Students' showed a marked increase of liking the Research Extension by the end of the semester.

24. On scale of 1-5 (1 minimum and 5 maximum), where would you rate your level of interest as a listener during the Research Extension oral presentation reports?

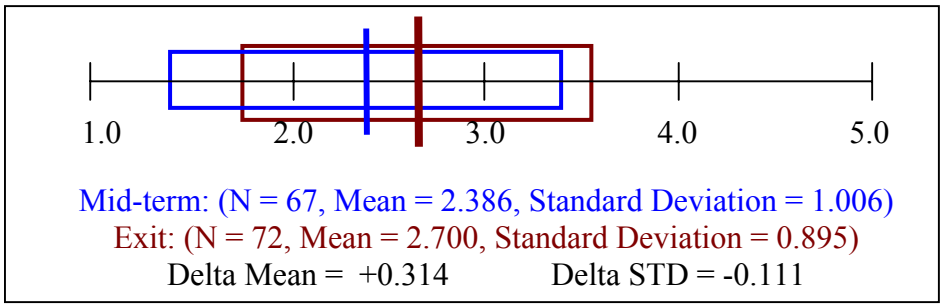


Figure 106: Students showed a continuously low but increased interest as a listener during oral reports.

25. On scale of 1-5 (1 minimum and 5 maximum), how well do you like participating with your Research Group in completing your Research Extension experiment, write-up, and oral report?

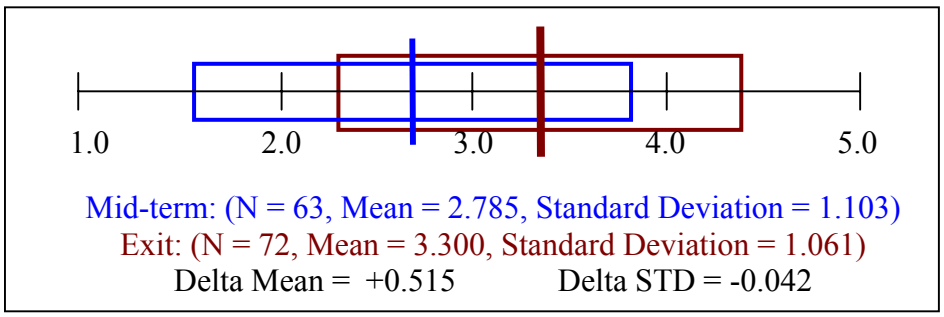


Figure 107: Students developed an appreciation for working in groups to complete their experimental and written works.

As in the other cases, a below mid-level perception was observed at the mid-term, but in the exit survey, more students perceived this approach to laboratory learning matched their style of individual learning.

27. On scale of 1-5 (1 minimum and 5 maximum), how effective is this Research Extension approach to your style of individual learning.

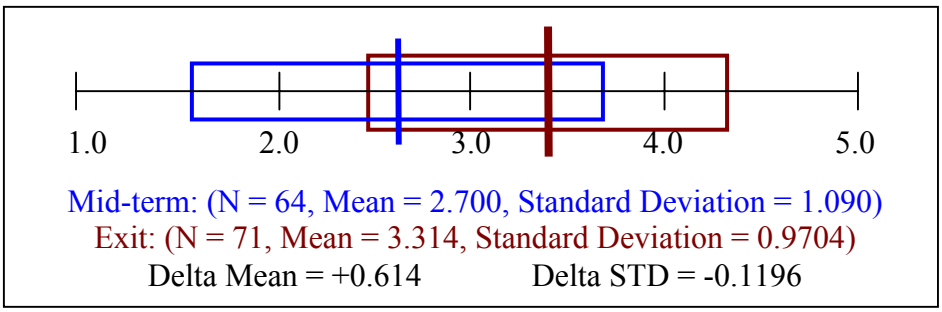


Figure 108: By the end of the term, more students perceived that this approach supported their individual learning.

A major reason for administering this survey was to find out what the students did and did not value in this experimental laboratory curriculum. Students seemed to value some aspects of the course more than others. Students seemed to value instrumentation as long as it had a purpose in lab and was not a "stand-alone" component. The largest positive net change in attitude during the implementation of the course was in student perception of their learning with respect to Research Extensions. It appeared that students required a period of time to build confidence in the process of experimental inquiry, validating the rationale for assigning more than one research extension during the semester. Performing two research extension projects seemed to cause students to gain a more positive attitude toward this approach and, quite possibly, in chemistry.

Students least valued WebCT, even though a majority of them were only logged on less than thirty minutes per week. From an instructor's perspective, the online quizzes and dialogues were invaluable tools in helping to both quantitatively and qualitatively evaluating students' conceptual understanding of content and process presented in lab. (Appendix B: Survey Instruments and Outcomes.)

Enrollment Data – Students, Chemistry, and
Lifelong Learning

Mechanical and Electrical Engineering students have constituted 16.3% of the total CHEM 131 population during the 1999-2000 and 2002-2003 academic years. Of this population, 88.5% of the Mechanical Engineering students and 82.5% of Electrical Engineers completed CHEM 131, respectively. Enrollment in the following semester of general chemistry, CHEM 132, was a low 2.9% and 0.8% for these students, respectively, with a combined weighted average of 2.3%.

Upon exiting this laboratory in Spring Semester, 2004, a final survey question asked:

32. Are you planning to take another chemistry course after this semester?
(N = 71)

Yes: 14
Maybe: 8
No: 48
N/A: 2

Commitment to taking CHEM 132 was running high for students since 30.3% of students either replied "yes" or "maybe" upon completion of the Treatment Group sections. Comparing this value to the three-year average for Mechanical and Electrical Engineering students, this would have been an increase of 13.2 times greater if these students had enrolled into the second semester.

Tracking these students throughout the 2004-2005 academic year, 8.3% of this Treatment Group enrolled in CHEM 132 in either Fall Semester, 2004, or Spring Semester, 2005. Although this may not seem like a large increase in enrollment, it was 3.6 times greater than the previous three-year average. Only 1.8% of the Non-treatment Group decided to take the second semester of general chemistry. This means that the Treatment Group was 4.6 times more likely to take the second semester than the Non-

treatment Group. This researcher interpreted these data as proof that this approach impacted the Treatment Groups' interest in chemistry beyond the requirements of their formal Engineering degree, thus reflecting the importance of lifelong learning.

Research Study Conclusions

Goals Achieved in This Research Study

In Spring Semester, 2002, research goals were presented and accepted by this researcher's graduate committee. At that time, it was recognized that changes in the Accreditation Board for Engineering and Technology requirements in 2000 caused several engineering curricula to require only one semester of a two part general chemistry series. As a result, these students were receiving an incomplete survey of general chemistry and missing important topics such as equilibrium and kinetics, acids and bases, and electrochemistry that are taught in the second semester. To achieve these approved research goals and solve the identified problem, the researcher developed, implemented, and assessed a general chemistry laboratory curriculum for these single-semester engineering students.

Interdepartmental collaboration with the College of Engineering was crucial in solving the problem. This partnership lead to gathering local and national perspectives that identified important general chemistry content and student learning objectives for a target population of engineering students. These student learning objectives served as guidelines in designing a laboratory curriculum that supported students' inquiry and problem solving skills through experimentation in the same manner as chemistry research

groups. Working in groups, students and instructors held informal research meetings outside of lab to discuss solutions to experimental problems and then formally shared results with peers in an oral presentation. During this process, students gained a research perspective and were guided in the development of measurement technology and mathematical skill-sets used in experimental design. An assessment plan was developed and implemented to accompany this curriculum. This plan was used to evaluate this approach and measure its alignment with the student learning objectives, described in Chapter 5.

These data demonstrate that the Treatment Group outperformed the Non-treatment Group in lecture tests and quizzes with a statistical significance. There was also a measurable positive increase in students' perception of this laboratory approach, the teaching methods, and the materials. Quantitative and qualitative evidence has been presented that the designed curriculum was in good alignment with the student learning objectives that were collaboratively developed between the Amend Research Group and the College of Engineering.

Alignment of this Research Study with the Student Learning Objectives

Data have been analyzed and presented, showing this research-based approach to teaching and learning is in alignment with the planned student learning objectives. The Treatment Group of Mechanical and Engineering students for this research study have:

1) exhibited the ability to apply their knowledge of chemical principles, mathematics, and measurement instrumentation that are important to chemists and engineers within a research laboratory setting.

2) identified, analyzed, and solved application problems in the laboratory through designing and conducting experiments that build scientific research methodology and skills.

3) used modern research skills and tools of mathematics and measurement technology to effectively collect, analyze, and interpret data when solving experimental laboratory problems.

4) communicated effectively in a research group when solving problems in the laboratory and when presenting results in both written and oral formats.

5) recognized a need for chemistry and the importance of lifelong learning.

Mechanical and Electrical Engineering students who were enrolled in these laboratory sections, the Treatment Group, have been shown to outperform Non-treatment students on lecture exams and quizzes. This, coupled with the quality of written and oral reports, has shown that the Treatment Group students have successfully applied their knowledge of chemical principles, mathematics, and measurement instrumentation both inside and outside of the laboratory setting. The students in the Treatment Group have worked in research groups to collaboratively solve problems using modern research skills and tools and have effectively communicated their methods in both written and oral formats. Upon completion of this laboratory course, over one third of these students expressed an interest in taking more chemistry coursework in the future. This showed an interest in continuing to learn chemistry content. In fact, the Treatment Group showed over a four and a half fold increase of enrollment into the second semester of chemistry as compared to the Non-treatment Group.

A majority of students gave favorable responses to the style of teaching and learning employed in this course. Many students thought this was too much work for the credit involved, but appreciated the opportunity to, “do science how real scientists do it.”

NSF guidelines for Engineering Education state, "Experience to date has shown that students can be attracted to and retained in engineering programs if they are exposed early to the joys of creation through design, discovery through research, and invention through hands-on experimentation." With a laboratory approach that integrates chemistry content identified as important to engineering students, combines clear student learning objectives, implements *The Scientist's Research Cycle* learning model, and supports the development of laboratory skill-sets and tools that make new experimentation possible, this research study has shown to improve engineering student learning in general chemistry.

Implications of this Research and Recommendations for Future Study

This research study has presented a method that helped to reorganize chemistry content and the process of laboratory experimentation around a particular focus population of engineering students and their needs. Building the laboratory experience of chemistry, as described by the Scientist's Research Cycle, *Research Extensions* were used to help build logical continuity from one laboratory experience to the next. This approach helps students to build an awareness of chemistry and the math and technology that support their laboratory experimentation. Students are able to understand key concepts and principles of science and apply this scientific knowledge in ways that help them to solve problems scientifically.

The practices and methodologies employed in this study show promise in the development of a viable model that not only supports the national goal for scientifically

literate college graduates, but has potential for transferability to other natural science laboratory curricula.

The main problem with science education has not changed much since the Committee of Ten in the 1890's, that is, the ability to create, develop, and implement curricula that are authentic to the process of science while attaining targeted student learning objectives. Part of the problem is best described by George DeBoer, one of the co-founders of AAAS's Project 2061, where:

> Science, perhaps more than any other area of the curriculum tries to deal with both the products and processes of the subject in the same courses. Whereas this may be viewed as science's greatest strength when compared to other areas of the school curriculum, it has also presented considerable problems for science educators.
>
> …we need to distinguish between learning about the processes and learning how to carry out the processes. One involves knowledge as the primary goal, whereas the other involves skill development as the primary goal. Thus, in organizing science instruction as a study of "process", we need to determine the extent to which we expect students to become proficient in manipulating equipment and science materials, the extent to which we expect them to become proficient in carrying out the logical operations of science, and the extent to which we expect them to have knowledge of those processes. (DeBoer, 1991, p. 271)

This research study presents a model that coordinates the "products" and the "processes" that only a general chemistry laboratory can provide for its student. Careful identification of chemistry content knowledge and the processes for laboratory experimentation must be outlined so that instructors can recognize and support students during their inquiry and problem solving in the laboratory. If this support is provided over the course of several experiments, a continuity can be achieved that offers students

the opportunity to master the use of equipment and measurement tools so that they can focus upon the underlying chemical principles.

This latter part, student mastery of the skill-sets and tools of analysis, is universal to all fields of science and helps to build the fundamentals of laboratory research practice that can be applied to solving real-world problems. This is why collaborative efforts must be made to diversify the viewpoint of laboratory curriculum in general chemistry to incorporate real world practices from other disciplines.

At the collegiate level, the laboratory has been shown to support effective student learning through inquiry-based methods and the use of microcomputer-based laboratories. As Leibig recognized well over 150 years ago, chemistry is not just learning complex theory in formal lecture, but rather a laboratory-centered science that demands a hands-on inquiry approach to learning. Students must be mentored and guided in the use of chemical knowledge, laboratory research design and techniques, and the tools of measurement and analysis so that they may inquire, experiment, and learn about chemical phenomenon that impact their lives. For this reason, chemical education research requires a focus and a determination to define, create, test, and disseminate effective laboratory learning materials, curriculum, and methods that empower students to become lifelong learners.

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APPENDICES

APPENDIX A

THREE-YEAR DEMOGRAPHIC STUDY OF CHEM 131

3-Year Demographics Study of CHEM 131

Prepared by Ben Sharp From The Office of Planning and Analysis, Montana Hall, Montana State University – Bozeman

Final version Prepared in the Fall Semester, 2003.

3-Year Totals	First Term	General Chemistry Demographics :3-year study	
Majors	Count Of ID	% Completing CHEM 131	% Enrolled in CHEM 132
Biological Sciences	273	85.0%	65.1%
Biotechnology	34	85.3%	69.0%
Business	34	79.4%	11.1%
Cell Bio. and Neuroscience	78	88.5%	79.7%
Chemical Engineering	69	91.3%	82.5%
Chemistry	33	78.8%	69.2%
Civil Engineering	235	88.5%	26.0%
Computer Engineering	27	81.5%	13.6%
Computer Science	31	83.9%	15.4%
Earth Sciences	99	80.8%	55.0%
Electrical Engineering	143	82.5%	0.8%
Environmental Science	48	85.4%	58.5%
General Engineering	54	75.9%	39.0%
General Studies	377	84.9%	39.7%
Health and Human Develop.	182	86.3%	44.6%
Horticulture	42	88.1%	48.6%
Ind. & Manag. Engr.	105	83.8%	43.2%
Mechanical Engineering	313	88.5%	2.9%
Microbiology	52	80.8%	66.7%
Pre-Veterinary Medicine	61	82.0%	74.0%
Other Majors (See Below)	286	75.5%	32.9%
TOTAL	2576	84.2%	38.82%

This 3-year study considers Academic Years 2000-2001, 2001-2002, and 2002-2003.

List of Other Majors:

Agricultural Business, Abused Land Rehabilitation, Agricultural Operations Tech, Animal Science, Architecture, Art, Construction Engineering Tech, Early Admit (HS Students), Economics, Electric/Electronic Engr Tech, Elementary Education, English, Environmental Design, General Agriculture, Health Promotion, Land Rehabilitation, Land Resource Sciences, Mathematics, Mechanical Engineering Tech, Media and Theatre Arts, Modern Languages & Literatures, Music, National Student Exchange, Non-Degree Graduate, Non-Degree Undergraduate, Nursing, Philosophy, Physical Education, Physics, Plant Science, Pre-Graphic Design, Pre-Nursing, Psychology, Range Science, Secondary Education, Sociology, Soils, and Technology Education

(Note: These individuals constitute less than 1% of the total population of this three-year study. each.)

APPENDIX B

SURVEY INSTRUMENTS AND OUTCOMES

National and Local Survey of University Engineering and Chemistry Faculty

(Completed the Spring Semester, 2002.)

Overview:

This two-part survey was distributed to better understand what chemistry content and learning objectives MSU engineering faculty (N=28) and nationally distributed chemistry faculty, (N=16), believe an engineering student should gain from university level general chemistry.

PART A: Chemistry Content List

Direction to faculties:

If a freshman engineering student took a single semester of freshman general chemistry; (A) place a CIRCLE around the items you deem critical for them to master and (B) place a BOX around the items you would like them to have surveyed upon completion of this freshman general chemistry course. (Engineering=BLUE, Chemistry=BLACK)

Measurement Mastery Survey 18,11 6, 2	Dimensional Analysis Mastery Survey 10, 13 5, 0	Thermodynamics Mastery Survey 5, 8 11, 2
Significant Figures Mastery Survey 16, 13 5, 1	Physical Properties of Matter Mastery Survey 12, 11 7, 4	Chemical Properties of Matter Mastery Survey 15, 6 6, 7
Atomic Theory Mastery Survey 14, 11 8, 3	Nuclear Chemistry Mastery Survey 1, 2 4, 8	Wave Nature of Light Mastery Survey 2, 5 7, 6
Electron-Filling Series Mastery Survey 4, 10 9, 2	Bonding Theory Mastery Survey 9, 11 7, 5	Architecture of the Periodic Table Mastery Survey 15, 10 5, 6
Electron Transfer Mastery Survey 5, 4 10, 7	Shapes and Polarities Of Molecules Mastery Survey 6, 6 6, 8	Chemical Formulas and Names Mastery Survey 14, 8 8, 4
Theory of Chemical Equation Mastery Survey 14, 13 7, 3	Mole Theory Mastery Survey 13, 11 5, 2	Stoichiometry Mastery Survey 10, 12 2, 4
Kinetic Molecular Theory Mastery Survey 3, 4 8, 7	Gas Laws Mastery Survey 17, 14 7, 2	Solutions, Colloids, and Suspensions Mastery Survey 5, 4 8, 7
Reaction Rates and Kinetics Mastery Survey 8, 10 8, 6	Catalysis Mastery Survey 3, 4 8, 8	Equilibrium Constants Mastery Survey 5, 10 7, 5
Acid/Base Theory Mastery Survey 10, 10 7, 4	Acid/Base Equilibrium Mastery Survey 8, 7 4, 6	Electrochemistry Mastery Survey 7, 8 5, 4
Organic Chemistry Mastery Survey 4, 7, 3 9	Biochemistry Mastery Survey 2, 3, 1 4	

PART B: ABET Student Learning Objectives

Direction to Faculties: Below is a list of Accreditation Board for Engineering and Technology (ABET) objectives. Please check those objectives you think should and could be specifically addressed in a freshman general chemistry course. (Engineering=BLUE, Chemistry=BLACK)

Engineering programs must demonstrate that their graduates have:

# Votes	ABET Accreditation Student Learning Objecitives
23, 15	(a) an ability to apply knowledge of mathematics, science, and engineering.
19, 14	(b) an ability to design and conduct experiments, as well as analyze and interpret data.
2, 3	(c) an ability to design a system, component, or process to meet desired needs.
11, 6	(d) an ability to function on multi-disciplinary teams.
10, 9	(e) an ability to identify, formulate, and solve engineering problems.
7, 7	(f) an understanding of professional and ethical responsibility.
11, 11	(g) an ability to communicate effectively.
6, 7	(h) the broad education necessary to understand the impact of engineering solutions in a global context.
9, 9	(i) a recognition of the need for, and an ability to engage in lifelong learning.
8, 6	(j) a knowledge of contemporary issues.
8, 8	(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Participating Faculty

MSU-Bozeman: Engineering Faculty: *(N=28; Distributed by Assistant to the Dean)*
Civil Engineering
Electrical and Computer Engineering
Mechanical and Industrial Engineering
Chemical Engineering

Institutions of General Chemistry Faculty: *(N = 16; Distributed by Prentice Hall Co.)*
Arizona State University – Tempe, AZ
Clemson University – Clemson, SC
University of Florida – Gainesville, FL
University of Houston – Houston, TX
New Jersey Institute of Technology – Newark, NJ
University of Idaho – Moscow, ID
Kansas State University – Manhattan, KS
University of Memphis – Memphis TN
Michigan State University – East Lansing, MI
Montana State University – Bozeman, MT
North Carolina State University – Raleigh, NC
Northwestern University – Evanston, IL
Oakland University – Rochester, MI
Rutgers University – New Brunswick, NJ
San Diego State University – San Diego, CA

Mid-Term Student Survey-CHEM 131 for Engineers

3-22-04

(N = 70)

The work done in-lab:

1. Is this Freshman General Chemistry lab section meeting your personal expectations? (Yes or No; please elaborate.)

Yes = 53

- Yes, my expectation where almost none existent so anything is good.
- Yes, the lab has been interesting. I came expecting to just be mixing chemicals, (but) the lab has been much more. We have studied light, electricity, etc., all ____ back to chemistry.
- Yes. It is exactly how I thought if would be.
- I really enjoy the labs, and although there is a lot of work, I am learning a lot.
- Yes. A little hard.
- Yes, during this lab I have learned the basic procedure of lab and lab reports.
- Yes, but it is hard to keep up with all the work.
- Kind of. I have noticed that our labs are similar to the non-engineering, but ours takes longer.
- Yes, it is helping me get used to applying the chemistry we learn so it is more understandable.
- Yes, I am learning a lot about chemistry through these labs; more than in class.
- Yes, it just seems the material is not in the same order as the class.
- Somewhat. I have no problem with the labs themselves; I really don't like the out-of-lab activities. Research extensions can be frustrating.
- Yes, it actually is a lot more enjoyable than I was expecting.
- Yes, but it is moving a little faster than I expected.
- Yes, it is much more demanding than I had expected.
- Yes, it is very interesting and is run very well giving us ample time for work.
- Yes, it is very extensive and thorough.
- Yes. This is just basic chemistry, and I really didn't set my expectation high.
- I didn't really know what to expect so, yes. Though I wouldn't mind playing with fire a little more.
- Yes, I knew it would be different from the other labs, and for the most part it is more interesting.
- Above and beyond, it was way more work than I expected.
- Yes because the labs go more in depth.
- I like that there is more flexibility in the curriculum.
- Yes, I am learning quite a bit in the way of experimental chem.
- Yes, the amount of work met a little more than my expectation but it is the engineering section so it in that sense was expected.
- Yes, it is fine.
- Yes, I didn't really have expectations.

- Yes, my expectation were few only because I had already learn a good deal of the material, but lab made the understating better.
- Yes, I'm very happy about this lab. It has been very fair and balanced. The only thing that surprised me was the amount of work that was involved.
- Yes, greater than. I had expected lots of boring lab procedure and stuff, but I've had quite a bit of fun.
- Yes, I like it because Tim is a nice guy.
- Yes, I have been interested all semesters, however there seems to be some busy work.
- Yes, teacher is good and helpful.
- Yes, helps but it is really too long. Time commitment hurts a lot.
- Yes. A bit harder than I expected, but it's going O.K.
- Yes, I am getting a lot of information.
- Exceeded.
- Yes, challenging my abilities of deduction well. Making me perform.
- Yes. I am getting good hand on experiences.
- Yes, everything and more.

No = 8

- No, it is too time consuming.
- No, I thought it would be much easier.
- No, engineering orientated unproven labs. (Chemistry lab)
- Too much work to do.
- Most of the experiments performed in this lab section were performed in high school.
- Not completely, some of the differences just seem to be extra work, not really knowledge enhancement.
- No; I have not blew anything up yet.
- No, this is covering the same stuff we did in high school..

Yes and No = 9

- This is good lab – the experiments are fun and well organized. However, the multiple out-of-lab activities are a bit excessive.
- The engineering lab is a lot more work than it was made out to be. The lab is good and insightful though.
- I don't really have very many expectations.
- I did not really know what to think before I came in.
- Didn't have expectation really, although lab is harder than I thought.
- I don't care.
- Yes and No. It <u>may</u> fit the class description, however in the engineering section we do more work for the same credit…is that fare? Not really.
- I had no expectation what so ever…I am fulfilled in that I am receiving credits.
- Yes and No, it is teaching me things fun, however it is also taking up a lot of outside time.

2. On scale of 1-5 (1 no impact and 5 big impact), what has been the impact of this laboratory section on your knowledge of chemistry?

1 = 1
2 = 13
- This is review for me. (2)

3 = 24
- Same as high school with new tools.
- I knew quite a bit already.
- Could be a little more exciting.

4 = 23
- Light lab was very interesting.
- My previous labs have been ineffective.
- In lab work doesn't cover all of lecture (materials).
- Very in depth, I now have solid grasp on key concepts.

5 = 9
- Too much work.

3. On scale of 1-5 (1 no impact and 5 big impact), what has been the impact of this lab section on your ability of using computer-based instrumentation towards solving experimental problems?

1 = 2
- Microlab is great, but I already know these techniques.

2 = 11
- I have extensive experience in the area already from my work.
- I have already aquired experiences. (2)
- I have a fairly good knowledge of computers; although I found microlab is new and interesting.

3 = 10
4 = 29
5 = 18

4. On a scale of 1-5(1 no impact and 5 big impact), what do you believe will be the future impact of this lab on your ability to solve experimental problems?

1 = 2
2 = 11
3 = 27
- Most of this lab's advantage has been bringing me up to speed.

4 = 24
5 = 5
N/A = 1

5. Do you believe that use of computers and sensors has enhanced your experience in this lab? (Yes or No; please elaborate on why or why not.)

Yes = 66

- Yes they are fun.
- Yes-the real time plotting and regression tools help put data into perspective.
- Yes. It takes more accurate data than we do.
- Yes-Good tools to learn to use more accurate.
- Yes, it makes for precise data collections.
- Yes. We actually get good results.
- A little with the colorimeter.
- Yes, being introduced to computers as lab tools definitely helped ____ the experiment.
- Yes, because they help show results.
- Yes. It allows to do more in-depth things.
- Electrics are the future.
- Yes, it allows us to get better readings.
- Yes, it makes data collection easier and allows me to pay more attention to making the experiment with as little error as possible.
- Yes. I have a better understanding of them.
- Yes, without them there really is no lab n, cause to many problems.
- Yes. They're a bit overused, but overall good.
- Yes it really has given me a base of computer based measurements.
- A little bit. (2)
- Yes, because our results are more accurate and we are therefore able to concentrate more on the concepts of the experiment than on accuracy.
- Yes, I had ___ ____ used a computer interface for experimentation.
- Yes, it is the first time I've really worked in depth with computer for experimentation.
- Yes, computers are very great tool and very useful in the lab work.
- Yes, the computers have allowed me to see more visual representations of the experiments.
- Yes, the sensors gave us a precise way of getting data.
- Yes, this way we can see real-time graphs and that helps.
- Yes, it makes it easier and more efficient to perform the experiments.
- Yes, provides more visual representation.
- Usually yes, but sometimes its just a hassle.
- Yes, because it makes experiments more reliable and graphics make it easier to understand.
- Yes, I have learned a lot about them.
- Yes, because it gives us real raw data to work with.
- Yes, because it allows you to visualize data more easily.
- As a EE, everything I do can be aided by computers, becoming familiar with these sensors makes this lab more applicable.
- Yes, but experiment using water, ice and temp gets old. I thought college chemistry would involve more than just water.
- Yes, computers and equipment is used in all the labs.

- Yes, I have never used them, at the very least I learned how to use those.
- Yes, I think using computer equipment is much faster, efficient, and more accurate.
- Yes, had made lab easier.
- Yes. I love computers.
- It makes it a lot easier and quicker.
- Yes. I had not used the computer in lab before and it enhanced my understanding.
- Yes, because without them a lot of this stuff would make sense.
- Yes, the MicroLab hardware is very versatile I've found.
- Yes, because they help to understand how things work.
- Yes, they eliminate unnecessary busy work.
- Yes, because it is something new.
- Yes, I haven't really used computers to get data like this; it's a new experience.
- Somewhat, its kind of repetitive though.
- Moderately…frankly I'm in different.
- Yes, it provide a concrete measurement of experiment.
- Yes I think so. I'm familiar with computers so it helped me understand what we were doing.
- Yes, it's more accurate.
- Yes, it made it so we can see things graphically.
- Yes, more real world experience.
- Preps me for future lab work with technology.
- Yes, it allows for one more problem that we ___ to solve.
- Yes, they have given me another visual aid.
- Yes, it gives a accurate reading for better results.
- Yes-made it better.

No = 3

- At times the computer sensors made the lob more frustrating than helping in any way, although much of what we have done could not have been done without them.
- No, I had a lob without computers and I actually understand more in that more "hands on" class.
- Not really, I've used them before.

N/A = 1

6. Are there any further comments you would like to make about the 'in-lab' portion of this laboratory section?

- Maki and Tim are great T.A.
- No more killer labs.
- I like the set up.
- Too long.
- 1/3 of lab is spent standing still and listening, or taking quizzes. No hands on and difficult to focus when standing still and ___fan in background.
- Perhaps research extensions should be longer, but replace the main lab rather than add to it.

- It's been fun. (I've) met a lot of cool people.
- It is just a little long.
- Sometimes the lab seems long, but overall it's no that big of deal.
- I think that the format is very good.
- All in all this is not a bad lab.
- Tim does a great job.
- More demos / packets.
- It is hard for me to judge because I've had previous knowledge of tools and information.
- Excessive work and often more advanced and ahead of the material covered in lecture
- More things should be lit on fire.

The work done out-of-lab:

7. Do you believe WebCT is being used effectively? (Yes or No; please elaborate.)

Yes = 32

- Yes, but it is to let it slip your mind.
- Yes. But still boring.
- Yes (sort of). I think the discussions are point less.
- Yes, correct some of the links though.
- Definitely, WebCT makes things a lot easier for __ quizzes and staying informed.
- Yes because I like getting graded for the work done in WebCT.
- I sometimes forget to use it but when I have it has been a useful tool.
- Yes, I don't see what else it could be used for.
- It has been for me, the discussions have helped out for the most part.
- It's a pain in my butt, but, yes it's been used effectively.
- Yes, I had never had a class before that had WebCT as a tool, it is very useful and beneficial.
- Yes, the discussions are helpful in understanding the concepts.
- Yes, the discussions and quizzes really test my ability sarcastically speaking.
- Yes, it is organized and thorough.
- Yes, it seems to be an effective way to communicate with the class outside of the classroom.
- Yes, but this is the first time I've used WebCT.
- Yes, it teaches responsibility to make sure you do things by a deadline.
- Yes, it really helps to keep organization out of class instead of with papers.
- Yes, because the quizzes are helpful.
- Yes, it is convenient for software downloads class messages and quizzes.
- Yes, it helps student attain material easier.
- Yes, it is pretty easy to access information for the lab.
- Yes, but it is hard to remember to do the out of class activities.
- Yes, it was a useful tool for finding lab information.
- Yes, it's very easy to use.
- Yes, it is giving plenty of schedules and syllabuses.

- Yes, the discussions and quizzes are very useful for improving our knowledge.
- It is useful in finding information about future labs.

No = 25

- No, it is used as busy work, it doesn't help me learn.
- No, I'm not learning much from it.
- No, I only used WebCT out of the necessity of doing the quizzes and comments.
- No-not many people use it.
- No, it is used mainly for obnoxious busy work.
- Not really, it isn't that useful.
- I have little time as it is, and WebCT not only brings my mood down, but I loathe logging on.
- No, it is hard to remember to take the quizzes and post discussions. And in the discussion only one original comment is made and all the rest are different wording.
- No. Feels like busy work; I don't really feel I learn from the discussions; it's more of a chore.
- It's kind of a hassle because all the things take time.
- No, WebCT seems to be nothing but busy work. The quizzes and discussion are already discussed in the lab and in the lecture.
- No, I am not a fan of the extra quizzes.
- Not really, it's kind of a busy work. It helps, but I think it is more of pain than anything.
- No, WebCT is more of a pain than a help.
- No, it's a pain.
- No, it really doesn't help much.
- No, because I do not use it all the time.
- No, I feel that it is just being used for points instead of an expansion of knowledge (not that, that is what it is intended to be).
- No, it is so minor an influence to take seriously, it would be better suited for a more in depth research based class.
- I don't like WebCT and I feel that it is, in large, a waste of time.
- No, the WebCT seems like busy work.
- No, it is only creating just more work.
- I don't know, it isn't helping me at all.
- No, it is easy to forget (hurts grade) and easy to just read the answers out of the book and not learn them.
- No, too much work outside.

Yes and No = 13

- Both-The discussions are great, but the pre and post lab quizzes are busy work.
- I wish there was more info about the lab procedure.
- It's pain at times with all the discussions and quizzes…. it is never ending. It would be nice if next weeks labs were posted on it so we know what to read.
- Yes and No. It has great potential but it is only 1% of our grade considering lab reports. Pre quizzes, post quizzes, peer reviews, lecture quizzes, group reports…
- I do not like it, but it is effective at enhancing the learning.

- Yes, the pre-lab and post-lab quizzes are great, but I don't really believe that the discussions are helpful.
- Pre-lab and post-lab quizzes are good discussions are not so effective.
- I think the quizzes are effective, the discussion s not as much.
- I think that WeCT is a little more work than necessary with the discussions and all the quizzes. Every once and a while would be better.
- The quizzes are lout, the discussions isn't.
- The quizzes seem to be effective, but the discussions seem to _____ what is thoroughly covered in the lab.
- Yes on pre-lab quizzes, no for all other stuff.
- It works, but it takes time and it is ____ _____ things we know.

8. What are some PROS and CONS of using WebCT for this lab section?

PROS

- Easy to look up future lab stuff (3)
- Seeing test like questions
- Discussions (2)
- TA can find out what we learned
- Use of information
- Good, clean way to test
- You can look up general lab information (2)
- Set to hear what other people way
- Quick, easy, ___, up to date
- Help understand things (3)
- Easy points
- Good resource
- Learn from others
- I am reminded of what happened in lab by reading the discussions
- Helpful
- The information provided there
- It's easy to look up what lab is due this week
- Pre-lab quizzes allow more experience and learning
- It allows you to collaborate with fellow students.
- It's very organized and works most of the time
- Allows to give tests and quizzes outside of class / the calendar feature is good / maps out the class for you
- Access to the programs used
- Lab write-up helps from lab discussions
- Teaches responsibility, discussions are good for conclusions
- Easier to type than write on paper, more organized and easier to access
- Helps to learn stuff before lab (3)
- Thinks about lab ahead of time
- Helps learn

- Help with materials(2)
- Has a good intent of getting us thinking about chemistry
- Easy to find what is going on in lab. Discussion area.
- Better understanding
- Good resource for info about the labs each week
- See what lab is coming up
- Keeps you always thinking about chemistry so you don't forget things and is a good source of information
- Good communication tool
- Easy to access (3)
- It is a good way to give us handouts
- Easy to use
- More practice
- More involvement out of lab
- Organized
- Easy to see when things are

CONS

- Easy to forget (18)
- Pain
- Quizzes are busy work
- It's hard to remember to do it and since it's only worth 5 pts. I feel more work than its worth.
- Boring
- Lack of ease of use
- Links
- Not really integrated with class
- Busy work (7)
- Pre-lab quizzes seem useless
- Takes too much time (10)
- Can't used it when net goes down
- What good is it to read WebCT when we could be reading our textbook or lab book? All of the problems are canned if we could use the knowledge from WebCT in experiments it might be better.
- Not enough time to do it
- It doesn't accomplish anything, large bother
- Quizzes and discussions (2)
- Discussions
- Discussion should be more personal, not a posted paragraph, a wait and a reply
- There can be technical errors
- Quizzes are no fun
- It's a waste of time (2)
- All the stuff to keep track of. Discussions, quizzes, etc…
- Don't always work right for me

- Some incompatibility with my computer. Think it's only my computer
- I don't really learn much from it. Our discussions in lab are enough
- More little things that need to be done
- Not effective
- Need internet connection to access
- Pre-lab quiz to ___ learning, post-lab it's too late
- It causes us to have one more thing to think about
- We need to log on multiple times per week and I usually forget at least once
- Too tedious
- Have a crappy ISP at home
- Hard to find time
- We have to do the pre and post-lab quizzes and they are pretty useless

9. On scale of 1-5 (1 no interest and 5 high interest), how interested are you in continuing the use of WebCT for the rest of the semester?

1 = 22
2 = 18
3 = 14
- It's good idea to keep it.

4 = 11
- Get rid of discussions because once one person posts the responses are just " I agree" or "I disagree".

5 = 4
N/A = 1

10. Reflecting back on you use of WebCT this semester, what is the average of minutes per week that you we logged in?

1 – 15 min = 36
16 – 30 min= 27
31 – 60 min = 1
over 60 min = 1
Other: 0 min = 1, 10 - 20 min = 1
N/A = 3

Use of computer-based measurement technology in lab:

11. On a scale from 1 to 5 (1 having small understanding and 5 having complete understanding), please circle your current understanding of the electric sensors you have used in lab. (*Electric sensors including pH probe, temperature sensors, light sensors…etc.*)

1 = 0
2 = 0
3 = 16
4 = 38
5 = 15
- This stuff is fun and interesting.

N/A = 1

12. On a scale from 1 to 5 (1 having no comfort and 5 for being at ease), please circle your comfortability level in using these electric sensors for collecting data in lab.

1 = 0
2 = 0
3 = 12
4 = 37
5 = 20
N/A = 1

13. On a scale from 1 to 5 (1 having small understanding and 5 having complete understanding), please circle your current understanding with using the MicroLAB interface and its software for data acquisition.

1 = 0
2 = 2
3 = 27
- It is becoming clearer and clearer.

4 = 33
- This was a new skill but I understand it well now.

5 = 7
N/A = 1

14. On a scale from 1 to 5 (1 having no comfort and 5 for being at ease), please circle your comfortability level in using the MicroLAB interface for data acquisition.

1 = 0
2 = 4
3 = 18
- MicroLab was useful, but in some aspects it was confusing… The unexpected shutdowns really sucked.

4 = 31
5 = 16
N/A = 1

15. On scale from 1 to 5 (1 not effective and 5 for most effective), please circle how effective you believe the use of electronic instrumentation is in solving problems within this laboratory.

1 = 0
2 = 0
3 = 10
4 = 32
- Great tool except when it malfunctions.
- Most of these experiments couldn't be ____ easily without the instrumentation.

5 = 27
- This helped us receive precise data, and it was very simple to use.
- Great skills

N/A = 1

Motivation for adding this experimental section of lab:

16. On scale from 1 to 5 (1 being lowest motivation and 5 being the biggest motivation), where would you rank "gaining chemistry knowledge" as your motivation for adding this section?

1 = 11
2 = 15
3 = 30
4 = 10
5 = 4
N/A = 0

17. On scale from 1 to 5 (1 being lowest motivation and 5 being the biggest motivation), where would you rank "satisfying core credits" as your motivation for adding this section?

1 = 2
2 = 2
3 = 12
4 = 14
5 = 40
N/A = 0

18. On scale from 1 to 5 (1 being lowest motivation and 5 being the biggest motivation), where would you rank "improving laboratory skills" as your motivation for adding this section?

1 = 12
2 = 17
- I work in lab.

3 = 22
4 = 15
5 = 4
N/A 0

19. On scale from 1 to 5 (1 being lowest motivation and 5 being the biggest motivation), where would you rank "gaining knowledge about measurement technology and instrumentation" as your motivation for adding this section?

1 = 16
2 = 14
3 = 25
4 = 12
5 = 3
N/A = 0

20. On scale from 1 to 5 (1 being lowest motivation and 5 being the biggest motivation), where would you rank "because my advisor told me" as your motivation for adding this section?

1 = 32
- I didn't even sign up for the engineering lab.
- I told myself to register this section.

2 = 6
3 = 10
4 = 12
5 = 9
N/A = 1

The overall format of this lab:

21. What do you like about the format of this lab section?
- You know what to do.
- I like the attitude we have of trying to get the most possible out of the ___.
- Not going straight out of the book.
- I like it. I wouldn't if I didn't have the weekend.
- I like the format of the lab, it is laid back.
- Easy to follow, good activities.
- The organization, and computer interface experiences.
- Maki is helpful.
- Although I was a lot of work I enjoyed the group research extensions.
- It is adequate.
- I like how we do a lot of work with the computer and other technologies.
- The labs we do as a group, it helps when we have an entire class to discuss questions and answers.
- The labs are helpful and can be fun.
- Our labs are different, week to week, as in the format for doing them. I like having things change.
- The use of the computer equipment.
- We are learning some interesting stuff.
- Everything is pretty cool. The lab write-ups make me think, but that understandable. The online quizzes and discussions keep me busy, but I have learned from.
- I appreciate the use of partners while in the lab which establish a more at ease environment.
- Gets me well prepared for lab work after college.
- The allotted time period and partner based work.
- I feel like I am getting much more out of my lab by challenging myself more in this section.
- Using the computer and instrumentation.
- Nice teachers; very helpful.
- I like the detailed layout for the write-ups.

- It's quick and efficient once we finally get going.
- Easy group access.
- Research extensions go more in depth.
- We learn how to do stuff in a lab.
- I enjoy the lab, sometimes it seems a little long.
- The group layout, great for communications during the "Active" lab.
- Everything we have to do is written on the board.
- It's super groovy.
- Yes, very organized.
- The physical layout.
- Good stuff all around quite effective.
- Using more technology in own experiments.
- Each lab group leaves when they want.
- It makes sense and has good transition.
- Good TA's, and I've learned a lot about chemistry.
- It is a good place to learn important chemistry facts.
- Seems straight forward.
- Kind of laid back. Personal attention.
- _____ just enough, but allows for independence.
- Very effective TA., thorough and complete.
- Gets you prepared for the lab.
- It presents material in a hands out and ____ ____.
- Pretty interesting experiments, I've learned a lot in lab.
- I like in-lab format, but I'm not too crazy about our out-of-lab activities.
- Partner and group work.
- Tim is a cool guy.
- Lots of freedom for procedure and methods. Organized.
- I really like the approach that this lab has on chemistry. It is very diplomatic and fair.
- It's helpful to understand the material as a whole.
- It organized.
- The labs are more real life with the lab extensions.
- Use of computers.
- I gained a better understanding than my other friends in the other labs got.
- Organized and relatively straight forward.
- Fairly well structured.
- Your willing to change things when they don't work, and are flexible, not being a jerk but challenging us.
- Originally I was concerned about the extra work, but now I think I prefer it to the standard format, particularly the research extensions.
- It is more depth than regular lab.
- I like the overall format of this lab.
- I like having the weekend to do lab reports.
- This is actually really interesting, because our TA makes it that way.
- I like when we do the lab as a class.
- Great communication between students and teachers.

22. What do you dislike about format of this lab section?
    - How much time it takes.
    - Sometimes we waste some time in the beginning between the quiz and research extension presentation.
    - Too much work.
    - WebCT. (3)
    - WebCT is used for busy works.
    - Too much lab write-ups. (2)
    - Not much.
    - The lab write ups.
    - I think it would have worked better to have always work as a group of 4 rather than just 2. The days it was a group 4 were more enjoyable.
    - I don't like how we use WebCT.
    - Laying out the entire lab at the beginning of class is time-consuming and confusing. Perhaps explaining each step every 20 min or so would be more helpful.
    - They are long and I am not sure the research extension help much.
    - The extra work, didn't really help further my engineering knowledge more than normal labs.
    - Sometimes labs have to be rushed, so I don't exactly know or remember what we did for the write-ups.
    - No chairs.
    - It seems to me a lot of the experiments are very alike previous experiments therefore establishing a very slow moving curriculum.
    - Very extensive and thorough.
    - Not much. I guess the write-ups and discussion/quizzes can be tedious at time though.
    - It's so challenging; it takes more out of ___ ___ than I expected.
    - I dislike the pace; I do realize that it is required but I feel we just brush over the subjects covered.
    - Lots of busy work.
    - The write-ups suck and 3 hours standing gets tiring.
    - It was all pretty likeable.
    - Takes an hour before we actually start the lab.
    - It is during prime weather.
    - It is too long sometimes.
    - Constant standing.
    - Groups should have two periods to present data and experimentation gives time to review.
    - All the stuff required outside of lab.
    - Takes a long time, I get hungry.
    - A lot of class work (that) have to keep track of and make time.
    - The time it takes.
    - Doesn't follow guide.
    - Excessive work load for same grad as the other lab sections set (working harder for no reason.)
    - Unnecessary explanations, just let us do it.
    - Sometimes it feels like there is a lot going on at one time.

- WebCT at time, but it's not too bad.
- It has some unneeded out of lab activities.
- Sometimes a little to laid back as far as lab handouts/assignments.
- Too long.
- Time-consuming and tedious at time.
- It was confusing at the start and hard to get used to.
- Just a little too much busy work.
- Lots of extra work out of lab, 3 hours is a long ___ for class. Especially without chairs/stools.
- 3 hours no break.
- It is 3 hours of standing.
- At times it really seems like there is lots of little stuff to do.
- It's kind of long.
- It's long.
- How each lab lasts 3 hours.
- The labs are so long and there are no stools to sit on.
- Many things to keep track of.
- Too long.
- The discussions.
- It is more in depth than regular labs.
- Long and during lunch.
- Sometimes, the research extensions and WebCT seem like busy work, which I usually forget about.
- It's long and we can't sit down. It is annoying to have to do the WebCT stuff every week.
- Standing, extra quizzes, discussion ____.

23. On scale of 1-5 (1 minimum and 5 maximum), where would you rate of your level of enjoying the Research Extension part of the lab?

1 = 21
- Minimal extended learning, but lots of extra time.
- I guess I learned a lot though.
- Terrible.
- Things can get really confusing and some do not contribute as much as other.
- They suck.
- Should only do it once per semester, not twice

2 = 20
- The experiment is fun, but the excessive extra work is not.
- I don't like giving presentation.

3 = 10
- Takes time.

4 = 7

5 = 5

N/A = 7

24. On scale of 1-5 (1 minimum and 5 maximum), where would you rate of your level of interest as a listener during the Research Extension oral presentation reports?

1 = 13
2 = 20
- Most are too monotone and boring
- Boring, not really important to me.

3 = 22
4 = 12
- Fun.
- I enjoy gaining knowledge by word and diagrams.

5 = 0
N/A = 3

25. On scale of 1-5 (1 minimum and 5 maximum), how well do you like participating with your Research Group in completing your Research Extension experiment, write-up, and oral report?

1 = 4
- It is pain for all of us to get together and work together. It would be nice to have grading sheet.
- They just happen to be _____ about it.

2 = 17
- Group slackers.
- I'm lazy.

3 = 17
- I am glad it was a group thing.
- I enjoy discussion verbally.

4 = 19
- Group is good

5 = 6
- My group is excellent and the report I found enjoyable, but making a college student put effort into something isn't going make them happy.

N/A = 7

26. To the previous question, please list a couple PROS and CONS of these Research Group activities? (If you haven't performed a Research Extension, please say so and leave blank.)
PROS
- Learn more about stuff
- Group work
- Lab write-up

- Chance to improve grade
- In depth look at ____ aspects of chemistry
- Good learning tool
- I like group presentation experience
- You can get more done
- Larger group, interesting problems
- Some are fun
- Group work in lab always helps understanding
- They can extend our knowledge about lab experiments
- Working together to really break down the concepts.
- Get to teach the section a little from your own knowledge
- Group project make it easier (2)
- More knowledge, new concepts
- Further investigation
- Lean more, makes you think
- Communication, semi original experiment, oral reports are fun
- Gain a more hands on feeling
- Work as a team
- Gain some extra knowledge of subject
- Good way to further exploration of chemistry
- The working as a group made the experiment go faster
- Better understanding
- Only one lab write-up
- Illustrates a better understanding
- Larger group, group work
- Better understanding of material
- Gain real world understanding of lab
- Kind of interesting. Like the presentations. We dud was pretty cool.
- Good learning experience
- Learn more, understand more
- One lab to turn in is good also 4 people putting in input is good for the lab
- They help you learn
- I like research info and knowledge gain
- More knowledge (2)
- It furthers my understanding. It is more interesting than most of regular labs.
- More information learned
- Learn more sometimes
- Ability to think more on your own as to how to solve a problem
- Didn't have to write a report
- It leaves you with complete understanding of the lab
- Work in groups and better learn
- Different than rest of class
- Leaning to communicate more efficiently
- It allow for more thought instead of busy work

CONS

- Time consuming (2)
- Adds more work to an already busy schedule
- Sometime people don't show up
- Have to work with Gus
- I am not interested in any of the research extensions.
- Extra work (5)
- It is hard o get together sometimes.
- Doing the regular lab as well
- Large write-up, presentation was a lot of work
- Rush in lab is _____
- It's a lot of work, it would be better if you only did your part of the lab
- Time is so stretched that we aren't really contemplating what we are doing
- It's just a lot of extra work. Between the labs, the write ups, the in-class quiz, post quiz, pre quiz, discussion, purpose _____. It's a lot for just 1 credit lab.
- I don't really learn more, a little bit, but not much / most people (including me) don't really pay attention to the presentations.
- Getting everyone together.
- So damn much time involved
- No fun lots of work
- All the time spent on the extra things in this lab is killing me
- More work during an already difficult semester for me
- Only further knowledge by the group
- Some of the extension are confusing and hard to understand
- Rush, extra effort
- Takes a lot of time (2)
- Can be hard to bring it all together
- It was more work and took added time
- Pain to get together
- More work (3)
- Meeting out of class (2)
- Hard for everyone to meet at one time
- Trying to integrate in schedules
- Puts class time over limit
- More busy work I feel than necessary since I ___ have to take chemistry again
- After listening to you for an hour it's hard to listen to the presentations. I couldn't care less about them either.
- Takes too much time – goes past lab time
- It is hard with my schedule
- I don't like doing research, living off campus is a trouble for meeting
- More work for nothing
- More work, not more learning
- It takes up more time
- Extra work, hard to fit in
- Any group activity is kind of a pain, just to coordinate everything with everyone.

- Hard to drew more relevance from it
- Didn't really save much time
- It takes a lot of time, and is hard to get everyone together
- Once again, more work outside of lab
- Extra trip into town to recap what we already talked about in class

27. On scale of 1-5 (1 minimum and 5 maximum), how effective is this Research Extension approach to your style of individual learning.

1 = 8
2 = 12
3 = 22

- The oral report is the only beneficial part I believe, because by teaching you learn a whole a lot.
- It difficult to coordinate 4 people on reports, and ends up being very time consuming.
- After listening to you for an hour it's hard to listen to the presentations. I couldn't care less about them either.
- Takes too much time – goes past lab time

4 = 19
5 = 3
N/A = 6

Student Survey Exit-CHEM 131 for Engineers

4-26-04
N = 72

The work done in-lab:

1. Did this Freshman General Chemistry lab section meeting your personal expectations? (Yes or No; please elaborate.)

Yes = 61

- Yes, within what I expected.
- Yes, I felt the most important thing I got out of lab was setting ___ the experiment and lab report process.
- Yes, it was appropriately challenging and fairly interesting.
- Yes, because we work hard and learned lots of things hand-on.
- Yes. About what I thought a chem. Lab would be.
- Yes-learned lab technique etc.
- Yes. It did we learned a lot.
- Yes. I enjoyed it _____.
- Yes, it was more fun than I expected.
- Yes. It helped me further my understanding in chemistry.
- Yes. I expected there to be more work intensive and it was.
- Yes, I didn't expect much from the general 131 course.
- Yes, it was a very good learning experience.
- Yes, it was much better than I expected. I leaned more in the lab than in lecture.
- Yes, it was fun and it helped me visualize the concept of the lecture.
- Yes, above and beyond.
- Yes it followed upon the lecture well.
- Yes. Learned a lot about chemistry hands on.
- It was fine.
- Yes, I enjoyed learning way I was taught.
- Yes. It was hard. Lots of work.
- Yes, it was enjoyable.
- Yes, it far exceeded them. It made chemistry interesting and fun.
- Yes, I thought you did good job making this lab fun, laid back and educational.
- Yes, we just ran through basic experiments as I expected.
- Yes, it was straight forward and simple, needs more cow bell.
- Yes, Tim stimulated interest within the lab.
- Yes, because it was very insightful.
- I didn't really have any expectations, so I was satisfied.
- It provided all the information I needed.
- Yes; very informative.
- Yes, it met expectations, and was a lot more involved than I thought it would be.
- Yes, lab was fine.
- Yes, I learned.

- Better understanding of chemistry.
- It was good.
- Yes. We got to do fun and interesting experiments.
- Yes, very enjoyable learning process.
- Exceeded.
- Yes, in fact it went above them; however, to much work.
- Yes; very effective lab almost excessive.
- For what I expected it did.
- Yes, it was more interesting than I thought it would be.
- Yes, the lab was interesting and taught us a lot. It also helped on the tests.
- Yes, it did. It went farther than I thought it would, but this is a good thing.
- Yes, it was all I had hoped it would be, and more.
- Yes, it exceeded my expectations. It really helped to do stuff hands on. I think I learned more in lab than in class.

No = 7

- No, it was really hard for a freshman class.
- No. I though it would be easier.
- No, it was more enjoyable and fun than I was expecting.
- No, I thought we would do more stimulating experiments, many of the experiments are boring.
- No, cooler lab needed.
- No, I thought it would be harder and require more thought.
- No, it was too much work.

Yes and No = 3

- I didn't have any expectations.
- Indifferent.
- Seemed a little disorganized at times, but that is to be expected since the Engineering section is new.

N/A = 1

2. On scale of 1-5 (1 no impact and 5 big impact), what has been the impact of this laboratory section on your knowledge of chemistry?

1 = 0

2 = 7

- I still don't know that much considering how much work I put in.

3 = 14

- Nothing too new.

4 = 42

- The lab we did furthered my understanding.
- Learned massive amount of information.

5 = 9

- Great experience.
- Much more than the lecture did.

3. On scale of 1-5 (1 no impact and 5 big impact), what has been the impact of this lab section on your ability towards solving experimental problems?

1 = 1
2 = 9
3 = 21
4 = 31
- Good problem solving technique.

5 = 10
- I have a better understanding of the process involved.

4. On a scale of 1-5(1 no impact and 5 big impact), what do you believe will be the future impact of this lab on your ability to solve experimental problems?

1 = 1
2 = 14
- I don't feel it relates to my life.

3 = 23
4 = 24
- MicroLab helped.
- It was fun.

5 = 9
- Teaches good experimental procedure.

N/A = 1

5. Do you believe that use of computers and sensors has enhanced your experience in this lab? (Yes or No; please elaborate on why or why not.)

