ABSTRACT

ALLEN, DEEDEE ANN. The Development and Assessment of an Active Learning Environment: $cAcL_2$, concept Advancement through chemistry Laboratory-Lecture. (Under the direction of Dr. Maria T. Oliver-Hoyo.)

Concept Advancement through Chemistry Laboratory-Lecture, or $cAcL_2$, was developed to establish an active learning environment in introductory chemistry courses. The program has incorporated elements believed to positively influence student performance and attitudes, namely, cooperative learning, hands-on activities, real-world applications, and engaging technology. A full year of curriculum materials was developed and pilot-tested in the classroom in order to achieve an active learning environment. The $cAcL_2$ instructional approach was evaluated through both quantitative and qualitative means. The quantitative study of two sections of a first semester general chemistry course revealed that $cAcL_2$ has a greater positive impact on student performance when compared to that of traditional lecture students. A subsequent qualitative study on a second semester general chemistry course gathered practical data on student problem solving and graphing abilities. The collected data provided insight on student practices allowing suggestions for classroom instructional strategies to be made. Attitudinal data from both the quantitative and qualitative studies revealed positive changes in student attitudes toward learning as well as recognition of the benefits and appreciation of the active learning environment offered by $cAcL_2$.

THE DEVELOPMENT AND ASSESSMENT OF

AN ACTIVE LEARNING ENVIRONMENT:

$cAcL_2$

CONCEPT ADVANCEMENT THROUGH CHEMISTRY

LABORATORY-LECTURE

by
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A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the requirements for the Degree of
Doctor of Philosophy

Chemistry

Raleigh
2003

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I dedicate this work to the most wonderful husband in the world -

Russell

and to my parents that have always encouraged me to excel -

Colin and Peggy Belcher

I love you!

BIOGRAPHY

DEEDEE ANN ALLEN was born to Colin and Peggy Belcher on Febuary 11, 1977 in Norfolk, Virginia. Doctors had long said that DeeDee would not survive, but much to everyone's surprise she made it and has lived a healthy life. She was the youngest of four children by at least ten years. The family moved to Suffolk, Virginia, when DeeDee was six.

Art was DeeDee’s first love. She dreamed of becoming the next Leonardo De Vinci. As life went on the love of art remained, but a love of science and math also developed. DeeDee graduated from Lakeland High School in 1995 as valedictorian of her class. She then attended Randolph-Macon Woman's College where she intended to major in math and become a high school math teacher. That goal quickly changed after taking freshman chemistry. Chemistry satisfied an appetite for mathematical problem solving that was not met by ordinary calculus.

DeeDee graduated Magna cum Laud in 1999 as the only chemistry major in her class. Upon persuasion of mentors, as well as family members, she entered graduate school in the fall of 1999 at North Carolina State University in Raleigh. Prior to moving to Raleigh DeeDee was married to Mr. Russell Allen on June 19, 1999 after a very short courtship. They moved to Raleigh two weeks after the wedding.

While in graduate school DeeDee decided that teaching was her calling. She gladly accepted TA responsibilities and soon found teaching to be the focus of her research. DeeDee was the first student to join the chemical education research group under the direction of Maria T. Oliver-Hoyo at North Carolina State University. Upon graduation DeeDee will be teaching chemistry full time.

ACKNOWLEDGEMENTS

"Many there be which say of my soul, There is no help for him in God. But thou, O LORD, art a shield for me; my glory, and the lifter up of mine head. I cried unto the LORD with my voice, and he heard me out of his holy hill."

Psalms 3:2-4

The Lord has been my strength and without him I could not have done it. It is first to Him that I give the glory for this work.

There is a very long list of people that I would like to acknowledge for their encouragement and help throughout my studies. I am blessed to have so many. I would like to acknowledge my husband, Russell, for his never ending support of who I am and the work that I do. My husband has been an encouraging coach, a faithful teammate, and my biggest fan through it all. His undying love and support have carried me through many obstacles. He is always there for me and willing to help in whatever way he can. He is indeed my closest friend.

I give honor to my parents and to my family. They have supported my education and encouraged me to always do my best throughout my entire life. They took the time to teach me right from wrong and instilled a strong set of values that could never be disrupted. Thank you.

All of the wonderful people at Raleigh's First United Pentecostal church deserve recognition for providing a spiritual atmosphere that has allowed me to grow and prosper over the last four years. They have encouraged me and given meaning to the work that I have done. I appreciate all of their support.

I would also like to acknowledge several of my colleagues here at NCSU. First of all, I want to thank Dave Conner for being a good friend. I acknowledge the various office mates and group members over the past four years that hold a special place in my heart for all the advice, help, support, and friendship they have offered. The professors in the department, especially Dr. Martin, Dr. Wertz, Dr. Shultz, and Dr. Gunnoe, are also due much credit for their patience and support as I learned more about life and inorganic chemistry. There are also three young men that deserve recognition for contributing to my research: Hugh Heldenbrand, Charlie Cox, and especially Nathan Cline.

I would like to recognize those who have provided the necessary resources and financial support for my research. I thank the NCSU Department of Chemistry for allowing $cAcL_2$ to be taught in the freshman chemistry setting. I give great appreciation to all of the TA's that helped me grade and conduct $cAcL_2$ sections. FIPSE has provided the necessary funding in order to make this research possible. I would also like to thank Dr. Robert Beicher and Physics Education Research and Development group for all of their support in disseminating the SCALE-UP philosophy into chemistry.

The final person that I would like to acknowledge is my advisor, Dr. Maria T. Oliver-Hoyo. Maria has been a tremendous mentor and friend. She has done more for me than I could ever express. In Exodus the Israelites only prevailed in war against Amalek when the hands of Moses were lifted up to the Lord; if he lowered them, then the enemy prevailed. His hands became heavy, so Aaron and Hur stood beside Moses and they each held a hand in the air until the going down of the sun. If I had to describe the two people that have been Aaron and Hur during the last four years, one would be my husband and the other would be Maria. She has carried me though good times and bad times both in my studies and in my personal life. For that, I am forever grateful.

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OVERVIEW & PROPOSAL

1.1 INTRODUCTION

Literature and research clearly address the need to improve the way chemistry is taught at the introductory level. Introductory chemistry was originally taught as a descriptive inorganic course. However, as high school reform efforts provided students with better math and science skills in the 1950's, introductory chemistry evolved into a lecture course discussing the complexity of chemical behavior relying heavily upon mathematical relationships. A lecture format loosely associated with a separate lab component has been the standard for chemical education since the 1970's (*1*). This traditional format has come under scrutiny in recent years. An NSF task force was created to review and evaluate the general chemistry curriculum (*2*). Among the issues noted were effectiveness of lecture on learning (*3*), implementation of a student-centered approach (*4*), conceptual understanding versus problem solving ability (*5*), development of high-order cognitive skills versus low-order cognitive skills (*6*), and student motivation (*7*).

As research in chemical education grows, these issues dictate the direction for new reform. The Task Force on General Chemistry Curriculum states that course material and goals should be altered. They make the following recommendations (*2*):

1. Throw out the course as it is now constituted and rethink objectives, starting afresh.
2. Retain certain elements of the current curriculum, but organize the course around a smaller number of topics.
3. Reorganize the course around the laboratory.

In the report the Task Force also noted the current project themes that fall in line with their recommendations: a core or modular approach, zero-base courses that incorporate relevant topics, and laboratory-centered instruction. The core/modular approach involves identifying a set of concepts that chemistry students should know and then supplementing that knowledge with modules that explore these concepts in a deeper context. A zero-base course evaluates important concepts of chemistry in light of the needs of non-chemists. Non-relevant topics would be removed from the curriculum as more pertinent topics would be added. Laboratory-centered instruction involves the use of scientific methods in data gathering and analysis followed by subsequent discussion in the classroom. Validation labs would no longer be the focus of laboratory instruction.

In accordance with these recommendations for reform, a new format is presented in which laboratory and lecture are combined into one seamless session. The lab and lecture components of introductory chemistry are fully integrated as students no longer attend a separate laboratory. In a highly cooperative, hands-on, active learning environment students experience research based activities as part of the curriculum design. Curriculum materials are developed and systematically implemented to foster a student-centered learning environment. The proposal, development, quantitative and qualitative assessment of this novel approach to teaching general chemistry are presented.

1.2 LITERATURE REVIEW

Chemistry is taught in two realms - lecture and laboratory. Lecture successfully communicates large amounts of factual material that constructs the knowledge base of students in particular areas of study. Therefore, lecture addresses the realm of knowledge. Although lecture has many advantages, such as allowing an instructor to efficiently and to effectively convey large amounts of information to a large number of students, there are areas in which the lecture format needs improvement. Research shows that lecture may have little impact on student achievement in a general chemistry course (*8*). Lectures can become impersonal (*9*) or provide little opportunity for students to construct their own knowledge through experience (*10*). Lecture successfully transmits lower level factual material that students can memorize, but a gap arises when the students need to retain that knowledge, apply it, develop higher-order thinking, and maintain motivation (*11*).

The issues associated with lecture methods of teaching can be amplified when combined ineffectively with large enrollment courses. Lecture decreases student interest and attendance leaving students feeling little sense of responsibility or accountability for their learning (*11*). Not only might student interest decline during extended lecture periods, it has been shown that exclusive use of passive lecture methods fails to sustain student interest in the sciences (*12*).

The second realm of chemistry is the laboratory. Laboratory addresses the realm of experimentation. The literature presents evidence that the laboratory component is also in need of reform. Many labs focus only on lower-order cognitive skills, which require students to repeat experiments according to detailed instructions with the primary goal of obtaining a correct answer rather than focusing on experimental design and investigation (*13*). These labs are often referred to as verification, or "cookbook", labs. This type of lab does not foster student inquiry and is ineffective in promoting the development of important cognitive skills (*14*). Although cookbook labs may lack valuable inquiry components, laboratory is still regarded as a central part of the chemistry experience. Students report greater enjoyment of the laboratory component of chemistry more than any other part of their chemistry instruction (*15*), even though it may not contribute to their conceptual understanding (*16*).

Further study reveals that labs have not demonstrated a measurable affect on student achievement (*17*).

Research-centered, or laboratory-centered, instruction originally played a much larger role in the teaching/learning process. Chemistry developed from a purely practical nature where specific laboratory training was necessary to meet industrial needs. By the early 1800's chemistry evolved into a recognized academic pursuit where the transfer of knowledge and the development of experimental technique became essential (*18*). As history reveals, lecture and laboratory were originally designed to complement one another, but the effective connection, today, is in question. Without an effective connection laboratory instruction fails because students do not interpret their data and observations within the context of chemical concepts discussed in lecture (*19*).