Yes = 68
- Yes, many of the experiments could not have been done without the computer.
- Definitely. (2)
- Yes-the aid of immediately plotting data really helps to understand the relationships of the variables we measure.
- Yes, it really helps to visualize experimental results.
- Yes, because we will probably work with them later and it was good to know how they work.
- Yes, they were helpful in analyzing.
- Yes. It was interesting and fun to use equipment besides simple thermometers. It was also nice to set graph read-outs.
- Yes, good to know how to use.
- Yes, it helps get the details.
- Yes, using electronic sensors gave us more accurate predictions.
- Yes. Life was easier.
- Yes, they provided for a more precise measurement experience.
- Yes, it speeds up the process and makes data easier to record.

- Yes, graphs and the extra visual data helped.
- Yes, it made it easy to collect and graph data.
- Yes, computers (are) very important in today's science.
- Yes, it makes things easier to understand.
- Yes, I had little experience with using a computer in a lab before this.
- Yes, it gave a clear representation of the values of the experiment.
- Yes, I had never used a computer interface before.
- Yes, MicroLab has allowed me to interact with computer better.
- Yes. Saved lots of time and were neat to use except calibrating got old.
- Yes, except almost overused.
- Yes, it made it more fun.
- Yes, get experience with technologies.
- Yes, it stream lines labs.
- Yes, things made more sense.
- Yes. Results were good.
- Somewhat.
- Yes, it made easier, didn't have to worry as much about human error.
- Yes, knowing how to integrate sensors into a full experiment was very effective.
- Yes, because without them a lot of what we did would be hard to see (such as trends).
- Yes, they made the experiments go smoother and quicker.
- Yes, though I have used program like this before, MicroLab was very easy to use.
- Yes, because we will use computer in the future.
- Using the computer has helped me problem solve and set up experiments.
- Yes, because they are more accurate and they give visual info.
- Yes, it heightened understanding.
- Yes, getting use to technology.
- Yes, they make results clear and reasonably easy to see.
- Yes, easier to keep data.
- Yes, need to be able to work with electrical equipment.
- Yes, it was very practical.
- Yes, it actually showed us what data was doing.
- Yes, made things much more precise.
- Yes, we're found to see it is the real world.
- Yes, you are able to better visualize result of experiment through graphs on computer.
- Tim did very good job at explaining how the computer and chemistry parts work
- They made it easier to gather and record data.
- Yes, it was easier to gather info.
- Yes, MicroLab was very easy to use. WebCT was _____.
- Yes, I haven't used them much before, it was interesting.
- Yes, simulating real world problem ____ technologies with technology _____ will prepare me for future work.
- A little-made lag a little more "high-tech".
- Yes, much less busy work.
- Yes, it allowed us easily measure and record data.
- Yes, because everything in the real world is computers or will become computers.

- Yes, it was more accurate.(2)
- Yes, they are used in every chemistry lab in America so we should be exposed to them too.
- Yes, I'm used to using computer so that aspect of lab helped me a bit.
- Yes, most labs couldn't be done without them.
- Yes, it has definitely helped to use computers and sensors.

No = 4

- No, I think it was at a much lower level than it could have been. As well as sensor technology used was rather _____.
- No, chemistry is chemistry, regardless of how you get the data.
- No, I think I would have understood just as well with or without computer.
- No, I had an old lab where we used no electronics, and I learned more; just more hands on.

N/A = 0

6. Are there any further comments you would like to make about the 'in-lab' portion of this laboratory section?

- It was nice to be introduced to technology in lab.
- The group labs were by far the best – I really feel we learn more because the burden of getting everything done ASAP is slightly lifted, so we can think more about what we're doing instead of how to do it.
- Good in lab experience.
- 3 hours is pretty long, but we did a lot.
- Because very long.
- In lab was fun.
- I was pleased with the handout and the work load was acceptable.
- Good job.
- Very challenging.
- We need to have conference time in a conference environment i.e. chairs, proper noise reduction.
- I don't like that it take at least an hour before we get started.
- It was alright but long sometimes.
- Too much busy work.
- It was grand.
- Really awesome overall, but still needs more cowbell and explosions; yeah explosions.
- Seemed long at time, but it was worth it.
- Fine by me.
- Good.
- Fun, and enjoyable to go to.
- The explanation were _____ sometimes.
- There were too many things to keep track of that the other labs didn't do.

- It was fun and Tim is a cool guy.
- Great job Tim. More in evaluation.
- Class was usually fun and very interesting, teaching us a lot about chemistry.

The work done out-of-lab:

7. On scale of 1-5 (1 no interest and 5 high interest), how would you rate the use of WebCT for this lab section?

1 = 14
- Most people forget, it didn't help us and it brought grade down.
- It was useful for communication, but I thought the quizzes were ridiculous.
- Took too much time
- WebCT sucks and was a huge waste of time and effort and very inconvenient.

2 = 20
- I didn't do much on WebCT.
- Seems like a waste of time.

3 = 18
- WebCT was a little waste of time.
- It crashed too many times.
- Pre labs were good to get us thinking.

4 = 15
- Great for accessing material that everybody needed.
- It makes you meet deadlines.
- Sometimes a pain, but for the most of part useful

5 = 5
- It was great help in contacting the TA's.

N/A = 0

8. What are some PROS and CONS of using WebCT for this lab section?

PROS
- Pre-lab quizzes from home updated often
- Discussions were great – I always read them all
- More in depth concepts
- Knowing what others thought of lab
- Putting labs online was nice
- Could see the schedule (2)
- Good experience
- Being informed
- Discussion was good open discussion for questions ____ _____.
- The layout was good, and it helped to get pre-lab info
- It kept you thinking about chemistry
- Kept a good discussion and easy to take quizzes

- It helped with the write-ups
- Further helped explanations
- It was good for communication from instructor to students and visa-versa
- Weekly announcements
- Got me thinking
- Lab handouts
- It was good way to do pre-lab
- Good communication and helped with questions
- Effective communication with class
- Nice resource
- It can stimulate some good thought
- Took little time
- Discussions helped general understanding
- Discussed ideas with others
- Discussions stimulate more thought
- Help when needed
- I know what labs about that week
- Checking grade, lab discussions
- Easy
- Easy to use
- Supplements
- Easy info gathering
- Got me more involved
- Excellent for planning and keeping up
- I could see my grade
- The schedule of labs was very useful
- Sure source of info 24 hours
- Get me thinking of chemistry outside of class
- A great communication tool for the teacher and students
- Learned shit

CONS

- Hard to remember to log on (5)
- Should be used more
- Quizzes sometimes didn't work well
- Remembering it / getting to a computer
- Time consuming (2)
- Time consuming, hard to remember to do it each week (2)
- I would forget a lot to do the WebCT tasks
- Didn't learn much
- The time
- People forget to use it
- Quizzes are not helpful.
- Waste of time (2)
- It was used mainly for busy work

- It was hassle logging on every week
- It took some time and thought
- Tedious
- WebCT really didn't seem to further the learning
- Pain. Need a ___ that use our current e-mail instead of a new one
- Quizzes and discussions are busy work
- It wouldn't work on my computer a lot
- It was hard to keep up with it
- Not as good as communication within the classroom
- Someone who doesn't have net access may find it a hassle
- Lots of time, little reward
- Took time, something I didn't have
- Pain in the butt
- The problems were mostly on my part. I didn't log in and use it often enough
- It can appear to be busy work (3)
- A lot of stuff to keep truck of
- Takes long time, tend to forget
- Takes time
- Easy to forget about it and sometimes it was hassle
- More things to remember during the week
- It's a pain to have to do things online in addition to the lab write-up
- Sometime didn't work
- Hard to use sometimes
- Nothing but busy work
- Discussion postings were a waste of times; many of us did not do them
- It was a pain
- Remembering all the little things
- Too much stuff to do on it
- Time out of our day
- Quizzes and discussions (20
- It would shut down every once in a while
- _____ to grade
- More quizzes to remember, too many little things to get done
- Took some time to do discussions
- Took time and didn't learn much
- It taught me nothing and waste of my time
- Pain in the ass
- Having "little" things to do outside of lab
- Took a lot of time

9. Do you believe WebCT is being used effectively? (Yes or No; please elaborate.)

Yes: 45

- Yes – it was little much, but it was useful.
- For what it was worth, yes.
- Yes, it was just a lot of work to a 1 credit lab.
- Yes, putting labs online was nice.
- Yes, maybe even to effective.
- Yes, but the posts labs were unnecessary.
- I don't see another way.
- Yes, you seemed to use all the functions of WebCT.
- Yes, it allowed us an easy way to communicate with classmates.
- For what it could do, yes.
- Yes. (It) had a good purpose.
- Yes, it allowed easy streaming of out of class activities.
- It was, but I didn't really like it.
- Yes, checking WebCT every week helped me stay on course and ready for the next lab.
- Sort of – the absence of cowbell really kicked it down
- Yes, but the pre/post lab quizzes could be cut down since often times they were same anyways.
- Yes, the pre-lab quiz forced you to know about the lab.
- It served to give the students, who actually used it, a greater understanding of the material.
- Yes, it keeps me a lot more organized and a place to go to find out what was going on in the class.
- Good use.
- For supplements, too much busy work
- Yes, we learned about all of the aspects at it and many instants.
- Yes, helped to illustrate lab material.
- If it's got to be used, it's got to be used.
- Somewhat.
- Yes, for the average person
- Yes, as effectively as it could be.
- Yes, it was organized in a simple, effective manner.
- Yes, that is why we fail.

No: 20

- No, I did not like the WebCT aspect of lab. (It) was busy work.
- No, used at last minute.
- No, could post lab information prior to lab.
- No, I didn't do it. I hated it.
- No, eliminating WebCT discussion would have been good.
- No, discussions hard to remember and do.
- Not really until the end of the semester.
- Not so much, maybe more if it was used in class.

- No, I really didn't like the 3-4 quizzes per week. It's redundant. Not time consuming, just redundant.
- No, I don't think that everyone used it like it was meant to be used.
- No, I just don't like it.
- No, too much emphasis.
- No, it could have been used to post grade more often.
- No, it just gave us more work.
- No, it was used for busy work. You should look at how Professor Walsh (Philosophy) is using it.
- It was used as effectively as possible, but it was still not effective.

Yes and No: 2

- In the middle. Okay.
- It was helpful in ways, and annoying in others.

N/A = 5

10. Reflecting back on you use of WebCT this semester, what is the average of minutes per week that you we logged in?

1 – 15 min = 41
16 – 30 min= 27
31 – 60 min = 2
over 60 min = 1
Other: Less than 1 min = 1
N/A = 0

Use of computer-based measurement technology in lab:

11. On a scale from 1 to 5 (1 having small understanding and 5 having complete understanding), please circle your current understanding of the electric sensors you have used in lab. (*Electric sensors including pH probe, temperature sensors, light sensors…etc*.)

1 = 0
2 = 0
3 = 10

- It did help.

4 = 42

- Enjoy the explanation of the pH probe.

5 = 20
N/A = 0

12. On a scale from 1 to 5 (1 having no comfort and 5 for being at ease), please circle your comfortability level in using these electric sensors for collecting data in lab.

1 = 0
2 = 0
3 = 5
- Confuse in set up.

4 = 27
5 = 40
N/A = 0

13. On a scale from 1 to 5 (1 having small understanding and 5 having complete understanding), please circle your current understanding with using the MicroLAB interface and its software for data acquisition.

1 = 0
2 = 0
3 = 8
- It helped but I'm not the best.

4 = 42
- MicroLab is easy and really useful.
- MicroLab is still a little confusing.

5 = 22
N/A = 0

14. On a scale from 1 to 5 (1 having no comfort and 5 for being at ease), please circle your comfortability level in using the MicroLAB interface for data acquisition.

1 = 0
2 = 0
3 = 9
- Very basic.

4 = 36
5 = 27
N/A =0

15. On scale from 1 to 5 (1 not effective and 5 for most effective), please circle how effective you believe the use of electronic instrumentation is in solving problems within this laboratory.

1 = 0
2 = 1
3 = 8
- It crashed.

4 = 27
- It helped.

5 = 36
- Very accurate.
- Computers make everything easier.

N/A = 0

16. On scale from 1 to 5 (1 not needing and 5 needing more), please circle your desire for being offered more information about the electronic instrumentation you used for solving problems in this laboratory.

1 = 8
2 = 20
- No desire.

3 = 27
- Only when necessary to understand concepts.
- It's interesting.

4 = 11
- It was self explanatory.

5 = 6
- I didn't think I needed more info, but I liked learning how the sensors work(like the pH probe) , I'd like to learn about more of the sensors.
- It was one of the things that interested me in this lab.

N/A = 0

17. About the previous question; would you prefer to have more information about instrumentation as part of the laboratory OR as supplemental material? (if you have any other ideas beside this, please share them with me here…)

Part of the laboratory: 6
- Understanding how sensors work shows a real application of what we do.
- No supplements. They don't get read.
- It would be nice to cover it briefly in the lab lesson with more material on it if wanted.
- Prior to the experiment.

- The instrumentation seemed to be well explained during the lab.
- Just a basic description of instrumentation prior to the lab would be nice.

Supplemental: 21

- During lab just lengthens lab and makes it more stressful.
- This would benefit both people who want and don't want to do it.
- I think that the more information could be supplemental material that is briefly touched on in class.
- Give the class more time.
- I think more information should be given as supplemental material.

Other: 25

- It was just right amount.
- Yes, I think so.
- Maybe a little more; that pH prove taught me a lot about the pH.
- More information on instrumentation.
- It is nice to have an understanding on how they work ___ it helps understand what is going on the lab experiment. But nothing too extensive.
- Yes, how they work.
- No. (3)
- Good to know how sensors do their job.
- Yes, I think it would be great to know how the instruments we use in lab work.
- More kinds of information.
- More info is not necessary.
- It was fine.
- More.
- Same amount.
- Sure.
- Right amount was given.
- No really sure, did fine without.
- No, not enough time.
- Not at all.
- Perhaps both?
- I don't know… either one would work. I suppose people would pay more attention if it were done as a lab lesson.
- No more learning do I require, already know that which I need.
- Don't care.

N/A: 20

The overall format of this lab:

18. What do you like about the format of this lab section?
- I liked the introduction to electronic instruments in lab.
- Group labs. (2)
- I liked the use of MicroLab.
- Getting the research extensions over during the semester
- We are not treated as kids, and the type of stuff we did in lab varied.
- The atmosphere of the lab was good. Everyone got along well.
- Using computer a lot.
- A lot of doing and not reviewing.
- Solving problems.
- I really liked MicroLab, and how they switched it up with class labs to group labs.
- The labs were more interesting.
- We were expected to not be stupid unlike the general lab section.
- The organized labs and the MicroLab. Plus the positive environment.
- I liked the group interaction. (2)
- I liked the different kind of labs we did.
- Working as a group at solving problems.
- Research extensions.(2)
- The process of using research extensions during the lab rather than at the end.
- The use of WebCT for communication about next lab.
- Small groups and class size.
- Good equipment.
- No individual project at the end.
- Experiments.
- How our finals were conducted.
- Group work.
- Streamlined, more organized.
- Partners, and working with the computer.
- In depth.
- It was cool being able to do stuff other lab didn't get to do.
- Great learning experience.
- Teachers were good.
- I enjoyed he flexibility in performing our lab.
- This is more education and informative.
- Everything was straight forward and very organized.
- It was simple and straight forward.
- Tim is a cool guy.
- The labs with demonstrations.
- Covered more stuff than regular labs.
- Advantaged labs.
- It wasn't strictly task oriented, you could enjoy it.
- Real world problems.
- That if was open and we worked as group to solve common problems.

- Tim made the boring experiments better, and his own experiments were stimulating.
- Relax environment.
- Interesting.
- Some experiments were really fun.
- Catered to engineering interests.
- It was well explained. The TA was helpful.
- Excellent teacher and small class.
- Lengthy/lab write-ups.
- Doing all of the experiments and learning all of the different types of concepts that went along with them.
- ME lab, I could find study partners.
- Long classes once a week help me learn concepts more full.
- Involved and being treated as hard working, smart engineering students.
- Very informative.
- The instructor's enthusiasm.
- One day a week.
- Plenty of time to finish labs and get them turned in.
- Working in the lab.
- Choosing lab partner.
- The partner set up.
- Enough time to work.
- The working in small group and one on one with you.
- Learning the nature of the force.
- Lab experiments.

19. What do you dislike about format of this lab section?
    - Knit-picking on lab reports.
    - WebCT (5)
    - I needed more time for the lab write-up.
    - Going overtime was not fun, too long some days.
    - The out of class work, ie WebCT.
    - Lengthy lab write-ups.
    - Not much, a little harder.
    - Lab write up took 3 to 4 hours. Lab ran long.
    - Post lab quizzes.
    - So long.
    - (No) chairs, and 3 hours long. (4)
    - Remembering to do WebCT stuff.
    - Presentations.
    - The tedious lab write-ups; but I understand their importance.
    - It was very difficult, and graded very harshly…Since we were doing more than we asked of it, I feel we should get additional credit.
    - Right before dinner.
    - Lack of diverse background in the lab and standing time.

- All the homework for if.
- Busy work.
- How long it is.
- Redundant experimentation.
- Extra out of lab work, extra labs.
- Very thorough write up.
- The lab write-ups.
- Research extensions were confusing.
- Busy work, long hours.
- There were actually little that I have to complain about for this lab; well done.
- All the extra work.
- That more work than other sections.
- No cowbell!
- 3 hours.(3)
- Spent too much time in here sometime.
- It was unpredictable.
- Time length (long at times).
- Length.
- Discussion posting on WebCT.
- Lab discussions. (2)
- Too long.
- The write up.
- Went longer than other sections.
- Amount of time listening to explanations and pre-lab lecture.
- The pre and post lab quizzes and discussions.
- All guy, no chicks.
- WebCT, quizzes.
- More work than lecture.
- Too much work.
- It was more than I would like to put into chemistry.
- Three hours straight is a bit to handle on some days.
- Some of he lecture were kind of confusing and it was hard to figure out what lab was next.
- Long lab write-ups; I must explain when I already understand them.
- How freakin' long it is.
- Took too much time.
- Sometimes the lab didn't coincide with what we were learning in the lecture.
- Dislike anything, I do not hate leads to suffering, the path of the dark side it is.
- The amount of time spent for one credit.

20. On scale of 1-5 (1 minimum and 5 maximum), where would you rate of your level of 'interest' in participating within the Research Extension part of the lab?

1 = 4

2 = 12

- Wasn't a huge fun, but some were interesting.
- Research extension can be big hassle when they come at the wrong time.

3 = 24

- Interesting, but a lot of extra work.
- Usually more interesting.
- Some were boring.

4 = 24

- It was a nice change, but sometimes seemed really repetitive.
- Research extensions were easier to get involved and learn things.

5 = 8

- At first I didn't like the idea and then I warmed up to it.
- No time, too little time to prepare proper presentation.

N/A = 0

21. On scale of 1-5 (1 minimum and 5 maximum), where would you rate of your level of interest as a listener during the Research Extension oral presentation reports?

1 = 10

2 = 17

3 = 35

- The topics were great, but college students are capable of better presentations.
- Some interesting, some were brutally boring.
- Kind of boring but if done well it ca be very interesting.

4 = 10

5 = 0

N/A = 0

22. On scale of 1-5 (1 minimum and 5 maximum), how well do you like participating with your Research Group in completing your Research Extension experiment, write-up, and oral report?

1 = 2

- I really do most of work, anyway.
- Boring.

2 = 18

- Lots of work.
- Oral report was good… extra effort is a lot to ask.
- Members didn't contribute equally.

3 = 25

- Like it better than single lab write ups.

4 = 17

- Less to do + more to observe = more learned

5 = 10

- Write-ups were not so fun to work with multiple people never ____.
- I like knowing stuff.

N/A = 0

23. To the previous question, please list a couple PROS and CONS you may have for this Research Group approach o solving experimental problems?

PROS

- Work as a group. (2)
- Gave us opportunity to work in groups, learn to manage people / splitting up work.
- The extra lab portion is interesting and worth-while. I really liked the real-life applications.
- In depth analysis.
- Leaning more. (3)
- Do not have to write report alone.(2)
- Get group input.
- Learn stuff, can be fun.
- Less work, more help.
- Bigger group gets more done.
- It is good if everyone is putting an effort otherwise it's ___.
- It was preferable to a final project.
- I liked the instructor's help in solving the problem.
- Great working with fellow teammates.
- Group activities bring together more knowledge, and give people better friendships.
- We get to work in a collaborative environment.
- Work as a team like real world. See other points of view.
- Further research.
- With groups you have to accomplish more tasks, but its fun.
- More background is given to solve problems.
- Learn to work effectively together.
- Good group experience.
- Having to get together as a group teaches good skills.
- Made lab write-up easier.
- This is the interesting application of lab.
- Learn to work with others.
- More people working allow for more ideas to be shared and faster progress.
- In depth subject matter.
- Don't have to do final project.
- Have a group to discuss problem with.
- Great except that I had to work with Kyle, and you know Kyle.
- Get the job done faster.
- It was good because it gave us a deeper understanding.
- Going more in depth into the material was good learning experience.
- Further understanding.

- Better understanding.
- Group lab.
- It split up the work.
- Learn something different.
- Team ____ work (theoretically).
- Good projects.
- Only things I learned in lab came from research extension.
- It gave us a complete understanding of lab.
- Groups work well.
- Being able to have 4 heads think about the problem rather than 1.
- Do or do not there is no try.

CONS

- Difficult to schedule time (4).
- On the last lab one guy didn't show up, but we kind of anticipate that so it was fine.
- There was a bunch of extra work for this class, so much that it was difficult to appreciate what you were doing.
- A lot of extra work.(3)
- Getting group together.
- More time needed out of lab.
- Sometimes people don't show up.(2)
- More time to work.
- If you are not interested in the extension, it was boring.
- Sucks on test day.
- One person might be gone.
- The presentation of the material was hard to make interesting.
- Took too much time.
- Lack of interest from other group.
- Potentially bad groups.
- You have to do a normal labs as well as research extension. If partners slack off or do poorly you do poorly.
- I got stuck with all the work.
- They were a lot of busy work out side of class.
- 4 people groups are too big, 2 (people groups are) better.
- Meeting with each other.
- Time consuming.
- Time frame in which to work.
- It just seems like extra busy work to write it all up.
- Lengthens lab time.
- We have to meet together with tight schedule.
- Can be difficult to work in a group.
- Some extra work.
- Went after lab hours.
- Extra time.
- Time out of the day, and meeting with other group member.

- Extra work over ____ labs, ___ ___.
- More out of class work.
- Dragged out experience (meeting and stuff), more work.
- It took a lot of time.
- Not much learning, more writing.
- I didn't care about any of the chemistry, ever.
- Tough time commitment.
- Trying to coordinate with other group members.
- Judge me by my size do you?
- I live off campus and it hakes a lot of time to come meet for ½ hour. I spend 30 min each way driving.

24. On scale of 1-5 (1 minimum and 5 maximum), how effective is this Research Extension approach to your style of individual learning style?

1 = 1
2 = 18
- I am a genius, I already know it all.

3 = 18
- It was fun.
- I am not sure what my learning style is.

4 = 29
- It made it easier to observe and learn.

5 = 5
N/A = 1

32. Are you planning to take another chemistry course after this semester?

Yes: 14
- 132 (5)
- Chem E 213 (4)
- 228
- Simply because chemistry is at interest to me.
- What ever I need for geology.
- I am taking material science.
- O-chem, bio-chem, gen-chem II

No: 48
Maybe: 8
- We will see.
- Hmm, difficult to see, always in motion the future is.
- If I have time, I would like to.

N/A: 2

APPENDIX C

ENGINEERING LAB SYLLABUS AND GRADING CRITERIA

Spring Semester '04
CHEM 131 Lab Sections

Instructors:	Tim Sorey	TA - X
Sections:	CHEM 131-15 and CHEM 131-09	CHEM 131-13 and CHEM 131-22
Office:	G.H. #127 and Help Center (G.H. #109)	Help Center (G.H. #109)
Phone:	994-5380	N/A
E-mail:	YYYYYY@hotmail.com	XXXXXX@hotmail.com
Help Center:	Tuesdays and Thursdays 9-10am	Wednesdays and Fridays 2-3pm

I. What to bring to the Lab

- Lab Manual and Research Extension: Purchased at bookstore or handed out a week prior to lab.
- Lab Notebook : This must have bound pages with lined paper, not loose leaf paper in a three-ring binder. An affordable, less than $3.00, laboratory notebook can be purchased at the MSU Bookstore.
- Pen: Blue Ink for writing notes in your lab notebook.
- Scientific Calculator
- Eye protection: Regulated Safety Goggles Only
- IBM formatted 3-1/2" computer disk (EVERY WEEK!!!)
- Proper lab attire: No "bare skin" from the neck down. You should wear long sleeve or short sleeve shirts to the elbow, long legged pants, and closed toed shoes. A laboratory jacket/apron can be purchased at the MSU Bookstore.

II. SAFETY IN THE LABORATORY

Please observe the following rules when in chemistry laboratory:

1. Always listen to the lab instructor when he/she is speaking.
2. Eye protection is required in all labs unless specifically indicated otherwise by the instructor. Regular glasses are *NOT* satisfactory. Carefully read your safety goggle consent form for further explanation. (*Hard and soft contact lenses are prohibited in the lab, even if you are wearing goggles over them.*)
3. DO NOT eat, drink, chew, smoke, or apply make-up in the lab. After being in a lab, wash your hands thoroughly before doing any of these previously mentioned things.
4. NO shorts, NO open shoes, and NO bare feet are allowed in labs. NO tank tops or loose fitting clothes will be allowed either. Lab aprons or coats are recommended. Long hair should be tied back or restrained, not flying loose. ANY DEVIANCE FROM THIS DRESS CODE WILL RESULT IN YOUR DISMISSAL FROM CLASS UNTIL YOU CAN GET CHANGED INTO THE PROPER ATTIRE!
5. Horseplay of any kind is not permitted. Serious injury can occur when people are not focused on the tasks that are required in lab.

6. Clean up all spills and broken containers immediately. Be sure to ask for help if you feel that this duty may be beyond your ability.
7. Dispose of all wastes in proper containers. Glass and some chemicals may have SPECIAL disposal procedures! Let's take care of each other, you could hurt your friend and fellow student accidentally if you do not follow the proper disposal methods.
8. Check your glassware before usage. If it is cracked or "starred" DO NOT USE IT! This could result in a horrible accident.
9. If glass, wire, or any other object has been heated, test to see if it is cool by placing the back of your hand NO CLOSER THAN about ONE INCH away from the object in question. If you feel heat, DO NOT TOUCH IT!
10. NEVER mouth-pipette anything; always use the proper devices provided in lab, such as a rubber bulb.
11. Read labels on reagent bottles carefully each time you use them. Some chemicals are very toxic; some are corrosive; some are flammable. If you do not know anything about the compound's property, it is best to ask than to assume anything. Ask the Lab Instructor before you make a decision.
12. Label all containers you use at your workstation and those that are stored in your locker. Be sure to ask your TA for permission before storing any chemical in your locker for more than one week.
13. Know where the safety shower, emergency eye wash station, and fire extinguisher are located and how to use them in an emergency.
14. Flush acids or bases from your skin or eyes or clothing with copious amounts of water for at least 15 minutes. If tingling or burning sensation continues, make sure to tell the instructor and you will get the proper medical attention. DO NOT try to neutralize acid or base spills; get help instead.
15. If you break a thermometer, tell your instructor and he/she will dispose of it properly.
16. Special instructions are given in the individual experiments. Always listen to the instructor for additional safety procedures that may be necessary to know for each experiment that is performed. It could save your physical well being.
17. Keep an eye on your neighbor for adverse effects of chemical exposure, calling it to your instructor's attention ASAP. (Dizziness glazed look, etc.)

III. Missing a Lab

BEFORE YOU ARE ABSENT, be sure that you have contacted your lab instructor prior to the missing of the LAB. You shouldn't simply attend another lab without talking to your TA first! The TA will negotiate a time that you may attend another lab for make-up. If you are unable to contact your TA prior missing your lab, then it is YOUR duty to contact your TA as soon as possible.

If you cannot make-up the lab that you missed, then you will need to negotiate with your TA about your next course of action. DON'T EVER LET A MISSED LAB GO BY WITHOUT SPEAKING TO YOUR TA ABOUT IT! There may be up to two excused absences this semester AT THE TA's DISCRETION. Any more excuses must be negotiated with Lab Coordinator Dallas Johnson and CHEM 131 Professor.

IV. What you can expect in a single laboratory day

1. Prior to lab, you will be asked to perform a "PRE-LAB QUIZ" on your WebCT account. This quiz will be available 48 hours prior to your lab section, but will not be accessible as your lab begins. This "PRE-LAB QUIZ" may contain three or more questions about the lab that you will be performing. This quiz is worth 0.5pts.
2. Next, this lab instructor will check your LAB NOTEBOOK for upkeep on your laboratory notes of procedure, observations, calculations, etc. A single paragraph, the PURPOSE STATEMENT, explaining the lab that will be performed during that day's experiment should be written up and placed in your LAB NOTEBOOK. If the LAB NOTEBOOK is up to date with notes from the previous lab and includes the PURPOSE STATEMENT, the TA will initial it at the beginning of lab for 1pt each.
3. The TA will begin the lab with either a mini-experiment OR present some theoretical basis for a chemical phenomenon that introduces the lab. You should listen carefully for explanation and take notes within your LAB NOTEBOOK in order to capture details about the experiment and SAFETY PROCEDURES.
4. Upon finishing your assigned laboratory exercises, please be sure to carefully wash all of your glassware, placing it in your drawer and making sure it is locked. Please wipe down your workstation with a damp paper towel, followed by a dry paper towel, to ensure that any chemical residue is properly cleaned up before the next class enters.
5. Before you leave, check with the instructor to make sure you finished all the experiment that you were assigned to accomplish in the session. Also check the white board for special instructions for next week labs and assignments that may be pending on WebCT. *(Remember that a PURPOSE STATEMENT is due every week, so be sure to write down the page numbers of your Lab Manual OR pick up the next week's laboratory experiment before you leave for the day.)*
6. Pick up a "Positive Peer Review" form that is available in lab OR from Tim Sorey's office door, Gaines Hall #127 so that you can fill it out and give your constructive input to another person's lab report. You should perform this task for another person more than twice this semester. This should be stapled to and turned in with the corrected report…worth 1pt.
7. The lab report is due within three days past the end of your lab session with the appropriate "Positive Peer Review" sheet. The lab write-up will be worth 15 pts., if turned into your TA's drop-box on time. *(Please see the late policy described below.)*
8. After lab, a "POST-LAB QUIZ" will be available on your WebCT account. This quiz will be available for the next 72 hours after your lab section, so be sure to get online and complete it because it will not be accessible after that. This "POST-LAB QUIZ" may contain three or more questions about the lab that you performed in lab. This quiz is worth 0.5pts.

9. Between your lab sections and on a weekly basis, you will be asked to participate in a WebCT DISCUSSION. You will have to post at least one original message to the discussion topic that is posed for the week and reply to at least two other people to earn full credit. The WebCT DISCUSSION will be worth 1pt. per week.

V. Grading Policies

The total points for each laboratory grade is 20 pts unless it is a Research Extension Week.

Part of lab	Point Value
WebCT PRE and POST QUIZES	1
WebCT (online) DISCUSSION	1
LAB NOTEBOOK	1
Positive Peer Review	1
PURPOSE STATEMENT	1
Procedure and Observations Data Calculations and Data Analysis Conclusions	15

LATE POLICY:
Your formal lab report write-up is due no later than three days after your lab at 5pm in the afternoon. Please file the lab properly in the slot outside of the main office Gaines Hall #108. For every day the lab report write-up is turned in late, 2 pts will be deducted from your final grade on that report. The instructor will NOT accept the lab report write-up 3 days after the due day.

(SPECIAL circumstances will be considered upon review.)

VI. Guidelines for Lab Report Write-ups

- All formal lab write-ups must be typed in 12pt., unless you need to draw diagrams or show any hand written calculations in PEN.
- You should always write your lab report in the second person, plural, and past tense.

Example: We added three drops of HCl(aq) to 10mL of AgNO3(aq).

- Each person must write his or her own lab report in its entirety. If two people share the same report or part of the same report, the allotted points will also be shared among the individuals. For example, if the lab earned the maximum point value of 20 points, each individual will be given 10 points each, a failing grade.

The lab report write-up should contain 6 major sections, Title and Name, Purpose, Procedure and Observations, Data, Calculations and Data Analysis, and Conclusions.

Below, you will find a short description of what each section should include:

- Title and NAME

This section of each laboratory write-up should contain the title of the lab in 14pt., which should be centered and at the top of the page. Next, you should place the CHEM 131 and the section number, followed by the due date of the lab, your name and student ID #, and your lab partner's name. (The rest of the lab typed in 12pt.)
Example:

> Colorimetry Lab: Determining the Concentration of Copper ion
>
> CHEM 131- Section # XXX
>
> Due Date: 9-17-03
> Tim Sorey ID# -12345678
> Lab Partner: Joe Shmoe

- Purpose

The purpose should state *IN YOUR OWN WORDS*, what are you trying to find out and what your goals are in this lab session. This purpose should be completed and in your LAB NOTEBOOK before the lab session has started and should contain no more than few sentences and no less than two.

- Materials

List the materials you used within this lab. This includes both physical and chemical materials, such as glassware and chemical reagents found in the fume hood.
Any instrumentation descriptions, electronic symbology, and diagrams should be referenced here and will go into an appendix where further elaboration can be placed, such as circuit diagrams and specific laboratory set-up you deem important to the data acquired within this lab.

- Procedures and Observations

The procedure DOES NOT need to restate all of the steps in the lab manual. However it does need to contain any information so that you or other people can repeat the experiment exactly by referring to your procedure. This means that you must include exact volumes and concentrations of any reagents used (if they are known). It must include any masses, temperatures, absorbances, or any other pertinent measurements taken during the procedure that affect the outcome of the experiment.

Example of Procedure:
1. We used a 50-mL graduated cylinder to measure 40.0mL of 0.1M Hydrochloric acid (HCl).

You also need to record any noticeable observations, listed as "*OBS:*", made during the experiment, like color changes, temperature changes, formation of precipitate, and so on.

Example of Observation:
OBS: When we placed a dropper of HCl $_{(aq)}$ into $AgNO_{3(aq)}$, a solid, white precipitate formed.

- Data (Raw Data!)

All data should be reported in neat tables. You can also restate and or include DATA SUMMARY sheets in your lab manual by simply stapling them to your lab report and placing a page number on them. Please refer to this DATA SUMMARY when discussing it in your Data Analysis or Conclusion! This is not an area for you to perform any calculations or data analysis, it is simply a place for you to record any and all of the data that was collected.

Example of referring to Data:
Please refer to page 4, graph 1, to see the pH vs. volume (mL of 3M NaOH).

- Calculations and Data Analysis

This section includes any of the graphs that contains important information or data you used to draw information from (calibration curves, titration curves…). These graphs need to be clearly labeled on each axis, including Units, and must contain a title describing what is plotted.

You will need to show any and all steps of your calculations that you performed on your data in this section, also. It is OK to write this section in by hand, but be sure to use neat handwriting in black ink

When accepted values are given or calculated, you will be asked to calculate the corresponding percent error that is correlated with your result.

- Conclusions

In the conclusions, you may sometimes need to discuss the accuracy of your results and compare them with the expected outcomes. The instructor's grading will not be based on how well your results correspond to the "expected" outcome, but rather your ability to describe your results in the context of the data that was acquired. The analysis of your data and what that data suggests should be your ultimate goal. If your results deviate from the "expected" result, you need to investigate and clearly state why this is. *(If you have enough time, it is encouraged that you try and make an experimental design correction and collect more data. If time does not permit, you are expected to discuss how you could have improved your procedure to experiment.)*

You should also mention what you learned and what you found out after the experiment by reviewing your Purpose, which was stated at the beginning of the report. ALWAYS discuss possible errors in this section and how you may have done things differently to control the parameters of your experiment.

Always pay attention to placing UNITS with every recorded number and the SIGNIFICANT FIGURES from the instrumentation that helped you to acquire your data!

Research Extension Group Written and Oral Reports
CHEM 131 – Spring 2004

Point Structure: (Two Parts)

A) 30 pts – Group Lab Write-up: *(This report is due 1 week after completion of lab.)*

You will follow the same write-up format as in previous lab reports for this semester, *except* for the following changes that are worth a total of 10 pts. :

- The "Materials" section that is located *after* the "Purpose" statement section and *before* the "Procedure and Observations" section must include an "MSDS Section" (Material Safety Data Sheet Section) and an "INSTRUMENTATION DETAILS Section". This MSDS will include the chemical formula and the potential health hazards of each chemical that is used within the given experiment. The "INSTRUMENTATION DETAILS" section may show detailed instrumentation circuit design that is used. Both sections should be reviewed with the TA for appropriateness and accuracy during the "Preparation Meeting".
- A "Practical Application" must be discussed in the conclusion. This should include the discussion of at least one real world application, who uses this piece of knowledge in the real world, and where in the world this can be found in use.
- A single report should written up for the research group, instead of separate individual reports. This is a GROUP project and the effort should be as a GROUP.

B) 10 pts – ORAL SEMINAR Presentation: *(Given 1 week after completion of lab.)*

The presentation is performed one week after the laboratory is completed. This presentation should be a minimum of 10 minutes and a maximum of 15 minutes. The point breakdown for this portion of the report is as follows:

1 pt – You will be asked to have a "Preparation Meeting" with the lab instructor prior to your presentation. The meeting time and place must be scheduled upon the conclusion of the laboratory that is to be presented.

1 pt – A title sheet and outline of your oral report should be placed on an overhead at the beginning of the oral report. (This will help you to show the logic of your discussion and help the audience to know where you are going.)

3 pts– At least two chemical equations, calculations, chemical structures, and/or instrumentation circuit diagrams should be done in front of the class on the overhead or chalkboard.

5 pts – All group members must contribute equally in some aspect of technical information that is presented *within the given 10-15 minute time limits*.

0 pts will be assigned to individuals who don't show for their report or don't contribute equally to the group reports.

Total point value of this Group Activity is = 40 points.

Positive Peer Review Form

(Completed by your Lab Partner before turn-in)

Name on report:_____

Your name::_____

Does the report follow the correct format?
(Numbered Procedure, Listed Observations, etc.)

1. Does the Conclusion discuss possible error and expected outcome of material in the report?(Discussion of graphs, key concepts, and other?)

1. If there are any graphs, is there reference in the text and are the axis labeled with units?

1. What does this person write in their report that you might incorporate into your own report?

1. What changes might you suggest this person to make their report "better"?
(Remember, answering "none" won't help this person improve.)

APPENDIX D

LABORATORY OUTLINE

Laboratory Outlines of Chemistry Content for each CHEM 131 Lab for Engineers.

Week and Class Topic	Chemistry Content From National and Local Survey	Chemistry Principles	
		Class Experiment	Research Extension Topic and Experiment
Week 1 Measurement Manual CH. 1-2	Measurement, Dimensional Analysis, Significant Figures.	M.M. CH. 1-2: History of Chemistry, Scientist's Research Cycle, The importance of Measurement, and Temperature.	M.M. CH. 1-2: N/A
Weak 2 Measurement Manual CH. 3-4	M. M. CH. 3-4: Measurement, Dimensional Analysis, Significant Figures.	M. M. CH. 3-4: pH buffers and measuring household solutions, light intensities within the laboratory, Pressure vs. Temperature, Celsius vs. Fahrenheit, Density, Pressure vs. Depth, Pressure vs. Volume, %T vs. Absorbers, and Radioactivity	M. M. CH. 3-4: N/A
Week 3 Measurement Manual CH. 5-7	M. M. CH. 5-7: Measurement, Dimensional Analysis, Significant Figures, and Chem. & Phys. Properties of Matter	M. M. CH. 5-7: Boiling point, freezing point, density, solubility, and evaporation of liquids.	M. M. CH. 5-7: N/A
Week 4 Quant. Analysis	Quant. Analysis: Measurement, Dimensional Analysis, Sig. Fig.s, Atomic & Bonding Theories, Chem. Formulas, Mass Relationships, and Stoichiometry.	Quant. Analysis: Using balanced chemical formulas, stoichiometry, mass relationships, atomic theory, bonding theory of chelation, and mole theory.	Quant. Analysis: *(Quant. Analysis of %P in Plant Food)* Calculation of % by mass
Week 5: Spectroscopy	Spectroscopy Measurement, Atomic Theory, Mole Theory, Electron Transfer, Chem. Formulas, and Electrochemistry.	Spectroscopy: Wave nature, wavelength, frequency, speed, and energy of light,the Bohr Model of the Atom with respect to line spectrum, and radiant blackbody heat with respect to band spectrum.	Fluorimetry: Excitation wavelength and emission wavelength of aqueous fluorescent molecules and the use of mole theory to create calibration curves for the quantitative analysis of these compounds in aqueous solutions.
Week 6: Colorimetry, Fluorimetry, Turbidimetry, and Nephalometry	Colorimetry, Fluorimetry, Turbidimetry, and Nephalometry: Measurement, Significant Figures, Chem. Properties, Bonding Theory, Mole Theory, and Solution Chemistry & Equilibrium.	Colorimetry, Fluorimetry, Turbidimetry, and Nephalometry: % T and A of Light through colored and turbid aqueous solutions, Fluorescence and Stokes Shift, Beer-Lambert Law, The Tyndall Effect, Equilibrium, Ksp, and Mole Theory & Standard Dilutions to create calibration curves. Solve for unknown concentration of Fluorescent sample from pre-made calibration concentrations.	Quantitative and *Qualitative* Analysis of an Ion Pair in an Aqueous Solution: Qualitative analysis of ions in solution with a test reagents and building an observations spot matrix to identify unknown ions. Measuring turbidimetrically and colorimetrically the insoluble and colored solutions from this analysis.
Week 7: Qualitative & Quantitative Analysis of H_2O	Qualitative & Quantitative Analysis of H_2O Measurement, Significant Figures, Chem. Properties, Bonding Theory, Mole Theory, Solution Chemistry, Chemical Formulas, Reactions, Stoichiometry, and Solution Chemsitry.	Qualitative & Quantitative Analysis of H_2O Beer-Lambert Law and the Tyndall effect, coupled with qualitative spot test matrices to determine the concentration of two unknown salts dissolved in an aqueous solution, along with their corresponding molecular formulas.	Using Conductivity to Quantitatify Dissolved Solids in a Solution: Measuring electrolytes in aqueous solutions that are a function of conductivity, building a calibration curve, and solving for concentration of solutes.

Week and Class Topic *(continued)*	Chemistry Content From National and Local Survey	Chemistry Principles	
		Class Experiment	Research Extension Topic and Experiment
Week 8 An Introduction to Thermodynamics	An Introduction to Thermodynamics Measurement, Significant Figures, and Physical Properties.	An Introduction to Thermodynamics: Flames, Heat, and Calories: Temperature, Heat Capacity, Heat of Fusion, and Heat of Combustion	Determination of 'The Heat of Solutions' and Hess's Law Heat of Solution, Hess's Law, and High Resolutions Temperature Measurements
Week 9	-SPRING BREAK-	-SPRING BREAK-	-SPRING BREAK-
Week 10 Molecular Geometry and Bonding of Organic Compounds	Molecular Geometry and Bonding of Organic Compounds: Reaction Rates & Kinetics Theory, Solution Chemistry & Equilibrium, Organic Chemsitry, and Shapes and Polarities of Molecules.	Molecular Geometry and Bonding of Organic Compounds: Lewis Structures, Octet rule, Oxidation number, Expanded octet, Formal Charges, Coordinate Covalent Bond, Resonance, Hybridization, Molecular Shapes/Geom., and dipole moment/polar/non-polar molecules.	Proof of Molecular Configuration and Quantitative Analysis of Sugars in Solution: Stereochemistry, circular dichroism, and optical rotation due to change in concentration, path length, OR in wavelength.
Week 11 FOOD CHEMISTRY AND COUNTING CALORIES	Food Chemistry and Counting of Calories: Measurement, Significant Figures, Thermodynamics, and Chemical Properties of Matter	ACME Food Analysis Labs: (Worker) Temperature, Heat Capacity, Heat of Combustion, and intensive properties of a single snackfood.	ACME Food Analysis Labs: (Manager) Temperature, Heat Capacity, Heat of Combustion, and intensive properties of a number of snackfoods
Week 12 The Behavior of Ideal Gases	The Behavior of Ideal Gases: Gas Laws, Thermodynamics, Significant Figures, Mole Theory, and Stoichiometry and Bonding Theory	The Behavior of Ideal Gases: Pressure, Boyles Law (P vs.V), Charles Law (T vs. V), Avogadro's Law (n vs. V),The Ideal Gas Law, Kinetic Molecular Theory, and deviations from the Ideal Gas Law (van der Waal's equation).	Determination of Partial Pressure using a 'High Resolution' Pressure Sensing: Dalton's Law of Partial Pressure, Volumes of gases in chemical reactions, and *Vapor Pressure. Bournoulli's Law of Pressure.*
Week 13 Electrochemistry	Electrochemistry: Measurement, Significant Figures, Chem. Equation & Mole Theory, Solution Chemistry, and Stoichiometry.	Electrochemistry: Oxidation/Reduction, Spontaneous and forced, Anode & Sacraficial Anode, Cathode, Voltaic Cell, Salt Bridge, Half-reaction and Half-Cell, EMF or Standard Cell Potential, Voltage, Current, and the Nernst Equation	Electroplating of Copper ions in Solution: Electrogravimetric Analysis, Electrolysis, Electrical Work, corrosion of metals, and Ohmic Potential & Concentration Polarization.
Week 14 Acid & Base Solutions	Acid & Base Solutions: Measurement, Dim. Analysis, Shapes & Polarities of Molecules, Solution Chemistry & Equilibrium, and Electroschemistry	Acid & Base Solutions: Electrochemistry of a pH electrode, Acid, Base, Hydronium Ion, Hydroxide Ion, Arrhenius Theory, Bronstead-Lowery Theory, Molar equivalence, Mono/Di/Polyprotic acid, Equilibrium (K_w, K_a, & K_b), Strong and Weak Acid/Base Systems.	Determination of Acid or Base in a Household chemical: Mole Theory, stoichiometry, pH electrode outputs and calibration, titration curve, and volumetric analysis of an unknown solution.
Week 15 Kinetics	Kinetics of Crystal Violet Reaction: Measurement, Significant Figures, Solutions, Colloids, and Suspensions, Reaction Rates and Kinetics, Acid and Base Chemistry, and Organic Chemsitry	Kinetics of Crystal Violet Reaction: Spectroscopy, Reaction Rates, Kinetics, Order of Reactant Effects, Concentration of Reactant Effects, Beer-Lambert Law, Forward Rate Constant, Pseudo-Rate Constant	N/A

Laboratory Outlines of Laboratory Process for each CHEM 131 Lab for Engineers.

Week and Class Topic	Research Design and Techniques	Measurement Technology Skills & Tools	Math Skills & Tools
Week 1 Measurement Manual CH. 1-2	Reading and collecting voltage, resistance, and current from a DVM, and equilibrating temperature sensors within water baths.	Physical and electronic instrumentation, computer interfacing, electronic symbology, DVM read-out, voltage, resistance, current, Ohm's Law, Sensor output (LM34 & LM35), and hand calibration.	Scientific notation, accuracy, slope, point-slope intercept formula, dimensional analysis, and significant figures. Use a single resistor to hand-enter the values of 20…run statistics.
Weak 2 Measurement Manual CH. 3-4	Interfacing software and hardware for sensor calibration and data acquisition	Measurement and calibration using of hardware (pH, Light, and pressure sensors with interface), software (computer), and sensor calibration via software manipulation.	Hand entering and collecting data for math modeling of physical and chemical systems, statistical analysis of radioactive systems, and transformation of data.
Week 3 Measurement Manual CH. 5-7	Interfacing software and hardware for sensor calibration and data acquisition, using an electronic balance, and using a boiling chip.	Use of previous skills and tools for data collection and using volumetric glassware (grad.cylinder),	Choosing calibration endpoints which contain the experimental parameters, Sea-level to Bozeman boiling point conversion, and mass vs. vol. determination of density.
Week 4 Quant. Analysis	Using electronic balances and weighing paper, and effectively using a filtration apparatus that includes a Buchner funnel, vacuum, and filter paper.	Using the electronic balances and recording all digits, where the last digit is 'questionable' due to fluctuations in air currents.	Using stoichiometrically balanced equations that implement molar ratios and dimensional analysis. Measuring masses accurately and propagating error with significant figures
Week 5: Spectroscopy	Using springs to create wave-nature interference and spectroscopes to measure emission spectra of gas discharge tubes, mastering volumetric glassware to create standards, and using these standards to create a calibration curves.	Using a spectroscope, Energy of Light Hardware and Software, Atomic Spectrum Software, the 6-color Colorimeter to determine best absorption and excitation wavelengths, and the 10-color Colorimeter to measure fluorescence vs. concentrations of knowns to solve for unknowns.	Using a Cartesian coordinate system to describe the theory of sinusoidal waves and their frequency against observed spectrum from a spectroscope, $c=3.0X10^{8}m/s$, $E=h\upsilon$, $\lambda T=hc/4.965kB$, and recognizing what function best fits the phenomenon of Fluorescence vs. Concentration at λ_{max}.
Week 6: Colorimetry, Fluorimetry, Turbidimetry, and Nephalometry	Mastering volumetric glassware to create standards and using these standards to create a calibration curves, Spot Plate/Test Matrix analysis, and choosing potential colorimetric and turbidimetric phenomena for creating standard calibration curves.	PT's, LED's, Colorimetry Software and 10-Color Colorimeter to measure colorimetric, fluorometric, turbidimetric, and naphalometric measurements vs. concentrations of known aqueous solutions.	$A=\varepsilon l[C]$, Turbidity vs. λ_{max}, $Ksp=[X^{-}][Y^{+}]$, and solving for Balanced Molecular formulas from concentration of ions in solution.
Week 7: Qualitative & Quantitative Analysis of H_2O	Mastering volumetric glassware to create standards and using these standards to create a calibration curves, Spot Plate/Test Matrix analysis, and choosing potential colorimetric and turbidimetric phenomena for creating standard calibration curves.	PT's, LED's, Colorimetry Software and 10-Color Colorimeter to measure colorimetric and turbidimetric/naphalometric phenomenon vs. concentrations of knowns to solve for unknowns. Using a conductivity probe to collect *Siemens* and calibrate in order to determine quantity of dissolved solids within a given	A=,l [C], Turbidity vs. [C], Ksp = [X-][Y+], and solving for Balanced Molecular formulas from concentration of ions in solution. Double checking this result w/ conductivity vs. [S +/-].

Week and Class Topic *(continued)*	Research Design and Techniques	Measurement Technology Skills & Tools	Math Skills & Tools
Week 8 An Introduction to Thermodynamics	Isolating thermodynamic systems for thermometric determinations.	Thermometry and computer software data acquisition	Thermocouple output to temperature conversions, Specific Heat calculations, Heat of Fusions Calculations, Heat of Combustion Calculations, and Heat of Solutions calculations.
Week 9	-SPRING BREAK-	-SPRING BREAK-	-SPRING BREAK-
Week 10 Molecular Geometry and Bonding of Organic Compounds	Mastering ball & stick models, qualitatively testing for solubility of chemicals, mastering volumetric glassware to create standards, and using these standards to create a calibration curves	LED's, PT's,linear polarizing filter, and manual and mechanical polarimeter.	Using Lewis Dot guidelines to determine the number of bonds & unshared pair of electrons, geometric shapes, solving for an unknown by choosing the best wavelength and concentration for optical rotation vs. concentration analysis ($\alpha=\epsilon l[C]$), and looking at kinetic polarimetric data.
Week 11 FOOD CHEMISTRY AND COUNTING CALORIES	Mastering thermometric determinations of food calories and standardization of technique.	Thermometry, computer software data acquisition.	Specific Heat calculations, Heat of Fusions Calculations, Heat of Combustion Calculations and handling of multiple sets of data to compare standardized experimental design.
Week 12 The Behavior of Ideal Gases	Isolating gaseous systems while measuring pressure, volume, molecular, and temperature. (P vs. V), (T vs. V), (P vs. T), and (n vs. V).	Absolute and differential pressure sensors, instrumental amplifier, and temperature IC probe	P vs. 1/V, T vs. V, P vs. T, n vs. V for ideal gases and van der Waals constants for non-ideal situations. Partial Pressure calculations for products after gas evolving reactions and Bournoulli's law of pressure.
Week 13 Electrochemistry	Developing a Half-reaction table from observed Half-Cell potentials with help of DVM and interface.	DVM's & interfaces for voltage and amperage readings, various metal electrodes, and potentiometric titration electrodes, instrumental amplifier, inverters, voltage offsets,	Deriving the Nernst Equation from basic measurement of voltage in various electrolytic solutions and electrodes. Using this knowledge to count electrons during the electrolysis of a metal ion. $E = Eo-0.05916/2 \log [Ox]/[Red]$.
Week 14 Acid & Base Solutions	Stabilizing pH electrodes in well mixed aqueous solutions and discuss temperature effects. Techniques in using colored indicators and discussing these color changes with respect to colorimetric data. Volumetric titration and allowing electrode to equilibrate.	DVM's & interfaces to read millivolts from pH probes, instrumental amplifier, inverters, voltage offsets, and software vs. hardware calibration of pH probes.	The Nernst Equation, $-\log[H+] =$ pH, stoichiometrically balanced equations for mono/di/polyprotic acids, K_w, K_a & K_b constants, and the Henderson Hasselbach equation.
Week 15 Kinetics	Discuss application of spectroscopy in monitoring purple Crystal Violet Solution with the analytical wavelength. Discuss importance of concentration effects of reactants and the importance of measurement of analytes.	PT's, LED's, Colorimetry Software and 10-Color Colorimeter to measure the colorimetric diminution of crystal violet with the addition of the hydroxide ion. Use of software to plot the zeroth, first, and second rate law functions versus time.	Derivation of the zeroth, first, and second rate laws via integration of rate law equation. Substitution of absorbance as a measure of change in crystal violet calculation. The calculation of order of hydroxide by taking ratios of the pseudo-rate constants as a function of concentration effects.