Numerous efforts are attempting to address the need for reform in chemistry education. Interdisciplinary projects combine the efforts of chemists, physicists, biologists and others to appeal to the interests of non-chemistry students (*20*). The modular approach is taken by ChemConnections (*21*) and ChemCases (*22*) to teach chemistry topics using themes like pollution, airbags, or Gatorade®. Projects like *Chemistry in Context* (*23*) and SENCER (Science Education for New Civic Engagements and Responsibilities) (*24*) strive to provide a real-world context to students. Problem-based teaching is the focus of Peer-Led-Team-Learning (PLTL) where students work in teams led by an experienced mentor during a more active recitation session (*25*). Cooperative learning is a component of many reform efforts like PLTL, Studio Chemistry at Rensselaer Polytechnic Institute (*26*) and Process Workshops at the State University of New York at Stony Brook (*27*). These programs place students into cooperative groups for problem solving and discussion during modified recitation sections closely tied to lecture. Some programs have offered outreach and mentoring opportunities to students in order to increase their involvement and interest in chemistry (*28,29*). Assessment techniques like ConcepTests are being developed and incorporated to enhance student understanding of chemical concepts. Research on misconceptions in chemistry is also being used to modify learning objectives and construct better assessment tools (*30*). Advanced computer technology is implemented to offer on-line labs through programs like the *irYdium Project* at Carnegie Mellon (*31*), develop interactive animations (*32*), and promote distance learning (*33*).

Many of the aforementioned initiatives could also fall under the category of active learning where students are involved in activities like reading, writing, discussing, problem solving, or participating in higher-order thinking tasks that require students to analyze, synthesize, and evaluate pieces of information (*34*). Numerous studies reveal the advantages to incorporating active learning into the classroom (*35*). Active learning creates interest in the subject, helps students to learn effectively, apply knowledge, develop independent learning skills and prepare for their future careers (*36*). Students are held more accountable for their own learning when active learning methods are implemented. In an active learning environment students obtain an enhanced understanding of course content (*37*), and retain more of the material covered (*38*).

The most active experiences in chemistry are typically found in the laboratory realm of instruction. For that reason many chemical education reformists are calling for more focus on laboratory rather than on lecture (*39*). Projects at California Polytechnic State University (*40*) and Rensselaer Polytechnic Institute (*26*) attempt to combine or better correlate lecture and laboratory. The Cal-Poly project has focused efforts on the technical aspects of integrating laboratory and lecture through a special room design and supporting technology. However, there is not sufficient assessment data available to evaluate the extent to which student learning experiences are affected. The program at Rensselaer uses the Studio Chemistry recitation session to tie the lecture to the lab through discussion. Each of these programs has attempted to address the needs of reform in a unique way.

1.3 PROPOSAL

A new program, $cAcL_2$ (concept Advancement through chemistry Lab-Lecture), approaches the reform effort quite differently. Laboratory and lecture components are combined into one integrated course, where students can experience the use of technology and inquiry-guided/discovery techniques in an active hands-on learning environment. The program is a dissemination project of SCALE-UP, Student-Centered Activities for Large Enrollment - Undergraduate Programs. SCALE-UP originated in the Physics department at North Carolina State University (*41*). Physics departments at several institutions have adopted the SCALE-UP format; $cAcL_2$ is the first program to disseminate SCALE-UP philosophies into chemistry. The project tackles the current goals of chemical education reform. The proposed new format has the following objectives:

- Improve student understanding of basic chemical concepts through an integrated lab-lecture format.
- Improve the higher order cognitive skills of students through "real world" problems and applications.
- Improve graph construction, manipulation, and interpretation skills.
- Increase student interest and improve student attitudes toward chemistry.

In this integrated approach to chemistry, lecture time is minimized, while time devoted to hands-on, student-centered activities is maximized. An active learning environment is created by shifting from teacher-centered instruction (lecture) to student-centered learning (activities). The activities allow students to perform simple experiments and reason through data and observations that allow them to answer directed questions and, in turn, discover and construct concepts for themselves. Therefore, the class more closely resembles a laboratory. Basic factual material, like definitions and equations, is conveyed through the reading of the textbook and short 20-minute intervals of lecture or class discussion.

The $cAcL_2$ project utilizes the key components of many successful reform efforts. For instance the team problem solving and discussion techniques found in PLTL, Process Workshops, and Studio Chemistry are embedded in the design of $cAcL_2$. Like the laboratory-lecture program at Cal-Poly, $cAcL_2$ combines lab and lecture into one integrated course that does not separate the two experiences. Although the similarities between the programs are numerous, there are notable differences. The PLTL, Process Workshops, and Studio Chemistry projects have not altered the lecture component of the course. The reform only affects the recitation sessions. Students in these programs continue to attend traditional lecture sections as a separate requirement. The Cal-Poly program has not implemented a systematic study of the integrated lab-lecture course in order to assess the effectiveness of combining laboratory and lecture. $cAcL_2$ has incorporated several modes of instructional reform and has also included a comprehensive assessment component. Research focuses on the systematic implementation and assessment of this new format in order to evaluate its effectiveness.

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CHAPTER 2

CURRICULUM DEVELOPMENT

2.1 CONCEPTION

In order to implement an active hands-on environment for $cAcL_2$, a special curriculum was developed for a full year of general chemistry. The curriculum was designed to compliment the unique structure of the current general chemistry program in place at North Carolina State University. In 1997, the one-year general chemistry course was revamped. The new general chemistry program, in one semester (CH101), exposes students to all the major topics typically covered throughout a year of general chemistry. Students concentrate on conceptual material, not intensive mathematical relationships. Students successfully completing the first semester can go on to either organic or the second semester of general chemistry. The major topics are revisited in the second semester course (CH201) placing more emphasis on mathematical relationships and problem solving. A total of 53 activities for the first semester and 40 activities for the second semester have been developed for $cAcL_2$. Although the activities were specifically designed for the general chemistry program at NCSU, the activity format and specific identification of concepts covered allow for easy adaptation into other programs. The development process is outlined below followed by specific examples of how major units were covered in the curriculum.

Each semester was divided into major topics based on the textbook (*1*) and lecture notes of the lead instructor. Those major topics were then divided into sub-topics focusing on specific concepts. First and second semester topics are listed below.

CH101

- Early Experiments
  - matter
  - historical research
- Quantum Theory
  - nature of light
  - quantum theory
- Atomic Nature
  - periodic families & e^- configuration
  - periodic trends
  - magnetic properties
- Bonding and Structure
  - Lewis structures
  - ionic bonding
  - covalent bonding
  - VSEPR
  - valence bond theory
  - resonance
- States of Matter
  - ideal gas laws
  - solids
  - intermolecular forces
  - phase changes
  - phase diagrams
- Reaction Energetics
  - enthalpy
  - entropy
  - free energy
  - kinetics
- Equilibrium
  - equilibrium expressions, K
  - meaning of K
  - Le Châtelier's Principle
- Solutions
  - dissolution
  - precipitation & solubility
  - electrolytes
- Electrochemistry
  - activity series
  - redox reactions
  - cells
- Acids and Bases
  - acid dissociation constant
  - writing acid-base reactions
  - pH
  - ionic equilibria
- Introduction to Organic
  - nomenclature
  - polymers

CH201

- Stoichiometry
  - balancing equations
  - reaction stoichiometry
  - composition
  - empirical formula
  - limiting reagent
  - yield
- Solutions
  - solution stoichiometry
  - concentration units
  - colligative properties
- First Law of Thermodynamics
  - energy & work
  - enthalpy
  - calorimetry
- Entropy, Free Energy & Temp. Dependence
  - entropy
  - free energy
  - temperature dependence
- Equilibrium
  - equilibrium
  - equilibrium constant
- Acids and Bases
  - concentrations and pH
  - ionic equilibria
  - buffers
  - titration
- Solubility & Complexation
  - pH dependence
  - complex ions
- Electrochemistry
  - activity
  - Nernst equation
- Kinetics
  - rates
  - rate laws
  - mechanisms
  - catalysis
- Nuclear Chemistry
  - atomic particles
  - nuclear reactions & radioactivity

A literature search was conducted for each topic and sub-topic using internet resources and relevant education journals. This information was sought in order to determine how topics have been presented previously (laboratories, demonstrations, analogies, etc), what technological resources are available, and what chemical education research has revealed about the nature of teaching and learning these concepts primarily in terms of student misconceptions and available evaluation procedures. The information was compiled and evaluated to determine the most student-oriented way to present the material in a hands-on environment.

2.2 ACTIVITY ORGANIZATION

There are several important components that must accompany each activity as part of the curriculum. Each component is listed and described below.

TITLE
Time: *time suggested for completing activity*
Topic: *topics covered by activity*
Type: *probe or investigation*
Level: *introductory, intermediate, or advanced*
Overview: *statement outlining the activity*
Materials and Equipment: *items needed to complete the activity*
Objective(s): *statements identifying the intended learning outcomes*
Misconceptions: *common misunderstandings that conflict with scientific theory*
Other Student Difficulties: *areas that should be given special attention*
Prerequisites: *concepts or material needed to complete the activity*

Activity Table *outlines every step of the activity for instructors*

Task	Reason	Notes
Action to be taken by students or instructors	*Why the action is important*	*Helpful information for instructors*

Related Activities: *activities that incorporate related concepts*
References: *the resources used in developing the activity*

Supplementary Material: *Discussion of concepts, explanation of demos and procedures*

Figure 2.1. Activity Form. Descriptions of each component are provided.

Title - The title provides a way of identifying a specific activity and is associated with the concept covered in that activity.

Time - Time denotes the amount of time suggested for completing an activity. The reported times are based on actual implementation of activities in the classroom to determine the time students require to complete it.

Topic - Important concepts covered by the activity are listed under the topic heading. A list of topics and sub-topics covered in CH101/201 were previously listed.

Type - The activities are divided into two main categories: probes and investigations. Probes are short hands-on activities that allow students to discover and develop chemistry concepts. Investigations are more involved hands-on activities that require students to apply concepts already discussed. There are also some activities classified as demonstrations and real world problems. Demonstrations are used as either probes or investigations in which students are asked to explain their observations. Real world problems are problems involving relevant topics like drinking water or recycling that require students to apply the concepts that they have learned.