APPENDIX E

LABORATORY EXPERIMENTS, RESEARCH EXTENSION

LAB EXPERIMENTS, AND STUDENT REPORTS

Organization of this section:

Flames Heat and Calories: Thermochemistry
And
Research extension #5
Heat of solutions

FOUR STUDENTS

March 9, 2004
Chem131 Section 15

Purpose: This lab is an introduction to Thermochemistry. We will perform several experiments regarding specific heat, calories, heat loss and heat gain. We will also observe the energy changes involved in chemical and physical changes. Because of the use of a burner, caution must be taken in regard to the flame and the surrounding areas.

Materials:
Bunsen burner, Metal cup, digital temperature probe, thermocouple, 2 temperature sensors.
Ring stand and rod, clay triangle, Styrofoam cups, candle, peanuts and index cards.

Procedure:

1. We lit and adjusted the flame on the Bunsen burner by turning the bottom, allowing more or less oxygen into the mixture. We then put a index card in the flame to see the heat distribution of a well mixed flame, oxygen rich and fuel rich flame (see attached card in data section).
   Obs: An oxygen rich flame burns bright blue and jumps around erratically, while a fuel rich flame burns bright yellow. The desired flame burns with an inner cone that appears violet, surrounded by a blue flame. The scorch test on the index car did not burn the inside of this cone, but only on the outer blue part, indicating this was the hotter part of the flame.

2. Using a thermocouple connected to Micro-lab, we then inserted the probe into several different areas of the flame, measuring voltage readout, and converting that to degrees Celsius by a given table.
   Obs: As predicted, the inner part of the cone was found to be much cooler than the other parts of the flame. See data section for exact temperatures and a drawing of the flame measurement points.

3. Taking two Styrofoam cups we weighed each empty, then filled one with hot water and the other with cold. Placing a temperature probe in each, we wait until both are fairly stable and then add the hot water into the cold water. Placing both probes into the one cup we stir until and temperature equilibrium is reached.
   Obs: The equilibrium reached can be seen on the attached graph, along with the heat gain/loss calculations in the data section.

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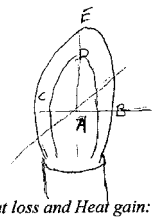
4. In order to find the amount of energy released from a candle and a peanut, we set up the rings stand, clay triangle and metal cup. The candle was placed on an index card, and directly above that (aprox. 1 inch) the ring stand was set up with the metal cup, containing aprox, 100 mls of room temperature water. We measured the mass of the cup before and after water, as we did the candle and card before and after burning. A temperature probe connected to Micro-lab was used, again being calibrated by using hot, cold and room temperature water to record the values. The results and energy calculations can be found in the data and calculations section.
   Obs: Both objects heated the water, but the candle appeared to release more heat over time, while the peanut heated the water faster in a short amount of time.

5. Obtaining a Styrofoam cup weighed, then added and reweighed aprox 100 mls of warm water. We monitored this with a temperature probe attached to Micro-lab. We then got a 100ml beaker 1/3 full of ice, and spread that out onto a paper towel, blotting out all the water. We added the ice to the cup of warm water, and stirred until all the ice was melted, all while Micro-lab recorded the change in temperature. We then waited until the temperature stabilized and recorded the data. The results can be found in the data and calculations section.

Data and Calculations:

Nature of a flame:

A:



		Temp
A	16.4	400
B	20.56	600
C	35.23	550
D	42.39	1020
E	37.69	910

Heat loss and Heat gain:

Mass of cold water: 93.02g Temp: 14.48 C
Mass of hot water: 88.28g Temp: 15.1 C
Equilibrium Temp: 28.52 C

Heat Gain
1 cal / g – C x 93.02g x 14.48 C = 1347 cal

Heat Loss

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1 cal x 88.28g x 15.1 C = 1333 cal
g - C

Heat and chemical change:

Candle Combustion

Mass of water: 91.88g
Mass of candle: 9.50g After burning: 9.16g
Temperature Change: 15.5 C

Nice job w/ calculations!

(1.0 cal) x 91.88g x 15.5c = 1424.14cal/ .34 = 4188.64 cal/gram
g x c

Combustion of a peanut

Mass of water: 80.23g
Mass of Peanut: 2.47g After burning: 2.16g
Temperature Change: 6.03 C

(1.0 cal) x 80.23g x 6.03c = 483.78cal/ .31 = 1560.58 cal/gram
g x c
The heat released per gram is greater for a candle than it is a peanut.

Heat and Physical change:

Mass of water: 89.41g Temperature before ice: 36.08c
After ice: 101.56g After ice: 23.37c
Mass of ice: 12.15g

Heat loss of water
(1.0 Cal) x 89.41g x 12.71c = 1136.4 cal lost by water
g x c

Heat gain of ice
(1.0 Cal) x 12.15g x 23.37c = 283.93 cal gained by ice
g x c

pretty good!

Heat of fusion
1136.4 – 283.93 = 852.47/12.15 = 70.16cal/gram heat of fusion

Conclusion: In our first experiment, we were able to quantitatively prove what we had observed about the nature of the flame. The temperatures proved what we could observe on the scorch card and in the way the flame burned. The second part allowed us to gain practice doing heat loss, heat gain calculations and observe how different temperatures of water form an equilibrium. It also allowed us to observe how adding a different solution (in the case, plain water) might cause the temperature

Page 3 of an A grade-level Research Extension Group Report..

The third part of the lab allowed us to observe, in a tangible way different, energy of different sources. We were able to see how much energy the peanut released compared to the candle. In the final part of the lab, we were able to calculate the energy needed to physically change a solutions state, in this case ice. Our result was 70.16 cal/g, and the expected result for this was 79.7. Some sources of error could be not letting the temperature fully stabilize. Also not every piece of ice made it into the cup, so that could affect the results. Another source of error could be not all the water was drained from the ice. Regardless, more tests and averaging of the results would help get our answer closer and show us how reproducible our data is.

Overall a good job w/ this part of the Lab!

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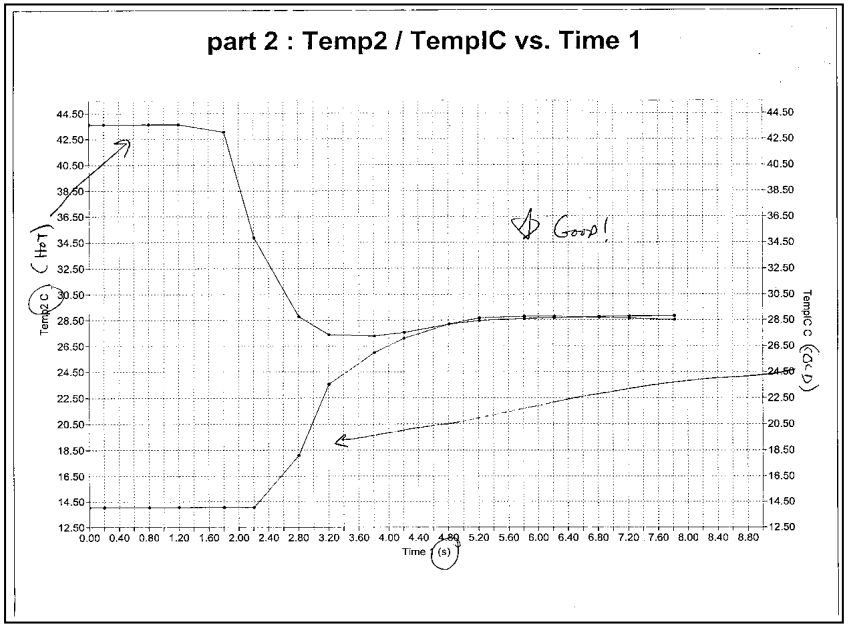

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Research Extension: Hess's Law and Heat of Solutions

Objective: In this research extension, we will be examining the heat of solution for two unknown solids. By utilizing calorimetry, we should be able to accurately determine the identity of our unknown from a given list of possible solutions. Through a utilization of percent error, group input, and these given heats of solution, we will be able to have a relatively good idea what our unknowns are.

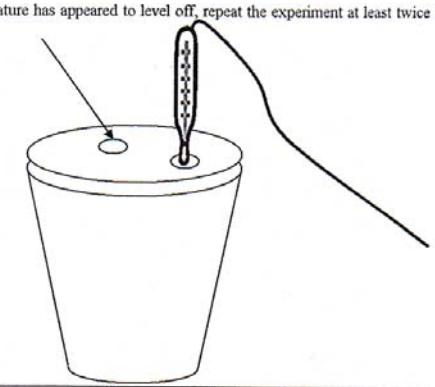
Materials: Unknown A and B, Styrofoam cups, Styrofoam lids, Deionized Water, IC Temp Probe

MSDS: Bases are corrosive and should be handled with care. It is important not to ingest, inhale, or contact with the skin, eyes, or clothes. When not in use it should be placed in a closed container in a cool, dry place. These substances can Hygroscopic (absorbs moisture from the air). A Good!

Procedures:

1. Create a calibration curve for our IC temperature probe using hot, cold, and room temperature water.
2. Mass the Styrofoam cup and then mass the cup with 50mL of water.
3. Mass a sample of about three grams of the unknown and record the actual mass of the sample.
4. Place the lid on the Styrofoam cup with water and place the IC temperature probe into the water.
5. Start the experiment in MicroLab so that a good baseline temperature for the water may be established.
6. Place one of the unknowns in the deionized water through the lid while monitoring the temperature.
7. When the temperature has appeared to level off, repeat the experiment at least twice for each unknown.

Instrumentation Details:



Data:

Unknown A- Trial 1				Unknown A- Trial 2			
Mass (g)		Temp (°C)		Mass (g)		Temp (°C)	
Cup	2.03	Initial	23.50	Cup	1.84	Initial	23.55
Cup & Water	51.51	Final	23.85	Cup & Water	51.38	Final	23.86
Unknown A	3.03			Unknown A	3.01		
Unknown B- Trial 1				**Unknown B- Trial 2**			
Mass (g)		Temp (°C)		Mass (g)		Temp (°C)	
Cup	2.03	Initial	22.75	Cup	1.84	Initial	22.50
Cup & Water	51.76	Final	36.00	Cup & Water	51.79	Final	34.50
Unknown A	3.07			Unknown A	3.02		

Page 6 of an A grade-level Research Extension Group Report.

Calculations:

$$LiOH \bullet H_2O = \frac{-6.69\,kJ}{mol} \times \frac{1\,cal}{0.004184\,kJ} \times \frac{1\,mol}{40.96g} = -\frac{39.04\,cal}{g}$$

$$NaOH = \frac{-44.51\,kJ}{mol} \times \frac{1\,cal}{0.004184\,kJ} \times \frac{1\,mol}{40.00\,g} = -\frac{266.0\,cal}{g}$$

Unknown A

$$Trial\ 1\ Heat\ Gain = \left(1.000\,{}^{cal}/_{g°C}\right)(49.48g)(0.35°C) = \frac{17.32\,cal}{3.03g} = 5.72\,{}^{cal}/_{g}$$

$$Trial\ 2\ Heat\ Gain = \left(1.000\,{}^{cal}/_{g°C}\right)(49.54g)(0.31°C) = \frac{15.36\,cal}{3.01g} = 5.10\,{}^{cal}/_{g}$$

$$Average = \frac{5.72 + 5.10}{2} = 5.41\,{}^{cal}/_{g}$$

Unknown B

$$Trial\ 1\ Heat\ Gain = \left(1.000\,{}^{cal}/_{g°C}\right)(49.73g)(13.25°C) = \frac{658.9\,cal}{3.07g} = 214.6\,{}^{cal}/_{g}$$

$$Trial\ 2\ Heat\ Gain = \left(1.000\,{}^{cal}/_{g°C}\right)(49.95g)(12.00°C) = \frac{599.4\,cal}{3.02g} = 198.5\,{}^{cal}/_{g}$$

$$Average = \frac{214.6 + 198.5}{2} = 206.6\,{}^{cal}/_{g}$$

Note: Above values are positive but that is representing the heat gained by the environment so if we were to look at these in comparison to our given values, the given values are negative because the represent heat given off by the reaction.

Accuracy:

$$\frac{-5.41}{-39.04} = 13.9\%$$

$$\frac{-206.6}{-266.0} = 77.7\%$$

Expected Change in Temperature:

$$266.0\,{}^{cal}/_{g}(3.00g) = \left(1.000\,{}^{cal}/_{g°C}\right)(50.00g)(\Delta x) \quad \Delta x = 15.96°C$$

$$39.04\,{}^{cal}/_{g}(3.00g) = \left(1.000\,{}^{cal}/_{g°C}\right)(50.00g)(\Delta x) \quad \Delta x = 2.34°C$$

A nice job w/ Calculations!

Conclusion: We found that our unknowns were LiOH•H2O for unknown A and NaOH for unknown B. We decided upon these by using our error in the previous experiment to come closer to the actual number. We used this, because of the heat loss of the system. Possible errors in our data could have been caused by stopping the experiment too early. In addition, heat was lost due to the system not being totally isolated. Through this experiment, we learned that the heat of solution for an unknown could be determined through experimentation. In our case, we had an exothermic reaction; it gave off heat, rather than an endothermic reaction.

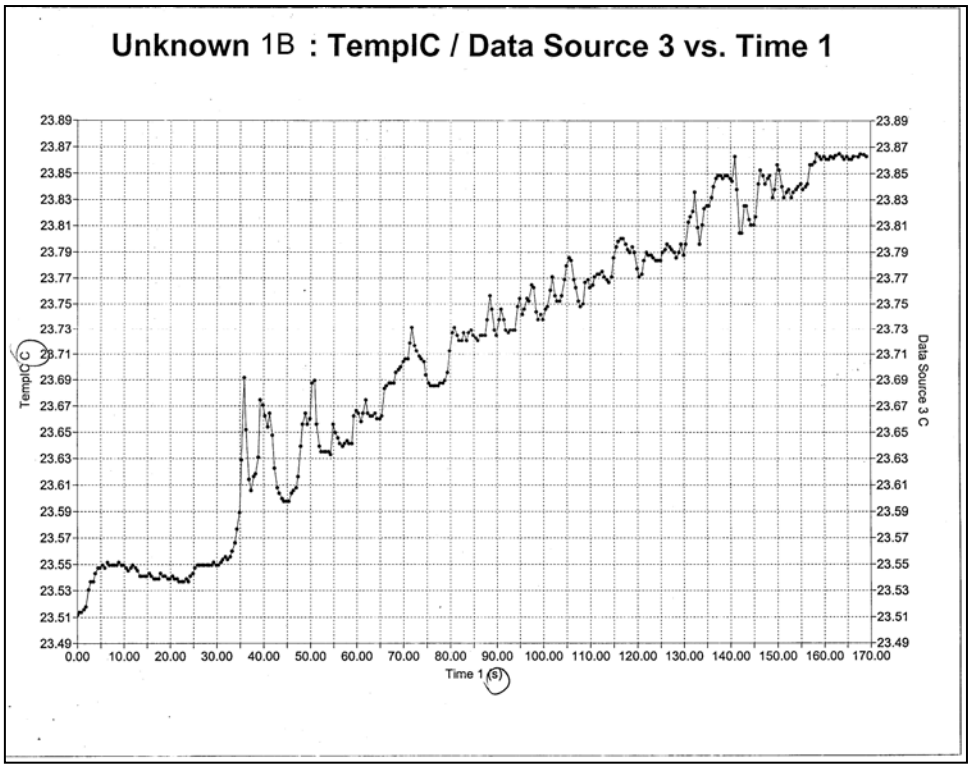
great job!

Very thorough & direct... A!

Keep up the excellent work, you scientist!

In 3rd BAR Reproducability!

Page 7 of an A grade-level Research Extension Group Report.



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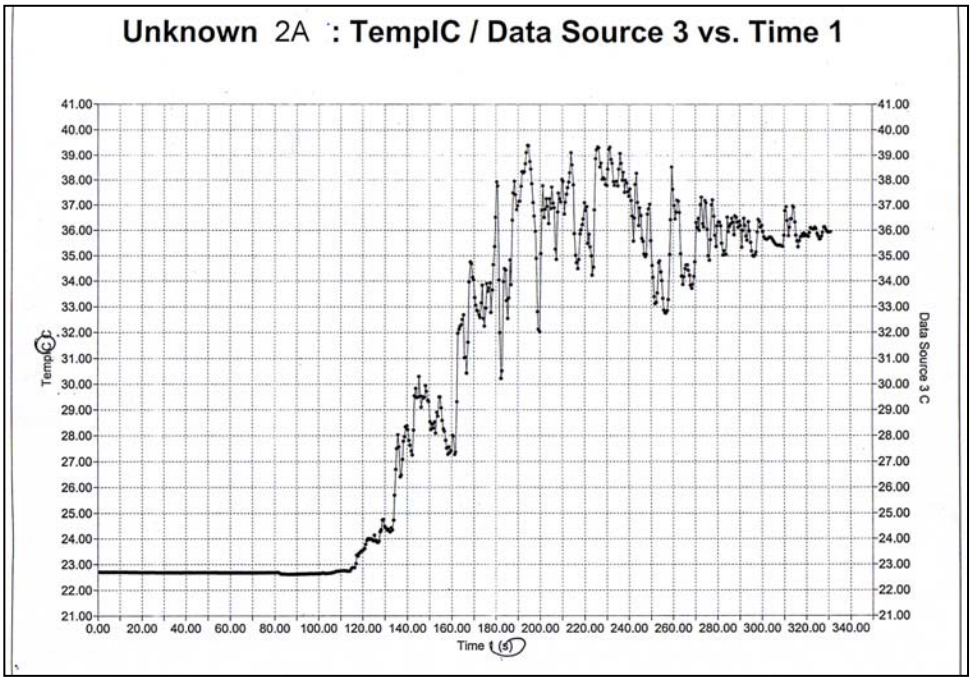

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ORAL SEMINAR Grading Sheet
CHEM 131

TITLE: Calorimetry & Heat of Solutions
DATE: 3/23/04

Group members: Four Students from Section 15

10 pts possible– Oral Report Presentation

The breakdown is as follows:

1 pt – A "Preparation Meeting" with the lab instructor prior to your presentation was held. The meeting time and place was scheduled upon the conclusion of the laboratory that is to be presented.

1.0 pts. awarded Meeting time and Place: 3/22/04 - my office

1 pts – A title sheet and outline of your oral report was placed on an overhead. (This helps you to show the logic of your discussion and helps the audience to know where you are going with this discussion.)

1.0 pts. awarded

3 pts– At least two chemical equations, calculations, chemical structures, and/or instrumentation circuit diagram was shown in front of the class on the overhead or chalkboard. ☆ Heat gain / Heat loss Calculations

3.0 pts. awarded

5 pts – All group members contributed equally in some aspect of technical information .

5.0 pts awarded

0 pts will be assigned to individuals who don't show or don't contribute to their group reports.

Names of people who did not attend:

Q: Heat loss : Heat Gain – expected 1:1 ratio?
– Yes – expected 1:1

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Research Extension: #5
Determination of the 'Heat of Solutions' and use of Hess's Law
Flames, Heat, and Calories:
An Introduction to Thermodynamics
CHEM 131N – Section # 13
Due Date: 3-30-04

Student Sample Report

Purpose:
In this lab, we learned how to use a Bunsen burner at optimal conditions and to be able to select the optimum height above the burner for quick heating. We learned about the concepts of calories and specific heat and how to perform heat-gain/loss calculations. We compared the energy changes involved in chemical and physical changes and measured specific heats of metal. We also designed an experiment to measure the caloric changes due to a heat gain or heat loss due to 'Heat of Solution' and determine the identity of the two unknown solids.

Material Safety Data:

- **NaOH - Health Hazards Acute & Chronic:**
  If inhaled – severe irritation to lungs and respiratory tract
  If touched – small skin burns with deep ulceration
  In eyes – severe burns and disintegration of conjunctival and corneal epithelium
  Signs & Symptoms of Overexposure:
  Sore throat, coughing, labored breathing – burns of skin, eyes, and mucous membranes.
  Medical Conditions Aggravated by Exposure:
  Lung condition, irritated or sensitive skin.

- **NaNO3 - Health Hazards Acute & Chronic:**
  If inhaled – irritation to lungs and respiratory tract
  If touched – skin irritation
  Signs & Symptoms of Overexposure:
  Coughing, vomiting, bloody diarrhea, headaches, convulsions, and mental impairment.

- **Propane - Signs & Symptoms of Overexposure:**
  If inhaled – dizziness and respiratory arrest
  If touched – frostbite
  In eyes – moderate irritation

You could've put reference to show the source of info

1

Page 1 of a B grade-level Research Extension Group Report.

Materials:
Bunsen Burner
Metal Cup
Thermometer
Thermocouple
2 IC Temperature Sensors
Ring Stand
Clay Triangle
Wire Screen
Styrofoam Cups
Candle
Index Cards
Peanuts
Ice
Unknown Salt A
Unknown Salt B

Procedure:
Part 1:
1. Connect Bunsen burner to gas valve, turn on gas, and light
2. Adjust air supply until flame is violet with a blue interior cone
OBS: Flame is violet has a distinct blue interior.
3. Place scorch card in middle of flame until card starts to burn and blow out
4. Adjust air supply until flame is yellow and repeat step #3
5. Readjust flame back to violet with the blue cone
6. Start MicroLab
7. Place thermocouple into the different parts of the flame and record the temperature

Part 2:
1. Connect two temperature sensors to MicroLab
2. Setup MicroLab to take temperature from two sensors
3. Weigh dry Styrofoam cup
4. Put 30mL of water into cup
5. Add ice and reweigh
6. Put 30mL of hot water into another cup
7. Place one sensor into each cup and start data acquisition
8. When temperate readings are stable, pour hot water into the cold water cup and place both sensors into cold water cup
9. Stir water with sensors until stable and then stop data acquisition (Indication of Good calibration)
OBS: The two temperature sensors recorded the same temperature.
10. Remove temperature sensors and drain water off them
11. Weigh cup of mixed water samples
12. Print temperature change graph

2

Page 2 of a B grade-level Research Extension Group Report.

Part 3A:
1. Setup ring stand with clay triangle on an iron ring to hold metal cup
2. Clean as much carbon off cup as possible and weigh cup
3. Place 100mL of cold water into cup and reweigh
4. Weigh candle and mesh screen together
5. Place candle and screen under cup and adjust height of cup to 1 inch above candle
6. Place temperature sensor into water
7. Start data acquisition and light candle
8. Stir water gently until water has risen 15 degrees Celsius
9. Blow candle out and continue data acquisition until temperature has reached a maximum
10. Allow candle wax to solidify and weigh candle and mesh screen to determine the amount of candle that was burned

Part 3B:
1. Repeat experimental procedures and calculations in Part 3A, but replace candle with a peanut

Part 4:
1. Weight Styrofoam cup of water and add 100mL of warm water and weigh cup again to determine mass of water
2. Start MicroLab
3. Place temperature sensor in water
4. Obtain 1/3 of a 50mL beaker of ice and remove any water from ice by spreading it on a paper towel and blotting it with another towel
5. Add ice to warm water
6. Monitor the temperature of the ice water sample and stir it with the sensor until the ice is melted and the temperature curve looks fairly flat
7. Stop the program
8. Weigh the cup again to determine the weight of the added ice

Research Extension:
1. Add 50mL of water into a Styrofoam cup
2. Start MicroLab program
3. Add 3 grams of Unknown A to water and place thermal lid on cup to prevent unwanted heat loss or gain.
4. Stir with temperature sensor until temperature is stable then stop data acquisition
OBS – Temperature of water decreases.
5. Repeat experiment
6. Repeat experiment two more times replacing Unknown A with Unknown B.
OBS – Temperature of water increases.
7. Use the list of 'Heat of Solutions' given to determine the identity of the Unknowns.

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Data and Analysis:

- Please see Torch Cards 1 and 2 attached on back of report.
  Torch Card 1 is the card that was placed into the violet flame with a blue interior cone.
  Torch Card 2 is the card that was placed into the yellow flame.
- For results and data and analysis from Part 2, please see pg. 5.
  For the graph, see pg. 11 labeled "Water Mixed".
- For results and data and analysis from Part 3, please see pg. 6.
- For results and data and analysis from Part 4, please see pg. 7.
- For results and data and analysis from the research extension, please see pg. 8-10.
  For the graphs of Unknown A, see pg. 12 and 13 labeled "Unknown A".
  For the graphs of Unknown B, see pg. 14 and 15 labeled "Unknown B".

Conclusion:

In this lab, we learned how to optimally set the Bunsen burner for quick heating. The hottest part of the flame is the edge of the blue cone. It left a burnt mark on the card by burning around it and not burning the middle of it. Heat loss/gain ratio is 1.58 and it means that more there is more heat gained than lost when mixing hot and cold water. The accepted value for heat of fusion is 79.7 cal/g and our value was 86.2 cal/g. That is an 8.15% error which is acceptable. For the research extension, Unknown A was $NaNO_3$ and Unknown B was NaOH. We knew Unknown A was an endothermic reaction, lost heat, and there was only one possibility for its actual identity. Knowing that, we calculated the percent error and took it into account when finding the identity of Unknown B, which was an exothermic reaction, meaning it gained heat. Possible errors would be heat leaking out of the system and calibration error. A calibration is used to tell the computer the actual values of what we want it to record. If this is done incorrectly, the computer's results will also be incorrect. One huge error that was almost made by us was confusing whether a reaction is exothermic or endothermic; this would have made our results absolutely wrong. Real world applications for this would be making heat and ice packs that do not heat up or cool down until they are crushed. The packs must be crushed to heat up or cool down up, because it adds the salts to the solution. How hot or cold the packs get and whether they get hot or cold is dependent on the type of salt that is used.

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Part II. Heat Loss and Heat Gain

Mass of cup and cold water	43.5	g
Mass of cup	2.07	g
Mass of cold water	41.43	g
Mass of cup and mixed hot and cold water	71.3	g
Mass of cup and cold water	43.5	g
Mass of hot water	27.8	g

	Cold water sample	Hot water sample
Temperature before mixing	6.0°C °C	39° °C
Temperature after mixing	23° °C	
Change in temperature	17 °C	-16 °C

Heat gain calculation:

$\frac{1.000\ cal}{g \cdot °C} \cdot (41.43g) \cdot (17°C) = 704.3\ cal$

Heat loss calculation:

$\frac{1.000\ cal}{g \cdot °C} \cdot (27.8g) \cdot (-16°C) = 444.8\ cal$

Ratio of (Heat gain) / (Heat loss):

$\frac{704.3\ cal}{444.8\ cal} = 1.58$

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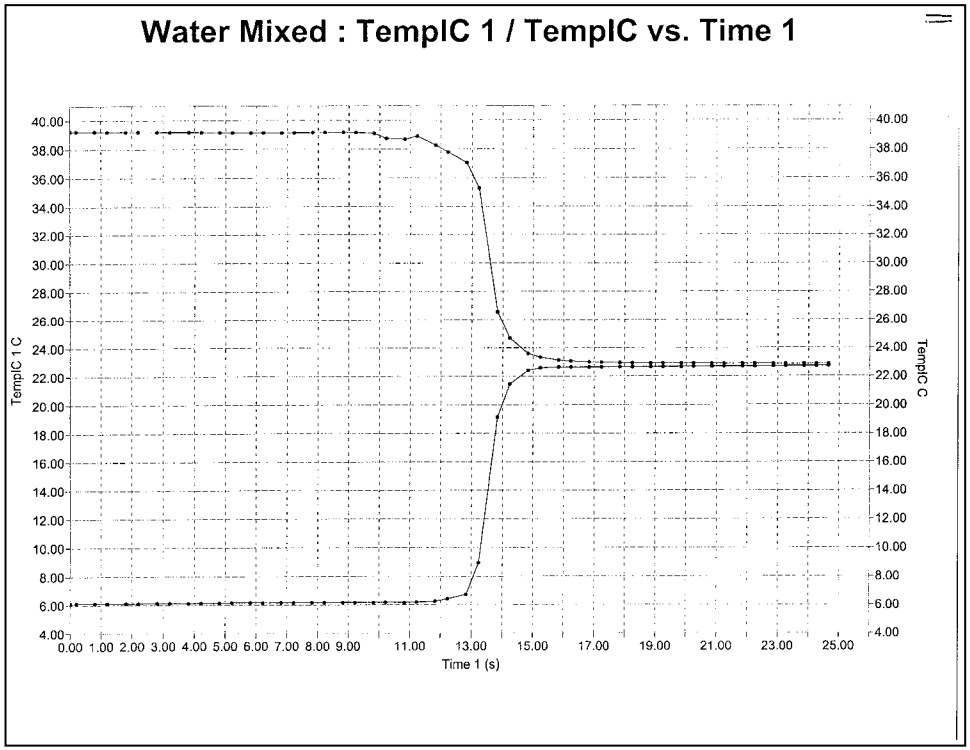

Graph #1 of a B grade-level Research Extension Group Report.

Part III. Heat Associated with Chemical Change

	Candle	Peanut
Mass of cup and water	106.506 ~~103.490~~ g	108.475 g
Mass of empty cup	10.490 g	10.490 g
Mass of water	96.016 g	97.985 g
Water temperature before heating	____ °C	23.9 °C
Water temperature after heating	____ °C	29.5 °C
Temperature change	____ °C	5.6 °C
Mass of candle and paper towel or peanut and screen before burning	____ g	33.568 g
Mass of candle and paper towel or peanut residue and screen after burning	____ g	33.330 g
Mass of candle or peanut burned	____ g	0.238 g

Calculate calories of heat from the burning candle absorbed by the water.

?

-0.8

Calculate the calories of heat produced per gram of candle wax burned.

Calculate calories of heat from the burning peanut absorbed by the water.

Heat gain = $\frac{1.000\ cal}{g \cdot °C} \cdot 97.985\ g \cdot 5.6\ °C = 548.7\ cal$

Calculate the calories of heat produced per gram of peanut burned.

$\frac{548.7\ cal}{0.238\ g} = 2306\ cal/g$

6

Page 6 of a B grade-level Research Extension Group Report.

Part IV. Heat Associated with a Physical Change

Mass of cup and water	101.3 g
Mass of cup	2.15 g
Mass of water	99.15 g
Mass of cup and water and ice	117.4 g
Mass of cup and water	101.3 g
Mass of ice	16.1 g
Temperature of water before adding ice	37.7 °C
Temperature after ice melted	23.7 °C
Temperature change of water sample	14.0 °C
Temperature after ice melted	23.7 °C
Initial temperature of ice	0.0 °C
Temperature change of melted ice sample	23.7 °C

Heat loss calculation:

$\frac{1.00\ cal}{g \cdot °C} \cdot 99.15\ g \cdot 14°C = 1388.1\ cal$

Heat gain and heat of fusion calculations:

Heat gained by melted ice: $\frac{1.00\ cal}{g \cdot °C} \cdot 16.1\ g \cdot 23.7°C = 381.57\ cal$

Heat required to melt ice: $1388.1 - 381.57 = 1006.53\ cal$

From your data, the heat required to melt one gram of ice is 62.5 calories.

(show % error calc!)

-0.1

7

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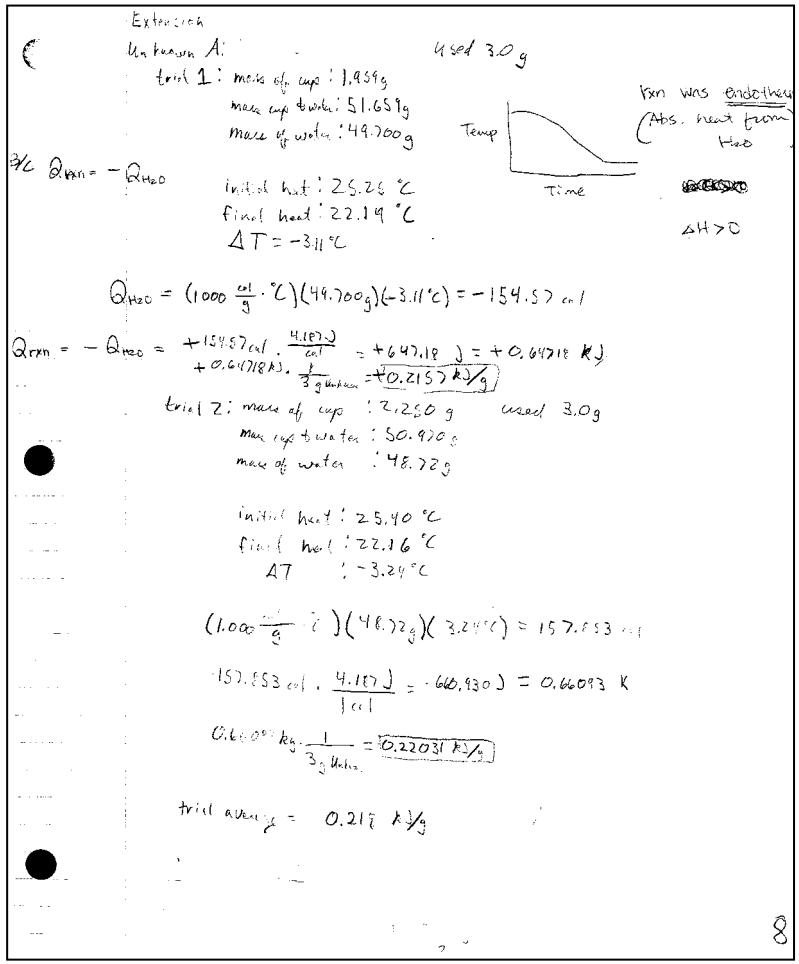

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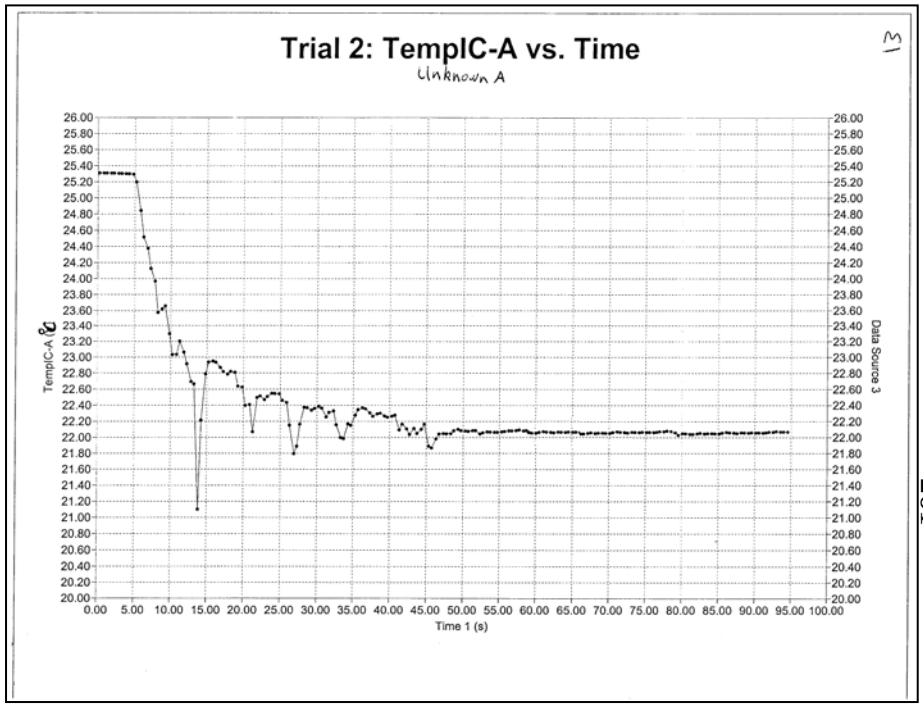
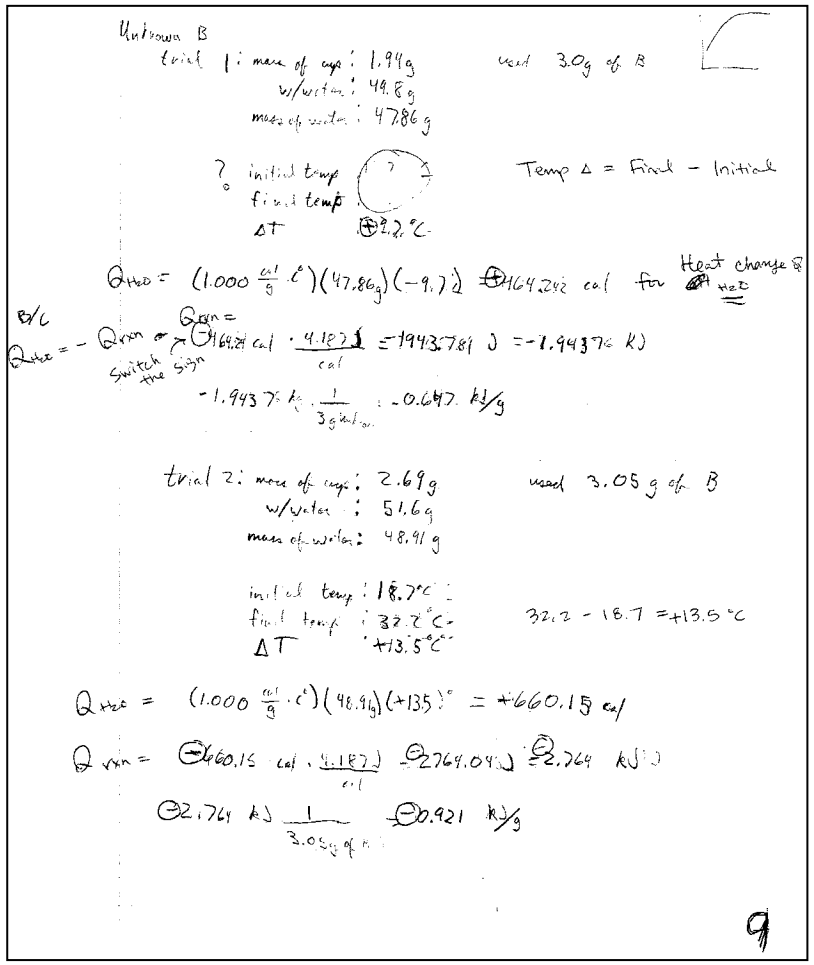


Graph #2 of a B grade-level Research Extension Group Report



Unknown B

trial 1: mass of cup: 1.99 g — used 3.0 g of B

w/water: 49.8 g

mass of water: 47.86 g

initial temp

final temp

ΔT +2.2 °C

Temp Δ = Final − Initial

$Q_{H_2O} = (1.000\ \frac{cal}{g \cdot °C})(47.86\ g)(-9.7\ °C) = -464.242\ cal$ for Heat change of H_2O

B/C

$Q_{rxn} = -Q_{H_2O}$ (switch the sign) $= +464.24\ cal \cdot \frac{4.187\ J}{cal} = 1943.781\ J = 1.94378\ kJ$

$1.94378\ kJ \cdot \frac{1}{3\ g\ B} = 0.647\ kJ/g$

trial 2: mass of cup: 2.69 g — used 3.05 g of B

w/water: 51.6 g

mass of water: 48.91 g

initial temp: 18.7 °C

final temp: 32.2 °C

ΔT +13.5 °C

32.2 − 18.7 = +13.5 °C

$Q_{H_2O} = (1.000\ \frac{cal}{g \cdot °C})(48.91\ g)(+13.5\ °C) = +660.15\ cal$

$Q_{rxn} = -660.15\ cal \cdot \frac{4.187\ J}{cal} = -2764.04\ J = -2.764\ kJ$

$2.764\ kJ \cdot \frac{1}{3.05\ g\ B} = 0.921\ kJ/g$

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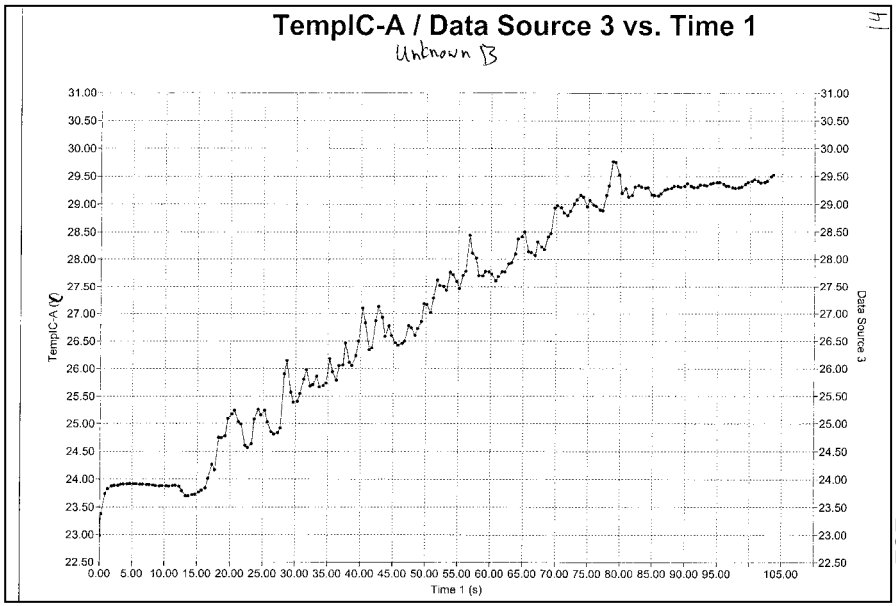
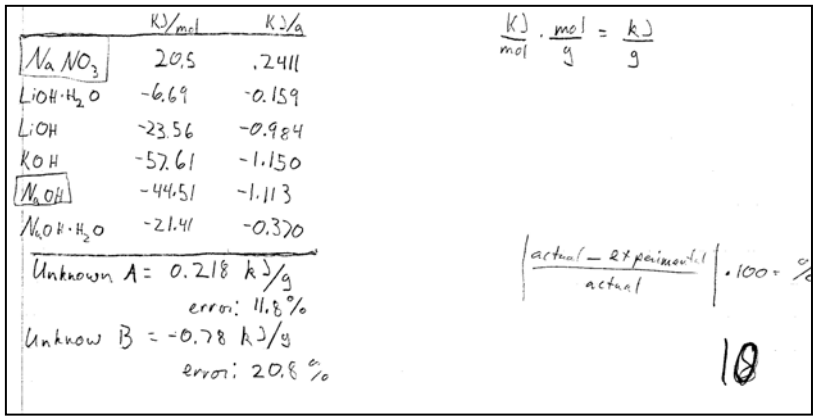


Graph #3 of a B grade-level Research Extension Group Report



	kJ/mol	kJ/g
$NaNO_3$	20.5	.2411
$LiOH \cdot H_2O$	-6.69	-0.159
$LiOH$	-23.56	-0.984
KOH	-57.61	-1.150
$NaOH$	-44.51	-1.113
$NaOH \cdot H_2O$	-21.41	-0.370

$\frac{kJ}{mol} \cdot \frac{mol}{g} = \frac{kJ}{g}$

Unknown A = 0.218 kJ/g
error: 11.8 %
Unknow B = -0.78 kJ/g
error: 20.8 %

$\left|\frac{actual - experimental}{actual}\right| \cdot 100 = \%$

10

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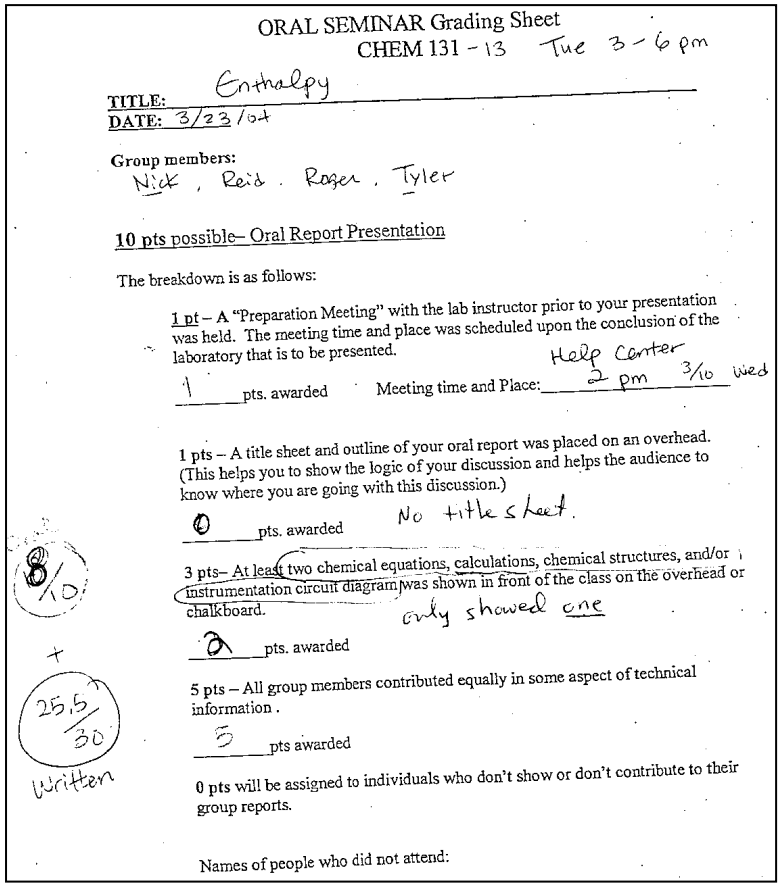


ORAL SEMINAR Grading Sheet
CHEM 131 – 13 Tue 3 – 6 pm

TITLE: Enthalpy
DATE: 3/23/04

Group members:
Nick, Reid, Roger, Tyler

10 pts possible– Oral Report Presentation

The breakdown is as follows:

1 pt – A "Preparation Meeting" with the lab instructor prior to your presentation was held. The meeting time and place was scheduled upon the conclusion of the laboratory that is to be presented.

1 pts. awarded Meeting time and Place: Help Center 2 pm 3/10 Wed

1 pts – A title sheet and outline of your oral report was placed on an overhead. (This helps you to show the logic of your discussion and helps the audience to know where you are going with this discussion.)

0 pts. awarded No title sheet.

8/10

3 pts– At least two chemical equations, calculations, chemical structures, and/or instrumentation circuit diagram was shown in front of the class on the overhead or chalkboard.

2 pts. awarded only showed one

+

25.5/30
Written

5 pts – All group members contributed equally in some aspect of technical information .

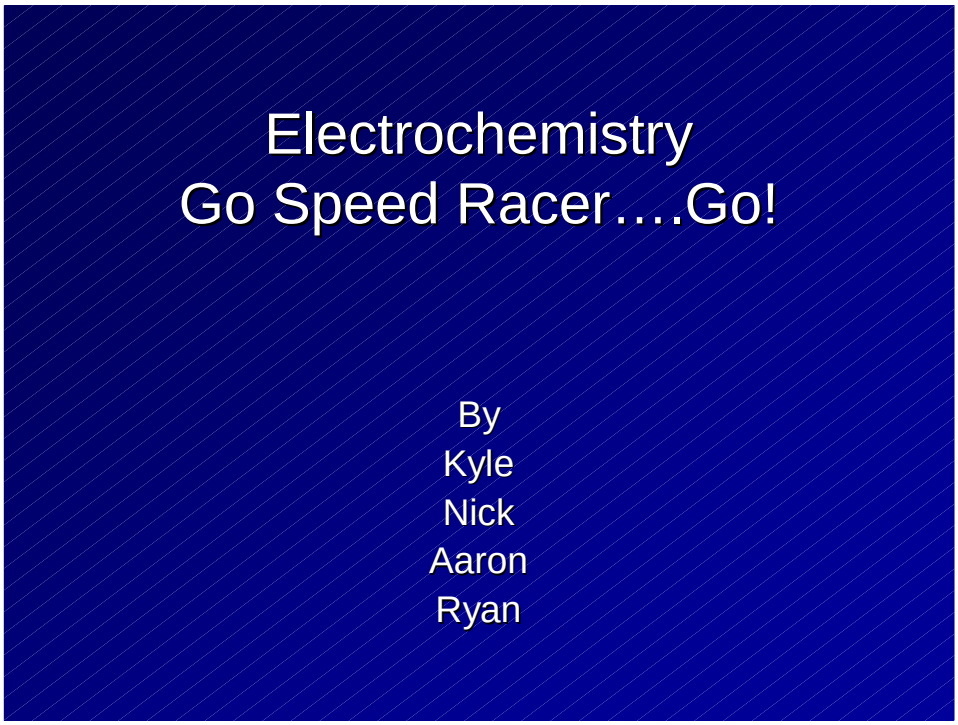
5 pts awarded

0 pts will be assigned to individuals who don't show or don't contribute to their group reports.

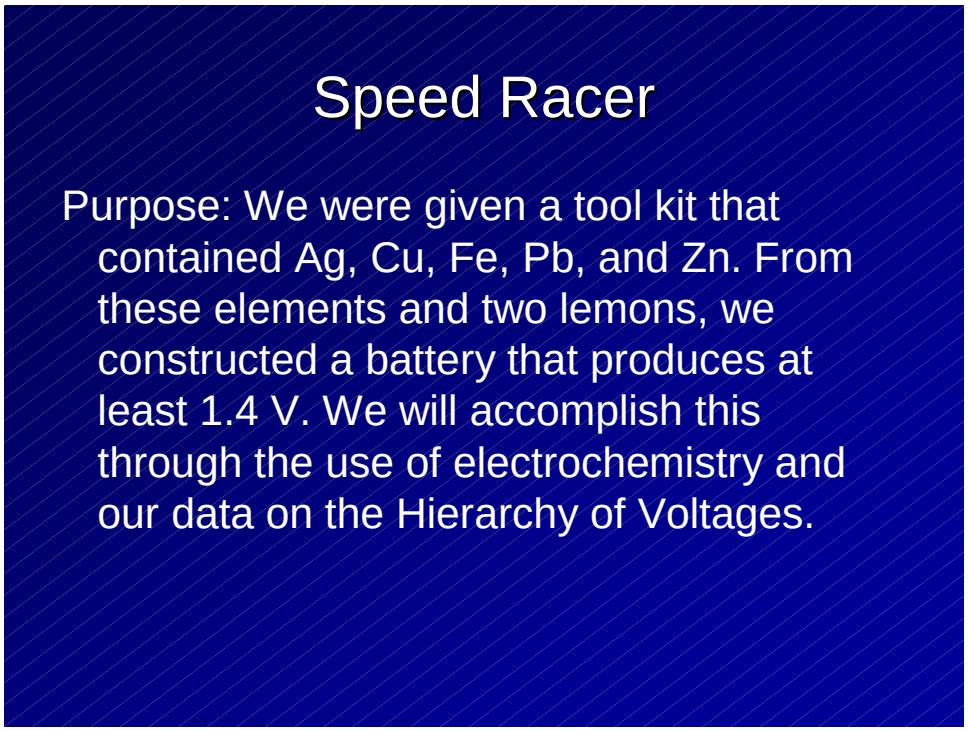
Names of people who did not attend:

The oral report assessment grading sheet for this of a B grade-level report.

Sample Oral Report – Power Point Slides



Oral Report Student Sample – Slide 1



Oral Report Student Sample – Slide 2

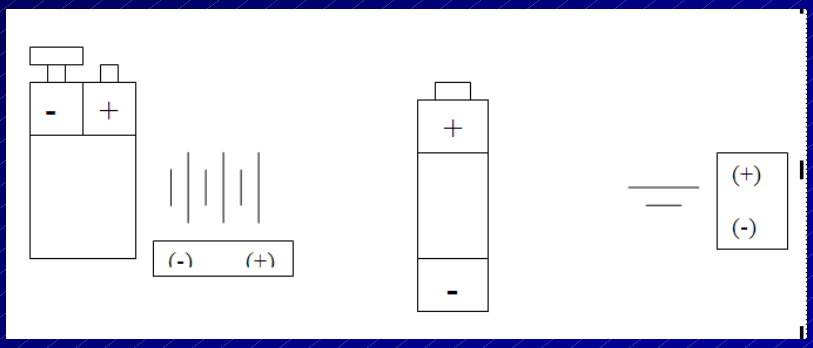
Materials & Safety

- Materials: Ag, Cu, Fe, Pb, Zn, DMV, alligator clips, lemons.
- Safety: Lemons are acidic so caution needs to be exercised to keep lemon juice out of eyes.

Oral Report Student Sample – Slide 3

Procedure

Part A: Measuring Voltage



Oral Report Student Sample – Slide 4

I. Tim has solutions of $Cu(NO_3)_{2(aq)}$ and $AgNO_{3(aq)}$

a. Initial observations of each

$Cu(NO_3)_{2(aq)}$ OBS: Blue transparent

$AgNO_{3(aq)}$ OBS: Clear

b. Tim places copper wire Cu^0 in the $AgNO_{3(aq)}$ and Ag^0 in the $Cu(NO_3)_{2(aq)}$

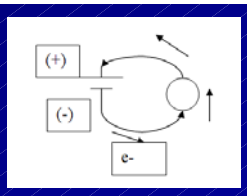
Final observations

Cu^0 in the $AgNO_{3(aq)}$ silver crystals formed on the copper wire

Ag^0 in the $Cu(NO_3)_{2(aq)}$ nothing appeared to have happened

II. Using the DMV

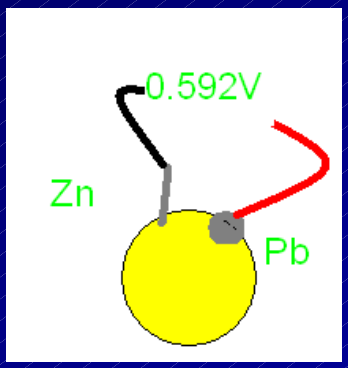
a. When the red lead is attached to the positive end of battery and black to negative, the voltage is positive. (1.612 V)
b. When the leads are switched the voltage is negative (-1.612 V)
c. This happens because the electrons are being pulled from the negative to the positive, and passing through the DMV.



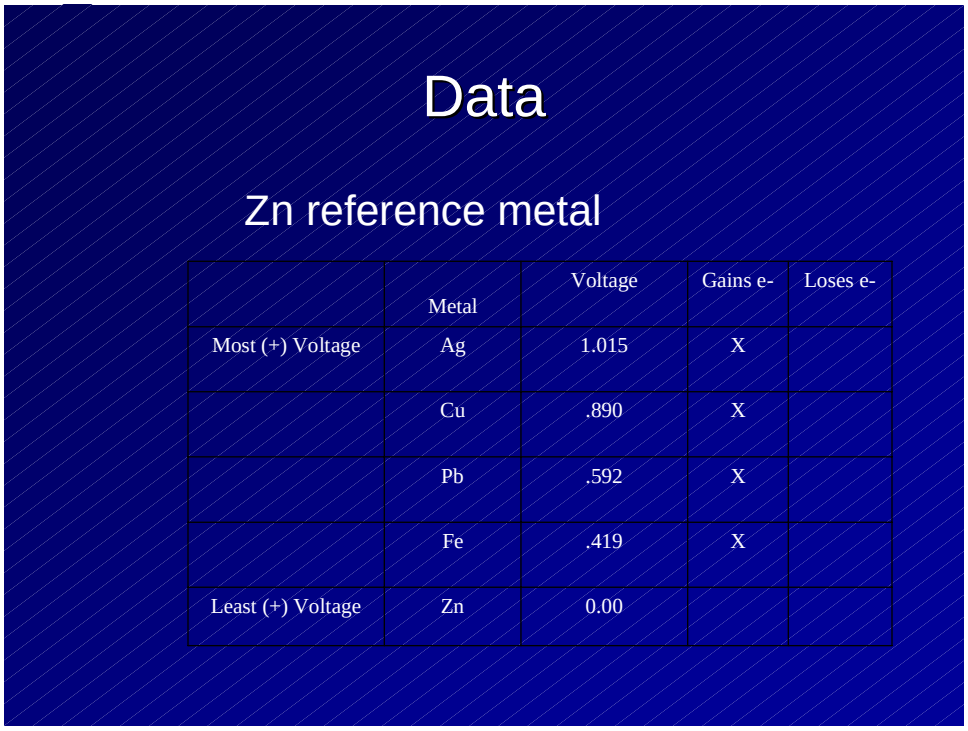
Oral Report Student Sample – Slide 5

Part B: Making a Hierarchy of Metals

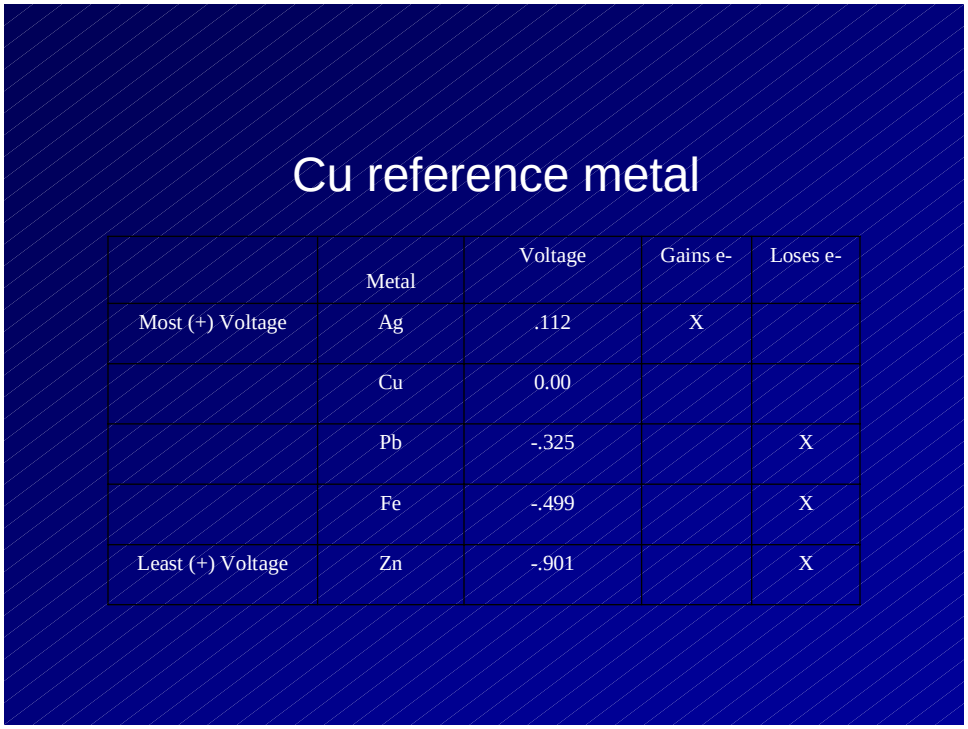
1. We measured the voltage produced when connecting two elements stuck in a lemon.



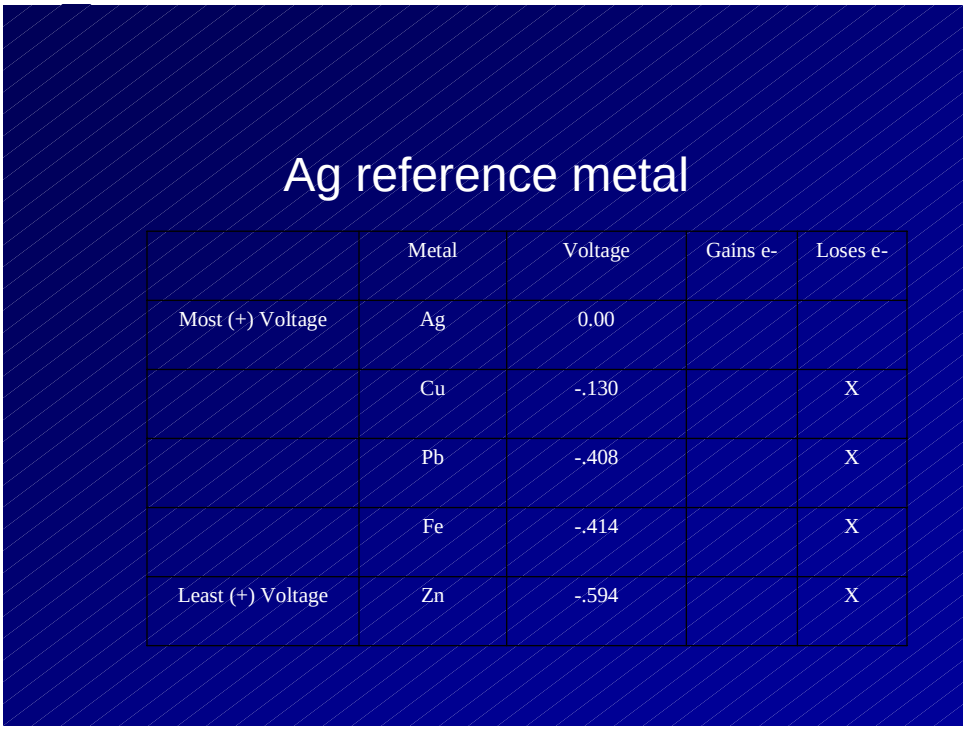
Oral Report Student Sample – Slide 6



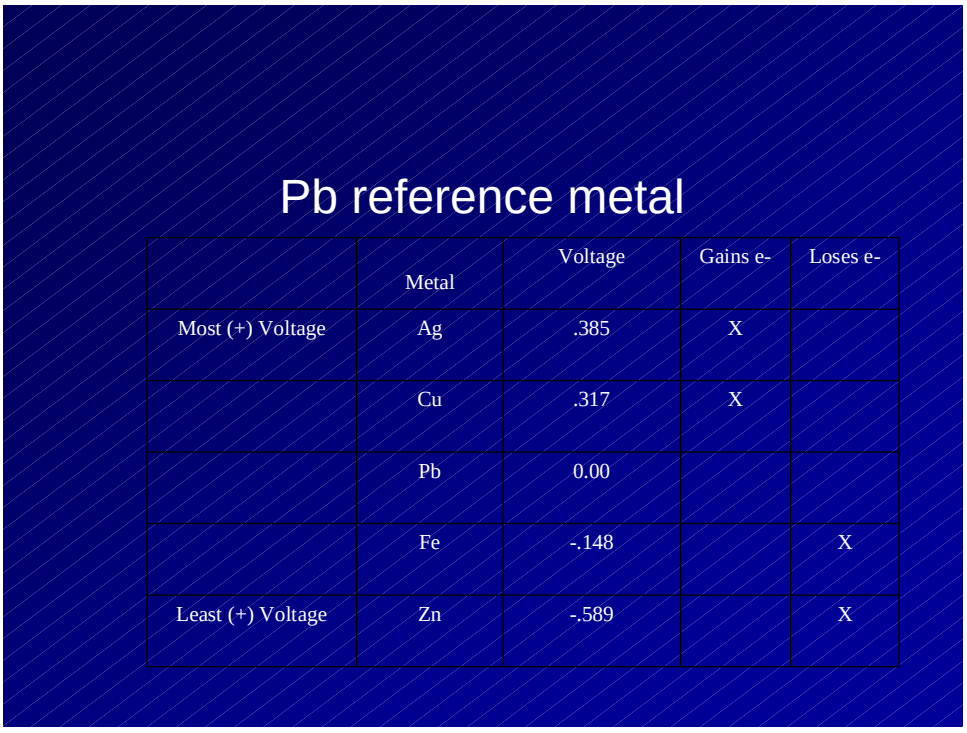
Oral Report Student Sample – Slide 7



Oral Report Student Sample – Slide 8



Oral Report Student Sample – Slide 9



Oral Report Student Sample – Slide 10

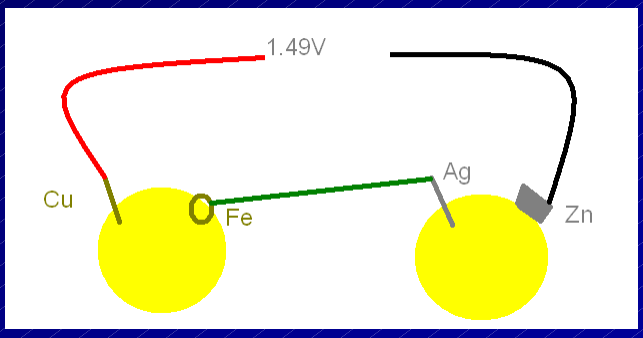
Fe reference metal

	Metal	Voltage	Gains e-	Loses e-
Most (+) Voltage	Ag	.593	X	
	Cu	.493	X	
	Pb	.170	X	
	Fe	0.00		
Least (+) Voltage	Zn	-.406		X

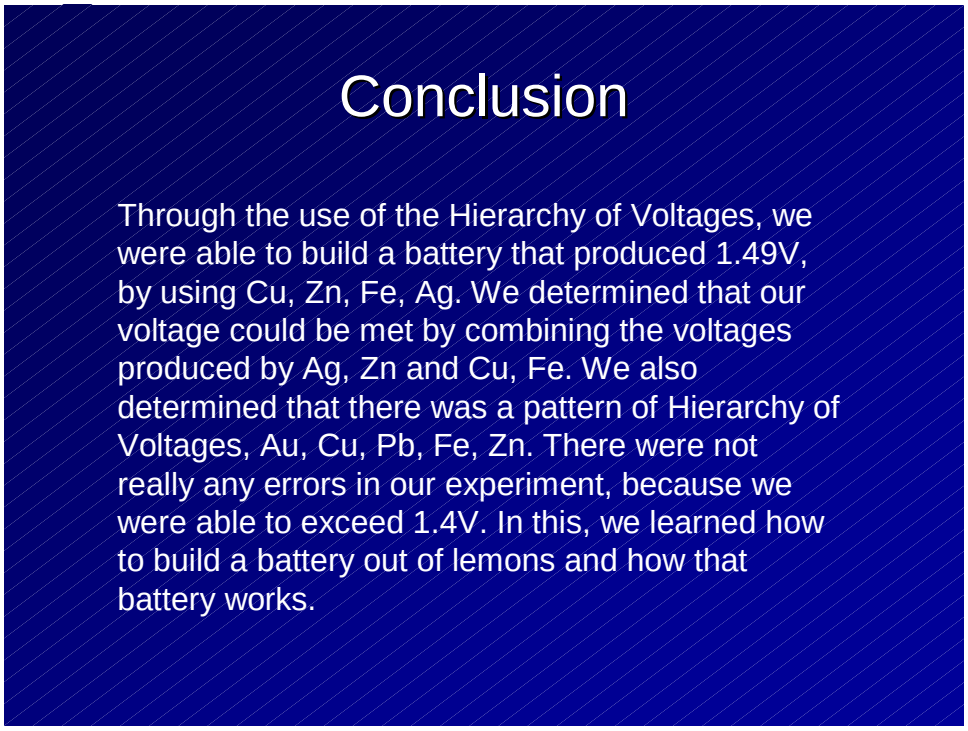
Oral Report Student Sample – Slide 10

Definitions & Part C

Oxidation: Losing electrons
Reduction: Gaining electrons

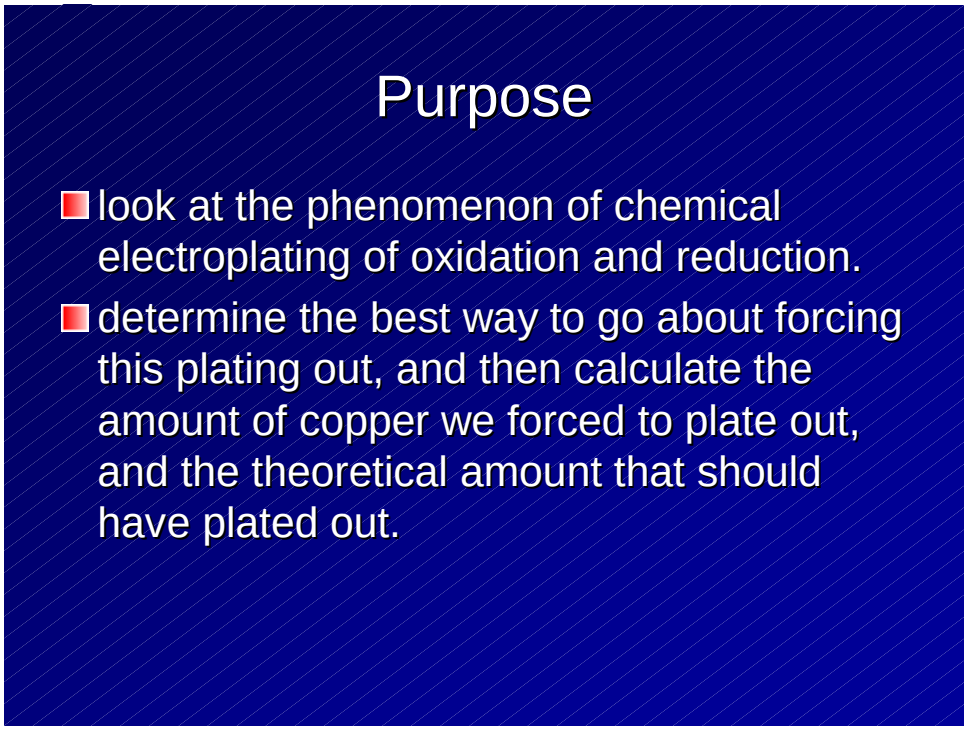


Oral Report Student Sample – Slide 12

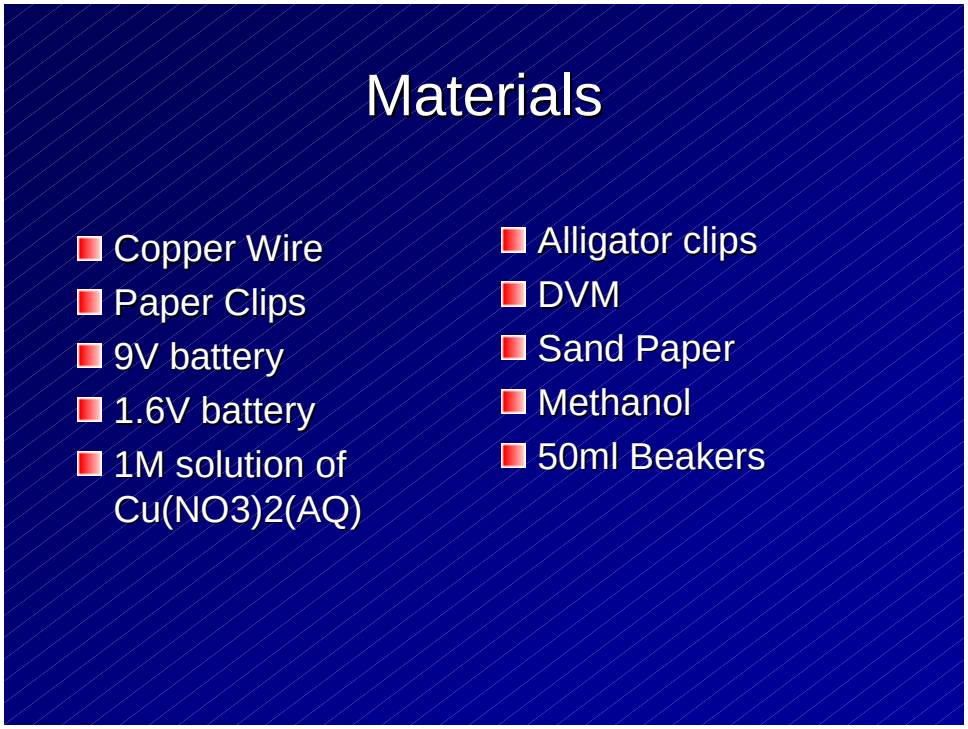


Oral Report Student Sample – Slide 13

Oral Report Student Sample– Slide 14



Oral Report Student Sample – Slide 15



Oral Report Student Sample – Slide 16

Procedure & Observations

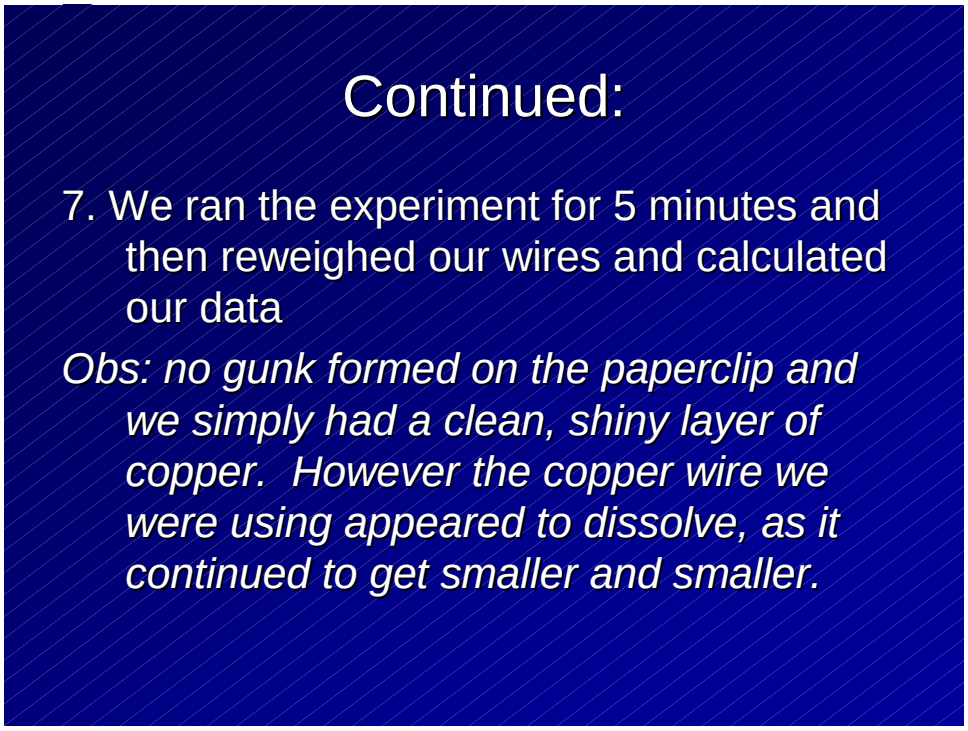
1. Filled a 50ml beaker ¾ full of the 1.0 M $Cu(NO_3)_2$*(aq)* solution.
2. Attached a copper wire to the red alligator clip (+) and the paperclip to the green clip (-).
3. Attaching our battery to the leads, we then placed both wires in the solution for at least 20 seconds and recorded the results.

Student Sample Oral Report – Slide 17

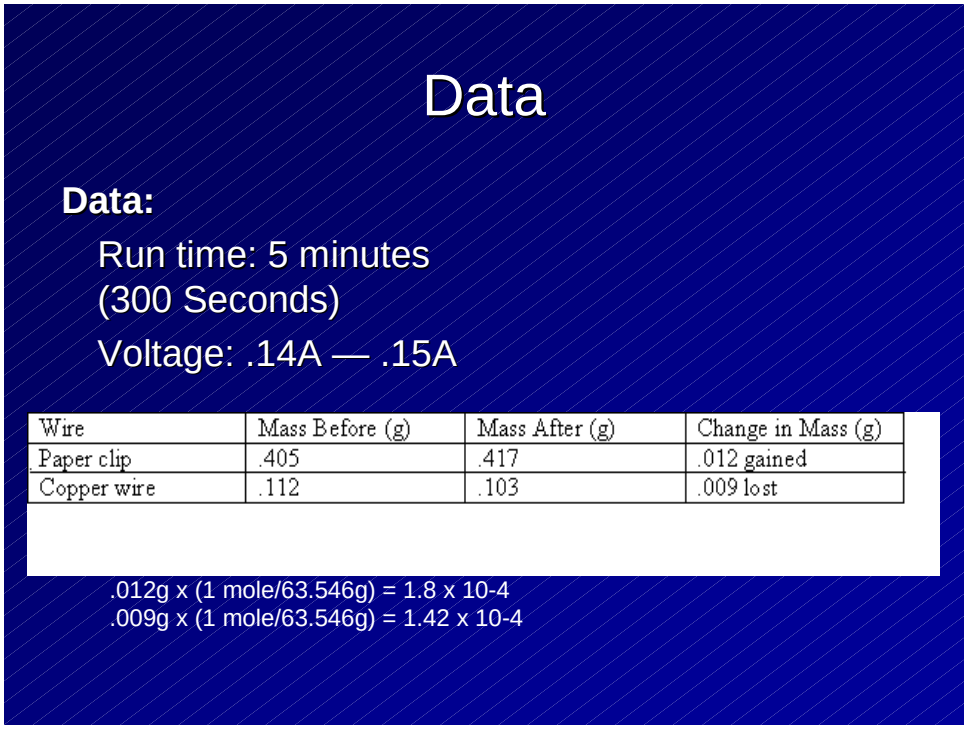
Continued:

4. We placed both wires on wax paper and then measured their masses before we started.
5. We emptied our beaker of solution, cleaned it and refilled it with pure solution
6. We looped the DVM into the circuit to measure the voltage as our experiment progressed.

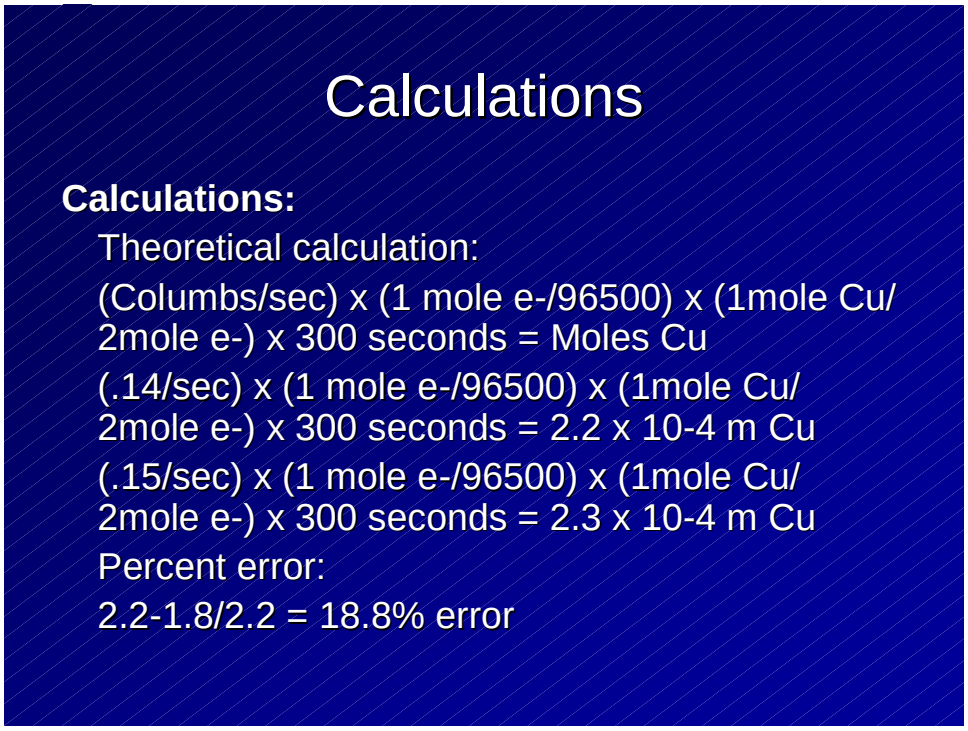
Oral Report Student Sample – Slide 18



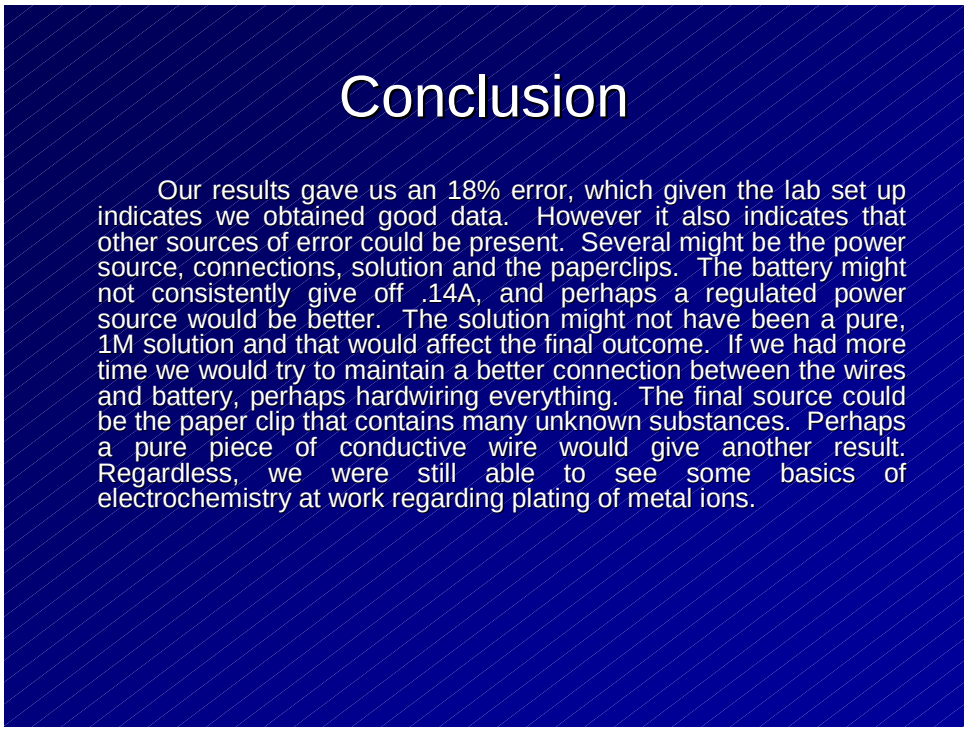
Oral Report Student Sample – Slide 19



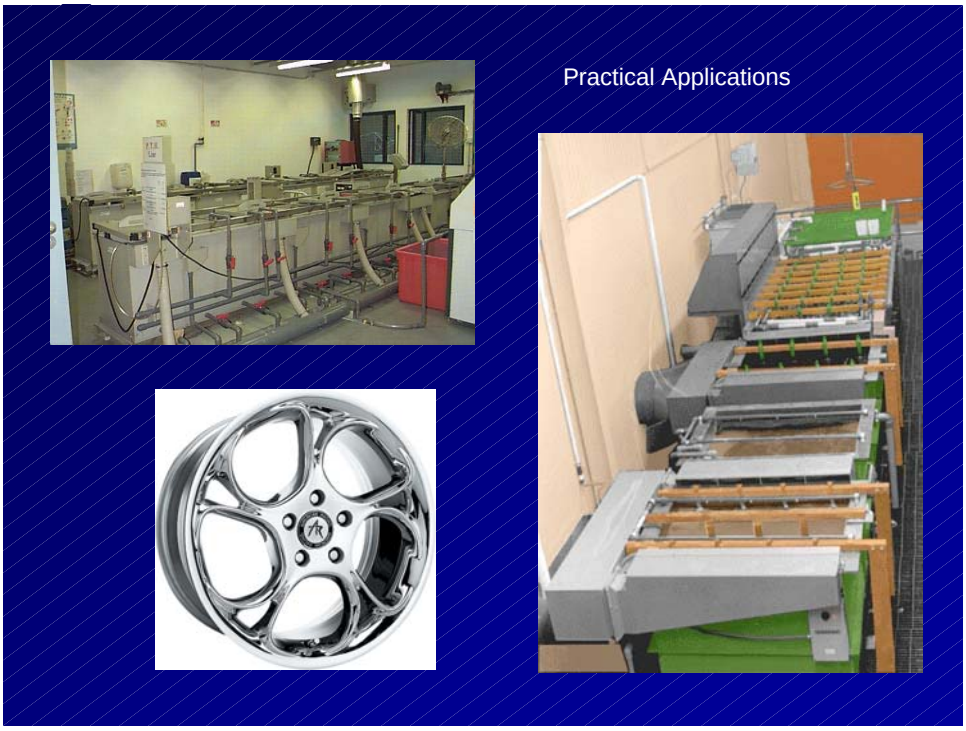
Oral Report Student Sample – Slide 20



Oral Report Student Sample – Slide 21



Oral Report Student Sample – Slide 22



Oral Report Student Sample – Slide 23 – Practical Application

Oral Report Student Sample – Slide 23 - Practical Application
(American Chopper Electroplated with Copper)

WEEK #6 CLASS EXPERIMENT

Quantitative Analysis of Solutions: Some Applications in Colorimetry, Fluorimetry, Turbidimetry, & Nephelometry

STUDENT OBJECTIVES

The objectives of this laboratory are to:

- Learn the nature of light absorption, fluorescence, and scatter that can occur within aqueous solutions and analyze their resultant spectra.
- Learn to predict the visible results of clear colored solutions and what happens when two different colors are mixed.
- Make a set of solutions from a known concentration, also referred to as a 'standard', by diluting it.
- Use light spectra and your standards to create a 'calibration curve' and solve for an unknown concentration:
    - Colorimetric determination of Red #2 Food Coloring.
    - Fluorometric determination of Sodium Fluorescein.
    - Turbidimetric and Nephelometric determination of $Ba^{2+}_{(aq)}$.
- Begin recognizing the recurring patterns of experimental design and techniques that are found within quantitative analysis of aqueous solutions in chemistry.

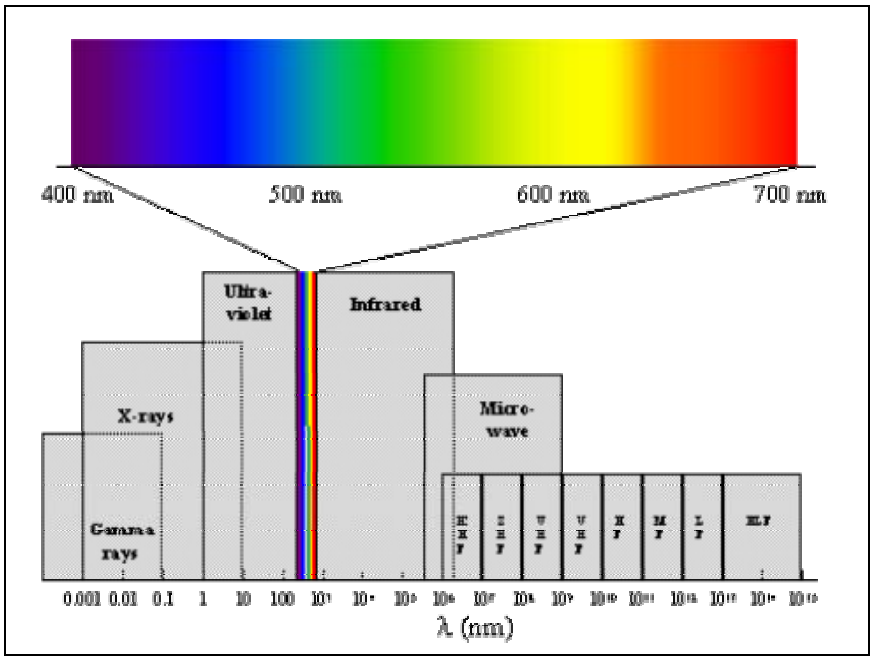
A 'Mini-Directive' as you perform today's lab:

This is a three-part lab that will introduce three chemically different phenomena of aqueous solutions that are (1) clear colored solutions that result from either organic or inorganic molecules, (2) clear and 'near colorless' solutions that fluoresce as a result of an organic molecule, and (3) colloidal and heterogeneous mixtures of solids that result from particles within clear aqueous solutions. These three subjects are presented in a particular order so that you may see some of the chemical phenomena that may exist in aqueous solutions, however this is not the only reason. As you search for understanding of colored, fluorescent, and colloidal aqueous solutions within chemistry, see if you can begin to recognize the common patterns of quantitative data analysis that helps you to solve your respective research problems in each section.

BACKGROUND

A Short Discussion on the Interaction of Light with its Surroundings

Many people mistakenly believe that colors are "emitted" by colored substances. In fact, the opposite is true. White light is a combination of all the visible colors, like red through violet and even some of the colors you cannot see, like ultraviolet and infrared. One can see, however, that visible light only makes up a very small fraction of a larger cross section of the electromagnetic spectrum, as seen below.



Some Preliminary Observations of the systems we will be working with today:

Light and Clear Colored Solutions

When you are thirsty, you may choose to go to the refrigerator for cranberry juice, the first thing that you may notice is that it is clear, but has a reddish/purple color. By looking through the solution of cranberry juice, you may observe certain colors while other colors you may not. What's more, when you pour yourself a glass from the large pitcher and taste it, it is sometimes too concentrated, so you add a little water. In doing so, you may have noticed that the both the concentration AND the *redness* has decreased accordingly. We will look at this phenomenon in more detail a bit later, but let's complete this section by stating that a change in concentration of a clear colored solution can sometimes lead to an observable change in color intensity.

Light and Fluorescence

When you go out trick-or-treating, or attend a Halloween party, sometimes there are black lights that make parts of your costume seem to glow. This is simply a high voltage incandescent lamp that simply has a colored glass bulb that filters out all light except for blue and ultraviolet. Depending upon the materials present in your costume, the light will fluoresce, or re-emit light at varying wavelengths lower than the blue and ultraviolet light source. We will look at this phenomenon in more detail a bit later, but le's complete this section by stating that a change in concentration of aqueous fluorescent compound can sometimes lead to an observable change in fluorescence given off.

Light and Reflection off of Solids

When you read a black and white newspaper, you usually don't read in a dark room. Turning on an incandescent light bulb that emits *white light*, you can now *see* the newspaper. Your eye *picks up* on the white light on the paper, especially in between the

black lettering. This is because the white paper reflects all of the visible spectra from its surface that is emitted by the incandescent bulb. The black ink, however, that is printed on the paper, doesn't reflect any of the colors from the light bulb at all. Stated another way, the white paper does not *absorb* any colors while the black ink *absorbs* all colors. We will look at this phenomenon in more detail a little later, but let's finish this discussion by saying that many solids of different sizes have the ability to reflect or scatter light.

Part I: Colored Solutions and Colorimetry

With colored solutions, there is a dependency on complex interactions between visible light and the electrons of atoms or molecules. This 'interaction' between light and molecules within a solvent can be explained, in part, by a theory called 'Particle in a Box'. One of the important questions is, "If light is absorbed by a molecule, where does it go?".

The basis for particle-in-a-box

A French scientist by the name of Lois Debrolglie postulated that all moving particles have an associated wavelength that in certain situations govern the behavior of particles. For a particle moving in a specific region of constant potential energy, the deBroglie condition states:

$$\lambda = h/mv$$

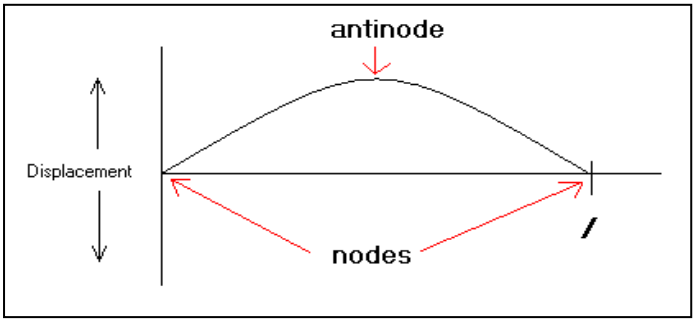
This relationship allows calculation of the particle's wavelength, λ, given mass, m, and velocity, v. This equation is the basis for the quantum mechanical "particle-in-a-box" because the potential energy is constant within a given region or 'box' in which to propagate. *(As a final note for this section, please recognize that this analogous 'box' is the bond energy that exists between any two atoms within a given molecule.)*

Looking at an analogy for the "particle-in-a-box" model.

The waves whose amplitude-squared determines the probability distribution of the electron's location within a given area, the box, create standing waves that are analogous to the wave motion of a plucked string on a guitar. Considering this guitar string analogy, when clamped at both ends and then plucked, the string will vibrate in fundamental "increments" based on the defined distance between the two clamps.

- *The Fundamental Mode*

A string vibrates from one clamped end to the next with a minimum displacement at the ends, called nodes. The maximum displacement of the string occurs in the center, which is called the anti-node. The most



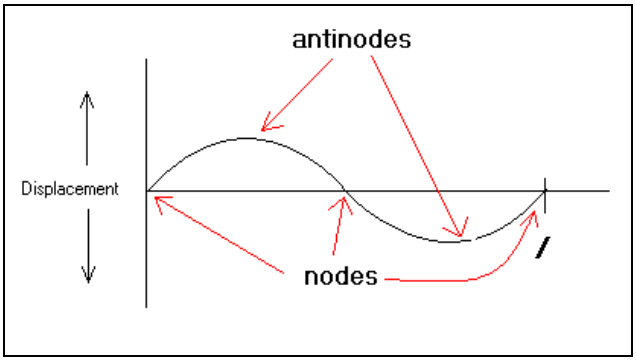
"simple" oscillation of the system is called the "Fundamental Mode", seen below. (Notice that the string is clamped a distance l from the origin and that a distance of $2l$ creates a single wave.

- *Several other modes called "Overtones".*

The fundamental mode is the most basic oscillation that can occur on this described string that has been clamped a quantized distance apart. *Do you think different types of oscillations can happen on this string?*

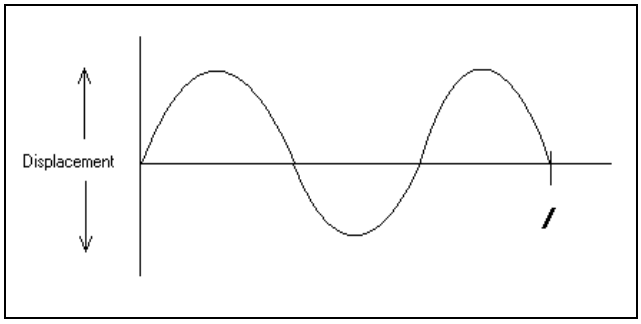
(Hint: The evidence of this is a guitar string being plucked at different overtones.)

- *The First Overtone*



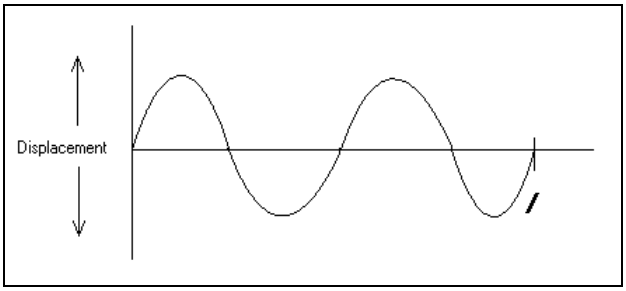
$\lambda = l$

- *The Second Overtone*



$\lambda = 2l/3$

- *The Third Overtone*



$\lambda = l/2$

- *The Math that describes these overtones*

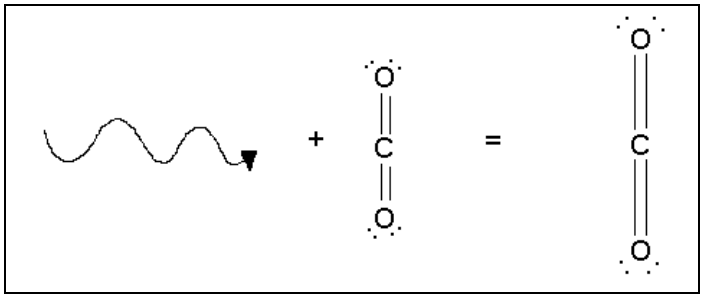
The wavelength of each of these modes is a multiple of , *l*. Sated another way, the distance for one complete cycle or wavelength is a multiple of the fundamental mode.

The fundamental mode takes distance of $2l$ in order to make a single cycle. To make the first overtone, it takes a distance of l in order to complete a single cycle. Overtones range from the fundamental to shorter and shorter wavelengths of $2l, l, 2l/2, 2l/3$.....

$$\lambda_n = (2l)/(n) \quad \text{with } n = 1, 2, 3, 4, 5, 6...$$

Why particle-in-a-box?

The distance and bond-types between two atoms are analogous to the plucked string model we refer to as "Particle in a Box". This analogy can be seen when a photon with specified energy is absorbed by a molecule, resulting in *excited state of higher energy*. This can be seen in the diagram below, as the CO_2 molecule comes into contact with a photon of particular energy that 'matches' its overtones.



- *A discussion about Molecular Absorbtion*

If what we said so far is true, then color results from the absorption of visible light from the molecules that interact with it. We should then look more closely at what happens to a molecule when a specific *quantized energy photon* or electromagnetic wave is absorbed by it. When a photon impinges upon a molecule and/or atoms and its energy matches the energy difference between the state in which the molecule initially finds itself, the ground state, and some excited state of the molecule, it can cause a change in that atom or molecule from a lower energy level to a higher one. The most important part of this prior information is that the energy of the photon must match the energy gap between specifically quantized values of these excited states.

$$E_{\text{ground state}} + E_{\text{photon}} = E_{\text{excited state}}$$

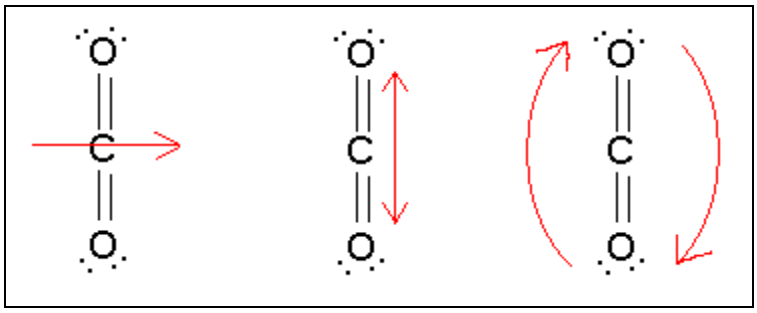
That is to say, in order for the light absorption to take place, the photon must have an energy that is the difference between the ground state and excited state of the molecule or atom.

$$E_{n\ \text{photon}} = l\,(hc)/(\lambda_{\text{overtone}}) = \Delta E_{n\ \text{molecule}} \text{ and therefore } \Delta E_{n\ \text{molecule}} = E_{\text{excited state}} - E_{\text{ground state}}$$

Where l is a specific quantized level, h is Plank's constant, c is the speed of light, and λ is the wavelength of light that has impinged on the molecule.

- *An Excited State of a molecule?*

After the photon-to-molecule energy exchange, the molecule can rotates and/or vibrates until the excess energy is dissipated to its surroundings in form of heat. This is the basis for "the greenhouse effect", where earth's temperature increases due to atmospheric gases converting a photon's energy into thermal energy by exciting gaseous molecules via frictional forces around itself. This is also the basis of spectroscopy and quantifying the concentration of molecules in a solution through Beer's Law. Below is a pictoral representation of three types of energy dissipations, that include translational, vibrational, and rotational energy states within a molecule of CO_2, respectively.

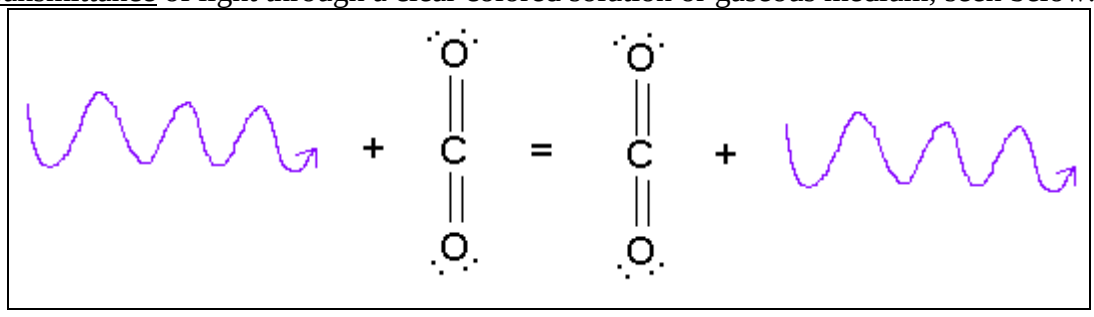


- *When a molecule, for example CO_2, doesn't absorb a particular wavelength, what happens?*

The short answer to this question is...nothing. As a light of a particular wavelength and energy translates through a molecule and its energy does not match the excitation energy,

$$E_{photon} = I\,(hc)/(\lambda_{overtone}) \text{ does not equal } \Delta E_{molecule} = E_{excited\ state} - E_{ground\ state}$$

…it simply TRANSMITS through the molecule. In essence, this is the basis for Transmittance of light through a clear colored solution or gaseous medium, seen below.



- *One last question: "What happens at high energy overtones?"*

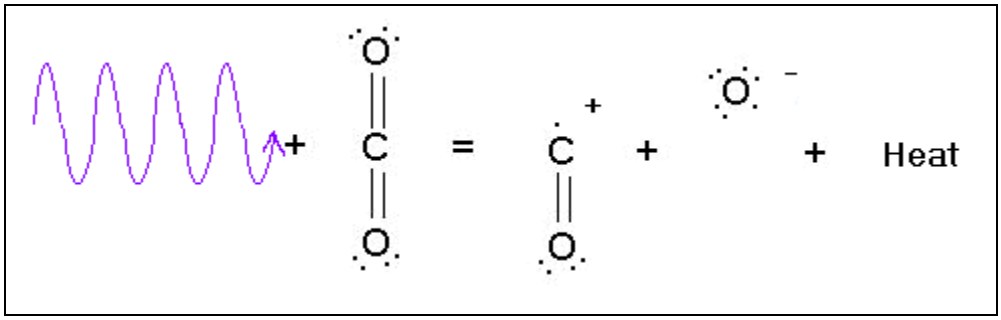
Decreasing overtone wavelengths are inversely related to their energy. That is to say, overtone energy, $E_{overtone}$, increase as the wavelength gets smaller and smaller, where h is Planck's constant, c is the speed of light, and λ is the overtone wavelength:

$$E_{\text{overtone}} = l\,(h)/(c\lambda_{\text{overtone}})$$

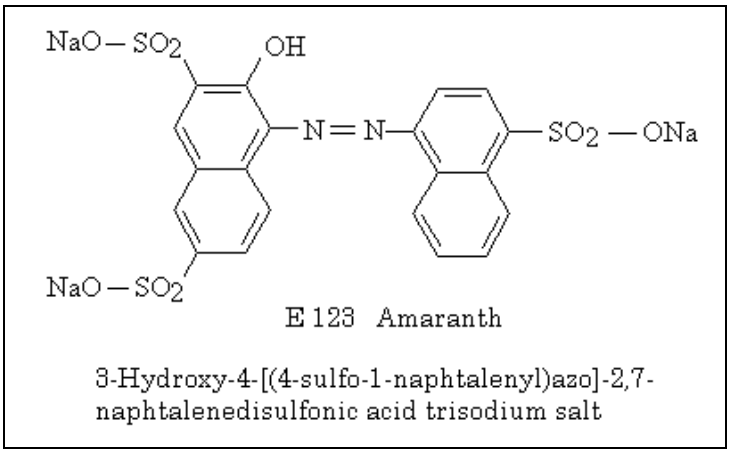
When a high energy photon matches a high energy overtone:

$$E_{\text{photon}} = E_{\text{overtone}}$$

The results can cause bond between the two atoms to break and sometimes even evolve heat!



The Red#2 Molecule is a bit more complex than this CO_2 example, but the same principles exist. Below is a picture of the Red #2, amaranth, molecule.



Part I: A survey in colored solutions

(A Group Project)

Materials: Overhead, Colorimetry viles, Meas.Glassware, Diffraction Grating, Red #2 Food Coloring – $2.47\text{X}10^{-5}$M, MicroLab's 10-Color Colorimeter, Colored Solutions

Your lab instructor will discuss and survey with you colored solutions. You will use the overhead and MicroLAB's 10-Color Colorimeter to qualitatively and quantitatively analyze 5 different clear colored solutions.

YOUR GOAL:
You will be asked to match the 5 spectral charts to the five colors you have seen and be able to discuss what happens when you mix these various colors together. (TAKE GOOD NOTES in your Lab Notebook for the write-up.)

Some key vocabulary you should be able to use after this section are:
Trasmittance *Absorbance* *Spectrum* *Beer-Lambert Law*

Some key ideas you should be able to discuss in your conclusions:
% Transmittance (100% to 0%) *Absorbance (0 to 1.1)*

Exercise B: Quantizing Colored Solutions and creating a 'Calibration Curve'
(A Group Project)

In this part of the lab, we will work together in creating known solutions from a 'standard' concentration of 2.5 $X10^{-5}$M RED #2 food coloring. We will work as a group in creating your first '*calibration curve*'.

YOUR GOAL:
Your lab instructor will guide you through proper lab technique and use of the colorimetry software in the determination of an Unknown RED #2 solution that *each table* has mixed up. (TAKE GOOD NOTES in your Lab Notebook for the write-up.)

Some key vocabulary you should be able to use after this section are:
Standard(s) *Dilutions* *Molecular Absorbance*

Some key ideas you should be able to discuss in your conclusions:
$M_1 * V_1 = M_2 * V_2$ *%T vs. Concentration* *molar absorbtivity (ϵ)*
Absorbance vs. Concentration *Lab Technique* *path-length*
Calculating Absorbance Calculating Absorbance from %T
A= -log(%T/100) $A = \epsilon * l * [C]$ Lambda MAX
$V_1 * M_1 = V_2 * M_2$

Dilution Strategies for Colorimetry:

Group #	[Red#2] $X10^{-5}$M	(mL) of Stock Red #2	(mL) of D.I. Water	Total (mL)
1	2.47			20.0
2	1.24			20.0
3	0.620			20.0
4	0.310			20.0

Note about Beer-Lambert Law and Linearity:
There are a number of limitations to Beer-Lambert's Law of which you should be aware. Beer-Lambert's Law is strictly valid only at low concentrations; thus, some deviations cannot be expected at higher concentrations. Beer-Lambert's Law also assumes a monochromatic (single wavelength) light source is used. In reality, 10 different light emitting diodes (LEDs) of your colorimeter emit a band or range of wavelengths rather than a single wavelength. If the constant, ϵ, in the absorbance equation happens to vary in this band of wavelengths, Beer-Lambert-Law will fail. What all these limitations mean is this: your data may not fit Beer's Law exactly, but it should be close.

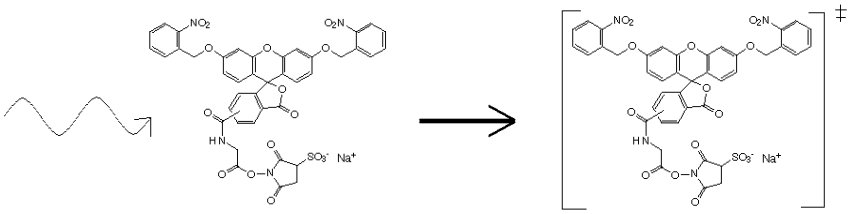
Part II: Clear and 'near colorless' aqueous solutions that Fluoresce

Fluorescence occurs in gaseous, liquid, or even solid chemical systems. The simplest kind of fluorescence, for example, starts when a single atom absorbs LIGHT ENERGY and promotes its outermost electron from a lower to a higher orbital. Almost instantaneously after this happens, the gaseous atom re-emits at the same wavelength.

In more complex systems, such as sodium fluorescein, the absorbance of light energy from an external source occurs in much the same manner as a single atom. The re-emission of light, unlike the single atom system, is usually observed to be at a lower energy and frequency, thus a larger wavelength is re-emitted. This lower frequency light implies that some energy has been lost somehow. Why do you think this is?

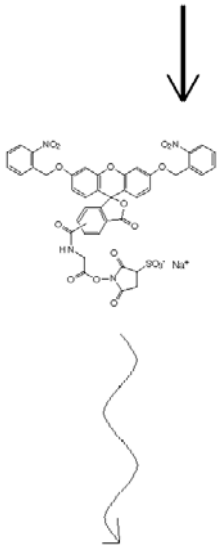
Since a molecule has bonds with multiple atoms, this loss of energy is usually attributed to the same vibrational, rotational, and translational energy states within the molecule, as seen in the previous section. Don't forget that these fluorescent molecules not only convert this energy into these three excited states, but will tend to collide and dissipate their energy to the surrounding fluorescent molecules and solvent.

Stated more succinctly, when particular wavelengths of light are absorbed by an aqueous fluorescent molecule, some of this energy will be dissipated throughout the molecule and to its surroundings, while the rest is released in the form of a lower energy wavelength. This shift towards longer wavelengths, or lower energies, is termed the *STOKES SHIFT. (See Diagrams Below)*



Blue Light is absorbed by Na-Fluorescein

Na-Fluorescein is excited.