Level - Level is used to denote the difficulty level of an activity and whether students need prior experience with a concept before attempting an activity. An introductory level activity is used to introduce a new concept to students. An intermediate level activity may be an investigation requiring students to apply concepts learned from an introductory activity. An advanced level activity would be a much more difficult investigation and may require students to apply multiple concepts.

Overview - The overview statement provides a summary of what students will do during an activity.

Materials and Equipment - This section provides a detailed list of necessary supplies to complete an activity. For instance chemicals, glassware, and necessary computer equipment would be listed here.

Objective(s) - The objectives are a list of intended learning outcomes that should be attained when implementing the activity. Instructional objectives are important because they direct instruction in developing cognitive, affective, and psychomotive skills in students and they also identify the concepts important for evaluating student mastery in a specific area (*2*).

Misconceptions - Misconceptions are a list of known inaccurate preconceptions that students already have or commonly formulate for a specific topic. Research in specific areas of chemical education reveals common misconceptions that students embrace (*3*). An extensive project entitled "Student Preconceptions and Misconceptions in Chemistry" is an effort to compile a comprehensive list of the misconceptions in chemistry in order to aid in course development and design an assessment tool to identify and overcome these misconceptions in chemical education (*4*). These reports on misconceptions provide conceptual questions that identify misconceptions as well as the extent of conceptual understanding. This research has been used to design activities for $cAcL_2$ that intercept or prevent misunderstanding about chemistry. The targeted misconceptions are explicitly stated for each activity.

Other Student Difficulties - This section lists areas that should be given special attention during instruction. The reported difficulties are based on actual implementation of activities in the classroom and the difficulties students experienced.

Prerequisites - The prerequisites are a list of the minimum concepts with which students should be familiar in order to effectively complete an activity.

Activity Table - The activity table is the most important part of the activity form because it guides the instructor in implementing and facilitating the activity in the classroom. Every task to be completed during the activity is outlined in the activity table. The reason each task is performed is also included. Notes, based on the actual implementation of the activity, are also provided to aid the instructor with each task. The activity table represents the dynamic nature of instruction in $cAcL_2$. The tasks follow a logical flow based on experience in the classroom and can be adapted for various methods of teaching particular concepts.

Related Activities - The related activities are a list of activities that incorporate concepts that are related to the concepts covered in a specific activity.

References - All resources used to develop the activity as well as additional resources that may aid the instructor are listed under references.

Supplementary Material - A discussion of detailed procedures, discussion of the important concepts, and any additional helpful information is included in the supplementary material section.

2.3 CONSIDERATIONS

Several factors were considered in the development of these activities. These factors included chemical handling, modification of demos and traditional labs, incorporation of microscale techniques, development of new activities, design of real-world problems and incorporation of available technology. Each of these issues was specifically addressed in order to construct hands-on activities for an integrated environment that combines both laboratory and lecture.

Chemical Handling

Chemicals add a demanding safety component to the curriculum. The special room used to teach $cAcL_2$ is not equipped with sinks, running water, gas lines, hoods, or special lab benches. To overcome these obstacles a small portable sink, bench and a portable eyewash were made available as needed. Deionized water is supplied via 10-liter carboy. Under these conditions, all hands-on activities must make effective use of small amounts of chemicals, take every precaution to protect computer equipment and furniture from damage, and impose no toxic threat while maximizing the learning experience for students. In order to comply with these stipulations, demonstrations and traditional macro/micro labs had to be modified for use as $cAcL_2$ activities.

Modification of Demos and Traditional Labs

Demonstrations are a familiar part of chemistry classes. Almost 600 demonstrations to date are referenced in the Journal of Chemical Education alone (JCE Index Online Search). If used effectively, demonstrations can greatly enhance any lecture and improve conceptual understanding (*5,6*). In $cAcL_2$ demonstrations are carefully chosen and implemented to study specific chemical concepts and must add to student learning. In many instances students are invited to do the demonstrations, thus making the experience a more active one. If the instructor conducts the demonstration then worksheets are used to guide student learning and keep them mentally engaged in observing and explaining the chemical phenomena being demonstrated. Demonstration assessments can be used to evaluate student comprehension of conceptual material by asking students to provide detailed observations and conclusions for a demo presented (*7*).

The literature suggests that traditional cookbook labs can be modified to emphasize student-centered learning (*8*). Other reports show how this instruction can be incorporated in small increments to avoid "costly and large-scale changes" (*9*). These aspects are considered as traditional labs are modified for inclusion in $cAcL_2$. Previously existing labs from the CH101 curriculum have also been incorporated, in modified formats, into $cAcL_2$.

CH201 employs a more traditional mathematical treatment of general chemistry, while the labs focus more on the development of various quantitative techniques. Due to a simultaneous need for access to computers, chemical instrumentation, and lecture facilities, the labs from CH201 were not incorporated into $cAcL_2$. Scheduling and transporting specialized equipment become significant issues if the equipment is to be shared between different laboratory rooms located in different buildings. Therefore, the students continued to meet for a separate laboratory during the second semester $cAcL_2$ course. However, activities were still included in the CH201 $cAcL_2$ curriculum. The activities were directed more toward problem solving or collecting quantitative data applicable to classroom discussion.

Incorporation of Microscale Techniques

Microscale labs fulfill the physical requirements of $cAcL_2$. Microscale labs use tiny quantities of chemicals to minimize waste (*10*) as well as chemical exposure and cost (*11*). These small quantities promote a safer classroom environment and circumvent any major spills that may damage computer and electrical equipment. For instance, mini-titrations requiring only drops of diluted hydrochloric acid and sodium hydroxide use approximately 2-3 mL of chemicals per group. These microscale techniques have been used to make the appropriate modifications to implement $cAcL_2$ activities in the classroom.

Development of New Activities

Newly developed activities introduce abstract topics with hands-on relationships. Developing an analogical relationship is one example of how to introduce an abstract topic. By using analogical relationships students are given more concrete examples on which to base their understanding. One example of a newly developed activity is "Fingerprinting" (*12*) (See Appendix A). In this activity barcodes are compared to emission spectra. The analogy between bar codes found in everyday items and absorption-emission spectra emerges from the fact that both contain information in the form of lines and those lines identify a specific product or element. At a certain point in the activity students are asked to draw both an absorption pattern for a bar code and a predicted bar code from a reflectance pattern. This exercise is necessary to test student understanding of whether light is reflected or absorbed. Objectives tackle the differences between absorbance and reflection, electronic transitions, and emission spectra. New activities are developed for topics such as these in which little hands-on material is available.

Design of Real-World Problems

Real-world problems are used to promote interest in chemistry (*13*) as well as to develop and evaluate higher order cognitive skills (*14*). The first semester course implements conceptual problems that require students to relate chemistry concepts to everyday phenomena. For instance, after conducting activities on the interaction of light and spectrophotometry, students are asked why air traffic controllers wear orange lenses on foggy, hazy, and clear sunny days (*15*). In the second semester of $cAcL_2$, students will focus on finding more quantitative solutions to real-world problems like how much energy is saved by recycling an aluminum can (*16*).

Incorporation of Available Technology

Technology is incorporated through the use of computers and projection tools. Every laptop has Internet access and basic software such as Microsoft Excel, Word, and Powerpoint. There are also special chemistry related programs, like WebLab Viewer Lite (*17*), and various multimedia plug-ins available for chemical applications. The use of computers in education has been both praised and condemned (*18,19*), but when used in ways that reach beyond a mere display medium, technology can greatly enhance student understanding of chemical concepts (*20,21,22*). In $cAcL_2$, computers are used in five major areas: class management, electronic homework, data collection, graphical analysis, simulations and animations

The class materials and notes are organized, managed, and distributed using WebCT (*23*). Daily electronic homework is assigned through WebAssign (*24*). When combined with chemical probes the computers can be used to collect data, which can, in turn, be analyzed through graph representation. Graphing skills are promoted by requiring students to prepare and interpret graphs of their data.

The Internet provides access to many simulations and animations that involve recreating historical experiments or offer tools for students to study chemical behavior. These simulations use student controlled parameters that allow students to perform experiments on the computer. Examples of topics covered using these simulations include the photoelectric effect (*25*), activity series (*26*), electrochemical batteries (*27*), and acid-base behavior (*28,29*).

2.4 ACTIVITIES

All activities developed for $cAcL_2$ are listed and briefly described in Tables 2.1-2.2.

Table 2.1. List of Activities developed for $cAcL_2$ CH101.

Type	Title	Overview	Concepts
I	A Sinking Suspicion	Students will demonstrate how the water level in a pool changes when large rocks are thrown from a boat in the middle of the pool	problem solving Intro to working in group
P	Microscopic View	Students will classify particulate drawings based on microscopic properties.	states of matter, compounds elements, pure substances mixtures/hetero/homo
D	Heavy Ice	Students will determine why one ice cube floats and another one sinks.	isotopes
P	Rediscovering the Atom	Students will revisit and experience the early experiments that led to the discovery of subatomic particles.	atomic particles history of the atom
P	How Many Pennies	Students will simulate Millikan's oil drop experiment using a beaker of pennies.	Millikan's oil drop exp.
P	Foiled Again!	Students will weigh a small square of aluminum foil and use conversion factors to find its thickness in centimeters and atoms.	weighing, size of an atom dimensional analysis
I	New Element	Students will determine the atomic mass of M&Ms treating them as if they were a real element.	atomic mass
P	Photoelectric Effect	Students will observe a simulation of the photoelectric effect and make predictions using collected data.	photoelectric effect
P	Fingerprinting	Students will see how an element can be identified by its emission spectra just like a consumer product can be identified by its bar code.	bar codes emission/absorb. spectra Hydrogen energy levels
P	Seeing the Light	Students will observe the colors absorbed and reflected from a colored solution.	light, absorbance color, emission
P	Making and Breaking the Rules in the Atomic Hotel	Students will explore quantum mechanical rules when working through an extended hotel analogy.	quantum mechanics
P	Who, What, When, and Where	Students will find the names of periodic families, observe orbital representations, and be exposed to electronic configurations.	Periodic Families, orbitals, electronic configurations
P	Some Periodic Trends	Students will view and explain graphical representations of periodic trends.	ionization energy electronegativity, e^- affinity