Na-Fluorescein re-emits at a lower wavelength.

Exercise C: Quantizing an Aqueous Solution of Na-Fluorescein

(A Lab Partner Project)

In this part of the lab, you will used pre-made concentrations of Na-Fluorescein from a stock solution of 5.5 $X10^{-6}$M. You will calibrate your instrument and scan in these solutions in order to create your *calibration curve*'. After curve fitting your calibration data with a linear-fit mathematical function, you will solve for the concentration of the unknown in PARTS PER 100.0mL and convert this into molarity of Na-Fluorescein.

YOUR GOAL:

Choose the *best wavelength* to analyze your fluorescent solutions and solve for the concentration of the Unknown Na-Fluorescein solution in Molarity from the given concentrations that are in PARTS PER 100.0mL. (TAKE GOOD NOTES in your Lab Notebook for the write-up.)

Some key vocabulary you should be able to use after this section are:

Standard(s) *Dilutions* *Fluorescence*

Some key ideas you should be able to discuss in your conclusions:

$M_1 * V_1 = M_2 * V_2$ *Fluorescence vs. Concentration*

Lab Technique *L*ambda MAX for flourescence

$V_1 * M_1 = V_2 * M_2$

Dilution Strategies for Fluorimetry:

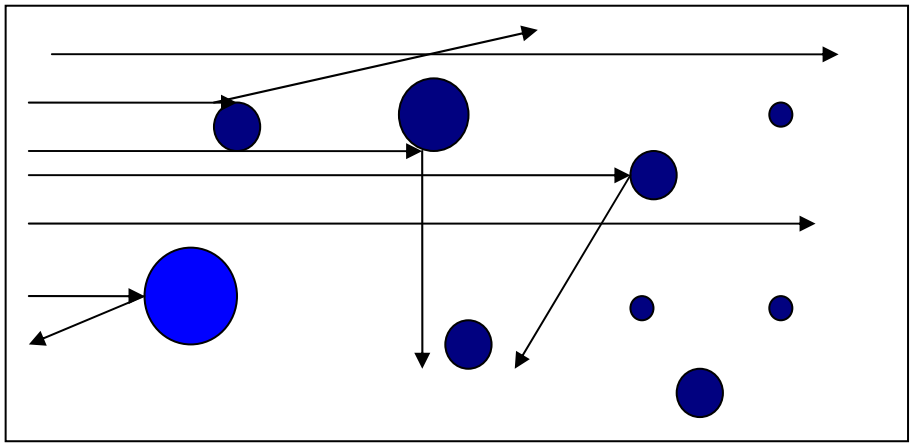
Stock Solution of NaFluoroscein = 5.5$X10^{-6}$M

Group #	[Na-Fluor.] Molarity	(mL) of Stock Na-Fluor.	(mL) of D.I. Water	Total (mL)
1		4.0	96.0	100.0
2		8.0	92.0	100.0
3		12.0	88.0	100.0
4		16.0	84.0	100.0

Part III: Colloids and Heterogeneous mixtures of solids

Colloids or colloidal dispersions are mixtures in which particles (or droplets, or bubbles) of one medium having diameters of 10^{-4} to 10^{-6} mm are suspended in another medium. If the particles are smaller than 10^{-6} mm in diameter, the mixture exhibits the properties of a "true solution" and is not considered to be a colloid. If the particles are larger than 10^{-4} mm in diameter, then the mixture is not colloidal but heterogeneous and the particles will more than likely "settle out" of solution when given time.

There are many other examples of colloids in which particles of solids or liquids are dispersed in other solids, liquids, and gases. Mayonnaise is a colloidal dispersion in which droplets of one liquid (salad oil) are dispersed throughout another liquid (vinegar). Another colloidal dispersion of this type is hand lotion. Fog and clouds exemplify liquids dispersed in gas, while butter contains tiny droplets of water that are dispersed in solid butter-fat. Below is a representation of light interacting with colloidal particles. Notice that some of the light is successful in "getting through" the solution, while the other light



is reflected off the surface of the surface of the colloidal particles. Sometimes colloidal solutions appear white, this is because ALL different wavelengths of light are being reflected or 'scattered' equally. Other times, colloidal particles appear colored, which may be due to the colored clear solution around the particles OR the particles themselves may be absorbing particular wavelengths.

When one measures the amount of light that "gets through" the solutions, this is the same idea as a measurement of % Transmittance, but is instead referred to as "Turbidimetry" of the solution. When one measures the amount of light that is scattered, at any angle other than 180 degrees from the light source, this is referred to as "Nephelometry".

Laboratory Exercises For Part III:

Materials: Overhead Turbid Solutions
Spot plate Spot Test Reagents

Exercise C : A spot plate to see what ions exist in Solution

(A Lab Partner Project)

You will get a glass spot plate and wash it clean with soap and tap water. Make your final rinse with deionized water. Next, get your spot test reagents, spot plate observation sheet, and begin to carefully mix the reagents in pairs. Be sure to use the ammonia reagent LAST, due to its strong odor.

YOUR GOAL:

You will be asked to observe all the different combinations of spot test reagents. You will notice, with qualitative observations and notes taken on your spot-plate matrix, which mixtures create SOLIDS and which just change colors. Please be sure to write the balanced equation for the reactions that create a precipitate. A solubilities table in your lecture text and on page 14 and 15 of your regular CHEM 131 lab manual may assist you. (TAKE CAREFUL NOTES on the shape of crystals and colors in your lab book and print-out the graphs that are generated.)

Some key vocabulary you should be able to use after this section are:

Precipitate or Crystal sizes, colors and shapes K_{sp} *Color changes*

Be sure to balance the equation of all solutions in which you see a precipitant form. Also, assign whether the compound is in an aqueous (aq) or solid (s) state, as shown in your lecture text.

For example:

$$AgNO_{3(aq)} + HCl_{(aq)} \rightarrow AgCl_{(s)} + HNO_{3(aq)}$$

SPOT TEST MATRIX for OBSERVATIONS

	$HCl_{(aq)}$	$HNO_{3\,(aq)}$	$H_2SO_{4\,(aq)}$	$KSCN_{(aq)}$	$K_2CrO_{4\,(aq)}$	$NH_4OH_{(aq)}$
$Fe(NO_3)_{3\,(aq)}$						
$Ba(NO_3)_{2\,(aq)}$						
$Ag\,NO_{3\,(aq)}$						
$Ni(NO_3)_{2\,(aq)}$						
$Pb(NO_3)_{2\,(aq)}$						
$CuSO_{4\,(aq)}$						

WEEK #7 CLASS EXPERIMENT

Quantitative and *Qualitative:* Analysis of an Ion Pair in an Aqueous Solution

You will couple your skills of qualitative analysis, such as creating an observation matrix via spot testing, with quantitative analysis, such as gravimetry, colorimetry, turbidimetry, and nephelometry, in order to determine what and how many ions are in a given aqueous solution. From this, you will determine WHICH solvated cation/anion pair was initially mixed into the solution as a dry salt. Think of the different types of data that are required for you to prove your case.

Background Information:

Your previous work in lab with respect to gravimetry, spectroscopy, colorimetry, fluorimetry, turbidimetry, and nephelometry will guide you during your lab today.

Your Laboratory Materials:

You will be given aqueous stock concentrations of Iron (III) Chloride, Iron (III) Sulfate, Copper (II) Chloride, and Copper (II) Sulfate. On each table within lab is an aqueous solution of Unknowns W, X, Y, Z or Q, which may contain any one of the four ion stock solutions. You will use your glassware and instrumentation within lab for the qualitative and quantitative analysis of your unknown.

The Laboratory Objectives for today:

When a soluble salt dissolves into solution, a positively charged ion called a cation (+) and negatively charged ion called an anion (-) are formed. Through quantitative and qualitative analysis, you will determine what and how many ions exist in a given solution. Your ability to collect data from these single salt aqueous solutions will put your skills and knowledge of chemistry to the test. These are the laboratory objectives for today:

- Apply your knowledge of spot testing in order to determine the identity of ions in solution.
- Apply your knowledge of the nature of light and choose from the phenomena of absorption, transmission, fluorescence, and the scatter of light that may be exhibited by your unknown solution.
- Apply this the phenomenon that you think show the best changes with respect to change in concentration AND will be methodologically reproducible in an experiment. From this, make a set of known dilutions from a given stock solution, create a calibration curve, then perform the same procedure with your unknown, solving for its final concentration.

Lab Questions that need to be addressed in your lab write-up:

1) What qualitative data from the spot test helps you deduce what ion pair you have in solution? What ions exist?

2) What quantitative data helps you to deduce the concentrations of Fe^{3+}, Cu^{2+}, Cl^-, and/or SO_4^{2-} ions in your unknown? What are their respective concentrations?

3) Which ion pairs exist in a given aqueous solution that was prepared from a single salt salt?

Week #13 Experiment

Electrochemistry: Go Speed Racer….Go!

Scenario

Juan has just arrived at the National Radio Controlled Car Championships in Florida when he realizes that he has left the battery to his battery-powered racer at home. Knowing that it's a 50 minute round-trip to the local RC shop to pick up another battery and the qualifying heat is only in 40 minutes, he's got to think fast. Luckily he has YOUR TEAM to help him figure this one out.

Your Task:

Juan needs your help to find a way to create a makeshift battery with the materials in his tool kit and in the local surroundings. In order to qualify, he only needs to "flinch" off the starting line. Juan calculates that he only requires 1.4V and next to no current…0.001amps. By this time, Juan's father will be able to drive to the local RC shop, pick up a new battery, and be back before the second heat, which is much more than just getting off the starting line.

Juan's Tool Kit and local surroundings:

In Juan's tool kit are a Silver (Ag) wire, a piece of Copper (Cu) wire and a small piece of Copper plate, an Iron (Fe) washer, a small piece of Lead (Pb) plate, two small piece Zinc (Zn) plate, two alligator clip leads, a miscellaneous motor, and a borrowed DVM from a friend. Juan has a 9V and 1.6V battery, but these batteries must be used for his RC Controller. Only 100 yards away, at one end of the stadium and on the other side of the Sloppy Joe's Café, there is a lemonade stand that sells freshly squeezed lemonade. There is also a goofy vendor, Tim, who likes to show off with chemistry "tricks".

Some background knowledge and exercises so your team can help Juan:

Part A: Spontaneous Corrosion, Batteries, DVM's, & Measuring Voltages

A Chemistry Show: Oxidation/Reduction Reactions and observations of spontaneous corrosion.

a) In front of your team, Vendor Tim has some solutions of Copper Nitrate, $Cu(NO_3)_{2(aq)}$, and Silver Nitrate, $AgNO_{3(aq)}$. Please note your initial observations of the clear solutions, below:

Initial observations of $Cu(NO_3)_{2(aq)}$:_____

Initial observations of $AgNO_{3(aq)}$:_____

b) Tim places a copper wire, Cu^0, in the $AgNO_{3(aq)}$ and a silver wire, Ag^0, in the $Cu(NO_3)_{2(aq)}$. *After sitting in the solutions for no less than 5 minutes, what are your final observations?*

Final observations of $Cu(NO_3)_{2(aq)}$ and Ag^0 wire:_____

Final observations of $AgNO_{3(aq)}$ and Cu^0 wire:_____

c) One of these solutions reacts with the metal wire. *Please identify which solution reacts with its metal wire and show this reaction via balanced oxidation/reduction equation below:*

Batteries and Voltage:

Electronics might be described as the science of moving and counting electrons for a useful purpose. Electrons are the currency of information exchange in an electrical motor and/or electronic instrumentation. A battery is a physical object that releases or pushes on electrons to a degree that depends on its environment. A Digital Voltage Multimeter *(DVM)* is a "read-out" device that presents a number in response to the presence or absence of electrons.

VOLTAGE is a measure of how hard an electron is being pushed from one place to another. A battery or power supply acts as an electron pump, pulling electrons into one terminal (+), and pushing them out the other terminal (-). Voltage is usually symbolized by the letter "V". The 9V battery and 1.6VAA batteries that Juan uses in his RC Controller are used to pull and push electrons the same way, but, as you can tell by the numbers in front of the "V", not to the same magnitude. Stated another way, larger voltage batteries can supply more electrons per second.

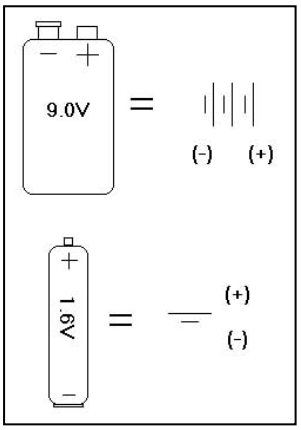


Figure 1: Batteries are "electron pumps" that pull electrons into their (+) terminal and push an equal number of electrons out their (-) terminal. The batter voltage is a measure of how hard the electrons are pushed or pulled.

Batteries (or voltage supplies) are symbolized with a series of short and longer bars, with the longer bars representing the (+) pole of the battery, into which electrons are pulled. Electrons are pushed out the (-) pole of the battery. In general, low voltage batteries, such as the 1.6V battery, can be symbolized with one long and one short bar, while higher voltage batteries, such as the 9V battery, are symbolized with more bars, as seen in Figure 1.

In most batteries, the small metal post on the end is the positive (+) terminal and the case of the battery (exposed at the other end) is the negative (-) terminal. Check your two batteries, some have different shapes, such as the 9V battery, but all have + and/or - signs on them.

A Few laboratory Exercises For Your Team:

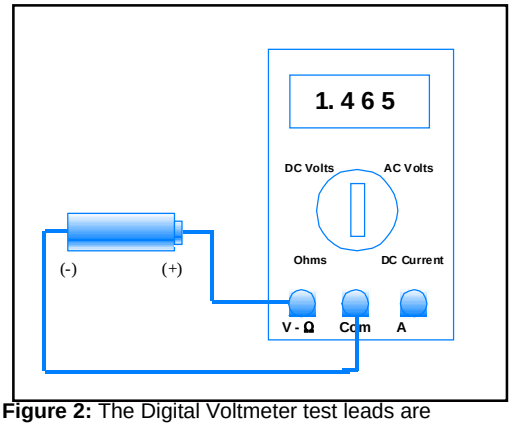


Figure 2: The Digital Voltmeter test leads are normally plugged into the common or **negative** (black) and Volts-ohms socket (red). This drawing shows how to measure the voltage of the 1.6V battery.

I. Using the DVM and reading each battery from the RC controller.

Voltage can be measured with a *Digital Voltmeter (DVM)*. Connect your black test lead to the "Com" or "common" terminal, and your red test lead to the "volts – ohms" terminal. Set the range selector to read volts in DC and place the black test lead to the negative end and the red test lead to the positive end of your 1.6V battery, as shown in Figure 2.

Q: What is the sign and magnitude of the voltage shown in the DVM display?

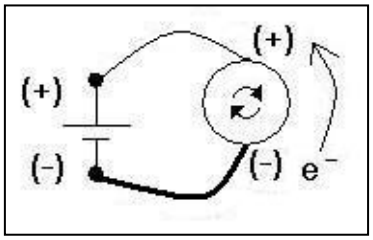
Q: Switch the black and red leads. What is the sign of the voltage in the DVM display, now?

Q: What do you think is going on here? (Hint: Where are the electron coming from and going to?)

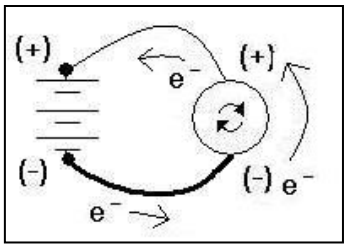
Q: Now, without looking at the sign of the posts, read your 9V battery with the DVM. From the output, which is the (+) post and which is the (-) post? *(Is the "crowned" post on the 9V battery the positive(+) or negative(-)?)*

II. The flow of electrons over a motor:

Below are some diagrams of a 1.6V and 9.0V battery that are connected to a motor. The red and black leads off the motor are the (+) and (-) poles of the motor, respectively. Connect the motor to the 1.6V and 9.0V battery, as seen in Exercise #1 and Exercise #2.



Exercise #1: Motor barely rotates with 1.6V



Exercise #2: Motor rotates faster with 9V

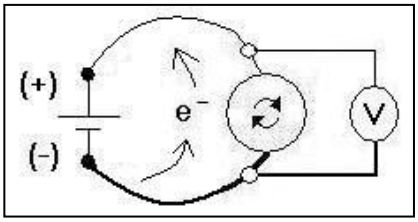
Notice that the motor, when connected to the 9V battery, has a higher RPM (rotation per minute). This is because more electrons are being pushed through the motor with the 9.0V battery. Also, when looking from the shaft side, each of these motor systems travel in a clockwise orientation when the electrons flow in the (-) pole and out the (+) pole of the motor.

Q: When you switch the poles of the motor with respect to the battery, which direction does the motor spin?

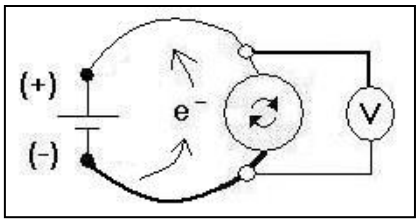
Q: Do you believe that e electrons are still coming from the (-) and going to the (+) post?

III. Measuring the voltage over a motor:

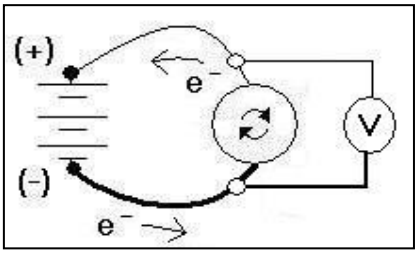
Now lets use the DVM to monitor the voltage drop over the motor, (V_{load}). Connect the battery to the motor and place the DVM, "V" in a circle, as shown in the following exercises. Set your DVM to read DC voltage and list the corresponding voltages and SIGN, either (+) or (-). *(Please note that the darker line on the DVM is the Black Lead or "COM" reference.)*



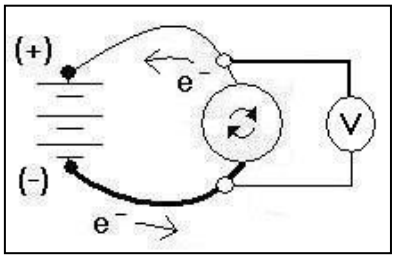
Exercise #3: V = _____



Exercise #4: V = _____



Exercise #5: V = _____



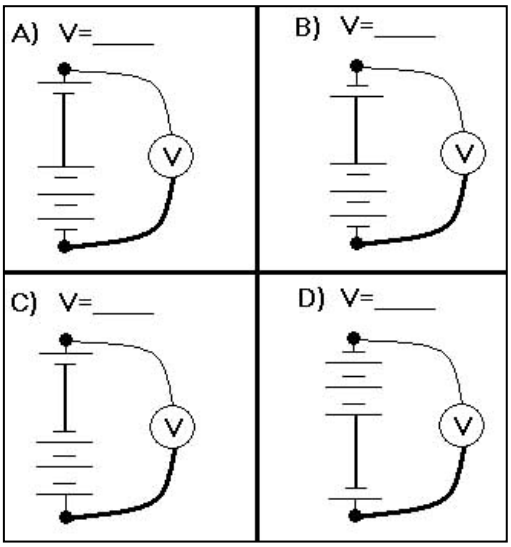
Exercise #6: V = _____

***Electrons don't flow through the DVM, it is simply an instrument that measures the "difference in potential" between two points within an electrical circuit. Stated another way, the DVM measures the "potential" for electrons to flow in a given direction. Notice that the motor remains oriented the same direction in all of the circuits above, but the DVM, represented by the "V" within a circle, changes orientation each time. The voltage drop over a motor is a measure of its voltage load,* $V_{load.}$

III. Measuring the voltage of a battery and predicting the flow of electrons:

As you have seen before, it's not always necessary to keep the motor in the circuit diagram while reading voltage from a battery. As a matter of fact, it will ultimately cause Juan's batteries to run low and eventually go dead. Use the DVM to read and record the voltages of the matching circuits below:

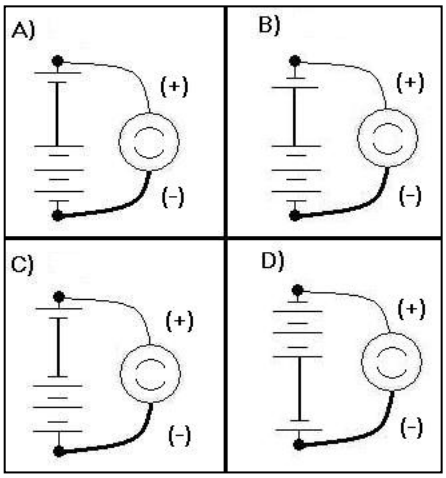
Exercise #8:



Let's see what this means when the motor is placed within the A, B, C, and D circuits above. Remember that when the poles of the motor match the poles of the battery, you get a clockwise rotation of the motor's shaft. This reflects the flow of electrons from the (-) pole of the battery, into the (-) pole of the motor, out of the (+) pole of the motor, and to the (+) pole of the battery.

Q: What direction would you predict the motor would rotate and electrons to flow in the diagrams below? Please show your predictions by placing 'arrowheads' on the direction you would expect the motor shaft to rotate and draw in your predictions for direction of the flow of electrons.

Exercise #7:



After you have made your predictions, create these circuits and check! *(Don't run the motor for more than 5 seconds at a time because the motor won't be able to take excessive heat.)*

Q: Were ALL your predictions for rotation correct? Please Circle →Yes or No

Q: What do you notice between the rotation of the motor, the flow of electrons, and the corresponding voltage of the resultant battery? (Designate the poles on the battery with (+) and (-).)

PartB: Making a "Hierarchy of Metals" with Juan's materials

On the way back from the lemonade stand, as you are carrying your freshly squeezed lemonade and 2 extra lemons, you take a sip, trip, and fall. Not only do you spill all of your lemonade on your teammates but also one of lemons you had intended to eat, because they never make the lemonade sour enough for you, has been punctured by *ALL* of the metal pieces from Juan's tool kit. Your perplexed teammates are not only aggravated by their current dilemma of helping Juan, but are now drenched in a sticky sugary drink. All but one of your teammates is angry with you.

On a mission, this teammate takes the borrowed DVM, connects the black lead to the Zinc plate, and touches the red lead to the other metals that are partially submerged in the lemon. As your teammate expected, voltage appears on the DVM display. EUREKA…we've got a battery!

A Few laboratory Exercises For Your Team:

IV: Measuring voltage and creating a table of "Hierarchy of Voltages":

a) Zn is referred to as your "REFERENCE", since you use it as a reference against all of the different metals. Making sure you keep the black lead from the DVM on the Zn metal, please collect the following voltage data to the nearest 100^{th} of a volt and fill in the table below:
(Notice that the reference metal connected with itself offers a 0.00 voltage battery.)

Data Table 1: (Zinc as a "Reference")

Voltage of Zn with Pb = _____V
Voltage of Zn with Cu = _____V
Voltage of Zn with Fe = _____V
Voltage of Zn with Ag = _____V
Voltage of Zn with Zn = 0.00 V *(There is a second Zn plate for you to check this value.)*

Please arrange these metals in a *Hierarchy of Voltages*, from the most positive voltage to the least positive voltage while using Zinc as your reference. List the corresponding voltages and check the column that mentions whether this metal GAINS or LOSES electrons from Zinc:

	Metal	Voltage	GAINS e^-	LOSES e^-	Neither
Most (+) Voltage	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
Least (+) Voltage	_____	_____	_____	_____	_____

Q: From your textbook, what are the definitions of oxidation and reduction?

Oxidation:

Reduction:

b) You decide to double check this Hierarchy of Voltages with other metals as your reference by making the corresponding data tables on your own paper. ALWAYS KEEPING THE BLACK LEAD CONNECTED TO THE "REFERENCE", you collect the following data:

Data Table 2: (Cu as a "Reference")

Voltage of Cu with Pb = _____V
Voltage of Cu with Zn = _____V
Voltage of Cu with Fe = _____V
Voltage of Cu with Ag = _____V
Voltage of Cu with Cu = 0.00V

Please arrange these metals in a *Hierarchy of Voltages*, from the most positive voltage to the least positive voltage while using COPPER as your reference. List the corresponding voltage and check the column that mentions whether this metal GAINS or LOSES electrons from COPPER:

	Metal	Voltage	GAINS e^-	LOSES e^-	Neither
Most (+) Voltage	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
Least (+) Voltage	_____	_____	_____	_____	_____

Data Table 3: (Ag as a "Reference")

Voltage of Ag with Pb = _____V
Voltage of Ag with Cu = _____V
Voltage of Ag with Fe = _____V
Voltage of Ag with Zn = _____V
Voltage of Ag with Ag = 0.00V

Please arrange these metals in a *Hierarchy of Voltages*, from the most positive voltage to the least positive voltage while using SILVER as your reference. List the corresponding voltage and check the column that mentions whether this metal GAINS or LOSES electrons from SILVER:

	Metal	Voltage	GAINS e^-	LOSES e^-	Neither
Most (+) Voltage	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
Least (+) Voltage	_____	_____	_____	_____	_____

Data Table 4: (Pb as a "Reference")

Voltage of Pb with Zn = _____V
Voltage of Pb with Cu = _____V
Voltage of Pb with Fe = _____V
Voltage of Pb with Ag = _____V
Voltage of Pb with Pb = 0.00V

Please arrange these metals in a *Hierarchy of Voltages*, from the most positive voltage to the least positive voltage while using LEAD as your reference. List the corresponding voltage and check the column that mentions whether this metal GAINS or LOSES electrons from LEAD:

	Metal	Voltage	GAINS e^-	LOSES e^-	Neither
Most (+) Voltage	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
Least (+) Voltage	_____	_____	_____	_____	_____

Data Table 5: (Fe as a "Reference")

Voltage of Fe with Pb = _____V
Voltage of Fe with Cu = _____V
Voltage of Fe with Zn = _____V
Voltage of Fe with Ag = _____V
Voltage of Fe with Fe = 0.00V

Please arrange these metals in a *Hierarchy of Voltages*, from the most positive voltage to the least positive voltage while using IRON as your reference. List the corresponding voltage and check the column that mentions whether this metal GAINS or LOSES electrons from IRON:

	Metal	Voltage	GAINS e^-	LOSES e^-	Neither
Most (+) Voltage	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
	_____	_____	_____	_____	_____
Least (+) Voltage	_____	_____	_____	_____	_____

Q: What do you notice about all of these lists of "Hierarchy of Voltages"? Is there a pattern that you see emerge? (Please discuss this pattern and how it relates to the Activity Series…page 131 of your text.)

Part C: It's go time!

It's time to think, now. You only have 10 minutes left and you need to HELP Juan into the qualifying heat!

Q: What COMBINATIONS of metals with the two lemons offer a voltage of 1.4V or greater to get his car to "flinch" off the starting blocks? (Remember, only use what is in Juan's tool box…)

Please test this system with your DVM, not the motor, finding a voltage no less than 1.4 volts. Draw a picture of the lemons, metals, and connections that need to be made with the DVM, below:

Now make another drawing below, but this time using electronic symbology to draw the electronic circuit that would make Juan's car motor turn in a clockwise direction:
(Note: If you test these lemon batteries with the motor that's provided, it won't not work. This is because this motor draws too much current to operate. Don't worry, though, Juan's motor draws much less current and will move with your set-up.)

Conclusions: (You may continue your conclusion onto the back of this page, if you wish.)

Research Extension #2:

Quantitative Analysis of Fluorescein Sodium Salt in an aqueous solution.

During this research extension, your task is to determine the molarity (M) of Fluorescein Sodium Salt that is dissolved in a solution of water. Before you get to this point, however, you will work with your 'Research Advisor' (TA) and explore the chemistry of this system together and how this task may be performed. The chemical reagents for this project are not common to household products, but similar fluorescent materials can be found in nature.

Your Research Question:

What is the concentration of the aqueous Fluorescein Sodium Salt solution: Unknown X?

Background Information and Keywords:

Fluorescein Sodium Salt is used as a dye in industry for creating colored textiles. Most recently, however, other fluorescein molecules are used as markers in biochemistry for 'tagging' DNA molecules. As various forms of fluorescent molecules are created to interact with particular DNA sequences, they not only indicate whether a certain DNA sequence exists in a solution, but help in the QUANTITATIVE ANALYSIS of the DNA sequence in question. *Quantitative analysis* is best described as the scientific measurement of *quantity*.

Your Research Materials:

You will be given a known stock concentration of aqueous Flourescein Sodium Salt (Standard), an Unknown X concentration of Flourescein Sodium Salt, , a set of LED's that range from BLUE to INFRA-RED, a six-Color LED Colorimeter with light cover, and the corresponding glassware that is required to solve this problem.

Some Questions that need to be addressed:

1) Which LED creates the best fluorescence? (Use your eyesight and different LED's to determine.)

-How is this phenomenon similar to today's lab?

-How is this phenomenon different than today's lab?

2) What color do you see 'fluorescing' at 90 degrees from the light source?

-Does this fluorescent material give off the same color that is causing it to flouresce?

-Is the color that "fluoresces" a higher or lower energy wavelength of light than what is being '*absorbed*' by the aqueous solution of Fluorescein Sodium Salt?

3) What is the correlation between the intensity of 'fluorescence' and the different concentrations of aqueous Fluorescein Sodium Salt?

-What equation best fits this phenomenon of fluorescence vs. concentration?

-How can we use this equation that fits our observations of fluorescence vs. concentration in order to help us 'quantify' the approximate concentration of our Unknown X concentration of Fluorescein Sodium Salt?

4) What is the concentration of the Unknown X concentration of Fluorescein Sodium Salt?

Particular Hazards you need to know about:

Although you will not be working with this substance in a dry powder form, you should know that it is a skin irritant and should be washed thoroughly for 15 minutes if you come into contact with it. If you come into contact with the solution at any time during the lab period, be sure to get to the sink and begin flushing with copious amounts of water. Let your TA know that this has happened as soon as possible.

If you feel more comfortable working with plastic gloves, please use the gloves supplied within the lab.

Oral Report

10 + 28.5

38.5/40

Quantitative Analysis of Fluorescein Sodium Salt in a Solution of Water

Research Extension #2
CHEM 131 -15
Instructor: Tim Sorey
24 February 2004

Student Sample Report

No need for cover page ... save some paper.

R.E.#2 - Fluorescence Report – Page 1

Introduction

Fluorimetry is the study of materials that emit light or radiation under certain conditions. In the type of fluorescence studied in our lab group, the material absorbed a certain wavelength of light and then emitted another. The nature of this absorption-emission lies in electrons absorbing energy – hereby rising to a higher energy level. Then the electron "falls" back to its previous energy level, releasing a photon of light in the process (1).

Fluorescence was observed in the early 19th century in both minerals and solutions. Sir David Brewster observed the emission of "blood red" light when chlorophyll was exposed to strong sunlight. Sir G. G. Stokes successfully explained the phenomena of absorption-emission in the fluorescence of the mineral fluorospar. In 1669, the element phosphorus was discovered and found to produce light when observed in a dark room. The element was given its name after the Greek word meaning "light bearing" (1).

The study of fluorescence has many uses in our society today. Fluorescent materials may be used as probes into the internal mechanisms of living cells. The fluorescent materials can be made to interact with certain enzymes in cells to track their movement within a functioning cell. This method could be used to observe the metabolic pathways through a cell (2).

Many living objects naturally exhibit fluorescent characteristics. Such an example is phytoplankton. Phytoplankton is a type of algae abundant in the oceans. The European Space Agency's MERIS instrumentation aboard the Envisat satellite can remotely sense radiation emitted from the Earth, and in 2002 detected a large phytoplankton bloom near Newfoundland, Canada. The plankton absorbed light in the blue spectral range and emitted some of the energy back in the red spectral range (3).

Other uses of fluorescent molecules are shown in agriculture. The can be used to study life processes of organisms as explained above. They may also be used to tag various sprays to determine their environmental drift (1). Fluorescent properties of known substances are also used in forensics to analyze materials found in crime scenes (2).

The fluorescent property of a substance may also be used in quantitative or qualitative analysis, as performed in our research extension. In our experiment, we had an unknown concentration of Fluorescein Sodium Salt solution (aq). We observed this material to emit green wavelength light while absorbing light within the blue range of visible light. The intensity of fluorescence increased as the concentration of the solution increased. By comparing the fluorescent intensity of the unknown with that of several known concentrations we would be able to estimate its concentration.

Sources:

1. *Fluorescence Analysis*, by White and Argauer: Copyright 1970 by Marcel Dekker Inc. New York, New York.
2. *Fluorescence Assay*, by Sidney Udenfriend: Copyright 1969 by Academic Press. New York, London.
3. Envisat's MERIS captures phytoplankton bloom. 13 November 2002, European Space Agency, Available: http://www.esa.int/esaSA/ESA4VK8OS7D_earth_3.html

Materials:

(2) 50 mL flask
50 mL beaker
flask with unknown "X" solution
LED detector
(2) eye droppers

Safety Data for Flourescein Sodium Salt in aqueous solution

Health Hazards (Acute and Chronic): May be harmful by inhalation, ingestion, or skin absorption. Causes eye and skin irritation. Marterial is irritating to mucous membranes and upper respiratory track.

Control Measures:

Respiratory Protection:	Necessary.
Ventilation, Local Exhaust:	Fume hood.
Mechanical:	Necessary.
Protective Gloves:	Rubber gloves.
Eye Protection:	Chemical safety goggles.
Other protective Clothing or Equipment:	Necessary.

-Do not permit eating, drinking, or smoking near material.
-Store in a cool, dark and dry place

} Nice job!

Procedure and Observation:

1. We observed different LED's shown through an aqueous Flourescein Sodium Salt solution.
   OBS: the best and only fluorescence came from the blue LED .
2. We set up microlab with its LED detector.
3. We cleaned our glassware and droppers before beginning the experiment.
4. We took the aqueous flourescein sodium salt solution, and we put 15 drops in a glass flask. We then filled it with water to a specified amount of 50 mL.
5. We put the mixed solution in to a separate, pre-washed beaker and placed it in an LED detector and recorded the results for a calibration test.
6. We then cleaned out our glassware and repeated the procedure another three times for amounts of 30, 45, and 60 drops of the sodium salt solution.
7. We created a calibration to measure the concentration of the flourescein sodium salt solution in drops by using flourescence.
8. We took our unknown solution X and placed it in the same measuring beaker we had cleaned and used before.
   OBS: we found that by using our calibration, we found our unknown solution X to be equal to 29.6 drops, or about 30 drops of the sodium salt solution.

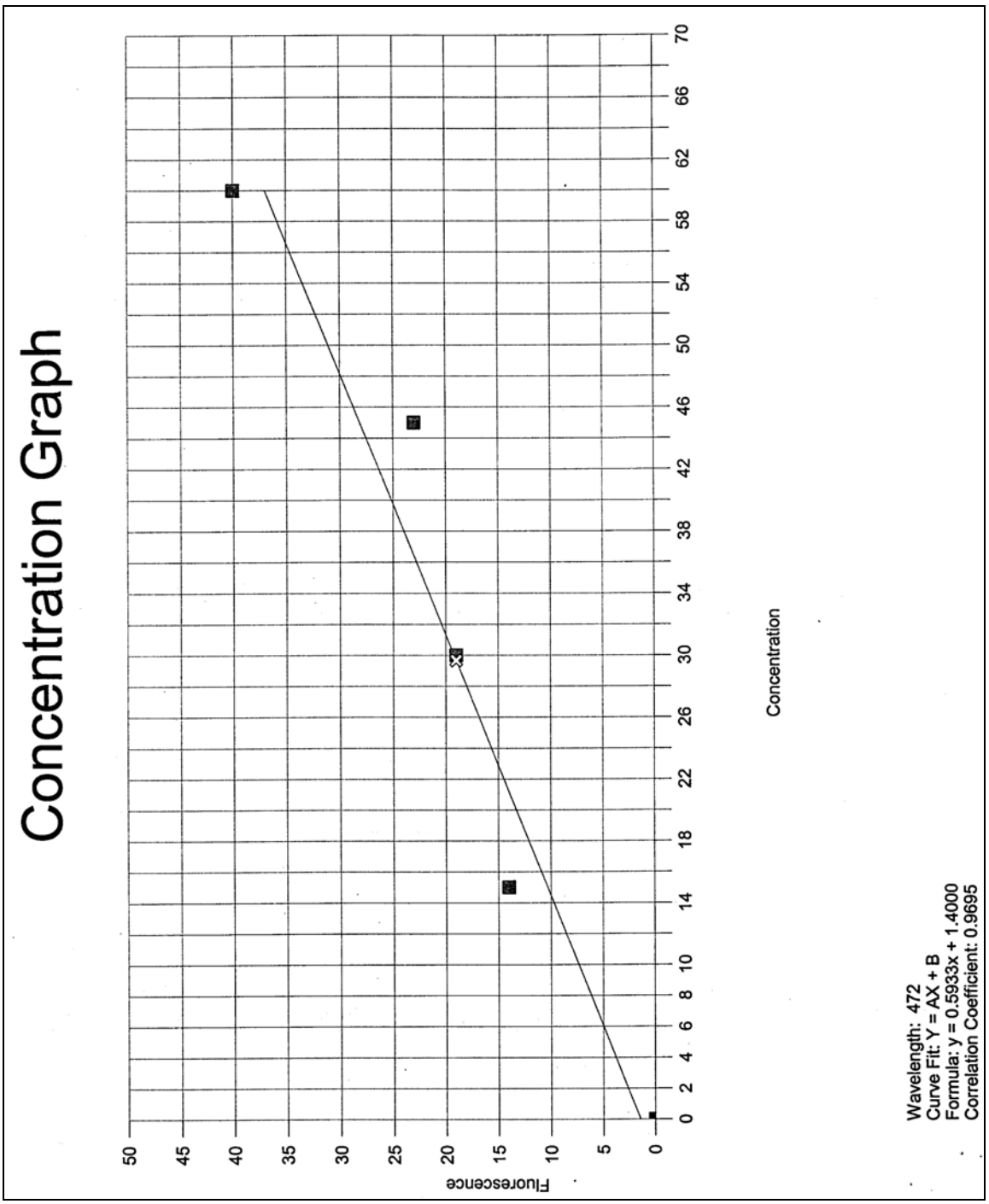
Data:

See attached tables and graphs

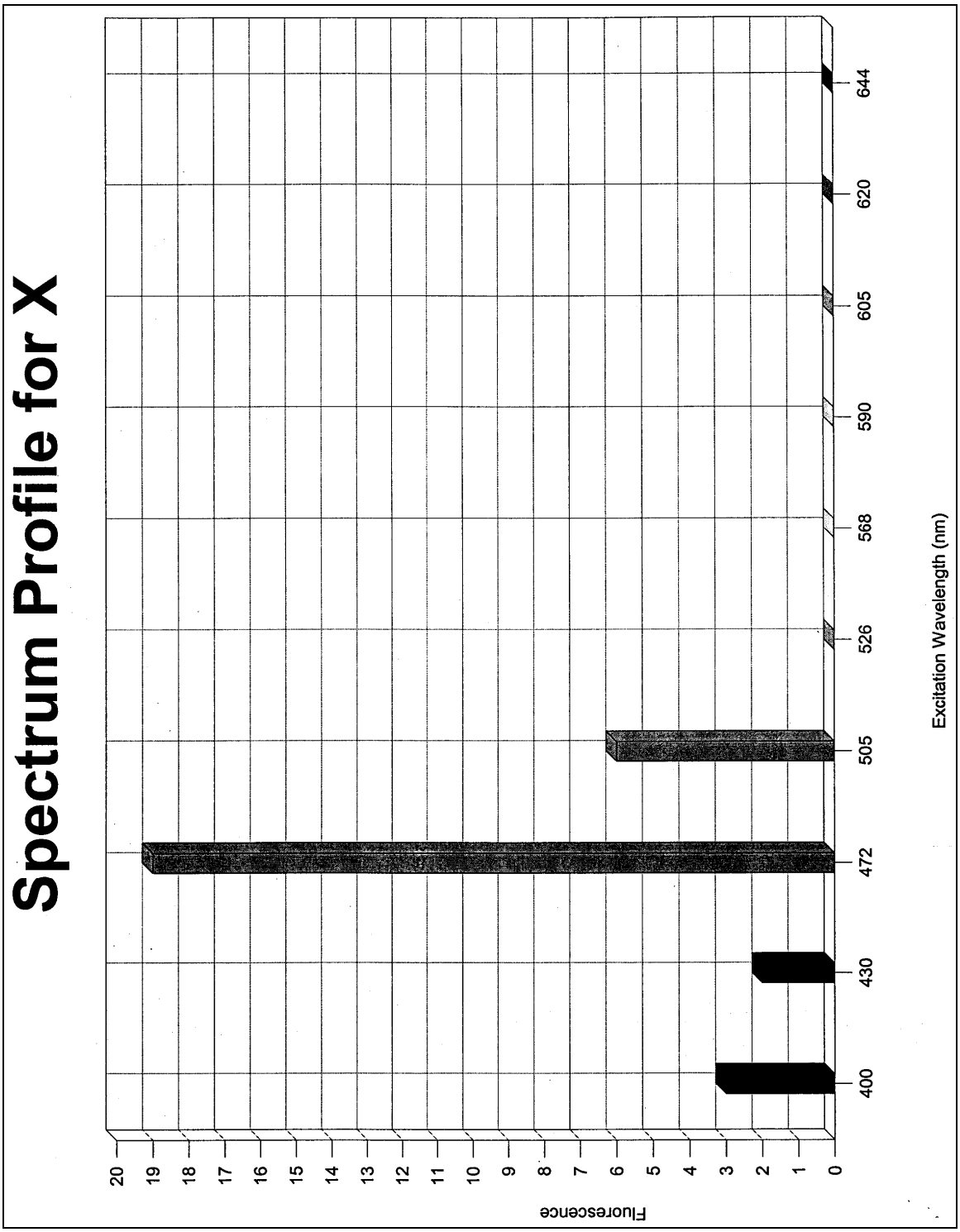
OK

Calculations and Data Analyses:

$$\frac{29.663\ drops}{50\ mL} \cdot \frac{.0041\ mL}{1\ drop} \cdot \frac{5.5\times10^{-6}\ mol}{L} = 1.34\times10^{-9}\ M$$



R.E.#2 - Fluorescence Report – Page 4



R.E.#2 - Fluorescence Report – Page 5

ORAL SEMINAR Grading Sheet
CHEM 131

TITLE: Flourimetry
DATE: 2/24/04

Group members: Section #15

10 pts possible– Oral Report Presentation

The breakdown is as follows:

1 pt – A "Preparation Meeting" with the lab instructor prior to your presentation was held. The meeting time and place was scheduled upon the conclusion of the laboratory that is to be presented.

1.0 pts. awarded Meeting time and Place: LAST WEEK

1 pts – A title sheet and outline of your oral report was placed on an overhead. (This helps you to show the logic of your discussion and helps the audience to know where you are going with this discussion.)

1.0 pts. awarded

3 pts– At least two chemical equations, calculations, chemical structures, and/or instrumentation circuit diagram was shown in front of the class on the overhead or chalkboard.

3.0 pts. awarded 1) ☆ calculation of molarity
2) Calibration graph

5 pts – All group members contributed equally in some aspect of technical information .

5.0 pts awarded

0 pts will be assigned to individuals who don't show or don't contribute to their group reports.

Names of people who did not attend:

Q ① Fluorescence I [C] Good exploration

Q ② Use same cuvette? A – reproducible $ Scratches can be "calibrated"

R.E.#2 - Fluorescence Report – Page 6

Research Extension #3:

Quantitative Analysis*:* Solving for concentration of Ba ion in solution.

You will apply your knowledge of spot testing with that of Turbidimetry and Nephalometry to determine what and how many Barium ions are in solution. Think of the type of data that are required for you to prove your case of what ions exist in an aqueous solution that you are given.

Some Helpful hints:

Look at your spot test and you recall what occurs between a solution of $Ba(NO_3)_{2\,(aq)}$ and $H_2SO_{4(aq)}$.....a precipitate forms, making the solution turbid!. You will use a stock solution of $2.0X10^{-3}M$ $Ba(NO_3)_{2\,(aq)}$ to create different dilutions, placing only a few drops of 3M $H_2SO_{4(aq)}$ to create the $BaSO_{4(s)}$ precipitate.

Be sure to create a set of standard solutions as indicated in the table below, thoroughly stirring the $BaSO_{4(s)}$ solution and wiping the cuvette of any finger prints before scanning with the colorimeter, since it is not truly a colloidal solution. This is, rather, a heterogenous solution and can start to 'settle out' within 20 minutes, so work fast! Using MicroLAB's 10-Color Colorimeter and software, you will create a calibration curve of known standards.

Your Research Question:

What quantity of Barium ions in this aqueous solution?
(TAKE NOTES in your lab book and print-out the graphs that are generated for your presentation next week.)

Your Research Objectives of this Research Extension:

- Apply your knowledge of the nature of light and the light scattering nature that can occur with particles. From this, analyze.
- Apply your knowledge of the previous class experiments, dilution concentrations, and the resultant SCATTER or %TRANSMISSION spectra in order to solve your research question.

Some key vocabulary you should be able to use after this section are:

Scatter *Turbidimetry* *Nephelometry* *Colloid* *Heterogeneous*

Some Questions that need to be addressed:

1) What qualitative data, from the spot test, helped you deduce your approach in solving the concentration of this aqueous Barium Nitrate solution?
2) What does your turbidimetric or nephalometric data suggest about the concentration of your Barium Nitrate solution.

Dilution Strategies for Nephelometry/Turbidimetry:

1) Stock Concentration of $Ba(NO_3)_2$ is $\underline{2.0\ X10^{-3}\ M.}$
2) Mix your concentrations with your 10.0mL graduated cylinder.
3) Put 4 drops of 3M H_2SO_4 in the diluted 20.0mL standard solutions and swirl for at least 3 minutes before scanning with the 10-color colorimeter.
4) Measure out 20.0mL of the unknown $Ba(NO_3)_2$ concentration and follow step three, above.

$$V_1*M_1 = V_2*M_2$$

Group #	$[Ba(NO_3)_2]$ $X10^{-3}$ M	(mL) of $[Ba(NO_3)_2]$	(mL) of D.I. Water	Total (mL) of Solution
1	2.0			20.0
2	1.0			20.0
3	0.50			20.0
4	0.25			20.0

Show calculations below:

Research Extension 3: Solving for concentration of Ba ion in a solution

Student Sample Report

24/30

Intorduction

This report covers both the research extension and the scheduled laboratory. In most cases the laboratory, which was conducted prior the starting the research extension, provided the needed background information that allowed the research group to conduct the laboratory.

Purpose

The overall purpose of both the laboratory and the research extension were to show how the optical properties of a solution could be used to extract information about the composition of the solution. The properties that were introduced in this laboratory are colorimetry, fluorimetry, turbidimetry, and nephelometry. In the general laboratory these concepts and the laboratory device, which allowed for their measurement, the MicroLab colorimeter, were introduced. The research extension the applied these concepts to the determination of the concentration of $Ba(NO_3)_2$ in a solution. The overall focus of the experiment was to determine how the light absorption and light scatter characteristics of the aqueous solution were affected by the concentration of the solution. Through this relationship a "calibration curve" was established from which the unknown concentration could be determined.

Research Extension Overview

We were given a stock solution of 2.0x10-3 M $Ba(NO_3)_2$ (aq) and created different dilutions. 3 M H_2SO_4 (aq) was used to form a $BaSO_4$ (s) precipitate. MicroLab was used to take reading of the scatter and %Transmission. From this a calibration curve was made which allowed for us to solve for the unknown. The concentration of the unknown was found to be 1.46x10-3 M.

MSDS Data

1.Barium Nitrate:
- Health Risk – 3 – Severe
- Flammability – 0 –None
- Reactivity – High
- Strong Oxidizer
- Contact should be kept to a minimum

1

R.E.#3 - Barium Ion Determination Report – Page 1

2.Sulfuric Acid
Health Risk – minor – burns are a concern
Flammability – flammable with acetone, alcohols or metals
Contact should be kept to a minimum

3.Barium Sulfate
Health Risk – 1 – Slight
Flammability – 0 – None
Reactivity – 1 - Low
Contact should be avoided, but overall this is not a very dangerous product

(You could put the reference – the source of this info. web address etc ...)

General Laboratory Procedure

Note on procedures, many of the procedures such as the preparation of solutions or the use of the colorimeter were repeated many times throughout this experiment. For these steps in the procedure a note is made referring to a more in depth explanation located at the end of this report.

Part 1. Colored Solutions and Colorimetery

Exercise A. Survey of Colored Solutions
1.We obtained five different clear colored solutions.
2.We used MicroLAB 10-Color Colorimeter was used to form spectral charts for each solution. For procedures on the use of the colorimeter see the proper use of the colorimeter on **PAGE 8** of the report.
3.We then matched the MicroLAB spectral charts to the ones on our spectral chart worksheet in order to identify their corresponding colors.
OBS. The color of the substance seemed to have the highest or one of the highest percentages of transmission for its substance, which makes sense because that color is the one being transmitted through the substance instead of absorbed.

Exercise B. Quantizing Colored Solutions
1. The standard concentration of food coloring 2.5x10-5 M was diluted to produce solutions of:
$2.5x10^{-5}$ M, $1.24x10^{-5}$ M, $0.620x10^{-5}$ M, $0.310x10^{-5}$ M
2.For the procedure followed in the preparation of the different solutions see the preparation of dilutions section on **PAGE 8** of this report
3.The calculations done to calculate these concentrations are located on **PAGE 10** of this report.
4.The colorimeter was then used to establish a calibration curve that allowed for the determination of concentration of the unknown solution. For the procedure of establishing a calibration curve with the colorimeter see **PAGE 11** of this report.
OBS. When more of the substance is present the percent transmission will be less. The main relationship that we observed through this was that

R.E.#3 - Barium Ion Determination Report – Page 2

between percent transmission and absorption. We learned that they are related through the equation, absorption = -log (%transmission/100)

Part 2. Quantizing an Aqueous Solution of Na-Flourescein

Exercise C:

1. Pre-made solutions of Na-Flourescein were obtained
2. The molarity of each of these solutions was calculated from the information given. For these calculations see **PAGE 12** of this report.
3. The colorimeter was then used to measure the fluorescence of the solutions, establishing a calibration curve that was used to determine the concentration of the unknown. See **Page 13** for curve.

   OBS. The substance absorbed wavelengths, causing it to excite and readmit different color spectra. A change in phenomenon of fluorescence is related to the change of the concentration. When forming the calibration curve we used the highest fluorescence or largest slope.

Part 3. Spot Tests ↳ which wavelength was it ?

1. We were given a spot plate, spot test reagents, and a mixing matrix.
2. We mixed the reagents in pairs.

   Obs. Refer to Matrix Mixing guidelines and Observations Sheet on **PAGE 4** for reagents pairs and for observed reactions.
3. The balanced equations for all precipitate forming reactions was determined.

Procedure – Research Extension

1. The stock solution of the $Ba(NO_3)_2$ and deionized water was used to create four concentrations that were used in the experiment. The solutions which were made are as follows $2.0x10^{-3}$ M, $1.0x10^{-3}$ M, $0.50x10^{-3}$ M, and $0.25x10^{-3}$ M. The amount of stock solution and the amount of deionized water was calculated, the sheet attached at the end of this report for these calculations. Once calculated the 10 mL graduated cylender was used to measure out the proper amounts of each and the solutions were mixed in the beakers available to us in lab.

   The next steps of the procedure was repeated for each of the four solutions.
2. Four drops of 3M H_2SO_4 was added to the diluted solution. This new solution was swirled for at least 3 minutes.

   OBS: After the addition of the H_2SO_4 the solution became milky. This is evidence o f the precipitate $BaSO_4$.

3. The solution was the placed in the 10 color colorimeter used in MicroLab. The %Transmittance and scattering was measured for each of these 10 colors. For notes on proper use of the colorimeter see **PAGE 8** of this report.

4.Steps 2 and 3 were then repeated for each of the diluted solutions in the order of decreasing morality.

5.Using the MicroLab readings for each of these concentrations a calibration curve could be produced in MircoLab. For notes on the creation of a calibration curve see on **PAGE 8** of this report.
OBS: With increasing concentration of the solution the %Transmitance decreased.

6.The H2SO4 was then added to 20 mL of the solution of unknown molarity, this solution was swirled for three minutes as done with all previous solutions and was then placed in the colorimeter. For proper procedure for colorimeter use see **PAGE 8** of this report.

7.Once the data had been taken by the colorimeter MicroLab and the calibration curve produced, see **Page 14**, using this data could be used to determine the molarity of the unknown.

Data

Colored Solutions Colorimetery

Exercise A. Survey of Colored Solutions

The data in the form of the spectrum charts that are matched to the colored solutions, which were tested using the colorimeter, are found in the data and graph section at the end of this report

Exercise B. Quantizing Colored Solutions

The calibration curve which was developed in this experiment is located in the data and graphs section at the end of this report.

Na-Flourescein Data

This section of the laboratory produced a MicroLab calibration curve that is located in the data and graphs section at the end of this report.

Spot Test Matrix Observations

	HCl	HNO3	H2SO4	KSCN	K2CrO4	NH4OH
Fe(NO3)3	Yellowish Color	NR	NR	Deep Red Color	NR	Yellow/ Orange Precipitate
Ba(NO3)3	NR	NR	White Precipitate	NR	Yellow Precipitate	NR
AgNO3	White Precipitate	NR	NR	Light Blue Precipitate	Rust Colored Precipitate	Brown Precipitate, disappeared after 2nd drop
Ni(NO3)2	NR	NR	NR	Blue/Green Precipitate	Light Yellow Color	Light Transparent Blue
Pb(NO3)2	Cloudy White Color	NR	Cloudy White Color	NR	Cloudy/Dark	Cloudy White
CuSO4	NR	NR	NR	Slight Lime Green Color	Cloudy/Dark	Blue/Cloudy

Research Extension Data

MicroLab Colorimetry Data				
Sample	Concentration x 10^-3 M	%Transmittance	Absorbtion	Scatter
Calibration	0.00	100	0.00	0.00
1	2.00	22.95	0.64	511
2	1.00	34.80	0.46	335
3	0.50	55.85	0.25	187
4	0.25	51.69	0.29	173
Unknown	1.46	29.57	0.53	370

Note: The calibration curve that was produced with MicroLab using the values listed above and used to determine the value of the unknown is attached at the end of this report.

Data Analysis

Much of this laboratory experiment is unique in that the actual data analysis of the experiments took place within MicroLab. Were possible the calibration curve which was used in this analysis has been attached at the end of this report.

5

Spot Test Balanced Equations

The data from the spot tests indicates that in many of the mixtures a reaction took place which resulted in the formation of a precipitate. In the cases were a reaction was shown to have taken place, the formation of a solid precipitate, the balanced chemical equations were determined. Those equations are located below.

$Fe(NO_3)_{3(aq)} + 3HCL_{(aq)} \Rightarrow FeCl_{3(s)} + 3H(NO_3)_{3(aq)}$

$Fe(NO_3)_{3(aq)} + 3KSCN_{(aq)} \Rightarrow Fe(SCN)_{3(s)} + 3K(NO_3)_{(aq)}$

$Fe(NO_3)_{3(aq)} + 3NH_4OH_{(aq)} \Rightarrow Fe(OH)_{3(s)} + 3NH_4(NO_3)_{3(aq)}$

$Ba(NO_3)_{2(aq)} + H2(SO_4)_{(aq)} \Rightarrow Ba(SO_4)_{(s)} + 2H(NO_3)_{(aq)}$

$Ba(NO_3)_{2(aq)} + K_2(CrO_4)_{(aq)} \Rightarrow BaCrO_{4(s)} + 2KNO_{3(aq)}$

$Ag(NO_3)_{(aq)} + HCl_{(aq)} \Rightarrow AgCl_{(s)} + H(NO_3)_{(aq)}$

$Ag(NO_3)_{(aq)} + K(SCN)_{(aq)} \Rightarrow Ag(SCN)_{(s)} + K(NO_3)_{(aq)}$

$2Ag(NO_3)_{(aq)} + K_2(CrO_4)_{(aq)} \Rightarrow Ag(CrO_4)_{(s)} + K_2(NO_3)_{(aq)}$

$Ag(NO_3)_{(aq)} + NH_4(OH)_{(aq)} \Rightarrow Ag(OH)_{(s)} + NH_4(NO_3)_{(aq)}$

$Ni(NO_3)_{2(aq)} + 2K(SCN)_{(aq)} \Rightarrow Ni(SCN)_{2(s)} + 2K(NO_3)_{(aq)}$

$Ni(NO_3)_{2(aq)} + K_2(CrO_4)_{(aq)} \Rightarrow Ni(CrO_4)_{(s)} + 2K(NO_3)_{(aq)}$

$Ni(NO_3)_{2(aq)} + 2NH_4(OH)_{(aq)} \Rightarrow Ni(OH)_{2(s)} + 2NH_4(NO_3)_{(aq)}$

$Pb(NO_3)_{2(aq)} + HCl_{(aq)} \Rightarrow PbCl_{2(s)} + 2H(NO_3)_{(aq)}$

$Pb(NO_3)_{2(aq)} + H_2(SO_4)_{(aq)} \Rightarrow Pb(SO_4)_{(s)} + 2H(NO3)_{(aq)}$

$Pb(NO_3)_{2(aq)} + 2NH_4(CrO_4)_{(aq)} \Rightarrow Pb(CrO_4)_{(s)} + 2K(NO_3)_{(aq)}$

$Pb(NO_3)_{2(aq)} + 2NH_4(OH)_{(aq)} \Rightarrow Pb(OH)_{2(s)} + 2NH_4(NO_3)_{(aq)}$

$Cu(SO_4)_{(aq)} + 2K(SCN)_{(aq)} \Rightarrow Cu(SCN)_{2(s)} + K_2(SO_4)_{(aq)}$

$Cu(SO_4)_{(aq)} + K_2(CrO_4)_{(aq)} \Rightarrow Cu(CrO_4)_{(s)} + K_2(SO_4)_{(aq)}$

$Cu(SO_4)_{(aq)} + NH_4(OH)_{(aq)} \Rightarrow Cu(OH)_{(s)} + (NH_4)_2(SO_4)_{(aq)}$

6

Accuracy of the research extension prediction

The experimentally determined molarity for the unknown solutions of $Ba(NO_3)_2$ was $1.46x10^{-3}$ M. The actual value given in the laboratory for the molarity of this solution was $1.50x10^{-3}$ M. The calculation of the % error in the experiment is shown below.

$(1.50x10^{-3}\ M - 1.46x10^{-3}\ M) / 1.50x10^{-3}\ M * 100\ \% = 2.67\%$ error

Conclusion

The experimental value found in the laboratory for the concentration of $Ba(NO_3)_2$ in the unknown solution was $1.46x10^{-3}$ M. The experiment was conducted with care that leads to the accuracy that is shown in the calculated error. This error was found to be 2.67% this is well below the accepted level of experimental error of 10%. This leads to the conclusion that the experiment was properly conducted and that the calculated value for the unknown can be trusted. By applying the concepts of colorimetry, turbidimetry, and nephelometry we were able to determine the optical properties of a solution and extract information that allowed for the determination of the unknown.

* In concl. section, talk about ALL parts (including regular lab) of yr expt.

(-5) * Real Life application ?

* There were some terms that I was looking for in concl.. Such as

(-5) Path-Length, Lambda Max, Beer's Law.

etc...

Otherwise this lab report has a lot of great discussions & info !!

7

R.E.#3 - Barium Ion Determination Report – Page 7

Excellent !!

Procedures Repeated Throughout the Laboratory Experiments

Establishing a Calibration Curve

The MicroLab colorimeter program has the ability to establish a calibration curve which can be used to determine the properties of a unknown solution. Within the program as the measurements are taken a name and the value for the property which varies between the known solutions is recorded. Once an adaquite number of data points have been taken MicroLab can produce a curveof best fit which allows the determination of the quantity of the variable property in the unknown solution.

Proper Procedure for Preparing Dilutions

The first step in the preparation of a dilution from a stock solution is to solve the ratio of stock solution to deionized water for each desired molarity. This ratio can be determined through the use of the equation $M_1V_1=M_2V_2$. This equation can be solved for any one of the variables to determine the amount of solution needed for a desired molarity or for the molarity of a specified ration of solutions. In all experiments in this laboratory 20 mL of each concentration was made. The equation mentioned before provides the amount of the stock solution needed to make 20 mL of the desired solution. The solution was then made by adding deionized water to bring the total amount of the new solution to 20mL. It is very important when making a solution to ensure that any glassware used is free on any contaminants. When filling a vile for use in the colorimeter with a solution it is important to rinse the vile at least three times with a small amount of the solution. This reduces any error in the experiment by removing any excess water, previous solution at different concentrations, or any other contaminants.

Proper use of the ten color colorimeter

The small chamber on the top of the MicroLab data acquisition box is a ten color colorimeter. When using this colorimeter there are many steps which must be taken to assure that your data is accurate. Before any solutions which have been prepared in lab can be tested the colorimeter needs to be calibrated. This is done by filling the vial which will be used in the rest of the experiment with deionized water and placing it in the chamber. MicroLab has a calibration routine to establish a zero point for the instrument. The readings which represent 100% transmittance and 0% scattering are determined by this calibration. It is very important in all future readings to used the exact same vile and to orient the vial in the exact same way as in this calibration. For this reason it is a good idea to place a mark both on the vial and the MicroLab box to allow the vial to be lined up the same in all tests run in the experiment.

8

$= \epsilon \ell [c]$ more abs → less trans

Part 1, Ex. B Colorimetry

Dilution Strategies for Colorimetry:

depends on 2 ↖ Good note $V_1 * M_1 = V_2 * M_2$

Group #	[Red#2] X10^{-5}M	(mL) of Stock Red #2	(mL) of D.I. Water	Total (mL)
1	2.47	20.0	0.00 mL	20.0
2	1.24	9.92 or 10 / 10		20.0
3	0.620	4.96 or 5 / 15		20.0
4	0.310	2.48 or 2.5 / 17.5		20.0

Show calculations below:

#1. $(2.47 \times 10^{-5})\ x = (2.47 \times 10^{-5})(20.0)$

$x = 20.0\ mL$

#2. $(2.5 \times 10^{-5})\ x = (1.24 \times 10^{-5})(20.0)$

$x = 9.92\ mL$

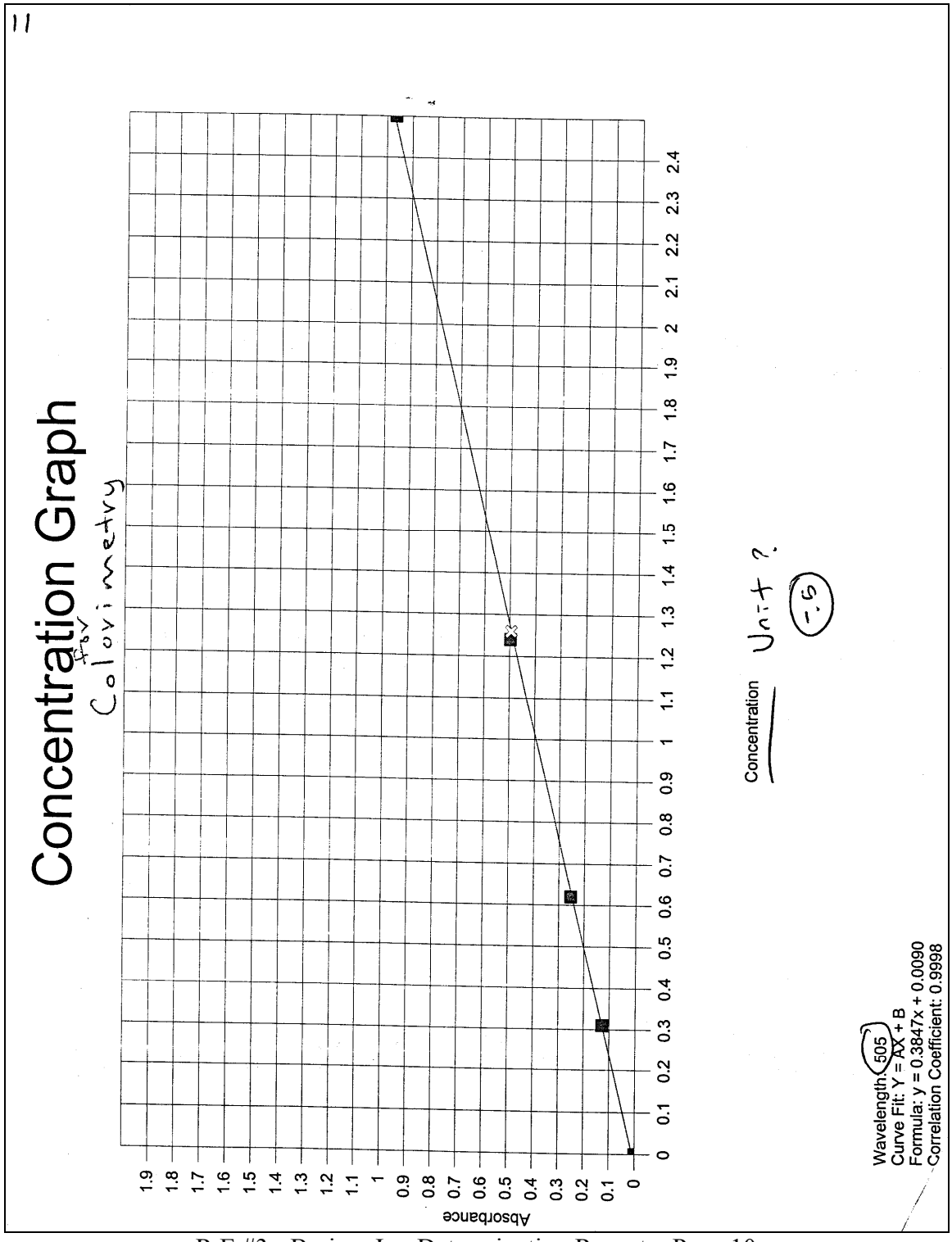
#3. $(2.5 \times 10^{-5})\ x = (0.620 \times 10^{-5})(20.0)$

$x = 4.96\ mL$

#4. $(2.5 \times 10^{-5})\ x = (0.310 \times 10^{-5})(20.0)$

$x = 2.48\ mL$

10



R.E.#3 - Barium Ion Determination Report – Page 10

Part 2, Ex. C — Na-Fluorescein

Dilution Strategies for Fluorimetry:

Stock Solution of NaFluoroscein = $5.5X10^{-6}M$ = M_1

$V_1*M_1 = V_2*M_2$

Group #	[Na-Fluor.] Molarity	(mL) of Stock Na-Fluor.	(mL) of D.I. Water	Total (mL)
1	2.2×10^{-7}	4.0	96.0	100.0
2	4.4×10^{-7}	8.0	92.0	100.0
3	6.6×10^{-7}	12.0	88.0	100.0
4	8.8×10^{-7}	16.0	84.0	100.0

Show calculations below:

#1. $(5.5\times10^{-6})(4.0) = x\,(100.0)$

$x = 2.2\times10^{-7}$

#2. $(5.5\times10^{-6})(8.0) = x\,(100.0)$

$x = 4.4\times10^{-7}$

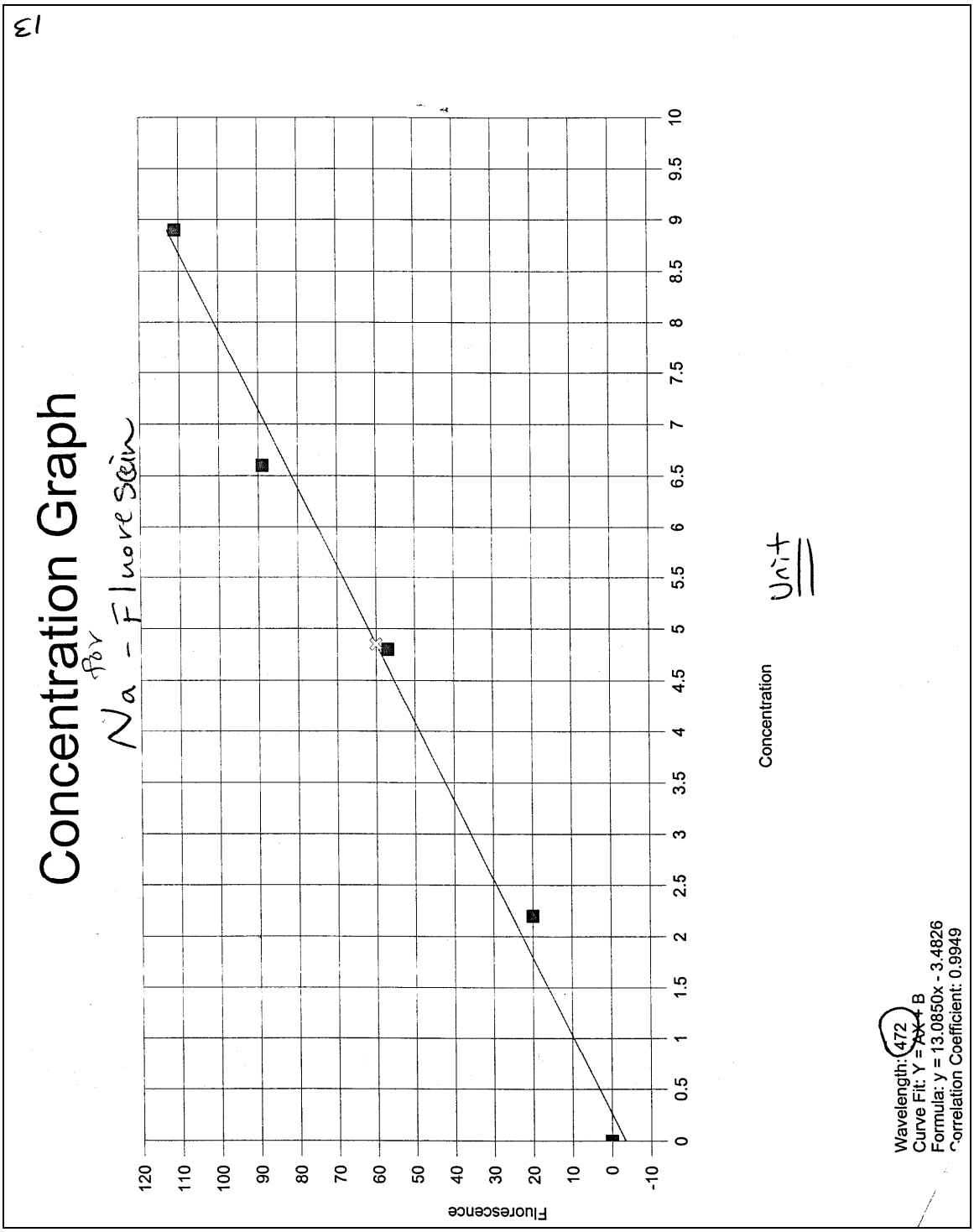
#3. $(5.5\times10^{-6})(12.0) = x\,(100.0)$

$x = 6.6\times10^{-7}$

#4. $(5.5\times10^{-6})(16.0) = x\,(100.0)$

$x = 8.8\times10^{-7}$

12



R.E.#3 - Barium Ion Determination Report – Page 12

Research Extension # 4

Using Conductivity to Quantitatively analyze Dissolved Solids in a Solution

Background information and Keywords:

At the beginning of the semester, you placed an electronic component within a circuit that *resisted* the flow of electrons, this was referred to as a *resistor.* You were able to measure the *resistanc*e of each resistor in ohms, Σ. Today, you will be placing something within an electronic circuit that *facilitates* the flow of electrons.

When something *facilitates* the flow of electrons, it's called a *conductor* and can be measured in inverse ohms (1/Σ) or semens (*s*). If ohms are the unit of measurement that reflects *resistance* within an electrical circuit, then semens are the units of measurement that measure *conductance* within an electrical circuit.

When a salt crystal dissolves in water, it ionizes and is dissolves. If these aqueous ions are then placed between two electrodes of opposite polarity, they are able to transport electrons from the cathode to the anode. This is the reason ions in an aqueous medium have been historically referred to as *electrolytes*. Differing concentrations of ions in solution will *conduct* electrons differently and can also be measured in units of conductance with a conductivity probe…this is where your research starts.

Your Research Questions:

What is the concentration of a *known* salt that has been dissolved in water? Is it possible to do the same thing for an unknown salt?

Your Research Problem Goals:

During this research extension, your tasks are to (a) create a calibration curve of a known salt solution with the conductance probe in semens vs. concentration, (b) identify the unknown concentration of the *same* salt via calibration curve analysis, and (c) create two more calibration curves from two different salt solutions. *(Be sure to address the questions below…)*

Your Research Materials and Chemicals:

an alkaline metal salt an alkaline earth metal salt an aluminum metal salt

deionized water volumetric glassware conductance probe - :LAB

conductance probe – Cole Parmer

Some Questions that need to be addressed:

1) What happens to the conductance of a solution as the concentration of electrolytes increases?

2) Can this knowledge be used to solve the unknown concentration of the same type of salt in an aqueous solution?

3) What about solving for an unknown concentration of an unknown salt in solution? (Why or why not may this be possible?)

Quantitative and Qualitative Analysis of an Ion Pair in an Aqueous Solution
-AND-
Using Conductivity to Quantitatively analyze Dissolved Solids in a Solution

Student Sample Report

1) Overview of regular experiment - Craig

2) Materials and Safety - Brandon

3) Diagrams for equipment - Conlin

4) Overview of research extension - Shea

Purpose Statement:

The purpose of our normal experiment was to find out the concentration and name of an unknown solution. We had to use our own knowledge to come up with the experiment we were going to perform to find this information out.

The second experiment we performed was our research extension. For this we had to find the concentration of an unknown solution. We did this by using the conductivity of the solution and comparing it to our calibration curve of known concentrations and conductivities.

Materials (normal experiment)

Unknown solution
Droppers
Microlab colorimeter
Glassware/graduated cylinders
Spot plate
Spot reagents
LEDs
Deionized water

Materials (research extension)

Conductance probes
$Cu(NO_3)_2$
Microlab
$NaNO_3$
$Al(NO_3)$
Glassware/graduated cylinders

Material Safety Data Sheet

Copper Sulfate: $CuSO_4$: A blue liquid, can cause eye irritation, may cause liver and kidney damage. Can cause digestive and respiratory tract irritation.

Copper Chloride: $CuCL_2$: Blue liquid. Harmful if swallowed. Can cause liver, kidney, and lung damage. Causes respiratory and digestive tract irritation Causes eye irritation. Can cause skin irritation.

Hydrochloric Acid: HCl: Clear liquid. Corrosive, harmful or fatal if swallowed. Harmful if inhaled. Causes severe eye and skin burns. Causes severe digestive and respiratory tract burns.

Nitric Acid: HNO_3: Clear to yellow liquid. Corrosive. Strong oxidizer. Contact with other material may cause a fire. Causes eye and skin burns. Check internal container upon receipt. Bottles should be vented periodically to relieve pressure. Causes digestive and respiratory tract burns.

Sulfuric Acid: H_2SO_4: Oily liquid. Causes eye and skin burns. May cause lung damage. Hygroscopic (absorbs moisture from the air). Causes digestive and respiratory tract burns. Contact with metals may evolve flammable hydrogen gas. May be fatal if mist

inhaled. Concentrated sulfuric acid reacts violently with water and many other materials with the evolution of heat. Strong inorganic acid mists containing sulfuric acid may cause cancer.

Potassium Thiocyanate: KSCN: Clear liquid. May cause eye, skin, respiratory and digestive tract irritation.

Potassium Dichromate: K_2CrO_4: Orange liquid. May cause allergic respiratory reaction. May cause allergic skin reaction. May cause cancer based on animal studies. Cancer hazard. May cause eye and skin irritation. May cause respiratory and digestive tract irritation.

Ammonium Hydroxide: NH_4OH: Clear liquid. Causes eye and skin burns. Causes digestive and respiratory tract burns. Harmful if swallowed.

Sodium Nitrate: $NaNO_3$: Clear liquid. Not as harmful in solution. In solid, strong oxidizer Contact with other material may cause a fire. May cause methemoglobinemia. Causes eye and skin irritation. May cause respiratory and digestive tract irritation.

Copper Nitrate: $Cu(NO_3)_2$: Clear liquid. Not as harmful in solution. In solid, strong oxidizer. Contact with other material may cause a fire. May cause methemoglobinemia. Causes eye and skin irritation. May cause respiratory and digestive tract irritation..

Aluminum Nitrate: $Al(NO_3)_3$: Clear liquid. Not as harmful in solution. In solid, strong oxidizer. Contact with other material may cause a fire. May cause methemoglobinemia. Causes eye and skin irritation. May cause respiratory and digestive tract irritation.

Procedures (normal experiment):

1) Did a spot test of our unknown.
OBS: it was either CuSO4 or CuCl because they were the only blue ones, and our unknown (z) was blue.
OBS: the spot test revealed that our unknown (z) had to contain Cu and Cl.
2) Tested the unknown's fluorescence with the LED's.
OBS: It did not fluoresce.
3) Mixed 4 solutions of CuCl2 (0.1, 0.075, 0.05, 0.025 M)
4) Calibrated the colorimeter.
5) Used colorimeter to test solutions' absorbance.
6) Graphed the information acquired in step 5 (absorbance vs. concentration).
7) Used colorimeter to test absorbance of our unknown (z).
OBS: concentration was 0.02 M.

Procedures (research extension):

1) Cleaned beakers with solution.
2) Diluted solutions from 0.1 to 0.01, 0.003, and 0.006 M.
3) Calibrated the conductance probe.
4) Created calibration curves for each solution. (AlNO3, NaNO3, and CaNO3)
5) Graphed each solution's conductivity curve.
6) Calculated each solution's concentration from the curve.

Calculations (normal experiment):

Y = 5.203X – 0.00000
Y = 5.203(0.2) – 0.000
Y = 1.0406 (absorbance vs. concentration)

0.1 M(20ml) = 20ml(X)
X = 0.1 M

0.075 M(15ml) = 20ml(X)
X = 0.056

0.05 M(10ml) = 20ml(X)
X = 0.025

0.025 M(5ml) = 20ml(X)
X = 0.006

Calculations (research extension):

M1(V1) = M2(V2)

(0.1M)(X) = (0.01M)(100ml)
X = 10ml
Mix 90ml H2O with 10ml of 0.1 M solution.

0.01 M(20ml) = 20ml(X)
X = 0.01 M

0.006 M(12ml) = 8ml(X)
X = 0.009 M

0.003 M(6ml) = 14ml(X)
X = 0.001

(0.00298 – 0.004)/0.004 = -25% error

Data analysis:

Please see attached graphs and spread sheets.

(normal experiment)

Unknown concentration of solution (z), was 0.02 M. We had no %error.
The absorbance of solution (z) was 0.105.

(research extension)

Conductance of unknown (z) was 0.2 semens.
Actual unknown concentration was 0.004 M.
Estimated concentration of unknown was 0.00298.

Practical Applications

Conductivity plays an important role in our lives. A big part is in human safety. You aren't suppose to go swimming during a lightening storm, the reason being that water conducts electricity well, and if the pool were to be struck by lightening, then you would be electrified. This is also why you don't use electric appliances near sinks or bathtubs. Ions are the major part of conductivity. These are what conduct currents. Ions play a more important role in our lives than most people think. You body uses ions to transport electrical impulses (nerve impulses and muscle contractions). The ions are better known as electrolytes. This is why you hear advertisements talking about sports drinks jam packed with electrolytes. They are designed to replace the electrolytes lost when you sweat.

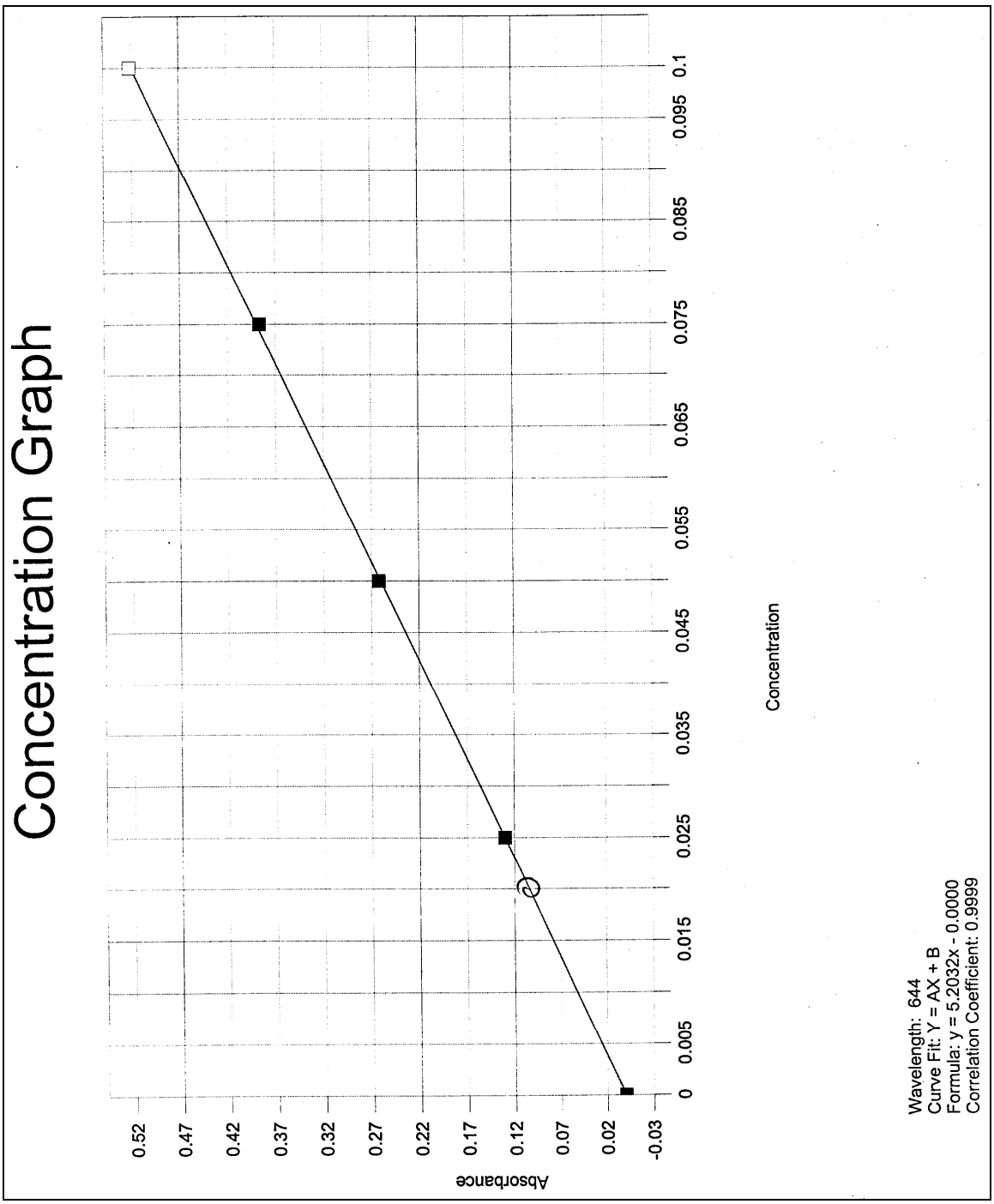
Conclusion:

(normal experiment)

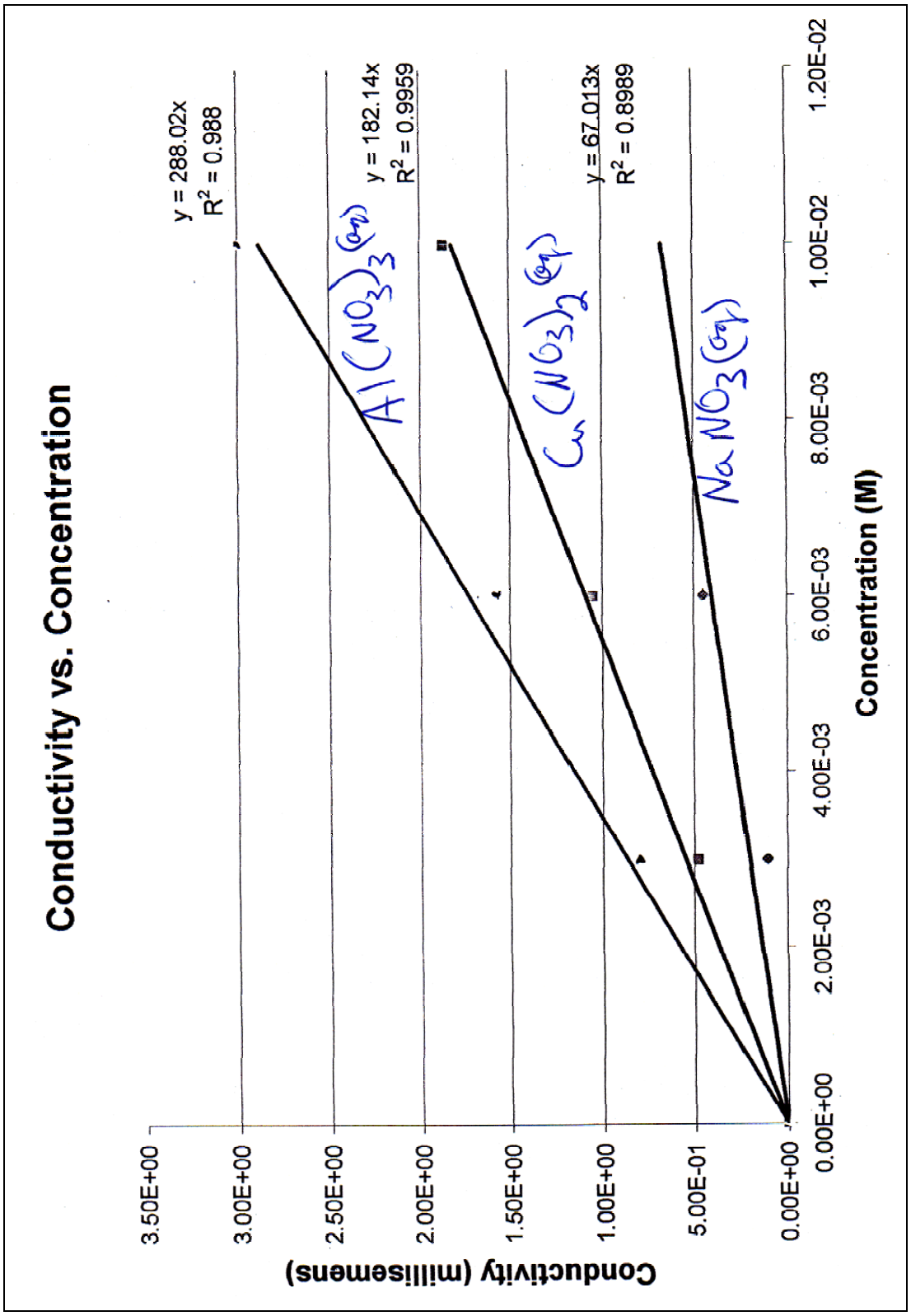
We concluded that our unknown (z) was CuCl, through the observation of colors, and a spot test. We then concluded that the concentration was 0.02 M. We calculated this from our graph of absorbance vs. concentration.

(research extension)

We found the concentration of our unknown salt to be 0.00298 M. This gave us -25% error from the actual value. Our % error was likely due to one outlier on our conductivity vs. concentration graph, which was probably caused by human error.
We also concluded that the conductance of a solution increases as the concentration of electrolytes increases.



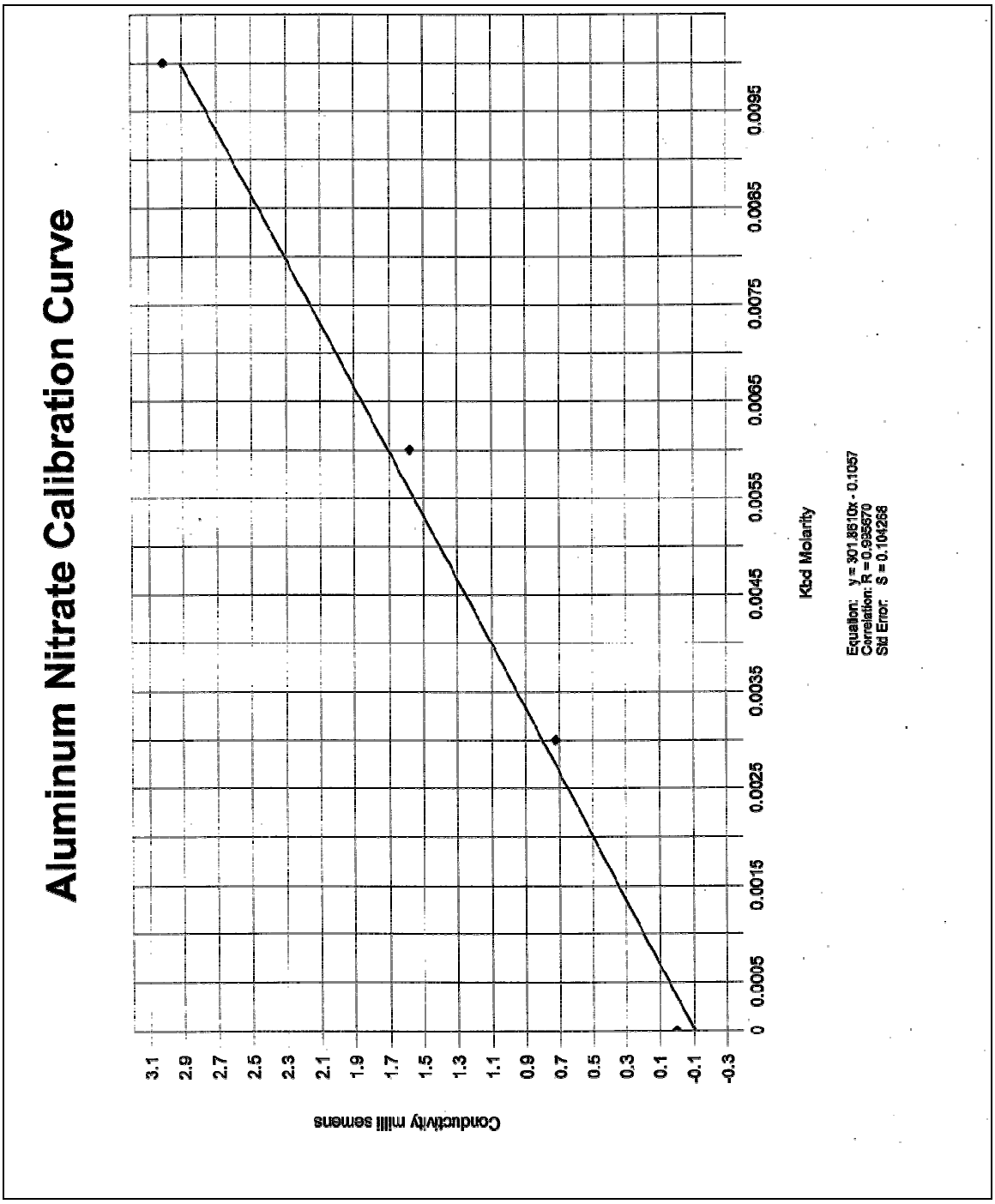
R.E.#4 - Quantitative and Qualitative Analysis Report - Page 6



R.E.#4 - Quantitative and Qualitative Analysis Report - Page 7

	A	B
1	CAT-5 A	Keyboard
2	Conductivity	Kbd Molarity
3	0.0000	0.00000
4	0.7218	0.00300
5	1.5781	0.00600
6	3.0129	0.01000

R.E.#4 - Quantitative and Qualitative Analysis Report - Page 8

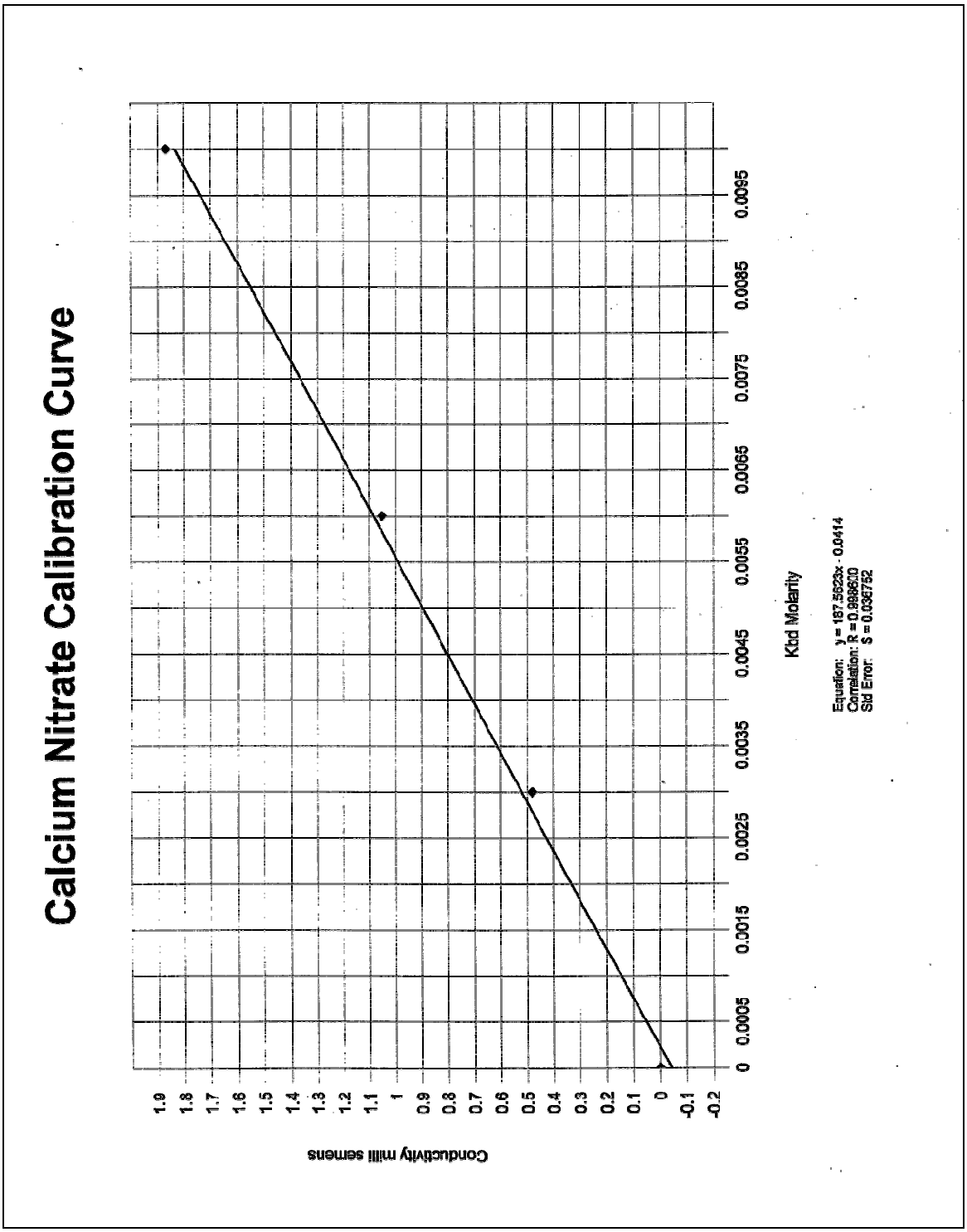


R.E.#4 - Quantitative and Qualitative Analysis Report - Page 9

	A	B
1	CAT-5 A	Keyboard
2	Conductivity	Kbd Molarity
3	0.0000	0.00000
4	0.4805	0.00300
5	1.0519	0.00600
6	1.8657	0.01000

03/02/04 18:03:30 Experiment Title: Conductivity_Calcium_Nitrate 1/1

R.E.#4 - Quantitative and Qualitative Analysis Report - Page 10



R.E.#4 - Quantitative and Qualitative Analysis Report - Page 11

Tim copy

ORAL SEMINAR Grading Sheet
CHEM 131 - 13 Tue 3-6 pm.

TITLE: Conductivity Expt
DATE: 3/9/04

Group members: Craig Haine, Brandon Thiesen, Shea Herbert, Collin Parrott

10 pts possible– Oral Report Presentation

The breakdown is as follows:

1 pt – A "Preparation Meeting" with the lab instructor prior to your presentation was held. The meeting time and place was scheduled upon the conclusion of the laboratory that is to be presented.

1.0 pts. awarded Meeting time and Place: 3:30 pm Fri Help Center

9/10

1 pts – A title sheet and outline of your oral report was placed on an overhead. (This helps you to show the logic of your discussion and helps the audience to know where you are going with this discussion.)

1.0 pts. awarded

3 pts– At least two chemical equations, calculations, chemical structures, and/or instrumentation circuit diagram was shown in front of the class on the overhead or chalkboard. How do NaNO3 $Cu(NO_3)_2$ $Al(NO_3)_3$ ionized ? in soln

2.0 pts. awarded

5 pts – All group members contributed equally in some aspect of technical information .

5.0 pts awarded

0 pts will be assigned to individuals who don't show or don't contribute to their group reports.

Names of people who did not attend:

What would you expect the slope ratio be ?

Research Extension #5
Determination of the 'Heat of Solutions' and use of Hess's Law

Background and Keywords:

When a crystal dissolves in an aqueous solution, there is either a release of energy, -)H, or an absorbance of energy,)H, with the surrounding solution. This phenomenon is called 'Enthalpy (or Heat) of Solution'. Capturing this heat gain or heat loss from dissolving a mass of solid in water, one is able to measure the caloric change and can therefore determine the identity of a given unknown solid. This measurement of heat change is generically referred to as *CALORIMETRY*, and will be the type of experiment you will perform.

Your Research Problem:

What is the identity of two unknown solids via dissolving them in water and solving for their respective 'Heat of Solution' in Kilojoules per mole?

Your Research Goals:

Today, you will be designing an experiment in which you will measure the caloric changes due to a heat gain or heat loss due to 'Heat of Solution'. You will be a list of 'Heat of Solution' values from the CRC handbook of physical constants and two unknown solids. Once you identify the unknown solids, you should then calculate how close your values match the *expected* values, calculating the % error and reporting it in your conclusions.

(Be sure to include all graphs of change in temperature and amount of solid used in each experiment.)

Questions to consider in your lab write-up:

1) What are some of the key experimental parameters for your experimental set-up?

2) What does exothermic and endothermic mean?

3) What is the change of temperature you *should* observe when placing 3.0 gram of known into 50mL of water at room temperature? *(How does this compare with your unknown experiment?)*

See pages 234 to 245 for student sample report for this experiment.

Research Extension #6

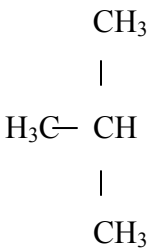
Molecular Configuration, Optical Activity, and Quantitative Analysis of Sugars

Background and Keywords:

As you have seen in previous lessons, different molecules in aqueous solutions can interact with light in such a way that results in different phenomenon. Today you will observe yet another example, using this phenomenon to ultimately solve a practical question.

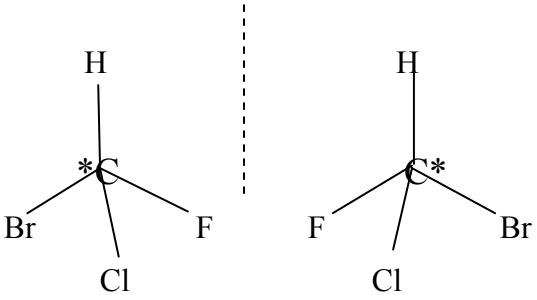
Today's phenomenon asks you to observe how isomers, which may have the same molecular formula but have different structures, interact with linearly polarized light. First, you need to know what an isomer is, for example, the simplest types of isomers are *constitutional isomers*, which differ in their order of connectivity. Let's consider two molecules with the same molecular formula, C_4H_{10}:

$CH_3CH_2CH_2CH_3$ Butane



2-Methyl Propane

You will be looking at a different group of isomers, however, that are called enantiomers, which are molecules that come in pairs and are mirror images of each other. These enantiomers (*enantios is Greek for opposite*) are a subset of specific isomers, called stereoisomers. Stereoisomers have atoms that are connected in the same order but have different spatial orientations to one another.



C*= "stereocenter"

In fact, one signifying feature of *chiral* molecules, mirror image molecules, is that they are not superimposable. To understand this concept better, hold your hands a couple

inches apart with your fingers outstretched and palms facing one another….mirror images, but not superimposable.

We will start this research extension with some laboratory materials listed below, exploring different aqueous sugar solutions that exhibit what is called optical activity. We will use this background knowledge and observations to quantitatively measure this phenomenon and the optical rotation of polarized light. This type of measurement is referred to as *POLARIMETRY* and will the method we will use to solve your research problem.

Your Research Problem:

What effects do some optically active sugars have on light and how can we use this to quantify an unknown concentration?

Your Research Goals:

Today, you will ultimately be designing an experiment in which you measure the optical rotation, ∀, of a sugar solution, solving for its unknown concentration. You will start, however, with some initial exercises in order to understand both the phenomenon of optical activity and how the different laboratory materials can be used to solve your research problem.

Lab Materials:

2 Polarizer Filters A Polarimeter Cell 5 LED sources Two sugar solutions

A pre-made Hand-held Polarimeter

Questions to consider in your lab write-up:

1) What is linearly polarized light?

2) Do the two aqueous sugar solutions have the same optical activity?

3) Does a single aqueous sugar solution show the same optical activity when using different LED light source that have been linearly polarized? If not, which LED has the greatest observed optical rotation?

4) What mathematical correlation best fits observed optical rotation and the increasing concentrations of an aqueous sugar solution? (Be sure to use the same LED for this observation.)

5) What is the concentration of an Unknown X concentration of the same type of aqueous

Research Extension: Effects of Solutions on Polarized Light

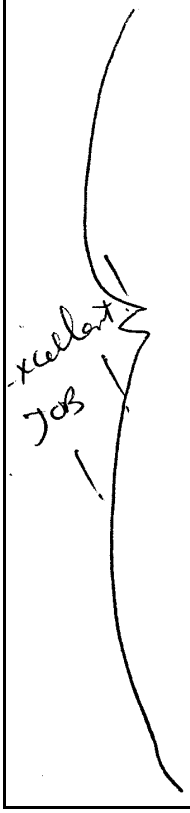
CHEM 131 – 15

Student Sample Report

Introduction

As we well know, light is affected in many sorts of ways when coming into contact with certain materials. It may be absorbed, transmitted, or fluoresced. In this research extension we studied the ability of light to be polarized. Then we observed what happened to the polarized light as it passed through a solution.

Light is said to be polarized when all the electric or magnetic fields of its photons are oriented in one direction. Light which comes from a regular light source is not polarized, that is, its light is oriented in many different directions. There are several ways in which light may be polarized. It could be polarized by absorbtion, in which unpolarized light passes through a material which absorbs all light except that which is oriented a certain direction. Other methods are by reflection or scattering.



A way to polarize light by absorption is to use a linear polarizing filter. This type of filter consists of a pane of clear plastic or glass with a coating of long molecular chains, which, by electric induction, absorb those electric fields which strike perpendicular to the chain length. This way, only electric fields which are oriented parallel to the chains are not absorbed.

This type of lenses is often used in sunglasses. The lenses of the sunglasses are designed to absorb light which is horizontally polarized, and not that which is vertically polarized. The reason for this is that when light strikes a horizontal surface, it is often reflected as being more horizontally polarized. By absorbing more light which is reflected off surfaces than regular light, the sunglasses greatly reduce the glare entering the wearer's eyes.

Different types of molecules affect polarized light in different ways. Isomers are molecules with the same component atoms but with different configurations. Enantiomers are isomer types where two molecules are mirror images of each other. Their effect on light is that one enantiomer will absorb one component of polarized light more than another, causing its orientation to be rotated.

There are many uses for polarizing light. Certain proteins and sugars in solution will have a rotating effect on polarized light which is proportional to the concentration of the molecules in solution. Using this information, the concentration of a solution could be analyzed by how much it rotated the polarization of light passing through it.

MATERIALS:

Substances

Water, D-Glucose and D-Sucrose Solutions

Equipment

LEDs of various colors
LED Battery Pack
Linear Polarizing filters (2)
T-Pipe viewing apparatus
Stand

PROCEDURE:

1. We discussed the nature of light, regarding magnetic fields and polarization.
2. We experimented with polar lenses, and saw the application of polarization at work.
   OBS: When we had the lines perpendicular, we could see through the lenses. When the lines were placed parallel, we saw black. (or absence of light)
3. We set up an experiment using an LED, polarized lenses, and different solutions.
4. We placed the LED underneath a suspended lens, and placed a beaker with clear water on top of the polarized lens. We then looked through the second lens, and tried to find a spot where the LED would not shine through.
   OBS: We got very close, but could never line up the polarized lenses enough to completely block out the red LED
5. We repeated step 4 with a beaker of an unknown concentration of d-glucose dissolved in deionized water.
   OBS: Once again, the lines on our polarized lenses did not match up as it was slightly right of parallel, and they did not completely block out the light.
6. We repeated step 5 with an unknown concentration of d-sucrose.
   OBS: The lines were moved, this time more than the glucose, and to the left. We also could not completely block out the LED light.

2nd PROCEDURE:

1. We used a field T with two Plexiglas squares attached to the ends instead of a cuvette.
2. We then filled the T with the solution and capped the open end.
3. We made observations using different color LEDs through the solution of d-sucrose.
   OBS: the polarization of different colors of light was rotated more than others.
   OBS: Some lights changed colors mainly orange and blue.

DATA:

All Data is listed through out the experiment under the observations, as there was no data that could be calculated by us in this experiment. All our data was observable.

DATA ANALYSES AND CALCULATIONS:

While we didn't have any calculations, we can analyze our data. A good way to analyze it would be to look at how the first experiment went into our second experiment. As shown through our observations in the first experiment, there were times that we were not probably using the most efficient manner for viewing our experiments. Also, we got more refined in the second experiment with the help of our lab leader. It goes to show also that the more controlled the experiment, the greater chance for usable data. We could have some errors in our data due to short amount of time after the in class experiment, and our original setup errors, such as the lines on the polarized lenses, and our chance for a lot of human error in the first experiment.

CONCLUSIONS:

Enantiomers are isomers that are mirror images of ~~each other; no matter~~ how they are lined up, they will never be the same. Enantiomers will absorb a component of polarized light, causing it to rotate its polarization. This shows why we had to rotate our second filter to block polarized light, and also shows why we couldn't completely block it out. The color change occurred because the sugar molecules rotated one component of color more than the other. By measuring the change in the polarization of the light, we could quantitatively measure the concentration of the sucrose in solution. We should mention one more time also that our errors were greatly reduced in the second experiment because we had a much more controlled situation, giving us less chance for error on our part.

on-superimposable

like your hands)

Gentlemen, Excellent JOB!

ORAL REPORT

+10.0

10.0

AVERAGE OF INDIVIDUAL REPORTS

(13.7+14.7+14.2) / 3 = 14.2

15.0

R.E.

+10.0

10.0

AVERAGE of INDIVIDUALL

- LAB NB = 2.6/3.0
- Pre/Post QUIZ = 1/1
- DISCUSSION = 0/1

3.6/5.0

11

34.2

3.6

37.8

40.0

R.E.#6 - Analyzing Sugar Solutions - Page 3

Equation: $\alpha = l\,[C]\,\epsilon_\lambda$

-The optical rotation of polarized light through solution equals path length times the concentration of the solution times the ~~energy of the~~ absorbtion due to wavelength. If the optical rotation is positive the path length or the concentration of solution may have increased or the ~~energy of~~ absorbtion due to wave length may have decreased.