Table 2.1 continued

P	Little Magnets	Students will observe and explain the magnetic properties of various metals.	paramagnetic diamagnetic
P	Covalent Bonding Geometry	Students will build models of water, ammonia and methane in order to determine likely structures and geometry based on a few simple rules.	molecular geometry VSEPR Lewis structures
P	Tug-o-war	Students will take part in a demonstration that portrays polarity in a tug-of-war format. Molecular geometry distortion will also be illustrated.	polarity
I	Orbital Construction	Students will construct 3-D orbital models of various structures using Lewis structures, VSEPR theory and VB theory.	VB Theory hybridization
I	Molecular Modeling	Students will use a molecular modelling program to visualize three-dimensional molecules and to rationalize the differences in predicted and experimental values.	visualization computer modelling rationalization
P	Graphical Analysis	Students will be introduced to graphical analysis methods. Then they will estimate mathematical relationships b/t two variables before using a computer to determine the actual relationship.	graphical analysis
P	Gas Law Day	Students will observe results of kinetics theory, Boyle's Law, Charles' Law, and the relationship b/t temperature and pressure through data collection, experiment, and demos.	kinetic molecular theory ideal gas laws
P	Twenty Solids	Students will classify solids into various groups based on physical properties.	properties of solids
P	Jumping the Gap	Students will study the properties of conductors, semiconductors, and insulators using LEDs.	band gap theory
P	Solid State Modeling	Students will build models of several basic unit cells and answer questions based on the structures.	unit cells, stoichiometry packing density
P	Evaporation	Students will predict the strength of intermolecular forces in various liquids and then compare predictions to measurements made on the temperature change due to evaporation.	intermolecular forces
P	Surface Tension	Students will float paper clips on water based on the concept of surface tension and break surface tension using a surfactant.	surface tension, surfactants intermolecular forces

Table 2.1 continued

P	Steply States	Students will collect and interpret data on the temperature change of water as it is heated over time.	state changes
P	Hot and Cold	Students will observe endo- and exothermic rxns and predict the higher energy side of the rxn eqn.	endothermic reactions exothermic reactions
I	Thermodynamics of a Rubber Band	Students will predict the thermodynamics of a stretched and contracted rubber band.	enthalpy, entropy free energy
P	Alka-Seltzer Eruption	Students will analyze the reactivity of an Alka- Seltzer tablet under different reaction conditions	kinetics (temp, surface area)
P	Vinegar-Baking Soda Rxn	Students will interpret how concentration affects reactivity.	concentration effects
D	H_2O_2 Kinetics	Students will observe how catalysis and catalyst surface area can effect reaction rates.	concentration effects
P	Counting Equilibrium	Students will determine when a "penny reaction" reaches equilibrium	equilibrium
P	Shifting Reactions	Students will predict the shift in a reaction based on their observations.	equilibrium, thermo. Le Chatelier's Principle
D	Reviewing Thermodynamics	Students will discuss the thermodynamics of the $NO_2(g)$ equilibrium and predict equilibrium shifts as the system undergoes temperature changes	equilibrium thermodynamics
P	Salt Solution	Students will observe how water dissolves salt, microscopically	dissolution
P	Precipitation	Students will observe precipitation reactions among various ions and develop general solubility rules.	precipitation solubility rules
P	Like Dissolves Like	Students will combine various substances to observe solubility then compare structures to determine similarities and differences.	intermolecular forces polarity, solubility
I	Predicting Solubility	Students will use the solubility rules to determine if precipitates will form when different solutions are mixed. They will also write balanced chemical equations for the reactions.	precipitation solubility rules
I	Selective Precipitation	Using the solubility rules, students will be able to determine how to precipitate a series of ions in the same solution one at a time.	selective precipitation

Table 2.1 continued

I	Not So Soapy	Students will observe how hardwater interferes with the effectiveness of soap and synthetic detergents.	specific precipitation
D	Up in Lights	Students will determine whether or not a solution will light up a light bulb by conducting electricity.	electrolytes
D/P	Activity Series	The class will construct a small portion of the activity series based on observations of demonstrations and animations.	activity series electrochemistry
D/P	Electron Hopping	Students will observe demos of redox reactions, learn about the microscopic nature of electron transfer, and analyze chemical equations for redox behavior.	redox reactions
P	Batteries	Students will observe electrochemical animations and describe the redox chemistry involved.	batteries, electrodes salt bridge
P	Electrolysis	Students will observe the process of electrolysis and write equations to describe the process.	electrolysis
D/I	KI Electrolysis	Students will explain and write half rxns for what occurs in the electrolysis of KI.	electrolysis
I	The Silver Cell	Students will construct a silver-silver chloride reference electrode and use it to determine potentials of other metals and construct a reduction potential table.	electrolysis reduction potentials
P	What is an ACID?	Students will observe and discuss the particulate nature of acid-base chemistry.	acids and bases proton transfer
P	What's in Your Kitchen?	Students will determine whater household chemicals are acids or bases and then write acid- base equilibrium equations.	acids and bases equations
I	Is It an Acid or a Base?	Students will react $Al(OH)_3$ with NaOH and acetic acid solutions to illustrate amphoteric behavior.	amphoterism acids and bases
I	Ionic Equilibria	Students will determine the pH of salt solutions and explain why a solution of salt is acidic, basic, or neutral.	pH of salt solutions
I	Read the Label	Students will look up information on chemicals listed on product labels.	nomenclature
P	Polymer Day	Students will observe the properties of different polymers	polymers

Table 2.2. List of Activities developed for $cAcL_2$ CH201.

Type	Title	Overview	Concepts
P	Sizing Up the Book	Students determine thickness of one sheet of paper and the diameter of a period.	estimation, sig figs, measurement
D	Balancing Act	water movement shows the stoichiometry of $2\ NO + O_2 \rightarrow 2\ NO_2$ reaction	rxn stoich, balancing (or Guy Lussac's Law)
P	Percent Composition	Students will determine the % composition of carbonate in an Alka-Seltzer tablet.	percent composition
P	What is it?	Students will determine the empirical formula of an unknown substance using only definition of empirical formula.	empirical formula
P	How Big is the Balloon?	Students will combine various volumes of reactants to illustrate the concept of limiting reagent.	limiting reagent
P	Pass the Salt	Students will react Na_2CO_3 with HCl in order to form salt and then calculate yields.	theoretical yield percent yield
D/P	Additive Volumes 500. + 500. = 1018?	Students will observe that volumes are not additive when 500 mL of 2 M NaOH is added to 500 mL if 2 M HCl.	additive volumes solutions, stoichiometry
I	Fishy Solution	Students will make a salt sol'n for a salt-water aquarium and describe concentration in various units.	solutions concentration units
P	Colligatively Speaking	Students will investigate colligative effects on freezing points and explain them.	colligative properties
RWP	Antifreeze Protection	Students will calc protection limits of antifreeze	colligative properties
D/I	How Sweet It Is	Students observed a solution rising in a tube due to osmotic pressure.	osmotic pressure
D/P	A Pressing Situation	Students will view demos and simulations of osmosis.	osmosis
P	Gimme Your Keys	Students will determine the concentration of an ethanol solution using spectroscopy.	spectroscopy beer's law
P	Dropping Acid	Students will perform mini-titrations using drops to determine concentration of an unknown HCl solution.	titrations indicators

Table 2.2 continued

P	Maximum Work	Students will measure work done when different intervals of mass are lifted by a spring in order to illustrate that max work is done be the most reversible process.	work
P	Chemical Work	Students will calculate expansion work done by a chemical reaction.	work and energy
P	Heat of Solution	Students will measure delta H of an endothermic reaction b/t ammonium nitrate and water.	solution calorimetry specific heat, ΔH
P	Watch that Cup	Students will determine specific heat of a metal through calorimetry.	calorimetry specific heat
I	Glad I'm a Chemist	Students will determine the temperature of hot water with a thermometer that does not read high enough to measure the temperature directly.	heat capacity
P	Defining Entropy	Students will make observations of moving particles and graphs of displacement and entropy vs time in order to define entropy.	entropy
RWP	ATP	Students will calculate ΔG, ΔH, ΔS and K under varying conditions.	thermodynamics
RWP	Energy Crisis	Students will use thermo calculations to determine how much energy is saved by recycling aluminum.	thermodynamics recycling
P	Reviewing Equilibrium	Students will review equilibrium concepts using concentration vs. time plots for a reaction.	equilibrium
P	K	Students will use an internet simulation to measure pressure in a system in order to determine K_c and K_p.	equilibrium constants
P	Counting Equilibrium	Students will determine when a "penny reaction" reaches equil.	equilibrium
P	Acid-Base Concentrations	Students will use pH to determine the hydronium and hydroxide ion concentration in household chemicals.	pH H_3O^+, OH^- concentration
P	Salty Dogs	Students will measure the pH of salt solutions using a simulation and use those observations to make rules for predicting the behavior of ionic salts in solution.	ionic equilibria

Table 2.2 continued

RWP	Aspirin	Students will calculate effects and availability of aspirin at various pH conditions.	acid/base rxn problems
P	Conjugates	Students will observe how a buffer resists change in pH.	buffers, conjugate pairs
P	Titration	Student will perform a titration (using drops) and then construct and interpret titration curves.	titration curves
D/P	Solubility and pH	Students will observe how pH affects the solubility of relatively insoluble compounds.	pH effects on solubility
D/P	Complexation	Students will observe the complexation of ions and its effect on solubility.	complexation
RWP	Drinking Water	Students will use EPA maximum contaminant levels to determine at what pH ppt of hydroxides becomes a problem.	K_{sp}, ion product
P	Metal Reactivity	Students will construct a portion of the activity series using observations of redox reactions.	activity series
P	Classic Concentration	Students will build virtual cells and observe the effect of concentration on potential.	Nernst Equation
RWP	Unknown Ore	Students will apply the concepts of the Nernst equation to a real world problem.	Nernst Equation
P	Diving for Rates	Students will use tangent lines to determine instantaneous rates from a distance vs. time plot.	instantaneous rates
P	Method of Initial Rates	Students will be introduced to method of initial rates by examining relationships to non-chemical situations.	method of initial rates rate laws
D/P	Buret Kinetics	Students will determine the order of water flow as water drains from a buret.	integrated rate laws
P	Nuclear Reactions	Students will write nuclear equations based on observations of simulations that make use of thermochromic paint properties.	nuclear decay