- $\uparrow \alpha = \boxed{l\,[C]}\ \epsilon_\lambda \downarrow$ OK

- $\uparrow \alpha = \boxed{\epsilon_\lambda\, l}\ [C] \uparrow$

- $\uparrow \alpha = \boxed{\epsilon_\lambda\,[C]}\ l \uparrow$

ORAL SEMINAR Grading Sheet
CHEM 131

TITLE: Molecular Configuration & optical Activity of Sugars
DATE: 4/6/04

Group members: Anders, Charlie, & Ben

10 pts possible– Oral Report Presentation

The breakdown is as follows:

1 pt – A "Preparation Meeting" with the lab instructor prior to your presentation was held. The meeting time and place was scheduled upon the conclusion of the laboratory that is to be presented.

1.0 pts. awarded Meeting time and Place: Last week / in lab

1 pts – A title sheet and outline of your oral report was placed on an overhead. (This helps you to show the logic of your discussion and helps the audience to know where you are going with this discussion.)

1.0 pts. awarded

3 pts– At least two chemical equations, calculations, chemical structures, and/or instrumentation circuit diagram was shown in front of the class on the overhead or chalkboard.

3.0 pts. awarded a) Diagram of Polarized light.
b)

5 pts – All group members contributed equally in some aspect of technical information .

5.0 pts awarded

0 pts will be assigned to individuals who don't show or don't contribute to their group reports.

Names of people who did not attend:

Q: What happened to the rotation of the light as the solution of D-glucose was decreased (solvated)?
A: Fewer molecules, less rotation (α)

Research Extension #7: Week #12

Determination of the [Cal./g] from the Combustion of Snack Foods

Your Research Problem:

During this research extension, your task is to (a) burn one of the given snack foods three times and average the FINAL results in determination of the amount of [Calories/gram] this snack food has produced, (b) acquire the data from each of the other research groups within the given lab and perform the same calculations, (c) convert the Calories per serving on the snack food container into [Calories/gram], (d) and solve for the % error from this 'accepted value'.

A brief Background and Keywords:

You have already performed this laboratory with a candle and a peanut in a previous lab. We will review together, with the class as an entire 'research team', some of the calculations that need to be performed and standardize our experimental methodology so that ALL of our experiments are comparable to one another.

Your research group will play the important roll of "quality control", making sure that everyone is performing their laboratory tasks in agreement with the recommended experimental design. This will take some "juggling", since you will also need to collect your own set of data and is especially important, since you will be acquiring everyone's data and compiling it for a final report!

Also, don't forget the difference between heat calories and food Calories:

1,000 heat calories = 1 food Calorie *or* 1 Calorie = 1 kilocalorie

Your Research Goals:

Perform the data acquisition for one snack food, acquire all of the data from the other groups, and perform all the calculations required. *(Be sure to include one good representational graph of change in temperature with respect to time.)*

Questions to consider:

1) What are some of the key experimental parameters, experimental steps, for your experimental set-up?….did you check on the other groups to see if they followed research protocol?

2) What are some of the possible errors that could occur in this experiment?

3) Was the calculated % Error consistent within (a) a single data set of snack food, and (b) across the entire set of snack foods?

4) What is an "oxygen bomb" and what does this experimental apparatus look like?

Data Sheet: Group #_____

Snack Food Tested:_____ Calories/serving_____ Ounces/ Serving_____

	Trial #1	Trial #2	Trial #3
Mass of empty cup	_____g	_____g	_____g
Mass of cup and water	_____g	_____g	_____g
Mass of water	_____g	_____g	_____g
Water temperature before heating (Room temperature tap water)	_____^{o}C	_____^{o}C	_____^{o}C
Water temperature after heating	_____^{o}C	_____^{o}C	_____^{o}C
Temperature change	_____^{o}C	_____^{o}C	_____^{o}C
Mass of paper, paper clip, and snack food before burning.	_____g	_____g	_____g
Mass of paper, paper clip, and snack food after burning	_____g	_____g	_____g
Mass of snack food burned	_____g	_____g	_____g

Calculate calories of heat gained by the water as a result of the burning snack food:

Trial #1:

Trial #2:

Trial #3:

Calculate the calories of heat produced per gram of snack food…(don't forget to convert to Calories):

Trial #1:

Trial #2:

Trial #3:

Calculate the average [Calories/g], compare it to the 'accepted' value found on the snack food container, and calculate the % error:

Average [Cal./g] snack food:_____ 'Accepted alue' [Cal./g]:_____ %Error:_____

Determination of Calories per Gram in Snack Foods

Sample Student Report

6 K

Determination of the [Cal./g] from the combustion of Snack Foods

Chem 131 - Section 9
Due – 4/7/04

Sample Student Report

Purpose:

It is our goal to find the calorie content of Lays BBQ Chips through the following process. We will light it on fire beneath a cup of water. Using an IC temperature probe, we will measure the amount of heat lost by the chip and absorbed by the water. From there, we can calculate the amount of calories given off by the chip. For the research extension, we had to compare the results from the other groups burning Bugles, Cheetos, Marshmallows, and Pork Skins to our results.

Good!

Materials:

-paper clip	-Lays BBQ chips	-Cheetos	-Marshmallows
-Pork Skins	-Bugels	-Note cards	-matches
-ring-stand	-ring	-metal cup	-IC temperature probe
-microlab	-graduated cylinder	-scale	

Data:

(See Data Tables and Graphs)

Nice job w/ Calculations!

Calculations:

Group #1 (Bugels)

Trial #1 49.28g * 6.70°C * 1.00 = 330.18 Cal
330.18 Cal * 1/1000 Cal * 1/0.50g = 0.660 Cal/g

Trial #2 49.14g * 7.40°C * 1.00 = 363.64 Cal
363.64 Cal * 1/1000 Cal * 1/0.48g = 0.757 Cal/g

Trial #3 49.05g * 6.30°C * 1.00 = 309.02 Cal
*309.02 Cal * 1/1000 Cal * 1/0.54g = 0.577 Cal/g*

Average Calculated Value = 0.660 Cal/g
Actual Value = 160 Cal / 30g = 5.33 Cal/g
Percent Error = (5.33 Cal/g – 0.660 Cal/g) / (5.33 Cal/g) = 87.6%

Group #2 (Lays BBQ)

Trial #1 49.26g * 3.63°C * 1.00 = 178.81 Cal
178.81 Cal * 1/1000 Cal * 1/0.15g = 1.192 Cal/g

Trial #2 49.56g * 2.20°C * 1.00 = 109.03 Cal

109.03 Cal * 1/1000 Cal * 1/0.13g = 0.839 Cal/g
Trial #3 48.98g * 5.20°C * 1.00 = 254.69 Cal
254.69 Cal * 1/1000 Cal * 1/0.25g = 1.019 Cal/g

Average Calculated Value = 1.017 Cal/g
Actual Value = 150 Cal / 28g = 5.35 Cal/g
Percent Error = (5.35 Cal/g – 1.017 Cal/g) / (5.35 Cal/g) = 90.0%

Group #3 (Cheetos)
Trial #1 34.73g * 45.60°C * 1.00 = 1583.69 Cal
1583.69 Cal * 1/1000 Cal * 1/1.20g = 1.320 Cal/g
*Trial #2 92.56g * 16.80°C * 1.00 = 1555.01 Cal*
1555.01 Cal * 1/1000 Cal * 1/1.20g = 1.290 Cal/g
Trial #3 47.46g * 39.00°C * 1.00 = 1850.94 Cal
1850.94 Cal * 1/1000 Cal * 1/0.97g = 1.910 Cal/g

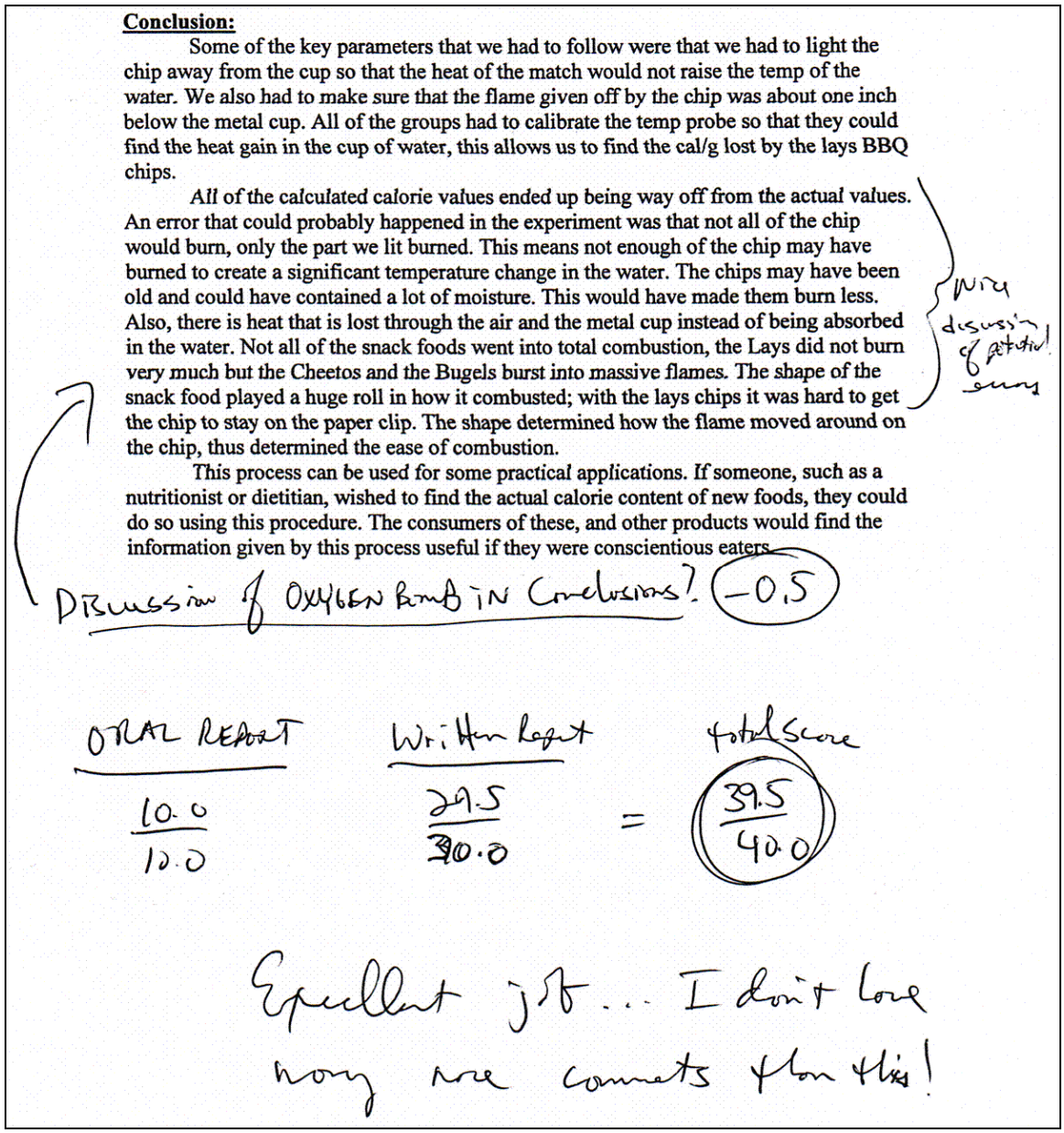
Average Calculated Value = 1.510 Cal/g
Actual Value = 160 Cal / 25g = 6.40 Cal/g
Percent Error = (6.40 Cal/g – 1.510 Cal/g) / (6.40 Cal/g) = 76.4%

Group #4 (Pork Skins)
Trial #1 49.18g * 4.50°C * 1.00 = 221.32 Cal
221.32 Cal * 1/1000 Cal * 1/0.13g = 1.702 Cal/g
Trial #2 48.15g * 1.28°C * 1.00 = 61.63 Cal
61.63 Cal * 1/1000 Cal * 1/0.08g = 0.881 Cal/g
*Trial #3 47.90g * 1.30°C * 1.00 = 62.27 Cal*
62.27 Cal * 1/1000 Cal * 1/0.01g = 6.230 Cal/g

Average Calculated Value = 2.91 Cal/g
Actual Value = 80 Cal / 14g = 5.71 Cal/g
Percent Error = (5.71 Cal/g – 2.91 Cal/g) / (5.71 Cal/g) = 49.0%

Group #5 (Marshmallows)
Trial #1 56.93g * 3.80°C * 1.00 = 216.33 Cal
216.33 Cal * 1/1000 Cal * 1/0.26g = 0.832 Cal/g
Trial #2 56.48g * 3.68°C * 1.00 = 207.83 Cal
207.83 Cal * 1/1000 Cal * 1/0.26g = 0.784 Cal/g
Trial #3 58.48g * 3.22°C * 1.00 = 188.29 Cal
188.29 Cal * 1/1000 Cal * 1/0.24g = 0.779 Cal/g

Average Calculated Value = 0.798 Cal/g
Actual Value = 100 Cal / 28g = 3.57 Cal/g
Percent Error = (3.57 Cal/g – 0.798 Cal/g) / (3.57 Cal/g) = 77.6%



Conclusion:

Some of the key parameters that we had to follow were that we had to light the chip away from the cup so that the heat of the match would not raise the temp of the water. We also had to make sure that the flame given off by the chip was about one inch below the metal cup. All of the groups had to calibrate the temp probe so that they could find the heat gain in the cup of water, this allows us to find the cal/g lost by the lays BBQ chips.

All of the calculated calorie values ended up being way off from the actual values. An error that could probably happened in the experiment was that not all of the chip would burn, only the part we lit burned. This means not enough of the chip may have burned to create a significant temperature change in the water. The chips may have been old and could have contained a lot of moisture. This would have made them burn less. Also, there is heat that is lost through the air and the metal cup instead of being absorbed in the water. Not all of the snack foods went into total combustion, the Lays did not burn very much but the Cheetos and the Bugels burst into massive flames. The shape of the snack food played a huge roll in how it combusted; with the lays chips it was hard to get the chip to stay on the paper clip. The shape determined how the flame moved around on the chip, thus determined the ease of combustion.

This process can be used for some practical applications. If someone, such as a nutritionist or dietitian, wished to find the actual calorie content of new foods, they could do so using this procedure. The consumers of these, and other products would find the information given by this process useful if they were conscientious eaters.

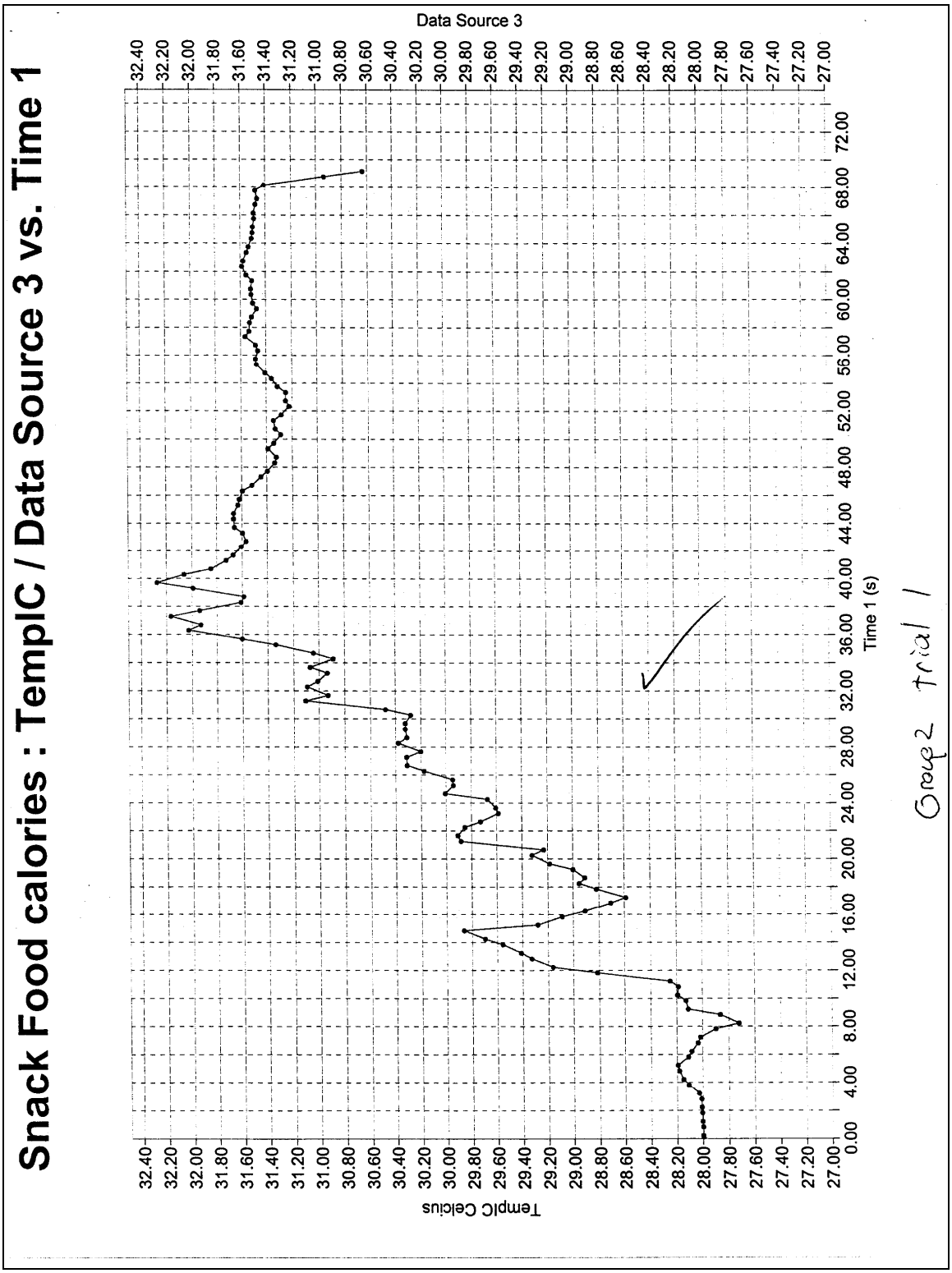
Why discussion of potential errors

Discussion of Oxygen Bomb in Conclusions? -0.5

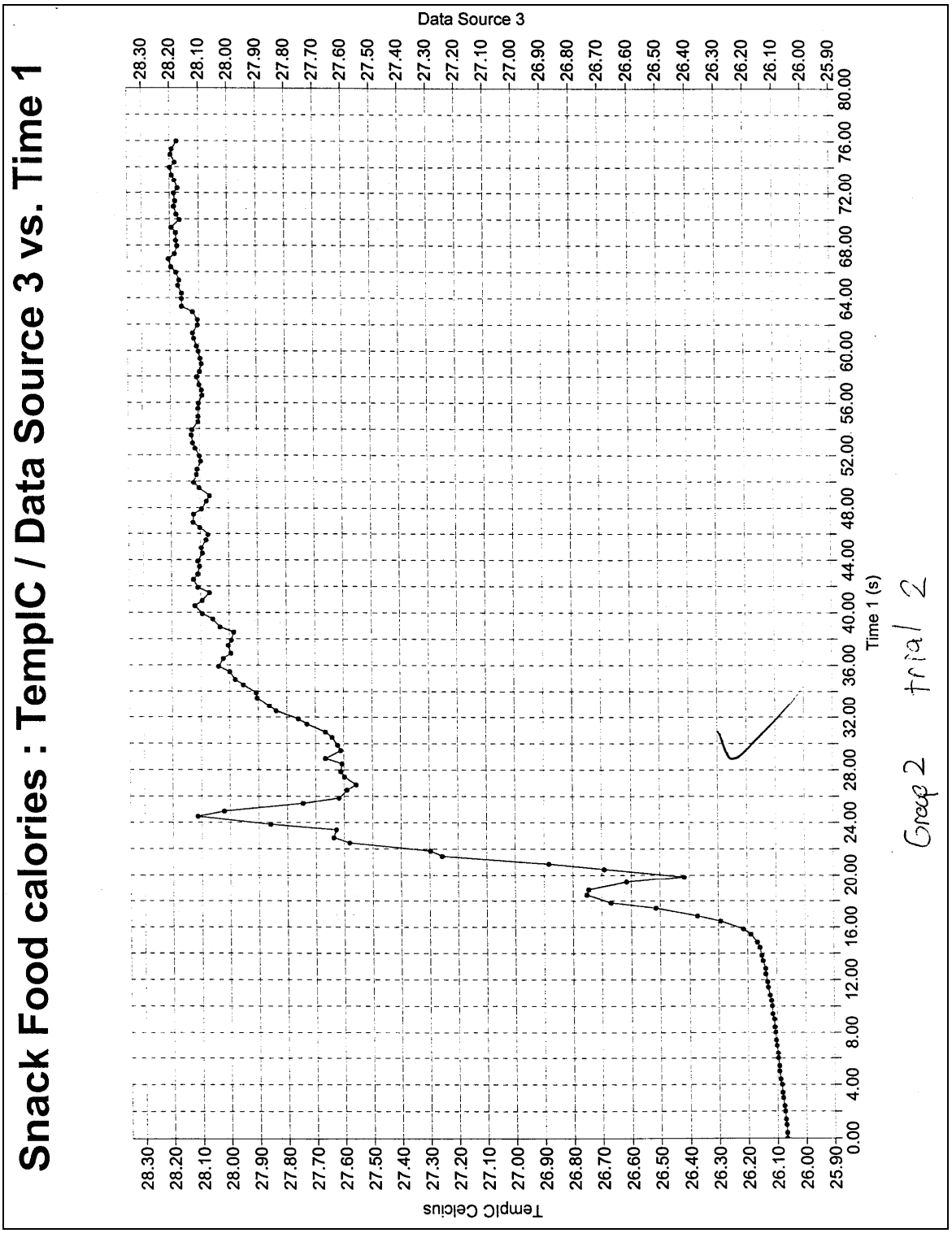
ORAL REPORT 10.0/10.0 Written Report 29.5/30.0 = total Score 39.5/40.0

Excellent job... I don't have many more comments than this!

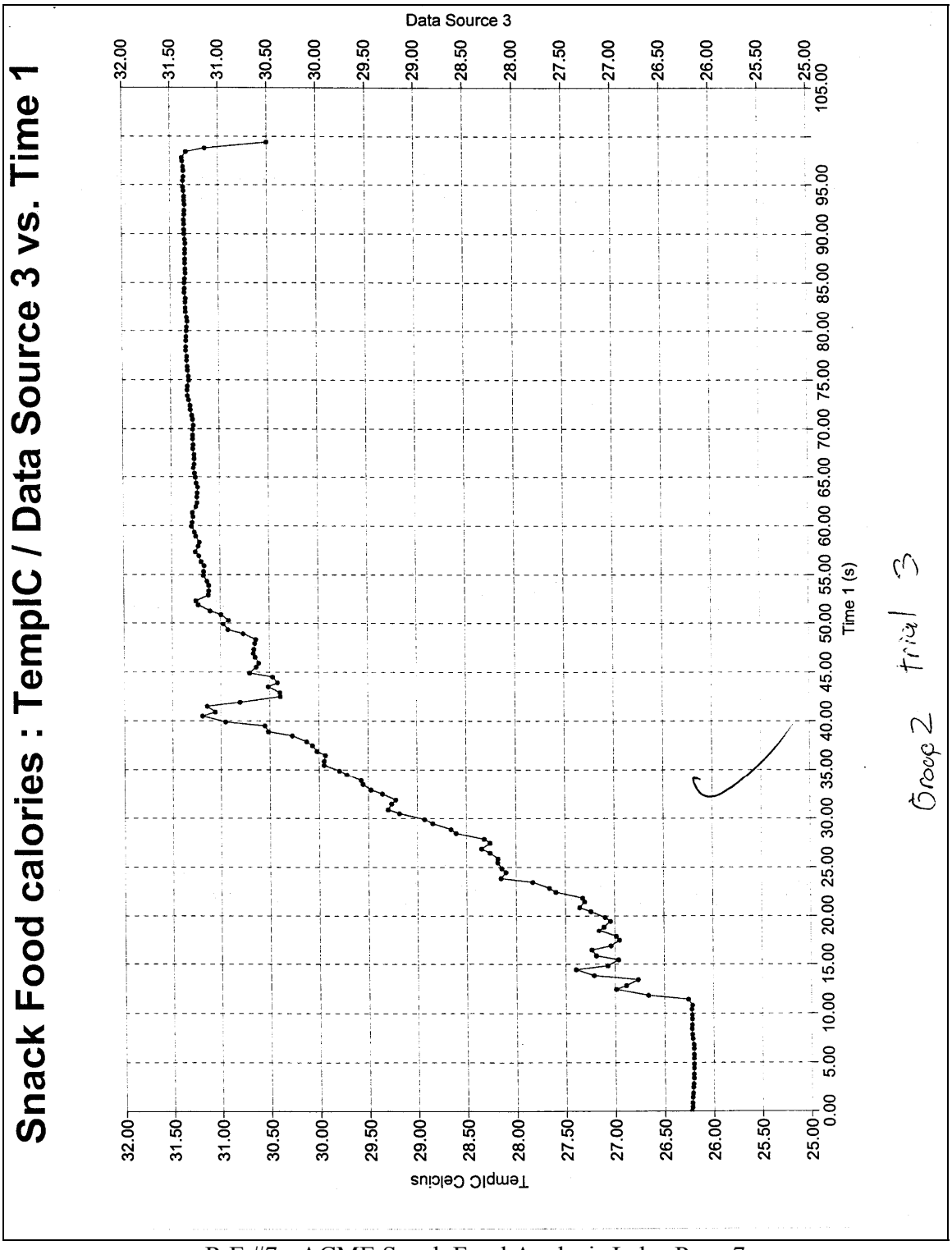
R.E.#7 - ACME Snack Food Analysis Lab - Page 4



R.E.#7 - ACME Snack Food Analysis Lab - Page 5



R.E.#7 - ACME Snack Food Analysis Lab - Page 6



R.E.#7 - ACME Snack Food Analysis Lab - Page 7

Snack Food Tested: Bugels Calories/serving 160 Ounces/ Serving 1 30

	Trial #1	Trial #2	Trial #3
Mass of empty cup	10.243 g	10.436 g	10.376 g
Mass of cup and water	59.541 g	59.383 g	59.481 g
Mass of water	49.281 g	49.14 g	49.105 g
Water temperature before heating (Room temperature tap water)	26.0 °C	26.1 °C	26.9 °C
Water temperature after heating	32.7 °C	33.5 °C	33.2 °C
Temperature change	6.7 °C	+7.4 °C	6.3 °C
Mass of paper, paper clip, and snack food before burning.	3.58 g	4.476 g	4.53 g
Mass of paper, paper clip, and snack food after burning	3.01 g	3.996 g	3.992 g 3.142
Mass of snack food burned	.50 g	.48 g	.538 g

Calculate calories of heat gained by the water as a result of the burning snack food:

Trial #1: $49.28_g \cdot 6.7°C = 330.176$ Cal

Trial #2: $49.14_g \cdot 7.4°C = 363.636$ cal

Trial #3: $49.05_g \cdot 6.3°C = 309.015$ cal

Calculate the calories of heat produced per gram of snack food…(don't forget to convert to Calories):

Trial #1: $330.176_{cal} \cdot \frac{1}{1000_{cal}} \cdot \frac{1}{.50_g} = .66$ cal

Trial #2: $363.636_{cal} \cdot \frac{1}{1000_{cal}} \cdot \frac{1}{.48_g} = .757$ cal

Trial #3: $309.015_{cal} \cdot \frac{1}{1000_{Cal}} \cdot \frac{1}{.538_g} = .577$ cal

Calculate the average [Calories/g], compare it to the 'accepted' value found on the snack food container, and calculate the % error:

.66 cal/g

Average [Cal./g] snack food: .66 'Accepted value' [Cal./g]: 5.33 %Error: 87.61 %

R.E.#7 - ACME Snack Food Analysis Lab - Page 8

Data Sheet: Group # 2

Snack Food Tested: Lays BBQ Calories/serving 150 cal Ounces/ Serving 28 g

	Trial #1	Trial #2	Trial #3
Mass of empty cup	10.32 g	10.54 g	10.54 g
Mass of cup and water	59.58 g	60.10 g	59.52 g
Mass of water	49.26 g	49.56 g	48.98 g
Water temperature before heating (Room temperature tap water)	27.97 °C	26.00 °C	26.20 °C
Water temperature after heating	31.6 °C	28.20 °C	31.40 °C
Temperature change	3.63 °C	2.2 °C	5.2 °C
Mass of paper, paper clip, and snack food before burning.	3.45 g	3.6 g	3.45 g
Mass of paper, paper clip, and snack food after burning	3.3 g	3.47 g	3.2 g
Mass of snack food burned	.15 g	.13 g	.25 g

Calculate calories of heat gained by the water as a result of the burning snack food:

Trial #1: $49.26\,g \cdot 3.63\,^{\circ}C = 178.814$ cal

Trial #2: $49.56\,g \cdot 2.2\,^{\circ}C = 109.032$ cal

Trial #3: $48.98\,g \cdot 5.2\,^{\circ}C = 254.696$ cal

Calculate the calories of heat produced per gram of snack food…(don't forget to convert to Calories):

Trial #1: $178.819\,Cal \cdot \frac{1}{1000\,Cal} \cdot \frac{1}{.15\,g} = 1.192$ cal/g

$\frac{150\,cal}{28\,g} = 5.35$ Trial #2: $109.032\,Cal \cdot \frac{1}{1000\,Cal} \cdot \frac{1}{.13\,g} = .839$ cal/g

Trial #3: $254.696\,Cal \cdot \frac{1}{1000\,cal} \cdot \frac{1}{.25\,g} = 1.019$ cal/g

Calculate the average [Calories/g], compare it to the 'accepted' value found on the snack food container, and calculate the % error:

1.017 Cal/g

Average [Cal./g] snack food: 1.017 'Accepted value' [Cal./g]: 5.35 %Error: 90.0 %

R.E.#7 - ACME Snack Food Analysis Lab - Page 9

Erik B.

Data Sheet: Group # 3

Snack Food Tested: cheetos Calories/serving 160 Ounces/ Serving 1oz. (25g)

	Trial #1	Trial #2	Trial #3
Mass of empty cup	22.88 g	10.34 g	22.88 g
Mass of cup and water	g	102.9 g	70.34 g
Mass of water	34.73 g	92.56 g	47.46 g
Water temperature before heating (Room temperature tap water)	15.6 °C	27.1 °C	28 °C
Water temperature after heating	30 °C	43.9 °C	67.0 °C
Temperature change	45.6 °C	16.8 °C	39 °C
Mass of paper, paper clip, and snack food before burning.	2.28 g	2.581 g	2.17 g
Mass of paper, paper clip, and snack food after burning	1.08 g	1.382 g	1.2 g
Mass of snack food burned	1.2 g	1.199 g	.97 g

Calculate calories of heat gained by the water as a result of the burning snack food:

Trial #1: $34.73\,g \cdot 45.6\,^{\circ}C = 1583.69\,cal$

Trial #2: $92.56 \cdot 16.8\,^{\circ}C = 1555.01\,cal$

Trial #3: $47.46 \cdot 39.0\,^{\circ}C = 1850.94\,cal$

Calculate the calories of heat produced per gram of snack food…(don't forget to convert to Calories):

Trial #1: $1583.69\,cal \cdot \frac{1}{1000\,cal} \cdot \frac{1}{1.2\,g} = 1.32\,cal/g$

Trial #2: $1555.01\,cal \cdot \frac{1}{1000\,cal} \cdot \frac{1}{1.2\,g} = 1.29\,cal/g$

Trial #3: $1850.94\,cal \cdot \frac{1}{1000\,cal} \cdot \frac{1}{.97\,g} = 1.91\,cal/g$

Calculate the average [Calories/g], compare it to the 'accepted' value found on the snack food container, and calculate the % error:

1.51 cal/g

Average [Cal./g] snack food: 1.51 'Accepted value' [Cal./g]: 6.4 %Error: 76.4 %

Data Sheet: Group # 4 — 14 grams

Snack Food Tested: Pork Skins — Calories/serving 80 — Ounces/ Serving 0.49 oz/serving

	Trial #1	Trial #2	Trial #3
Mass of empty cup	10.627 g	10.32 g	10.49 g
Mass of cup and water	59.81 g	58.47 g	58.39 g
Mass of water	49.183 g	48.15 g	47.9 g
Water temperature before heating (Room temperature tap water)	25.6 °C	25.47 °C	25.7 °C
Water temperature after heating	30.1 °C	26.75 °C	27.0 °C
Temperature change	4.5 °C	1.28 °C	1.3 °C
Mass of paper, paper clip, and snack food before burning.	1.055 g	4.229 g	3.05 g
Mass of paper, paper clip. and snack food after burning	0.925 g	4.153 g	3.04 g
Mass of snack food burned	0.13 g	0.076 g	0.01 g

Calculate calories of heat gained by the water as a result of the burning snack food:

Trial #1: 49.183 g · 4.5°C = 221.324 ~~cal~~ Cal

Trial #2: 48.15 g · 1.28°C = 61.632 ~~cal~~ Cal

Trial #3: 47.90 g · 1.30°C = 62.270 ~~cal~~ Cal

Calculate the calories of heat produced per gram of snack food…(don't forget to convert to Calories):

Trial #1: $221.324\ cal \times \frac{1}{1000\ Cal} \times \frac{0.13\ g}{1} = 1.702\ cal/g$

Trial #2: $61.632\ cal \times \frac{1}{1000\ Cal} \times \frac{0.076\ g}{1} = .811\ Cal/g$

Trial #3: $62.270\ cal \times \frac{1}{1000\ Cal} \times \frac{0.01\ g}{1} = 6.230\ Cal/g$

Calculate the average [Calories/g], compare it to the 'accepted' value found on the snack food container, and calculate the % error:

2.91 cal/g

Average [Cal./g] snack food: 2.91 'Accepted value' [Cal./g]: 5.71 %Error: 49.0%

Data Sheet: Group # 5

Snack Food Tested: Marshmallows Calories/serving 100 ~~Ounces~~ 28 grams/ Serving 28

	Trial #1	Trial #2	Trial #3
Mass of empty cup	10.862 g	10.659 g	10.467 g
Mass of cup and water	67.190 g	67.135 g	68.942 g
Mass of water	56.928 g	56.476 g	58.475 g
Water temperature before heating (Room temperature tap water)	24.2 °C	26.9 °C	26.5 °C
Water temperature after heating	28.0 °C	30.58 °C	29.72 °C
Temperature change	3.8 °C	3.68 °C	3.22 °C
Mass of paper, paper clip, and snack food before burning.	3.325 g	3.295 g	3.453 g
Mass of paper, paper clip, and snack food after burning	3.065 g	3.03 g	3.211 g
Mass of snack food burned	0.26 g	0.265 g	0.242 g

Calculate calories of heat gained by the water as a result of the burning snack food:

(1.0 cal/g°C)

Trial #1: $56.928_g \cdot 3.80°C = 216.326$ ~~kcal~~ Cal

Trial #2: $56.476_g \cdot 3.68°C = 207.832$ ~~kcal~~ Cal

Trial #3: $58.475_g \cdot 3.22°C = 188.290$ ~~kcal~~ Cal

Calculate the calories of heat produced per gram of snack food…(don't forget to convert to Calories):

Trial #1: 216.326 ~~kcal~~ cal $\cdot \frac{1 Cal}{1000 cal} \cdot \frac{1}{0.260_g} = 0.832$ Cal/g

Trial #2: 207.832 ~~kcal~~ cal $\cdot \frac{1}{1000 cal} \cdot \frac{1}{0.265_g} = 0.784$ Cal/g

Trial #3: 188.290 ~~kcal~~ cal $\cdot \frac{1}{1000 cal} \cdot \frac{1}{0.242_g} = 0.779$ Cal/g

Calculate the average [Calories/g], compare it to the 'accepted' value found on the snack food container, and calculate the % error:

0.798 Cal/g

Average [Cal./g] snack food: 0.798 'Accepted value' [Cal./g]: 3.57 %Error: 77.6

ORAL SEMINAR Grading Sheet
CHEM 131

TITLE: Det. of the [Co/g] from combustion of SNACK FOODS
DATE:

Group members: DALEN, CANCE, COREY, JUSTIN

10 pts possible– Oral Report Presentation

The breakdown is as follows:

1 pt – A "Preparation Meeting" with the lab instructor prior to your presentation was held. The meeting time and place was scheduled upon the conclusion of the laboratory that is to be presented.

1.0 pts. awarded Meeting time and Place: in-LAB

1 pts – A title sheet and outline of your oral report was placed on an overhead. (This helps you to show the logic of your discussion and helps the audience to know where you are going with this discussion.)

1.0 pts. awarded Slam in Purpose Statement & OBJECT

3 pts– At least two chemical equations, calculations, chemical structures, and/or instrumentation circuit diagram was shown in front of the class on the overhead or chalkboard.

3.0 pts. awarded – last formed – % error

5 pts – All group members contributed equally in some aspect of technical information .

5.0 pts awarded

0 pts will be assigned to individuals who don't show or don't contribute to their group reports.

Names of people who did not attend:

Q: S.H. & A: Energy it takes to raise 1g of water 1°C! excellent!

R.E.#7 - ACME Snack Food Analysis Lab - Page 13

Research Extension #8 (Week 12)

The Determination of Acetic Acid in Vinegar via Pressure Analysis of CO_2

Background and Keywords:

As a youngster, you may have seen a chemical reaction that evolves CO_2, when baking soda is mixed with vinegar. What is the chemical reaction?

Baking soda, $NaHCO_3$ or sodium bicarbonate, reacts with a component of vinegar, $HC_2H_3O_2$ or acetic acid, evolving gaseous CO_2. See balanced equation below:

$$HC_2H_3O_{2(l)} + NaHCO_{3\,(s)} \rightarrow CO_{2(g)} + H_20_{(l)} + Na\,C_2H_3O_{2(aq)}$$

Your Research Problem:

What is the % by mass of acetic acid in vinegar?

Your Research Goals:

Today, you will be determining the % of acetic acid in vinegar via the ideal gas equation. Be careful, though, it may not seem as straight forward as this. Your lab instructor will guide you through the use of equipment and data acquisition when the time comes.

Lab Materials:

250mL Erlenmeyer flask Rubber stopper/tube system MicroLAB's Pressure sensor

1.00L Graduated Cylendar Litmus Paper

Experimental Steps:

1) Take 10.0 mL of vinegar and place it into the 250mL Erlenmeyer flask.

2) Mass out 0.250 grams of sodium bicarbonate.

3) Configure the MicroLAB program with time on the X-axis and Pressure on the Y-Axis.

4) Connect the rubber stopper/tube system to the back of the mMicroLAB and press start, building at least a 10 second base-line for pressure.

5) As you place the sodium bicarbonate into the flask of vinegar, quickly put the stopper on the Erlenmeyer flask and shake vigorously at least twice. After you shake it twice, place the Erlenmeyer flask CAREFULLY on the mouse pad, holding the stopper firmly in place with downward pressure. Don't bump the flask from here on out…

6) Allow pressure to come to equilibrium, without keeping your hands on the tube OR the flask. Once the pressure comes to equilibrium, pull the stopper off the flask and test the pH of the solution with the litmus paper.

7) Record the initial pressure, final pressure, and room temperature after each of the reactions.

8) Repeat the previous steps, keeping the vinegar volume the same, but increasing the sodium bicarbonate by 0.250 grams each time. Do this experiment in succession of 6 times.

Questions to consider in your lab write-up:

1) What is so important about step #6, keeping your hands off the Erlenmeyer flask and glass tube while pressing down on stopper?

2) From your pressure data, what can the increase in pressure be attributed towards?

3) Why are you measureing pH and how does this play an important role in this experiment?

4) What is the % mass of acetic acid in a volume of vinegar?

The Behavior of Gases &
The Determination of Acetic Acid in Vinegar via Pressure Analysis of CO_2

CHEM 131- Section #13

Student Sample Report

Purpose:

In the first part of this lab, we determined the relationships between pressure and volume and temperature and volume. Then, we related them to Charles' and Boyle's law. We also estimated the triple point pressure of carbon dioxide.

During the research extension, we determined the percent by mass of acidic acid in vinegar using the ideal gas equation.

Materials:

Part 1:

Hot Plate	Thermometer	Temperature Sensor	Graduated Capillary Tube
Pressure Sensor	Syringe	400 mL Beaker	Beral Pipettes
Scissors	Micromanometer		IC Temperature Sensor
Dry Ice			

Part 2: (Research Extension)

250 mL Erlenmeyer Flask	Rubber Stopper/Tube System	Litmus Paper
MicroLab Pressure Sensor	1.00 L Graduated Cylinder	

Material Safety Data Sheet:

$NaHCO_3$ – Sodium Bicarbonate

Appearance: white crystals. Causes eye irritation. May cause skin and respiratory tract irritation.
Target Organs: Eyes.
Potential Health Effects
Eye: Causes eye irritation. Causes redness and pain.
Skin: May cause skin irritation. Repeated or prolonged exposure may cause drying and cracking of the skin.
Ingestion: May cause irritation of the digestive tract.

$HC_2H_3O_2$ – Acetic Acid

Inhalation: Dusts may irritate the respiratory tract with symptoms of coughing, and shortness of breath.
Ingestion: May irritate the G. I. tract. Abdominal pain, nausea, and vomiting may occur. Ingestion of large amounts may result in dieresis and systemic ammonia poisoning. Normal human subjects infused with ammonium acetate exhibit flaccidity of facial muscles, tremor, generalized discomfort, anxiety and impairment of motor performance .
Skin Contact: May cause irritation with redness and pain.
Eye Contact: May cause irritation, redness and pain. Splashes from solutions may produce severe eye damage.
Chronic Exposure: Chronic ammonium acetate ingestion may cause some liver dysfunction.
Aggravation of Pre-existing Conditions: Persons with pre-existing liver damage may be more susceptible to the effects of this material.

Instrumentation Details:

See attached Instrumentation Detail diagram

Procedures and Observations:

Part 1:
1. Using MicroLab, we set up a pressure program that measured pressure vs. inverse of volume.
2. With the syringe attached to MicroLab, we pulled the plunger out to 12 cc.
3. We started the program and decreased the measurement increments of 1 cc (starting at 12) and recorded data at each point

OBS: (see attached pressure data sheet)

Part 1.5:
1. We filled a 400 mL beaker about 2/3 full with room temperature water and placed beaker on hot plate
2. We then placed capillary tube into the water and turned on the hot plate
3. We then waited for the water to heat to 80° C then turn off hot plate
4. As the water cooled we recorded various pressure readings

OBS: (see attached temperature data sheet)

Part 1.75:
1. We first cut the tip off of a pipette and filled the bulb ¼ full of crushed dry ice
2. We then set a micromanometer into the pipette recorded the reading of the mercury
3. We then used thongs to pinch close the top and allowed the pipette to pressurize and recorded the reading of the mercury

Part 2:

1. We took 10 mL of vinegar and placed it into the 250 mL Erlenmeyer flask
2. We then massed out .250 grams of sodium bicarbonate
3. We then configured MicroLAB with time on the X-axis and Pressure on the Y-Axis
4. We then connected the rubber/tube system to the back of the MicroLAB and press start, building at least a 10 second base-line for pressure
5. We then placed the sodium bicarbonate into the flask of vinegar, quickly put the stopper on the Erlenmeyer flask and shake vigorously at least twice. We made sure to hold the stopper firmly in place
6. We then allowed the pressure to come to equilibrium and pulled the stopper off of the flask and recorded the pH using litmus paper
7. We recorded the initial pressure and the final pressure after each trial, and we recorded the room temperature only once at the beginning because it stayed constant.
8. We then repeated each of the previous steps with the same amount of vinegar with an increase of sodium bicarbonate by 0.250 grams each time. Stop after a total of six trials.

Observations:

Trial 1: All sodium bicarbonate appears to have disappeared and the litmus paper was red.
Trial 2: All sodium bicarbonate appears to have disappeared and the litmus paper was red.
Trial 3: All sodium bicarbonate appears to have disappeared and the litmus paper was a purple.
Trial 4: Most of the sodium bicarbonate disappeared, but there was still some left in the bottom of the flask. The litmus paper was purple.
Trial 5: Most of the sodium bicarbonate disappeared. Also, when we removed the top of the flask, the products began reacting again, even when it had stopped when the cap was on. The litmus paper was purple.
Trial 6: there was a good amount of sodium bicarbonate left after the reaction, and the litmus paper was purple.

Data: For part one, see Gas laws and triple point data summaries and graphs.
For part two:

Mass of $NaHCO_3$	Initial Pressure (mmHg)	Final Pressure(mmHg)
0.25g	634.6	829.5
0.50g	635.1	1000.7
0.75g	634.7	1092.5
1.00g	634.8	1120.5
1.25g	634.8	1047.5
1.50g	634.9	1098.6

Data Analysis and Calculations:

Part 1: See Gas Laws and Triple Point Pressure data sheets

Part 2: See Moles of CO_2 Calculations sheet

Conclusions:

When we used Microlab to construct a curve of the relationship between pressure and volume, the inverse of volume and pressure should be linear. In our graph, we had a correlation of 0.968. However, the graph of pressure verses inverse of volume does not show a linear relationship. A possible error could have been due to human error in reading the syringe.

The temperature vs. pressure part of the experiment turned out very well. We came up with a correlation of 0.999 and the line fit is completely linear. With our equation, we came up with a value for absolute zero to be -273.04°C which is a 0.01% error to the actual temperature of -273°C.

When we calculated the triple point pressure of CO_2, we came up with a value of 2.4 atm. This value could have possible errors that are contributed to leaking gas from the pipette. We found it difficult to completely seal off the pipette so in our measurements it is possible that some CO_2 gas escaped from the pipette, which would make our readings less than the actual.

We found the first part of this experiment to help us understand the relationship between pressure, volume, and temperature. This can be very useful in the real world application of easy cheese. Easy cheese relies on gas pressure located at the bottom of the can to push the cheese out of the top. The pressure must be between certain values to allow the easy cheese to flow out smoothly. Too much pressure can cause the can to blow up, while too little pressure will not allow the easy cheese to come out. This could be very detrimental to a small, hungry child. There are many more world applications including the pressure of hot air balloons and deep water diving.

During the research extension, we found it very important to keep your hands off of the flask and glass tube because the equation PV=nRT, pressure and temperature are directly related to each other and placing your hands on the flask will cause an increase in temperature and therefore an increase in pressure. Furthermore, a dramatic increase in pressure or forcefully pushing down on the stopper could cause the explosion of the small flask.

From our pressure data, we found that an increase in pressure is due to the chemical reaction that takes place and the release of CO_2 gas into the constant volume flask. This can be seen in the equation $HC_2H_30_{2(1)} + NaHCO_{3(s)} \rightarrow CO_{2(g)} + H_2O_{(l)} + NaC_2H_3O_{2(aq)}$.

We are measuring the pH because it tells you whether the solution is basic or acidic. Whether the solution is basic or acidic tells you the limiting reactant in the reaction. Solution was acidic when there was not enough baking soda to react with all of the vinegar, and the solution turned basic when there was enough baking soda to neutralize all of the vinegar. When we added more baking soda than needed, it resulted in leftovers after the reaction occurred.

Our calculated % mass of acetic acid was 3.7%. The accepted value is from 4%-5.5%. This is a %error of 7.5%-32%. Some possible errors for our experiment could have been not capping the flask fast enough which would let out CO_2 gas that could not be documented in our calculations. Also, touching the side of the flask would increase the pressure resulting in accurate data points. We found it hard to maintain permanent seal around the stopper, in which we had to repeat part of our experiment. Our % mass was lower which was expected because some of the CO_2 was lost to the atmosphere before we could cap the flask.

Some practical applications of the gas law PV = nRT would be airbags in cars and the combustion engine. Engineers can use the gas law to find out how much CO_2 is needed to fill a certain volume (the airbag). Then, they can use a chemical equation to determine how much of the reactants is needed to formulate this specified amount of CO_2. During the combustion of engines, engineers to need calculate the oxygen to fuel ratio in order to form the "perfect" combustion. Using the same methods seen in this lab, they can easily determine the"pefect" combustion through a balanced application.

We found the research extension to bring our friendships closer together. It gave use time to hang out while doing some thinking. It allowed us to reinforce our skills in stiochiometry and helped our understanding of the real world applications.

R.E.#8 – Behavior of Gases - Page 5

pressure

	A	B	C
1	Pressure	Keyboard	f(x) = 1 /
2	Press (torr)	mL mL	one over ml
3	203.60	12.00	0.083
4	231.82	11.00	0.091
5	252.75	10.00	0.100
6	270.33	9.00	0.111
7	304.22	8.00	0.125
8	333.55	7.00	0.143
9	372.34	6.00	0.167
10	421.51	5.00	0.200
11	492.82	4.00	0.250
12	567.11	3.00	0.333
13	661.90	2.00	0.500
14	636.42	2.00	0.500

04/06/04 15:49:23 Experiment Title: pressure 1/1

temperature

	A	B
1	CAT-5 A	Keyboard
2	TempIC (C)	Kbd(mL)
3	79.49	3.20
4	66.66	3.10
5	56.97	3.00
6	45.01	2.90
7	34.52	2.80
8	22.89	2.70
9	12.78	2.60
10	2.24	2.50
11	18.19	2.50

04/06/04 17:03:32 Experiment Title: Untitled1 1/1

R.E.#8 – Behavior of Gases - Page 7

Name_____

Gas Laws

Date_____

Lab Section_____

DATA SUMMARY

Boyle's Law

Correlation coefficient (P vs 1/V graph) 0.968

Attach your P vs 1/V graph.

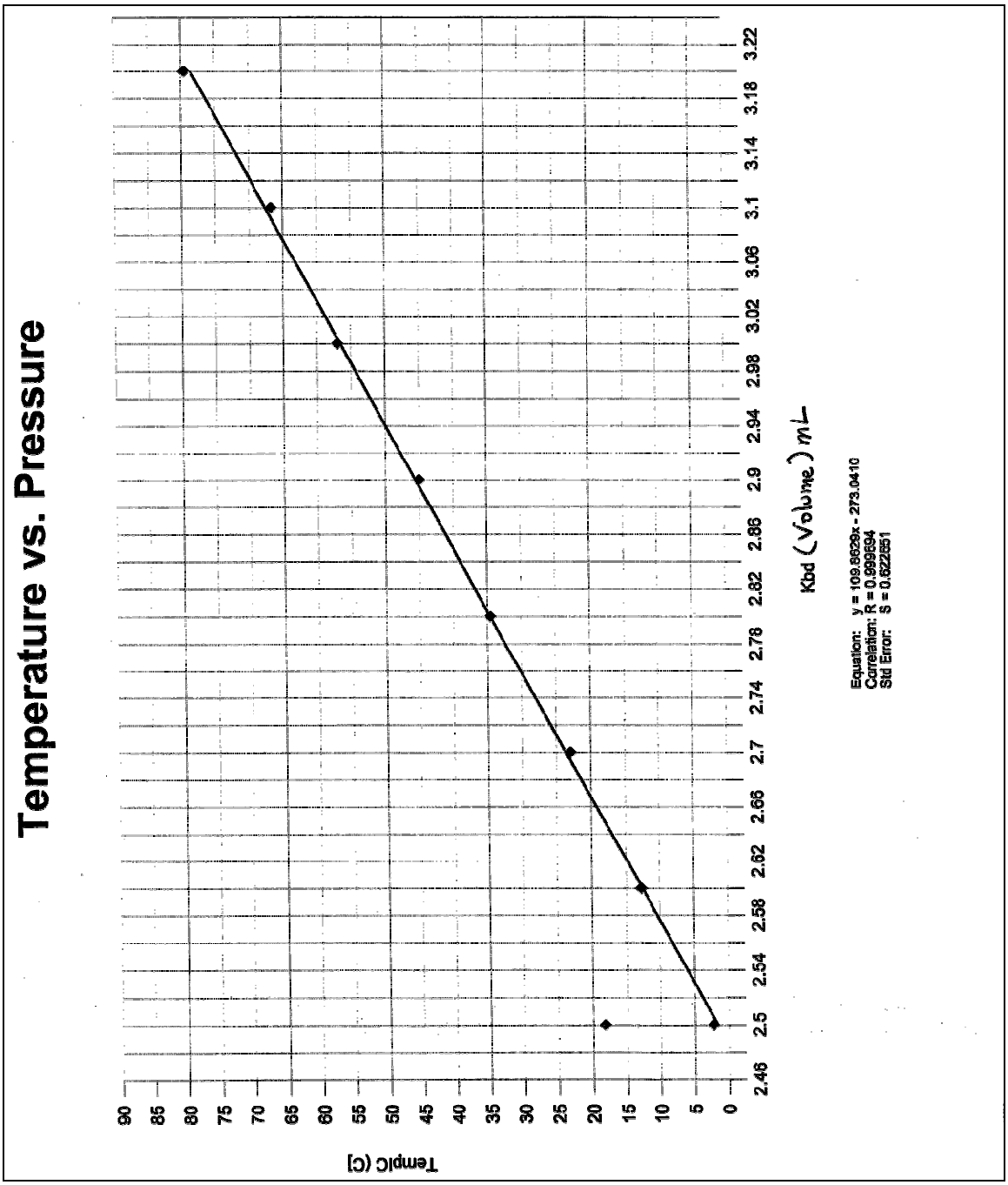
Charles' Law

Correlation coefficient (V vs T) 0.9996

Experimentally determined absolute zero −273.04 °C

Percent error 0.01 % $\frac{|-273.00+273.04|}{-273.00}$ = 0.01 % Error

Attach your P vs 1/V and V vs T graphs.



R.E.#8 – Behavior of Gases - Page 9

Calculations [Pg #1]

$$HC_2H_3O_{2(l)} + NaHCO_{3(s)} \rightarrow CO_{2(g)} + H_2O_{(l)} + NaC_2H_3O_{2(a}$$

$$PV = nRT$$

$$P_{CO_2} = P_{TOT} - P_{ATM} = 1089.65\ mmHg - 634.78\ mmHg = \frac{454.87\ mmHg}{760\ mm} \frac{1\ atm}{}$$

$$= 0.5985\ atm$$

$$V_{CO_2} = V_{TOT} - 10\ mL = 265\ mL - 10\ mL = \frac{255\ mL}{1000\ mL} \frac{1\ L}{} = 0.255\ L$$

$$R = \text{constant} = 0.08205\ \frac{L \cdot atm}{mol \cdot K}$$

$$T = 26.0°C + 273.15 = 299.15\ K$$

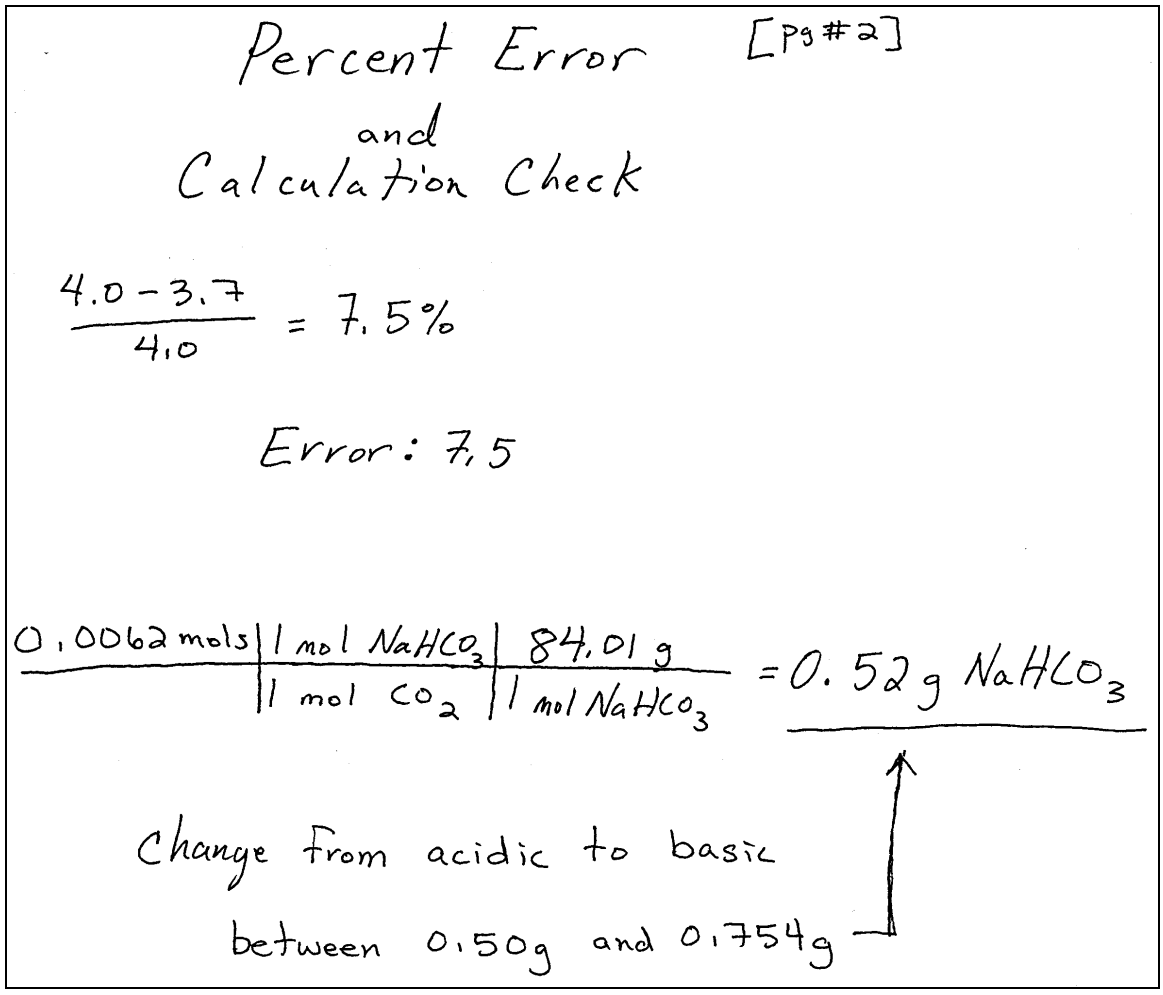
$$n = \frac{PV}{RT} = \frac{(0.5985\ atm)(0.255\ L)}{(0.08205\ \frac{L \cdot atm}{mol \cdot K})(299.15\ K)} = 0.0062\ mols\ CO_2$$

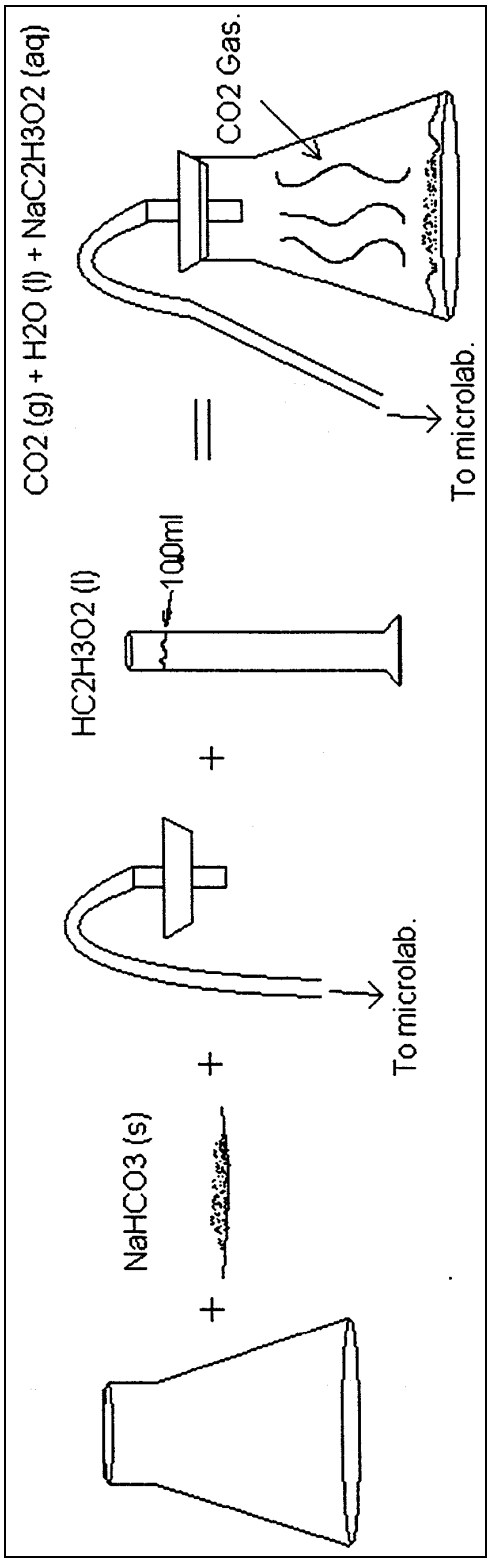
$$\frac{0.0062\ mols\ CO_2}{} \frac{1\ mol\ HC_2H_3O_2}{1\ mol\ CO_2} \frac{60.06\ g}{1\ mol\ HC_2H_3O_2} = 0.373\ g\ HC_2H_3O$$

$$\frac{0.373\ g\ acetic\ acid}{10.005\ g\ Vinegar} = 0.037 \times 100 = \boxed{3.7\%\ Acetic\ Acid\ in\ Vinegar}$$

Actual Percent Acetic Acid in Vinger:

4.0 – 5.5 %





R.E.#8 – Behavior of Gases - Page 12

Tim Copy

ORAL SEMINAR Grading Sheet
CHEM 131 - (13) Tue 3-6

TITLE: Baking Soda + Vinegar
DATE: 4/13/04

Group members:
Dgilan, Erik, Chad, Jon.

10 pts possible– Oral Report Presentation

The breakdown is as follows:

1 pt – A "Preparation Meeting" with the lab instructor prior to your presentation was held. The meeting time and place was scheduled upon the conclusion of the laboratory that is to be presented.

1.0 pts. awarded Meeting time and Place: R: 2:15 pm. GH 127

1 pts – A title sheet and outline of your oral report was placed on an overhead. (This helps you to show the logic of your discussion and helps the audience to know where you are going with this discussion.)

1.0 pts. awarded

oral 10/10

3 pts– At least two chemical equations, calculations, chemical structures, and/or instrumentation circuit diagram was shown in front of the class on the overhead or chalkboard.

3.0 pts. awarded Excellent!

5 pts – All group members contributed equally in some aspect of technical information.

5.0 pts awarded

0 pts will be assigned to individuals who don't show or don't contribute to their group reports.

Names of people who did not attend:

Research Extension #9 (Week 13)
The Determination of Copper via Electrogravimetric Analysis

Background and Keywords:

You've seen electroplated jewelry and/or silverware from flea markets to shopping malls. How is the chemical phenomenon of oxidation/reduction used to perform this task?

Solvated metal ions, like Cu^{2+} or Ag^{+}, can be forced to 'plate-out' on another conductive surface, as long as there is a battery, 'sacrificial cathode', and some solvated ions in solution.

$Cu^{2+} + 2e^{-} \rightarrow Cu^{0}$ or $Cu^{0} \rightarrow Cu^{2+} + 2e^{-}$

reduction oxidation

Q: Which of the above reactions is important for electroplating
A: BOTH!

Your Research Problem:

What amount of Copper has been electroplated onto a paperclip? (Both the theoretical value via current (amps) measurement over time and experimental value via electrogravimetric analysis?

Your Research Goals:

Today, you will be determining the amount of copper that has plated out onto a paperclip. (a)You will be measuring the amount of current (amps OR coulombs/second) vs. time (seconds). From this, you will be able to calculate the amount of copper that has been theoretically deposited onto the paperclip surface. (b)You will also be massing the paperclip prior to and after electrodeposition of copper. The change in mass should be attributed to the amount of copper that has been deposited. (c)How do these two values agree with one-another?

Lab Materials:

1.0M $Cu(NO_3)_{2(aq)}$	A copper plate (Cu^{0})	A DVM that reads current on the computer
a metal paper clip	sand paper	a volatile organic for cleaning
a 9V battery		

Some potentially helpful experimental tips:

*Your TA will discuss the simple apparatus and experimental set-up with you. Make sure that this experiment's run-time totals no less than 5 minutes total.

*Be sure to sand paper the entire paperclip before massing it. Sometimes the paperclip has a plastic coating that may impede electroplating.

*Clean the paperclip off before massing and electroplating with a volatile organic so that any loose metal filings or finger oils aren't figured into the initial mass. Also be sure that the paperclip is cleaned and DRIED after electroplating it so that any mass is purely attributed to the plating out of copper onto the paperclip.

Questions to consider in your lab write-up:

1) How many moles of copper have plated out onto the paperclip? (Determine the theoretical and experimental values of copper via current vs. time parameters and via electrogravimetric analysis, respectively.)

2) What is the agreement of these two different calculations?

3) If the same experiment was run, but the copper was uniformly electroplated out onto a ball bearing that was 2.5 cm in radius, what would be the final radius of the ball bearing?

Research Extension
Electrochemistry: Go Speed Racer….Go!

Student Sample Report

April 13th, 2004
Chem131 Section 15

Purpose:
We were given a tool kit that contained Ag, Cu, Fe, Pb, and Zn. From these elements and two lemons, we constructed a battery that produces at least 1.4 V. We will accomplish this through the use of electrochemistry and our data on the Hierarchy of Voltages.

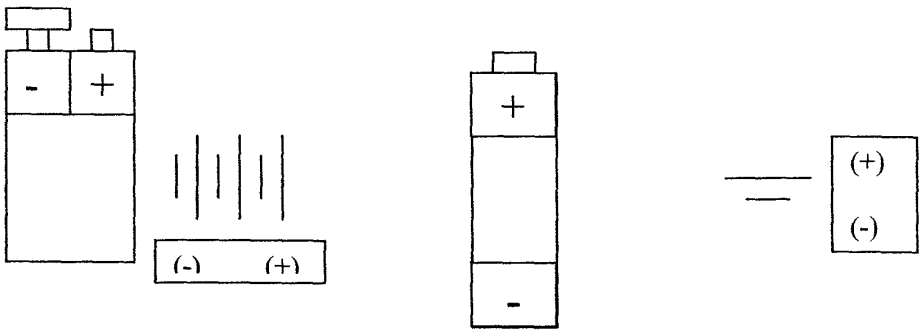
Materials:
Ag, Cu, Fe, Pb, Zn, DMV, alligator clips, lemons.

Safety:
Lemons are acidic so caution needs to be exercised to keep lemon juice out of eyes.

Procedure:

Part A: Measuring Voltage.

nice job!



I. Tim has solutions of $Cu(NO_3)_{2(aq)}$ and $AgNO_{3(aq)}$

a. Initial observations of each

$Cu(NO_3)_{2(aq)}$ OBS: Blue transparent

$AgNO_{3(aq)}$ OBS: Clear

GK

b. Tim places copper wire Cu^0 in the $AgNO_{3(aq)}$ and Ag^0 in the $Cu(NO_3)_{2(aq)}$

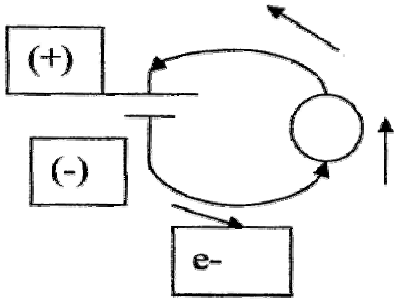
Final observations

Cu^0 in the $AgNO_{3(aq)}$ silver crystals formed on the copper wire

Ag^0 in the $Cu(NO_3)_{2(aq)}$ nothing appeared to have happened

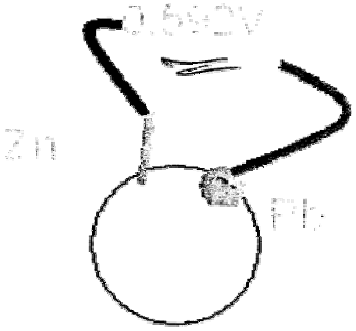
II. Using the DMV

a. when the red lead is attached to the positive end of battery and black to negative, the voltage is positive. (1.612 V)
b. When the leads are switched the voltage is negative (-1.612 V)
c. This happens because the electrons are being pulled from the negative to the positive, and passing through the DMV.



Part B: Making a Hierarchy of Metals

1. We measured the voltage produced when connecting two elements stuck in a lemon.



Nice job!

Data:

Zn reference metal

	Metal	Voltage	Gains e-	Loses e-
Most (+) Voltage	Ag	1.015	X	
	Cu	.890	X	
	Pb	.592	X	
	Fe	.419	X	
Least (+) Voltage	Zn	0.00		

Cu reference metal

	Metal	Voltage	Gains e-	Loses e-
Most (+) Voltage	Ag	.112	X	
	Cu	0.00		
	Pb	-.325		X
	Fe	-.499		X
Least (+) Voltage	Zn	-.901		X

Ag reference metal

	Metal	Voltage	Gains e-	Loses e-
Most (+) Voltage	Ag	0.00		
	Cu	-.130		X
	Pb	-.408		X
	Fe	-.414		X
Least (+) Voltage	Zn	-.594		X

Pb reference metal

	Metal	Voltage	Gains e-	Loses e-
Most (+) Voltage	Ag	.385	X	
	Cu	.317	X	
	Pb	0.00		
	Fe	-.148		X
Least (+) Voltage	Zn	-.589		X

Fe reference metal

	Metal	Voltage	Gains e-	Loses e-
Most (+) Voltage	Ag	.593	X	
	Cu	.493	X	
	Pb	.170	X	
	Fe	0.00		
Least (+) Voltage	Zn	-.406		X

Defintions:
Oxidation: Losing electrons
Reduction: Gaining electrons

Research Extension
Determination of copper via Electrogravimetric Analysis

Student Sample Report

April 13th, 2004
Chem131 Section 15

Purpose: We will look at the phenomenon of chemical electroplating of oxidation and reduction. In other words, the process of forcing certain metal ions to plate out onto another conductive metal surface when placed in a ion solvated solution, and using a power source such as a battery. We will determine the best way to go about forcing this plating out, and then calculate the amount of copper we forced to plate out, and the theoretical amount that should have plated out.

Excellent!

Materials:
Copper wire, paperclips, sandpaper, DVM, 9V and 1.6V batteries, 50ml beakers, methanol (Or another volatile organic for cleaning), 1M solution of $Cu(NO_3)_{2(AQ)}$, alligator clips.

Procedure and Observations:

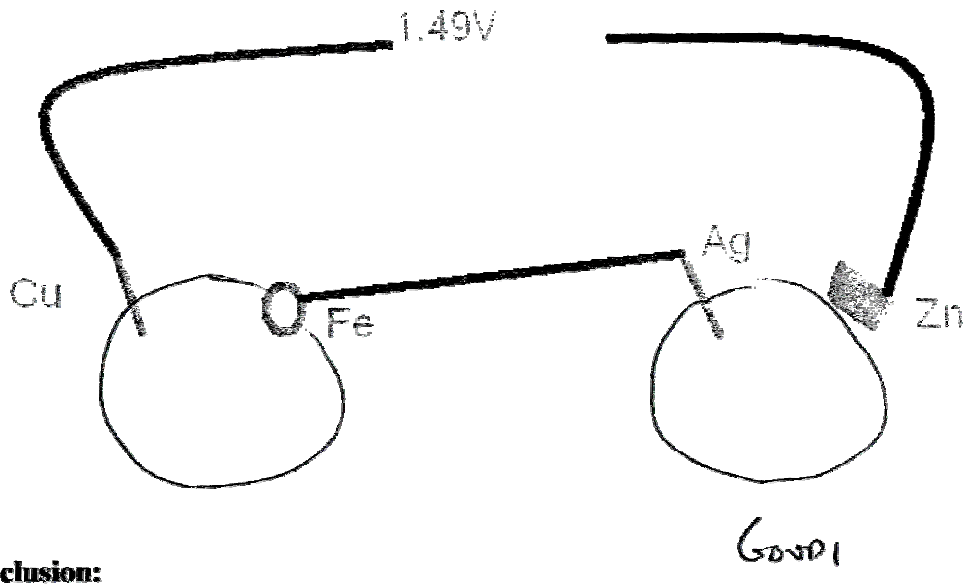
1. Our first step was to set up to main parts of our experiment and do different trials of different methods to see which one we would take data from. We took and filled a 50ml beaker ¾ full of the 1M $Cu(NO_3)_{2(AQ)}$ solution. We then attached a copper wire to the red alligator clip (+) and the paperclip to the green clip (-). Both the copper wire and paper clip were sanded to ensure that we would have a clean, pure metal surface area for our trials. We then attached the positive lead to the positive terminal of the battery, and the negative lead to the negative terminal. The copper wire was attached to the positive side because we were trying to force off positive Cu+2 ions and then attract them to another surface (Requiring that surface, our paperclip to be negative). Attaching our battery to the leads, we then placed both wires in the solution for at least 20 seconds and recorded the results.

   Good Descriptions!

   Obs: We started by using the 9V battery. Placing the wires into the solution, immediately we could see flakes from the copper wire fall off and see a blackish gunk form on the paper clip. We cleaned off our wires and did this several times, with the results the same. We then tried the same using the 1.6V battery and saw that while visible flakes fell from the copper wire, no gunk formed on the paperclip. Rather a shiny copper layer (copper plating perhaps?) formed on the paper clip. This was the method that we decided to use

2. Before we began, we took all of our wires and cleaned them by sanding the surface, cleaning with methanol and handling them with tweezers. We placed both wires on wax paper and then measured their masses before we started. We

Part C:



Conclusion:
Through the use of the Hierarchy of Voltages, we were able to build a battery that produced 1.49V, by using Cu, Zn, Fe, Ag. We determined that our voltage could be met by combining the voltages produced by Ag, Zn and Cu, Fe. We also determined that there was a pattern of Hierarchy of Voltages, Au, Cu, Pb, Fe, Zn. There were not really any errors in our experiment, because we were able to exceed 1.4V. In this, we learned how to build a battery out of lemons and how that battery works.

R.E.#9 - Electrochemistry - Page 4

R.E.#9 - Electrochemistry - Page 5

emptied our beaker of solution, cleaned it and refilled it with pure solution. We also taped both leads to the battery to ensure that we maintained a constant connection during our trial. We looped the DVM into the circuit to measure the voltage as our experiment progressed. We ran the experiment for 5 minutes and then reweighed our wires and calculated our data. The results can be found in the data section and the calculations section.
Obs: Again, no gunk formed on the paperclip and we simply had a clean, shiny layer of copper. However the copper wire we were using appeared to dissolve, as it continued to get smaller and smaller.

Data:
Run time: 5 minutes (300 Seconds)
Voltage: .14A — .15A

Wire	Mass Before (g)	Mass After (g)	Change in Mass (g)
Paper clip	.405	.417	.012 gained
Copper wire	.112	.103	.009 lost

Converted to moles
.012g x (1 mole/63.546g) = 1.8×10^{-4}
.009g x (1 mole/63.546g) = 1.42×10^{-4} } ok

Calculations:
Theoretical calculation:
(Columbs/sec) x (1 mole e^-/96500) x (1mole Cu/ 2mole e^-) x 300 seconds = Moles Cu

(.14/sec) x (1 mole e^-/96500) x (1mole Cu/ 2mole e^-) x 300 seconds = 2.2×10^{-4} m Cu

(.15/sec) x (1 mole e^-/96500) x (1mole Cu/ 2mole e^-) x 300 seconds = 2.3×10^{-4} m Cu

Percent error:
2.2-1.8/2.2 = 18.8% error

especially 108!

Conclusion:
Our results gave us an 18% error, which given the lab set up indicates we obtained good data. However it also indicates that other sources of error could be present. Several might be the power source, connections, solution and the paperclips. The battery might not consistently give off .14A, and perhaps a regulated power source would be better. The solution might not have been a pure, 1M solution and that would affect the final outcome. If we had more time we would try to maintain a better connection between the wires and battery, perhaps hardwiring everything. The final source could be the paper

clip that contains many unknown substances. Perhaps a pure piece of conductive wire would give another result. Regardless, we were still able to see some basics of electrochemistry at work regarding plating of metal ions.

excellent job w/ this!

OHP Light	White Light	LBL
9.5	30.0	39.5
10.0	30.0	40.0

Week #13: Electrochemistry: Go Speed Racer….Go!

Scenario

Juan has just arrived at the National Radio Controlled Car Championships in Florida when he realizes that he has left the battery to his **battery powered** racer at home. Knowing that it's a 50 minute round-trip to the local RC shop to pick up another battery and the qualifying heat is only in 40 minutes, he's got to think fast. Luckily he has YOUR TEAM to help him figure this one out.

Your Task:

Juan needs your help to find a way to create a make-shift battery with the materials in his tool kit and in the local surroundings. In order to qualify, he only needs to get off the starting line, which takes about 1.4V. By this time, Juan's father will be able to drive to the local RC shop, pick up a battery, and be back before the second heat, which is much more than just getting off the starting line.

Juan's Tool Kit and local surroundings:

In Juan's tool kit are a Silver (Ag) wire, a piece of Copper (Cu) wire and a small piece of Copper plate, an Iron (Fe) washer, a small piece of Lead (Pb) plate, a small piece Zinc (Zn) plate, one alligator clip lead, and a Digital Voltage Multimeter (DVM). Juan has a 9V and 1.6V battery, but these batteries must be used for his RC Controller. Only 100 yards away, at one end of the stadium and on the other side of the Sloppy Joe's Café, there is a lemonade stand that sells freshly squeezed lemonade. There is also a goofy vendor, Tim, who likes showing chemistry tricks.

Some background knowledge and exercises so your team can help Juan:

Part A: Voltage, Batteries, DVM's, and Measuring Voltages

Electronics might be described as the science of moving and counting electrons for a useful purpose. Electrons are the currency of information exchange in a motor or electronic instrument. A battery is a physical object that releases or pushes on electrons to a degree that depends on its environment. A Digital Voltage Multimeter ***(DVM)*** is a "read-out" device that presents a number in response to the presence or absence of electrons.

VOLTAGE is a measure of how hard an electron is being pushed from one place to another. A battery or power supply acts as an electron pump, pulling electrons into one terminal (+), and pushing them out the other terminal (-). Voltage is usually symbolized by the letter "**V**". The 9V battery and 1.6V AA batteries that Juan uses in his RC Controller are used to pull and push electrons the same way, but, as you can tell by the numbers in front of the "V", not to the same magnitude. Stated another way, larger voltage batteries can supply more electrons per second.

Batteries (or voltage supplies) are symbolized with a series of short and longer bars, with the longer bars representing the (+) pole of the battery, into which electrons are pulled. Electrons are pushed out the (-) pole of the battery. In general, low voltage batteries, such as the 1.6V battery, can be symbolized with one long and one short bar, while higher voltage batteries, such as the 9V battery, are symbolized with more bars, as seen in Figure 1.

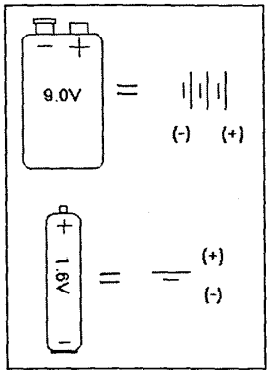
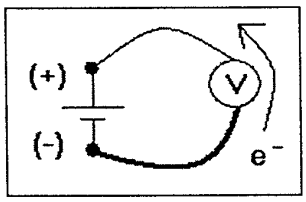


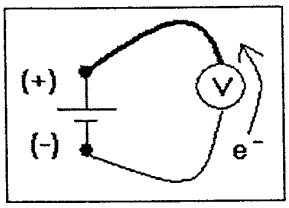
Figure 1: Batteries are "electron pumps" that pull electrons into their (+) terminal and push an equal number of electrons out their (-) terminal. The batter voltage a measure of how hard the electrons are pushed or pulled.

III. Reading voltages of batteries and "adding" them together)

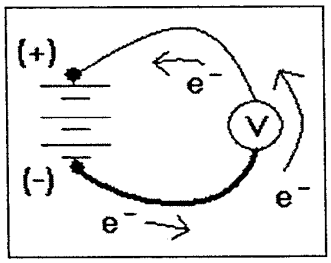
Below are some diagrams of batteries that are connected by a wire from their (-) to (+) poles of the two different batteries. A DVM has the symbol of V in a circle when reading voltage. In fact, Figure 2 and Exercise 1 are synonymous in theory, we have just used an electronic circuit diagram and electronic *symbology* to simplify it. Before you start these exercises, *please notice that the darkened wire in the diagram is the black lead from the DVM.*



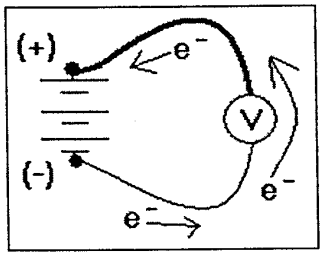
Exercise#1: V = + 1.61



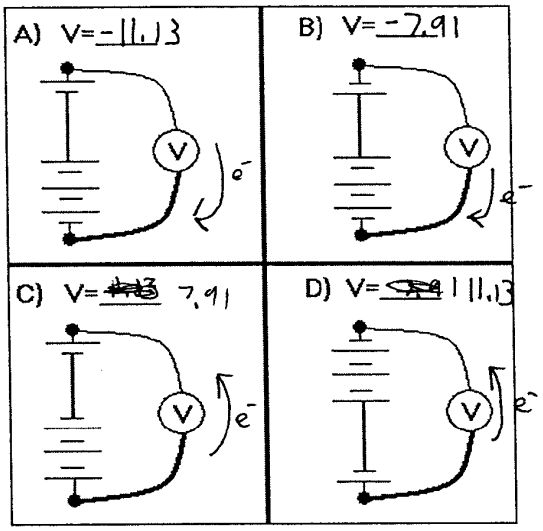
Exercise #2: V = − 1.61



Exercise #3: V = + 9.52



Exercise #4: V = − 9.52



Using the banana clip lead, connect the posts of the battery as shown above in each of the four diagrams above. Don't forget to record the proper sign and voltage in the space provided.

Please draw in the flow of electrons in the diagrams above!

Please arrange these metals in a *Hierarchy of Voltages*, from the most positive voltage to the least positive voltage while using COPPER as your reference. List the corresponding voltage and **check** the column that mentions whether this metal GAINS or LOSES electrons from COPPER:

	Metal	Voltage	GAINS e⁻	LOSES e⁻
Most (+) Voltage	Ag	.112	✓	
	~~Pb~~ Cu	0.00		
	Pb	-.325		✓
	Fe	-.499		✓
Least (+) Voltage	Zn	-.901		✓

Data Table 3: (Ag as a "Reference")

Voltage of Ag with Pb = -.414 V
Voltage of Ag with Cu = -.130 V
Voltage of Ag with Fe = -.594 V
Voltage of Ag with Zn = -.408 V

Please arrange these metals in a *Hierarchy of Voltages*, from the most positive voltage to the least positive voltage while using SILVER as your reference. List the corresponding voltage and **check** the column that mentions whether this metal GAINS or LOSES electrons from SILVER:

	Metal	Voltage	GAINS e⁻	LOSES e⁻
Most (+) Voltage	Ag	0.00		
	Cu	-.130		✓
	Zn	-.408		✓
	Pb	-.414		✓
Least (+) Voltage	Fe	-.594		✓

Data Table 4: (Pb as a "Reference")

Voltage of Pb with Zn = -.589 V
Voltage of Pb with Cu = .317 V
Voltage of Pb with Fe = -.198 V
Voltage of Pb with Ag = .385 V

Please arrange these metals in a *Hierarchy of Voltages*, from the most positive voltage to the least positive voltage while using LEAD as your reference. List the corresponding voltage and **check** the column that mentions whether this metal GAINS or LOSES electrons from LEAD:

	Metal	Voltage	GAINS e⁻	LOSES e⁻
Most (+) Voltage	~~Ag~~ Ag	~~.594~~ ~~.414~~ .385	✓	
	~~Cu~~ Cu	~~.495~~ .317	✓	
	~~Pb~~ Pb	~~.170~~ 0		
	~~Fe~~ Fe	0.00 -.148		✓
Least (+) Voltage	~~Zn~~ Zn	~~-.404~~ -.589		✓

Data Table 5: (Fe as a "Reference")

Voltage of Fe with Pb = .170 V
Voltage of Fe with Cu = .495 V
Voltage of Fe with Zn = -.404 V
Voltage of Fe with Ag = .594 V

ORAL SEMINAR Grading Sheet
CHEM 131

TITLE: ~~RYAN~~ Electrochemistry - Speed Rotor
DATE: 4/20/04

Group members: Ryan, Aaron, Nick, & Kyle

10 pts possible– Oral Report Presentation

The breakdown is as follows:

1 pt – A "Preparation Meeting" with the lab instructor prior to your presentation was held. The meeting time and place was scheduled upon the conclusion of the laboratory that is to be presented.

1.0 pts. awarded Meeting time and Place: in-LAB

1 pts – A title sheet and outline of your oral report was placed on an overhead. (This helps you to show the logic of your discussion and helps the audience to know where you are going with this discussion.)

0.5 pts. awarded

3 pts– At least two chemical equations, calculations, chemical structures, and/or instrumentation circuit diagram was shown in front of the class on the overhead or chalkboard.

3.0 pts. awarded Nice calculations from Amps → moles Cu^0

5 pts – All group members contributed equally in some aspect of technical information .

5.0 pts awarded

0 pts will be assigned to individuals who don't show or don't contribute to their group reports.

Names of people who did not attend:

Why clean & w/ Method?
A: Clean & evaporate!

★ I liked the way you all 'played' find the solution for a "best plating" plot.

R.E.#9 - Electrochemistry - Page 11

Research Extension #10: Week #14

Determination of Concentration of acid or base in an aqueous solution

Your Research Problem:

What is the % by mass of base or acid in an aqueous household solution?

During this research extension, your task is to measure the quantity of the acid or base in a household aqueous solution.

A brief Background and Keywords:

When a known concentration of base is added to a monoprotic acid, its pH increases. If the base is added until the pH reaches 7.0, then you have reached the 'equivalency point', or where there is an equivalent amount of hydroxide ion for every hydronium ion. This is a quantitative analytical method referred to as "titration", where the unknown concentration of solution is determined by the volumetric addition of a known concentration. (You will be working with monoprotic acids and bases today, so you may assume a stoichiometric ratio of one to one in your calculations.)

Your Research Goals:

Today, you will be designing an experiment in which you will measure the amount of acid or base in a give household acid or base. The Solutions that you may choose to titrate includes vinegar, lemon juice, or windex. If it only takes a couple drops to neutralize your analyte, you may have to adjust your known concentration by diluting it.

(Be sure to include all graphs of change in temperature and amount of solid used in each experiment.)

Your Materials:

Your known concentrations are either 0.010M Hydrochloric Acid or 0.010M Sodium Hydroxide. Be careful, these are considered strong acids and bases, even though their concentrations seem low.

You will be using a pH electrode and an analytical piece of glassware referred to as a burette. Your instructor will show you the proper handling and usage of the burette.

Questions to consider:

1) What are some of the key experimental parameters for your experimental set-up?
2) What does acidic and basic mean on a pH scale?
3) What calculations are necessary in the determination of % by mass of acid or base is in your unknown household chemical? (What do you need to know about the acid or the base to determine the % by mass?)

Acid and Base Solutions: understanding pH via pH electrodes, and performing a pH titration

CHEM 131- Section #9

Student Sample Report

Due Date: 4-26-04

Purpose:

In the first part of this lab, it was our goal to determine the percent of acidic acid in vinegar by using a pH titration.

a bit brief

Materials:

Part 1:

White Vinegar	300 mL beaker	10 mL graduated cylinder
50 mL graduated cylinder	Burette	Stand w/ ring clamp
0.10 M NaOH	Deionized Water	

Procedures and Observations:

1. We calibrated microlab using a pH probe and known pH solutions of 4, 7, and 10
2. We measured 5.0 mL of Lemon Juice with a 10mL graduated cylinder.
3. We diluted a sample to 30.0 mL using 25 mL of deionized water.
4. We filled up our Burette with 0.1 M NaOH and set up a stand with clamp.
5. Then we started microlab and recorded the beginning pH.
6. We added specific amounts of NaOH until the solution becomes a pH of 7. (See attached Acetic acid neutralization graph).
7. We recorded the amount of NaOH required to neutralize the acetic acid. (See Data)
8. Finally, we repeated two more times.

Data:

Trial 1: Our solution made a large pH jump about 5.8 to about 10 between the range of 34 to 38 mL, so we did not get as close of an estimate as we would have liked.

ok

Trial 2: 36.75 mL

Trial 3: We ran out of lemon juice, but another group confirmed that they reached right about 37 mL also.

Calculations and Data Analysis:

(0.037 L NaOH)(0.1 M NaOH) = 0.0037mols acetic acid

ratio of NaOH : Acetic acid? (-0.1)

$(0.0037\text{mols } H_2C_2H_3O_2)(60.06\text{ g/1mol } H_2C_2H_3O_2) = 0.222\text{ g } H_2C_2H_3O_2$

$(0.222\text{ g } H_2C_2H_3O_2/5\text{ g Vinegar}) \times 100 = 4.44\%$ by mass of acetic acid in lemon juice

Error: $(5 - 4.44)/5 = 11.2\%$ error

Very Good!

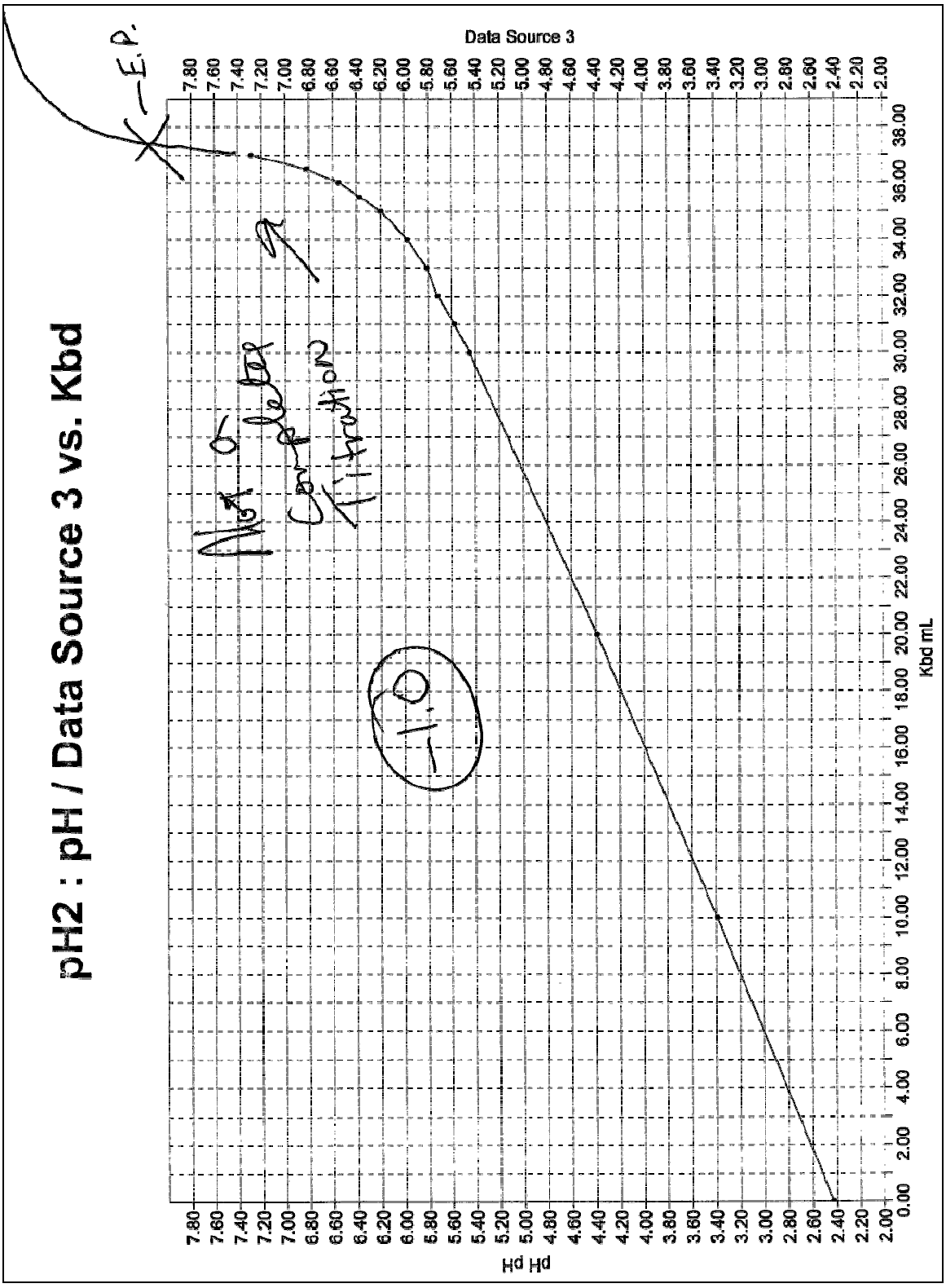
Conclusion:

We found the amount of acetic acid in our lemon juice sample using pH sensors and titration techniques. Our error could have come from a number of different sources. We could have made some errors in our measuring of lemon juice, water, or NaOH. We also ran out of lemon juice so we could not do a third trial and our first trial did not give us any accurate results. We did learn some new experimental techniques using some new tools including a pH probe and the Burette. This lab also shows how to neutralize an acid or base.

GOOD JOB!

13.9 pts

15.0 pts



R.E.#10 – Acid-Base - Page 3

APPENDIX F

ONLINE QUIZZES DISCUSSIONS

Online Quiz Sample: Quiz #2: Week of 2-16-04

1) White light is composed of all colors from the visible spectra and in some cases, parts of the spectra that are not visible to the human eye. From the five colors listed below, please rank them from highest to lowest energy with the numbers to the right. (For example, 1 is the highest energy light and 5 is the lowest energy of light.)

• Yellow	• 4
• Ultraviolet	• 2
• Blue	• 3
• X-Ray	• 1
• Red	• 5

2) Please evaluate the following statement and type in either 'true' or 'false':

Different colored light has the same Energy. (T or F)

3) Different colored light has different wavelengths
Please evaluate the following statement and type in either 'true' or 'false':

Different colored light has the same frequency. (T or F)

4) Please evaluate the following statement and type in either 'true' or 'false':

Light has an experimentally observable wave motion. (T or F)

5) Please evaluate the following statement and type in either 'true' or 'false':

Different colored light has different wavelengths. (T or F)

6) All light travels at $3.0X10^{8}$ meters per second in a perfect vacuum. The speed of light is represented in the following equation:

(speed of light = frequency * wavelength)

a) What is the frequency of light if the wavelength is 405.0nm?

b) What is the wavelength of light if the frequency is 3.530X1014 Hz?

Online Discussion Questions

Example of typical view of Posted Assignment to Students:

Message no. 3 Week #4
Posted by Tim Sorey (s04CHEM13109) on Wednesday, February 11, 2004 1:16pm

Subject: Discussion Instructions and Topics!

Hello Section #09,

This is the first discussion of the semester.

Please carefully follow the 2 instructions below (Part A & Part B):

Part A) Please choose a topic from the list below and compose a message within this discussion area that addresses it. (Write one paragraph with a minimum of 3 sentences and a maximum of 8 sentences.) Worth 0.5pts

Topic #1: Why is it important to thoroughly dry the NiDMG compound before taking the final mass AND why does this final step include using acetone?

Topic #2: Why should you slowly stir in the Dimethyl Glioxime (DMG) reagent into your aqueous Nickel solution before the filtration process?

Topic #3: What are some possible reasons for your calculations of %Ni in the unknown nickel compound being lower than the expected results?

Topic #4: What are some possible reasons for your calculations of %Ni in the unknown nickel compound being higher than the expected results?

Part B) Please read other people's messages and reply to at least two them with agreement, constructive criticism, or further thoughts on the points they may have brought up. (Write at least 2 full sentences per thoughtful reply, remembering to be constructive in your answers.) Worth 0.5pts

The Complete list of essay questions:

Posted by Tim Sorey (s04CHEM13109) - Week #5
Topic #1: How does the Bohr Model of the atom help to explain observed line spectra from an electrical gas discharge tube?

Topic #2: What's the evidence of 'quantized' electron orbitals in excited gaseous atoms?

(What did you observe in lab that supports this statement?)

Topic #3: How does frequency of light relate to its respective energy? (Mathematically and/or qualitatively)

Topic #4: How are frequency and wavelength of light related, assuming this light is traveling in a complete vacuum? (Mathematically and qualitatively)

Posted by Tim Sorey (s04CHEM13109) – Week #6
Topic #1: What is the relationship between the color of a clear solution and the wavelengths that it absorbs?

Topic #2:What electromagnetic wavelength does water absorb and how does this affect us?

Topic #3: From the lab we performed this week, what is STOKES SHIFT and where did you see the evidence for this?

Topic #4: What does solubility have to do with the formation of precipitates in the final exercise of this week's lab?

Posted by Tim Sorey (s04CHEM13109) – Week #7
Topic #1: Without naming the exact observations, what was your team's overall research strategy when using the Spot Test Matrix in solving for your unknown ions in solution?

Topic #2: What experimental methodology did you use to quantify the concentration of your unknown ion AND what could have been a secondary methodology you could have used to do the same thing? (Colorimetry, Fluorimetry, Turbidimetry, Nephelometry, Gravimetry, etc....?)

Topic #3: Please list the most experimentally frustrating obstacles of this lab AND what you did to overcome them?

Posted by Tim Sorey (s04CHEM13109) – Week #8
Topic #1: In Part II, what experimental ratio of heat gain/heat loss did you get

when mixing the hot water with the cold water? Does this match your theoretical ratio? If not, what are some experimental parameters that contributed your perceived errors?

Topic #2: In Part IV, what were your experimental values for the amount of heat that was required to melt one gram of ice? Does this match the theoretical value? (80 cal/g) If not, what are some experimental parameters that contributed your perceived errors?

Topic #3: Experiments that quantitatively measure the amount of heat are called calorimetry. Other than the experiments you performed in this lab, what are some other practical applications for experimental calorimetry...where do you see this in the real-world? (Each answer must be unique and thorough in describing experimental design.)

Posted by Tim Sorey (s04CHEM13109) – Week #10
Topic #1: What aspects of this lab helped you understand creating Lewis Dot structures?

Topic #2: Looking on the web and/or in your textbook, what is the importance of isomers and the role they play in our everyday lives?

Topic #3: Did the use of molecular model kits help you to understand the structure and dipole moment of different molecules? Please elaborate on your answer with a couple reasons of why or why not.

Posted by Tim Sorey (s04CHEM13109) - Week #11
Topic #1: What aspects of this lab have helped you to better understand the Caloric energy contained by snack food? (For instance, did you know that snack food was such a good fuel and burned so well?)

Topic #2: What aspects of this lab helped you to understand the importance of having a "Standardized Approach" in analyzing snack food? (What experimental parameter was not minimized by this standardized approach...what would you have included?)

Topic #3: What are the PROS and CONS of performing this type of group experiment within lab? (What did you like or dislike about working as an analysis laboratory with a quality control group?

Posted by Tim Sorey (s04CHEM13109) - Week # 12
Topic #1: What aspects of this lab have helped you to better understand the relationship of Pressure vs. Volume AND Volume vs. Temperature? ...what remains unclear?

Topic #2: Notice that we always talk about "ideal" gas laws...when are gases NOT ideal? Hint: There are discussions within your text if you need help. However, if you choose to discuss this topic, please translate what you read or know into YOUR OWN WORDS.)

Topic #3: What did you 'get' out of performing the last exercise in lab, where you observed and monitored the triple point of carbon dioxide? (Was this part of the lab worth your while...did you like it...etc.?)

Posted by Tim Sorey (s04CHEM13109) – Week #13
Topic #1: What aspects of this lab have helped you to better understand the Activity Series on page 131 of your text? ...what remains unclear? (If you need further understanding of how the lemon battery works, look on the homepage for "Electrochemistry Supplement".)

Topic #2: You have used batteries your whole life and have seen them 'go dead'. Can you explain what is happening electrochemically as a battery 'goes dead'? (If you need further understanding of how the lemon battery works, look on the homepage for "Electrochemistry Supplement".)

Topic #3: What evidence, within your life experiences, do you have of spontaneous electrochemical oxidation and reduction? (Be sure to give this answer some though, sitting actual instances and the potential chemical reactions involved.)

Posted by Tim Sorey (s04CHEM13109) – Week # 14
Topic #1: What aspects of this lab have helped you to better understand pH and performing a "potentiometric" titration? ...what remains unclear?

Topic #2: You have heard the term "pH" your whole life. In your own words, what exactly does pH mean with respect to (a) the concentration of [H+] and (b) the dissociation of water and Kw?

Topic #3: Does understanding HOW an electrochemical sensor, like the pH probe, help you to understand pH OR does this type of information 'get in the way'? (Please be honest.)

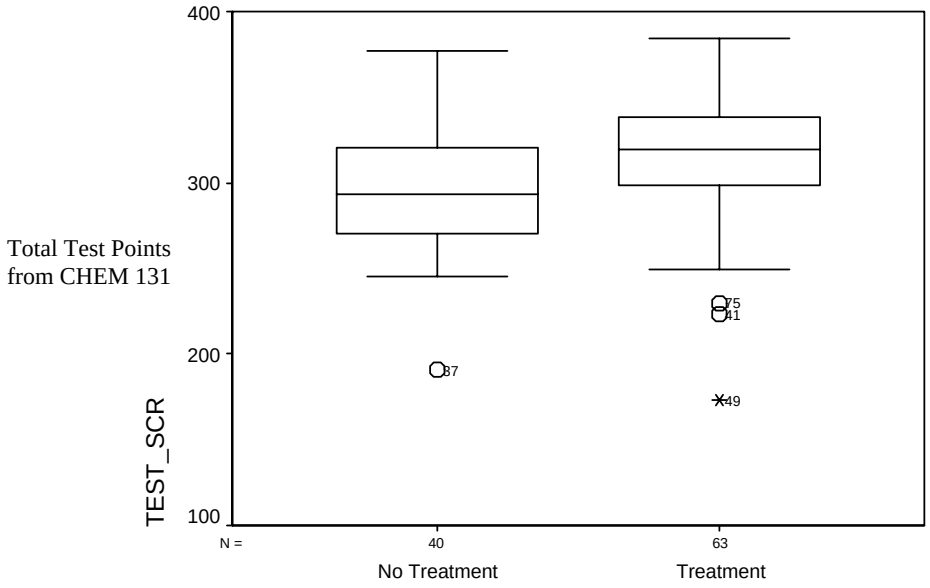
APPENDIX G

LECTURE TEST AND QUIZ STATISTICAL ANALYSIS

Test Scores for Non-Treatment and Treatment Groups

Discussion about the Independent Samples t-test for lecture Tests:

The *t-value* column displays the observed *t* statistic for each sample, calculated as the ratio of the difference between sample means divided by the standard error of the difference.



Comparing Groups on Test Scores

Group Statistics for Test Scores

TEST_SCR	TREATMENT	N	Mean Points	Mean Percentage	Std. Deviation	Std. Error Mean
	No Treatment	40	295.86 pts.	73.97%	37.33	5.90
(400pts)	Treatment	63	314.01 pts.	78.50%	38.75	4.88

Independent Samples t-test for Test Scores

TEST_SCR: t-test for Equality of Means for Treatment and Non-Treatment Groups						
t-test value	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
					Lower	Upper
2.349	101	0.021	18.1454 pts.	7.72507	33.46990	2.82097

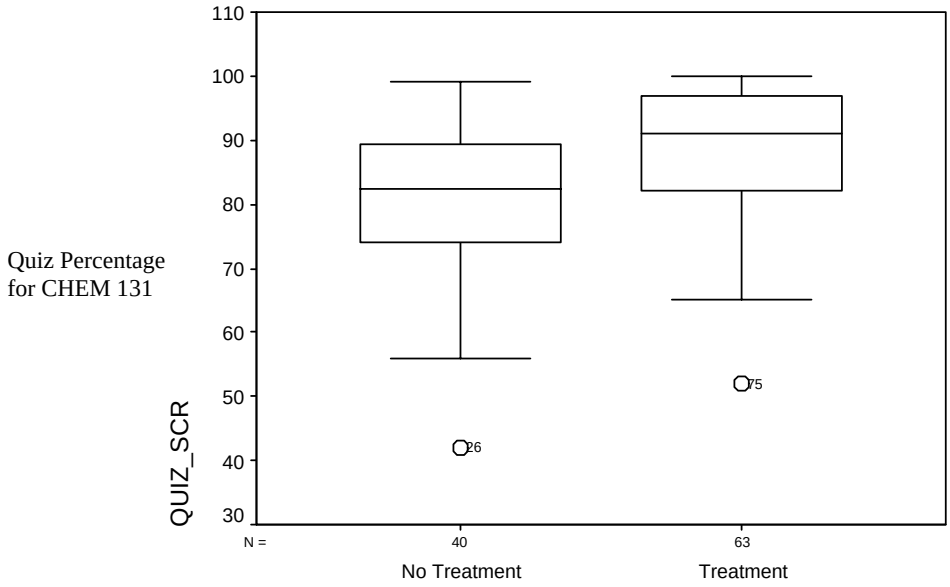
- The *df* column displays degrees of freedom. For the independent samples *t* test, this equals the total number of cases in both samples minus 2.
- The column labeled *Sig. (2-tailed)* displays a probability from the *t* distribution with 101 degrees of freedom. The value listed is the probability of obtaining an absolute value greater than or equal to the observed *t* statistic, if the difference between the sample means is purely random.

- The *Mean Difference* is obtained by subtracting the sample mean for group 2 (The Non-treatment Group) from the sample mean for group 1 (The Treatment Group).
- The *95% Confidence Interval of the Difference* provides an estimate of the boundaries between which the true mean difference lies in 95% of all possible random samples of 101 students.

Since the significance value of the test is less than 0.05, it is safe to conclude that the treatment group outscored the non-treatment group on combined lecture exams by an average of 18.14 points is not due to chance alone. In fact, it can be said that there 97.9% certainty that the treatment group will score an average of 18.14 points higher on exams throughout the semester.

Discussion about the Independent Samples t-test for lecture Quizzes:

The *t-value* column displays the observed *t* statistic for each sample, calculated as the ratio of the difference between sample means divided by the standard error of the difference.



Comparing Groups on Quiz Scores

Group Statistics for the Quiz

QUIZ_SCR	TREATMENT	N	Mean Percentage	Std. Deviation	Std. Error Mean
	Treatment	63	88.57%	10.79	1.359
	Non-Treatment	40	81.18%	12.58	1.988

Independent Samples t-test for Quiz Scores

QUIZ_SCR: t-test for Equality of Means for Treatment and Non-Treatment Groups						
t-test value	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
					Lower	Upper
3.178	101	0.002	7.40	2.327	2.780	12.013

Discussion about the T-Test: (Quizzes)

- The *t-value* column displays the observed *t* statistic for each sample, calculated as the ratio of the difference between sample means divided by the standard error of the difference.

- The *df* column displays degrees of freedom. For the independent samples *t* test, this equals the total number of cases in both samples minus 2.
- The column labeled *Sig. (2-tailed)* displays a probability from the *t* distribution with 101 degrees of freedom. The value listed is the probability of obtaining an absolute value greater than or equal to the observed *t* statistic, if the difference between the sample means is purely random.
- The *Mean Difference* is obtained by subtracting the sample mean for group 2 (The Non-treatment Group) from the sample mean for group 1 (The Treatment Group).
- The *95% Confidence Interval of the Difference* provides an estimate of the boundaries between which the true mean difference lies in 95% of all possible random samples of 101 students.

Since the significance value of the test is less than 0.05, you can safely conclude that the treatment group outscored the non-treatment group on combined lecture quizzes by an average of 7.40 points is not due to chance alone. In fact, it can be said that there is 99.8% certainty that the treatment group will score an average of 7.40 points higher on quizzes throughout the semester.