P = Probe, I = Investigation, D = Demo, RWP = Real World Problem

2.5 PRACTICAL APPLICATION

An overview of all aspects of development has been presented, but it may be helpful to describe some examples of how activities were developed for specific topics. Due to the parallel coverage of equilibrium and electrochemistry in both CH101 and CH201, the development of curriculum materials for these topics will be discussed. Full write-ups of all activities included in this discussion are available in Appendix A.

a) Equilibrium

During the first semester of $cAcL_2$ equilibrium is covered by introducing students to the concept of equilibrium, writing equilibrium expressions (K), discussing the meaning of K, and predicting shifts in equilibrium reactions based on Le Châtelier's Principle. Equilibrium is considered an abstract and very difficult concept for students to understand (*30,31*). The most common misconceptions that students have about equilibrium include the belief that the forward reaction goes to completion before the reverse begins, distinguishing between rate and extent of reaction (*30*), the forward and reverse reactions behave independently of each other (*32*), the overall dynamic nature of equilibrium (*33*), and the fact that using everyday terms like "shift", "equal", "stress', and "balanced" leads to confusion when chemical definitions do not match the visual images implied by these terms (*34*). Based on these common misconceptions, teachers have implemented the use of analogies to help students build understanding of abstract concepts through concrete examples (*35,36*). Various analogies have been developed to introduce equilibrium to students (*37,38*). It has also been suggested that more quantitative approaches be taken to help students better comprehend equilibrium concepts (*39*), and more specifically that concentration vs. time curves be used to help students visualize equilibrium concepts (*30*). Demerall began advocating the use of concentration vs. time curves as early as 1945 to tackle common errors made by students (*40*). Therefore, an analogy was chosen in which physical objects are used to simulate the process of equilibrium in order to collect data to construct a concentration vs. time curve (37). This activity would serve as a *probe* to provide an active hands-on approach to introducing equilibrium to students in the $cAcL_2$ environment.

The *probe* is entitled "Counting Equilibrium" and the following learning objectives are designated for this activity: observing how a reaction comes to equilibrium, defining equilibrium, explaining a graph of concentration vs. time, defining k_f and k_r for a reaction, writing equilibrium constant expressions, and determining the effect of a perturbation. These learning objectives serve as a guide to direct instruction in order to develop appropriate knowledge levels and to develop specific assessments to measure student attainment of this knowledge. Therefore, each of these objectives is specifically linked to tasks in the activity. Specific examples of questions used in evaluation are presented later in this section.

Students are first introduced to rate constants, k_f and k_r. Then students are given 24 pennies representing reactant A at time zero. The reaction then proceeds in one-minute intervals according to the following equation

$$A \underset{\frac{1}{4}\ \text{min}^{-1}}{\overset{\frac{1}{2}\ \text{min}^{-1}}{\rightleftharpoons}} B \qquad [1]$$

During the first minute ½ of reactant A (or 12 pennies) reacts in the forward reaction and ¼ of product B (zero pennies) reacts in the reverse reaction. During the second minute ½ of A and ¼ of B, 6 and 3 respectively, react leaving 9 A and 15 B (sum must always equal 24). During the next minute values must be rounded because pennies cannot be divided. Students continue the reaction until they realize that the concentration of A and B is no longer changing, which is after three minutes. At this point the reaction has reached equilibrium. The students are then asked to graph their data. The data and graph of concentration vs. time are provided below.

Table 2.3. Concentration Data.

Time	[A]	[B]
0	24	0
1	12	12
2	9	15
3	8	16
4	8	16
5	8	16

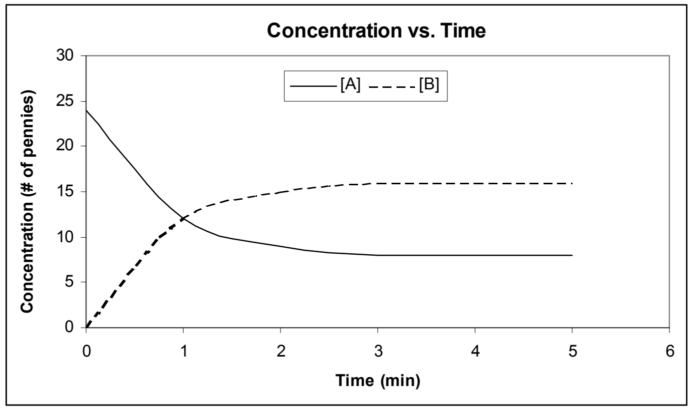


Figure 2.2. Plot of Concentration vs. Time.

After the graph is constructed, k_f and k_r are used to define the equilibrium constant. Students then calculate the equilibrium constant for the penny reaction. Students are then given 6 more pennies to simulate adding more of reactant A. Students continue the reaction with the six pennies and quickly see that equilibrium is reestablished. The data is plotted and students make observations of how the reaction initially shifted as a result of adding more of reactant A. There is an overall shift to the product side of the reaction after more reactant is added. Students use the new equilibrium concentrations to calculate K and find that it remains the same.

Table 2.4. Data After Perturbation.

Time	[A]	[B]
6	14	16
7	11	19
8	9	21
9	10	20
10	10	20
11	10	20

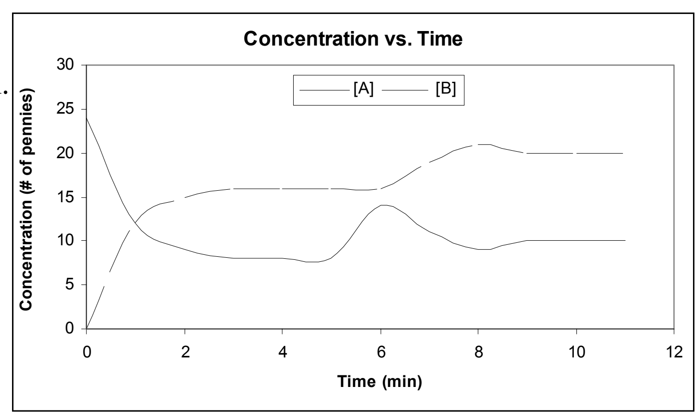


Figure 2.3. Plot of Concentration vs. Time.

Counting Equilibrium allows students to visualize what goes on in an equilibrium reaction. After completing this activity students have a concrete conception of equilibrium, equilibrium constants, and the effect that adding more reactant has on a reaction. From this point the class can move on to Le Châtelier’s Principle.

In the traditional general chemistry program at NCSU students study Le Châtelier’s Principle using two equilibrium systems in the laboratory: Fe^{3+}/SCN^{-} and $CoCl_4^{2-}$ / $[Co(H_2O)_6]^{2+}$ (*41*). These equilibrium systems are incorporated into the probe activity entitled “Shifting Reactions”. The objective of this probe is to develop the ability to predict the shift in a reaction. This objective is accomplished by having students observe visible shifts in equilibrium reactions. This activity makes use of microscale techniques. Students conduct the reactions in well plates using only drops of chemicals. Therefore, chemical exposure and waste are minimized.

First a demo is performed using the Fe^{3+}/SCN^{-} system shown in the equation below

$$\underset{}{Fe^{3+} + SCN^{-}} \; ƒ \; \underset{\textbf{\textit{deep red}}}{Fe(SCN)^{2+}} \qquad [2]$$

Solutions of $Fe(NO_3)_3$ and KSCN are mixed to show the formation of a dark red complex. The solution is then diluted and separated into five 200-ml aliquots. One aliquot is used as a color comparison while the rest are use to show the effects of change in temperature and the addition or removal of a reacting species. Students observe the increasing or decreasing intensity of the deep red color to identify whether $Fe(SCN)^{2+}$ is forming in the forward reaction or reacting in the reverse reaction.

Students are then given the cobalt chloride equation as shown below

$$\underset{\textbf{\textit{blue}}}{CoCl_4^{2-}} + 6\,H_2O \; ƒ \; \underset{\textbf{\textit{pink}}}{Co(H_2O)_6^{2+}} + 4\,Cl^{1-} \qquad [3]$$

This cobalt equilibrium provides an excellent illustration of Le Châtelier's Principle due to the drastic color change between reactants and products (*42*). Students observe the effects of adding HCl, water, and $AgNO_3$ to the cobalt equilibrium. The original cobalt solution is pink. The addition of HCl results in a blue solution. The subsequent addition of water changes it back to pink. The addition of $AgNO_3$ to the blue solution causes precipitation of AgCl, which results in a pink solution. Students then observe temperature effects by heating and cooling solutions. Heating a solution results in a blue solution and cooling a solution results in a pink solution. Students are asked to collect observations on these reactions and then answer questions based on the observations. The questions lead the students in discovering Le Châtelier's Principle and how the addition or removal of a reactant will affect an equilibrium reaction as well as the effect of temperature. Once students develop general rules for Le Châtelier's Principle then they use them to explain their observations of the initial Fe^{3+}/SCN^- equilibrium. Additional details on the procedure of the activity as well as the questions given to students are included in the complete activity write-up found in Appendix A.

An investigation activity is then conducted in the form of a demonstration. The activity is entitled "Reviewing Thermodynamics". In this activity students review thermodynamic concepts learned previously in the semester by discussing the thermodynamics of the NO_2 / N_2O_4 gas equilibrium and predicting equilibrium shifts the system undergoes during temperature changes. See the equation below.

$$\underset{\textbf{\textit{brown}}}{2\ NO_{2\,(g)}} \rightleftharpoons N_2O_{4\,(g)} \qquad [4]$$

The objectives of this activity include reviewing reaction coordinate diagrams, enthalpy, activation energy, catalysis, and applying Le Châtelier's Principle to predict the direction the reaction will shift when undergoing temperature changes. Once students estimate the enthalpy of the reaction and make predictions, they observe the demonstration. Based on their observations they identify which gas is brown, NO_2 or N_2O_4. The activity is conducted using a worksheet to lead students through the activity.

Activities are followed with conceptual questions to gauge student understanding. Table 2.5 provides examples of the questions.

Table 2.5. Example Equilibrium Conceptual Questions.

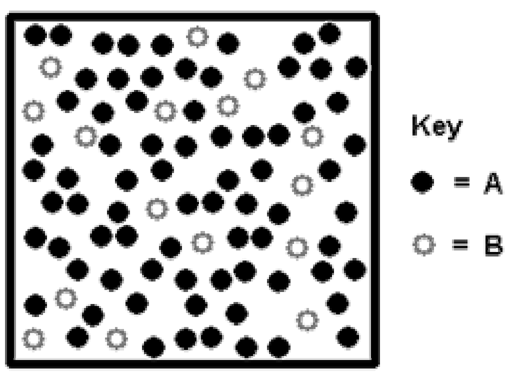
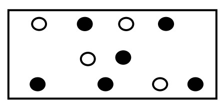
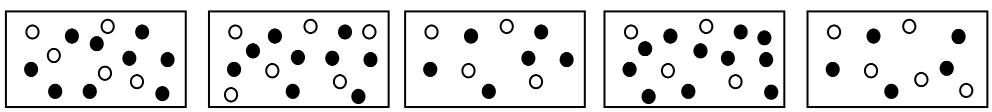
1)	Equilibrium is defined as the point in a reaction when a) concentration of products equals the concentration of reactants. b) there is not net change in concentrations of products or reactants. c) there is no more reactant left to continue the reaction. d) both a & b
2)	The figure represents a portion of an equilibrium mixture of two compounds related by the equation 2 A = B.  1) How many molecules of "A" are in the mixture? 2) How many molecules of "B" are in the mixture? 3) Describe the nature of the equilibrium constant Reference: http://jchemed.chem.wisc.edu/JCEWWW/Features/CQandChP/index.html

Table 2.5 continued

3)	Explain why chicken eggshells become dangerously thin in hot weather given the following equations and information. (Place the explanation on another sheet to turn in) $CO_2\ _{(g)} + H_2O\ _{(blood)}$ ƒ $H_2CO_3\ _{(blood)}$ $H_2CO_3\ _{(blood)}$ ƒ $H^+\ _{(blood)} + HCO_3^-\ _{(blood)}$ $HCO_3^-\ _{(blood)}$ ƒ $H^+\ _{(blood)} + CO_3^{2-}\ _{(blood)}$ $CO_3^{2-}\ _{(blood)} + Ca^{2+}\ _{(blood)}$ ƒ $CaCO_3\ _{(eggshell)}$ Notes: Eggshells are made of calcium carbonate. Chickens do not have sweat glands. Animals pant to remove excess body heat. Reference: DeLorenzo, Ron. *J. Chem. Educ*. **2000**, 78, 191-194.
4)	The exothermic reaction ○ (g) ⇔ ● (g) was allowed to come to equilibrium, as represented in the box below.  Equilibrium System Box A Box B Box C Box D Box E  Use boxes A-E below to answer the following questions ____ Some ● was added to the system at equilibrium. Which box (A-E) best represents the new position of equilibrium? Explain your answer. ____ The temperature of the system at equilibrium was increased. Which box (A-E) best represents the new position of equilibrium? Explain your answer. Reference: Huddle, Benjamin P. *J. Chem. Educ.* **1998**, *75*, 1175.

During the second semester of $cAcL_2$ students review the concept of equilibrium through "Counting Equilibrium". Students taking the first semester of $cAcL_2$ do not necessarily take the second semester and vice versa. Therefore, the activity is repeated to make sure that students hold the correct conceptions of equilibrium. Equilibrium is further reviewed using concentration vs. time graphs in the “Reviewing Equilibrium” activity. In this activity students consider the equation

$$H_2 + I_2 \rightleftharpoons 2\,HI \qquad [5]$$

Students are given the following problem to think about:

> Suppose you have a dual syringe in which one half contains 0.02 mole/L I_2 gas and the other half contains 0.01 mole/L H_2 gas. When the two syringes are depressed, the two gases are mixed and the reaction described in the above equation occurs. Predict how the concentrations of H_2, I_2, and HI will vary as a function of time.

Some students describe the reaction as an equilibrium while others describe a reaction that goes to completion with decreasing concentration of the reactants and increasing concentration of the product until reactants are used up. Students then observe what happens when the syringes are depressed via a simulated concentration vs. time graph. The characteristics of the plot are then discussed in terms of equilibrium. See Figure 2.4.

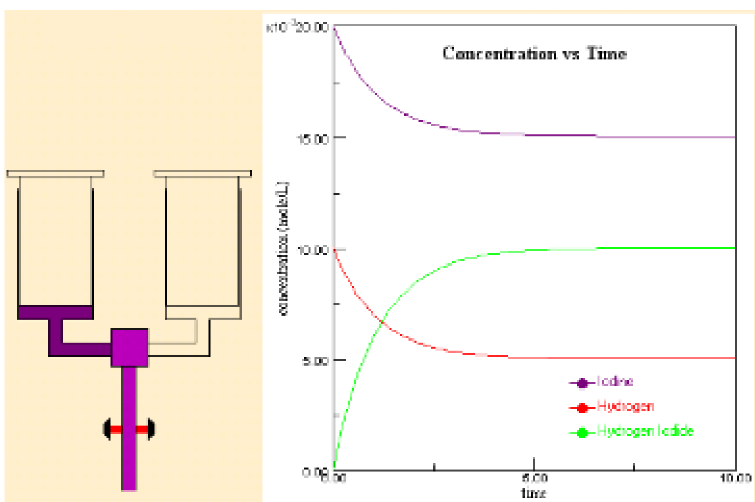


Figure 2.4. Simulated Concentration vs. Time Graph. Snapshot obtained from http://www.chm.davidson.edu/ChemistryApplets/equilibria/BasicConcepts.html.

After concepts of equilibrium have been reviewed students are then given a more quantitative introduction to equilibrium constants through derivations using k_f and k_r. The relationship between K_c and K_p is also discussed. Students then conduct a simulated experiment to determine the equilibrium constant of the following equation:

$$NaHCO_{3\,(s)}\ f\ \ NaOH_{(s)} + CO_{2\,(g)} \qquad [6]$$

Students collect temperature and pressure data from the simulated experiment in order to determine the equilibrium constant. Both K_p and K_c are provided for this experiment so that students can check their answers to be sure they are conducting the experiment correctly. Students then complete a parallel experiment for the following equation:

$$Ca(OH)_{2\,(s)}\ f\ \ CaO_{(s)} + H_2O_{(g)} \qquad [7]$$

Equilibrium constants are not provided for this equation, therefore, students determine the values and hand in their answers. See Figure 2.5 for a snapshot of the experiment.

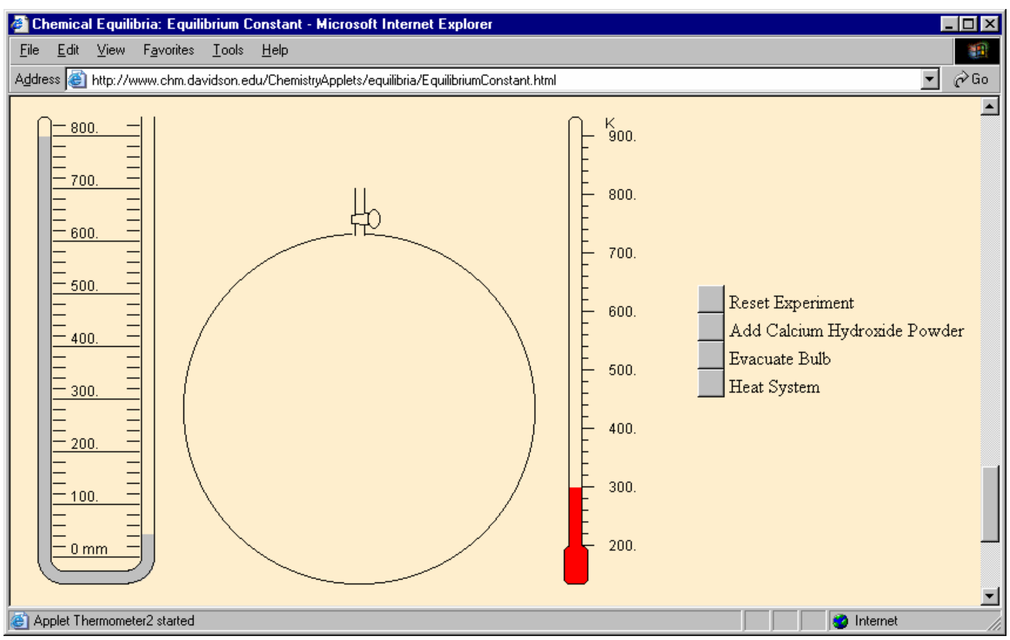


Figure 2.5. Simulated Equilibrium Experiment. Snapshot obtained from http://www.chm.davidson.edu /ChemistryApplets/equilibria/EquilibriumConstant.html

Once students have become familiar with equilibrium concepts and the nature of equilibrium constants they are then introduced to equilibrium calculations using the typical initial, change, and final reaction table method. The problems are worked individually, then discussed in groups, and then discussed as a class. See Table 2.6 below for the problems worked in class.

Table 2.6. Equilibrium Problems Worked in Class.

1)	At very high temperature, $K_c = 1.0 \text{ X } 10^{-13}$ for the following equation: $2\,HF_{(g)}\ f\ \ H_{2\,(g)} + F_{2\,(g)}$ At a certain time the following concentrations were detected: $[HF] = 0.500$ M $[H_2] = 1.00 \times 10^{-3}$ $[F_2] = 4.00 \times 10^{-3}$ Is the system at equilibrium?
2)	In one experiment, 2.00 moles of NOCl were placed in a 1.00L flask and the [NO] after equilibrium achieved was 0.66 M. Calculate K_c at 25°C for the equation: $2\,NOCl_{(g)}\ f\ \ 2\,NO_{(g)} + Cl_{2\,(g)}$
3)	The equilibrium constant K_c for: $H_{2\,(g)} + I_{2\,(g)}\ f\ \ 2\,HI_{(g)}$ Was determined to be 55.17. If you place 1.00 mole of each reactant in a 0.500 liter flask at 699K, what are the equilibrium concentrations of all the gases involved?
4)	K_p for the equilibrium $N_2O_{4\,(g)}\ f\ \ 2\,NO_{2\,(g)}$ is 0.15 at 25°C. If the total pressure of an equilibrium mixture is 1.5 atm, calculate the partial pressure of each gas.
5)	1.00 mole of bromine is placed in a 1.00-liter flask and heated to 1756K at which the halogen molecules dissociate to bromine atoms. If bromine is 1.0% dissociated at this temperature, calculate K_c.
6)	At a given temperature the equilibrium constant is 5.0 for: $CO_{(g)} + H_2O_{(g)}\ f\ \ CO_{2\,(g)} + H_{2\,(g)}$ Analysis showed that an equilibrium mixture at this temperature contained 0.90 mole of CO, 0.25 mole of water, and 0.50 mole of hydrogen in a 5.0 L. How many moles of CO_2 were there in the equilibrium mixture?

These problems represents the types of problems used to introduce equilibrium calculations involving reaction quotient, calculation of equilibrium constants and use of them in determining equilibrium concentrations, and the difference between K_p and K_c.

b) Electrochemistry

Electrochemistry is plagued with many areas of difficulty and misconceptions for students. Studies have reported student difficulty in predicting reactions, drawing diagrams of electrochemical cells (*43*), and answering conceptual questions when quantitative questions are answered successfully (*44*). Student misconceptions in electrochemistry are too numerous to list, however, several gross misconceptions, identified by Sanger and Greenbowe (*45*), have been summarized: electrons are transferred into aqueous solution and carried by cations and anions through the salt bridge, electrons can exist in solution, only negatively charged ions induce current flow, cathodes and anodes are identified by physical placement, the zero standard reduction potential for the hydrogen electrode is based on the chemistry of the reaction. Garnnett and Treagust have also pointed out that some students believe that cations and anions move until their concentrations are uniform and oxidation occurs at the cathode and reduction occurs at the anode in electrolytic cells (*46*). Many of these misconceptions are attributed to the fact that students are unaware that reduction potentials are relative (44) and many textbooks mislead students with vague or incorrect statements (*3d*).

Electrochemical concepts introduced to students during the first semester of $cAcL_2$ include the activity series, reduction potentials, writing redox reactions, predicting spontaneity, and electrochemical cells. Activities for $cAcL_2$ were designed to focus upon microscopic electrochemical behavior in order to remove misconceptions about what occurs during redox chemistry, specifically in electrochemical cells.

In $cAcL_2$ the topic of electrochemistry is introduced using the “Activity Series” probe. During this activity students use internet simulations to make observations of metal reactivity, derive a small portion of the activity series, and observe various demonstrations to place new metals into their activity series. The objectives of the activity include being able to order metals according to reactivity based on chemical observations and being able to identify oxidation and reduction processes in a reaction. The internet simulation allows students to work through four experiments to determine relative metal reactivity. The website denotes each experiment as an activity. Activity 1 involves placing magnesium, copper, zinc and silver into solutions of these same metal ions. See the snapshot of Activity 1 in the figure below.

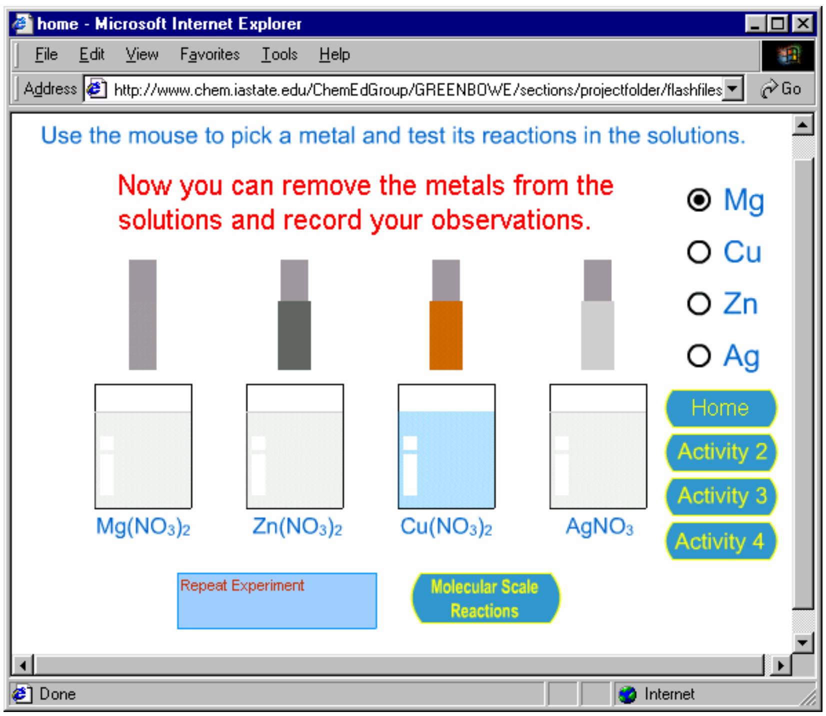


Figure 2.6. Activity series experiment. Snapshot obtained from http://www.chem. iastate.edu/ group/Greenbowe/sections/projectfolder/flashfiles/redox/home.html.

Students collect their observations and then move on to Activity 2 and 3 which follow the pattern of experiment 1 using a different set of metals. Iron, copper, zinc, and lead are used in experiment 2, while iron, lead, nickel, and tin are used for experiment 3. Based on these observations students can arrange these eight metals according to reactivity. Students then compare these metals to hydrogen in Activity 4.

Upon completion of the internet simulation, demonstrations are conducted to determine the relative placement of other metals in the activity series. These demonstrations include the following combinations: $Zn_{(s)}/Fe(NO_3)_{3\ (aq)}$, $Cu_{(s)}/AgNO_{3\ (aq)}$, $Sn_{(s)}/HCl_{\ (aq)}$, $Zn_{(s)}/SnCl_{2\ (aq)}$, $Sn_{(s)}/Fe(NO_3)_{2\ (aq)}$. Once students have developed the activity series and the relative nature of reactivity has been discussed students are given the combinations of $Fe_{(s)}/CuSO_{4\ (aq)}$ and $Zn_{(s)}/Pb(C_2H_3O_2)_{2\ (aq)}$. They are asked to predict reactions and begin writing chemical equations for redox reactions. Their predictions are checked based on observations of these reactions. Half reactions and basic terminology are discussed using the equations that students have written. The activity series is then related to oxidation followed by a subsequent introduction to standard reduction potentials.

The next activity, "Electron Hopping", deals more specifically with the microscopic behavior of electron transfer, predicting and writing equations, and using standard reduction potentials. The objectives of the activity include being able to do the following: explain what is happening microscopically, determine if a substance will behave as an oxidizing agent or reducing agent, use a table of standard reduction potentials effectively, write and balance simple redox reactions, and distinguish between spontaneous and non-spontaneous processes.

The activity begins with the Can Ripper demonstration in which aluminum is oxidized by $CuCl_2$ enabling a can to be easily ripped in half. This reaction is used to identify oxidation and reduction processes and label reactants as reducing or oxidizing agents. The microscopic behavior of redox reactions is then discussed using diagrams similar to the one presented in Figure 2.7. Students are also presented with concepts relating free energy, spontaneity, and sign of reaction potential.

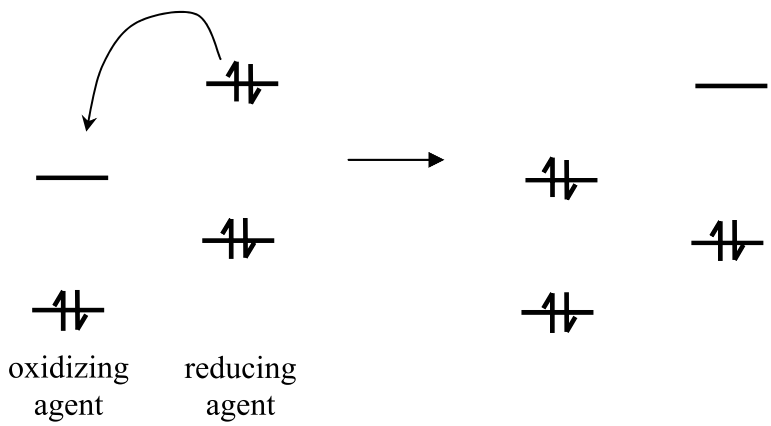


Figure 2.7. Example of a diagram used to discuss microscopic nature of electrochemistry.

Worksheets attempt to reinforce concepts and relationships discussed/observed in class. Once the students are familiar with these concepts they are presented with the "Penny Demo". During this demonstration a penny is placed in nitric acid and students observe the formation of a brown gas. Students must then use their observations to write an equation describing their observations. This is a challenging task because students automatically assume that the copper penny is reacting with the acidic hydrogen from nitric acid. However, students quickly determine that no reaction would be expected between copper and H^+ since copper is located below hydrogen in the activity series. Students then turn to their observations of the demonstration. The formation of a brown gas is a critical clue in determining the correct equation, which is provided below.

$$Cu_{(s)} + H^{+}_{(aq)} + 2\ NO_3^{1-}{}_{(aq)} \rightarrow 2\ NO_{2\,(g)} + Cu^{2+}_{(aq)} + 2\ H_2O_{(l)} \qquad [8]$$

$$\text{Oxidation: } Cu_{(s)} \rightarrow Cu^{2+}_{(aq)} + 2e^- \qquad [9]$$

$$\text{Reduction: } NO_3^{1-} + 1e^- \rightarrow NO_2 \quad \text{(simplified)} \qquad [10]$$

The gas is identified for students when they realize that it is important in the equation. Students are not expected to obtain a balanced chemical equation because they have not been introduced to balancing redox equations in acidic medium, however, they should be able to determine the partial equations given above.

The next activity is "Batteries". This activity involves making observations of a Cu/Zn battery demonstration as well as a simulation. The demonstration is used to introduce galvanic cells and the various components of a cell. Students are then required to make detailed observations of a battery simulation in order to explore the movement of electrons, cations, and anions as they are fully animated. A snapshot of the animation is given in Figure 2.8.

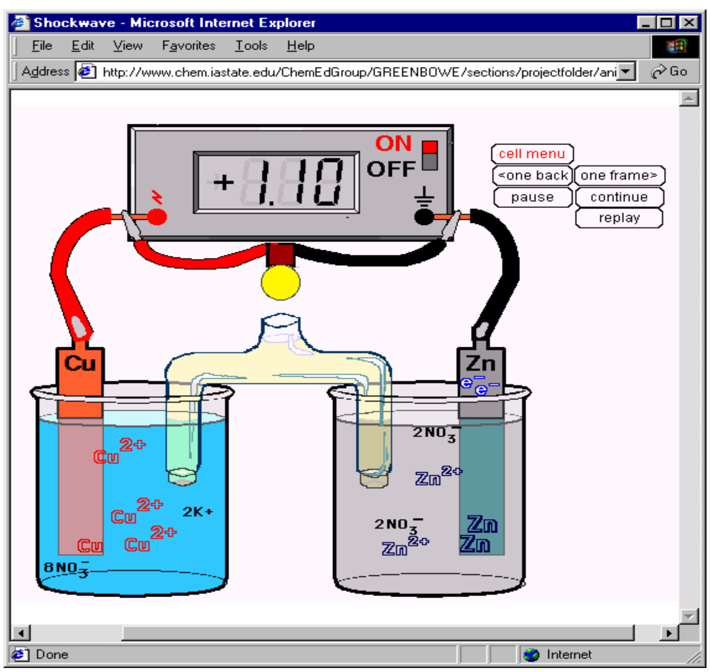


Figure 2.8. Battery animation. Snapshot obtained from http://www.chem. iastate.edu/group/Greenbowe/sections/projectfolder/animations/CuZncell.html.

The objectives of this activity include being able to describe how a galvanic cell works, identify anodes and cathodes, explain why a salt bridge is needed, write half reactions for oxidation and reduction, and write and balance simple redox equations. The battery animation is specifically designed to combat many of the misconceptions developed by students during other modes of instruction (*3b*). Students carefully monitor the flow of electrons, cations, and anions to describe how the anodes, cathodes, salt bridge, and electrolyte work in making up a functioning battery. Students then write half reactions and confirm the potential reported in the animation as shown below.

In the "Electrolysis" activity, students make observations of electron flow in the static diagram given in Figure 2.9. The microscopic behavior of the reaction between iodide and sodium ions (molten NaI) is portrayed.

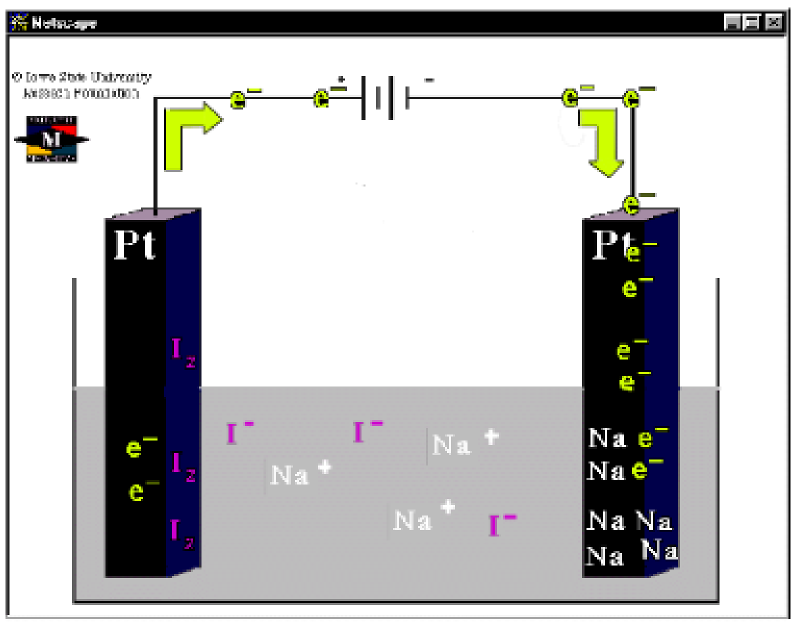


Figure 2.9. Electrolysis picture created from a snapshot of an outdated link to an animation that ran too fast for the students to figure out what was going on. Original animation obtained from http://www.chem.iastate.edu/group/Greenbowe /sections/projectfolder/animationsindex.htm.

Based on the observations made from the diagram, students determine that this is not a spontaneous process based on the reaction and cell potential they are able to write. Students are now prepared to discuss electrolysis. Discussion of the NaI electrolysis is followed by a demonstration of the electrolysis of water in which students are asked to write appropriate half reactions and a balanced chemical equation to explain their observations. A 2:1 ratio of the gases will be visible just as the equation stoichiometry indicates.

Students are then presented with an investigation in which they observe the electrolysis of a potassium iodide solution. Platinum wires are connected to a battery terminal and placed in a solution of 1-M KI with phenolphthalein added. The students typically predict that the potassium ion is going to be reduced because cations can accept electrons. However, this prediction does not match the students' observations. The solution near the cathode (positive terminal) turns yellow-brown while the solution near the anode (negative terminal) turns pink. The students have to extend their knowledge to explain their observations in the context of electrolysis. The typical response of students as well as the correct response is given below.

Typical First Response:

Anode: $2\ I^{1-}_{(aq)} \rightarrow I_{2\ (s)} + 2e-$ [11]

Cathode: $K^{1+}_{(aq)} + e- \rightarrow K_{(s)}$ [12]

Correct Response:

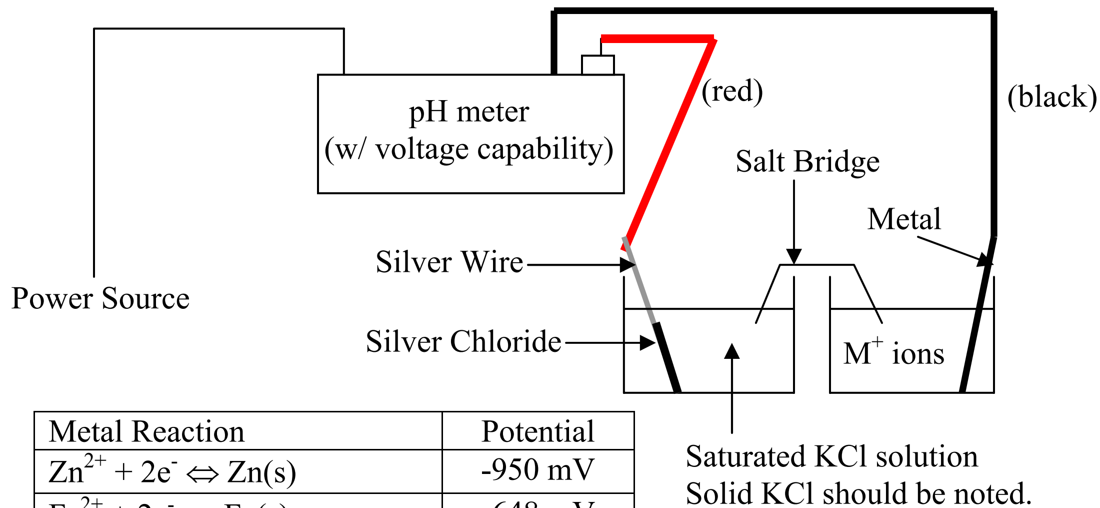
Anode: $2\ I^{1-}_{(aq)} \rightarrow I_{2\ (s)} + 2e-$ [13]

Cathode: $2\ H_2O + 2e- \rightarrow H_{2\ (g)} + 2\ OH^{1-}_{(aq)}$ [14]

$$2\ I^{1-}_{(aq)}\ 2\ H_2O \rightarrow I_{2\ (s)} + H_{2\ (g)} + 2\ OH^{1-}_{(aq)} \quad [15]$$

During discussion students realize that it would take a much higher electromotive force for electron transfer to occur between K^{1+} and I^{1-} than between I^{1-} and water.

The topic of electrochemistry is wrapped up with a wet-laboratory investigation called "The Silver Cell". In this activity students construct a Ag/AgCl reference electrode and use it to determine relative potentials of other metals. The students are asked to build electrochemical cells using appropriate solutions, electrodes, and salt bridges. After measuring the potentials students use their data to construct a table of reduction potentials based on the Ag/AgCl reference rather than the standard hydrogen electrode. A diagram of the set-up and an example reduction table is provided in Figure 2.10.



Metal Reaction	Potential
$Zn^{2+} + 2e^- \Leftrightarrow Zn(s)$	-950 mV
$Fe^{2+} + 2e^- \Leftrightarrow Fe(s)$	-648 mV
$AgCl(s) + e^- \Leftrightarrow Ag(s) + Cl^-$	0 mV
$Cu^{2+} + 2e^- \Leftrightarrow Cu(s)$	25 mV

Figure 2.10. Apparatus used in “The Silver Cell” with example data provided.

This investigation requires students to apply all the concepts they have learned in the electrochemistry unit. Additional worksheets, example questions, and homework aim at reinforcing conceptual understanding.

During the second semester of $cAcL_2$ students are introduced to balancing redox reactions in acidic and basic media, the Nernst relationship, cell notation, and Faraday’s Law. Students are first instructed on how to balance redox reactions in acidic and basic media and how to appropriately describe redox reactions using cell notation. Worksheets allow students the opportunity to work various sorts of balancing and cell notation problems. Then students complete a small portion of the "Activity Series" activity in order to review the concepts of metal reactivity, writing equations, and redox terminology.

After reviewing the basic concepts, students are introduced to the Nernst relationship. In the "Classic Concentration" activity each group of students is assigned two metal redox couples from which they must determine an anode and a cathode for a galvanic cell. They must write the appropriate half reactions, overall reaction, determine the cell potential, and describe how to build a galvanic cell with these redox couples. Students are then asked to check their work by constructing their cells using an online simulation. Students must choose the appropriate connections and electrolytes for their galvanic cell.

Students are then directed to a similar simulation in which they are able to vary the concentration of the electrolyte solution. Students are instructed to collect data at varying concentrations. See Figure 2.11 for a snapshot of how the concentration is varied on the simulation.

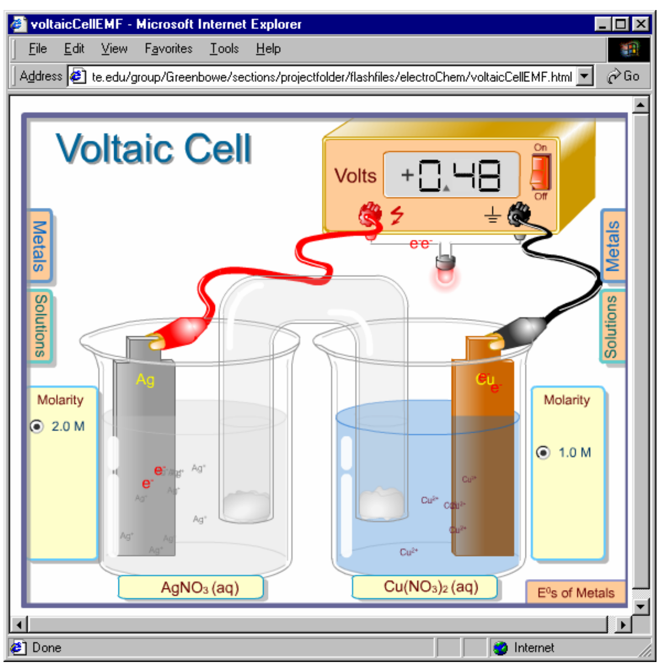
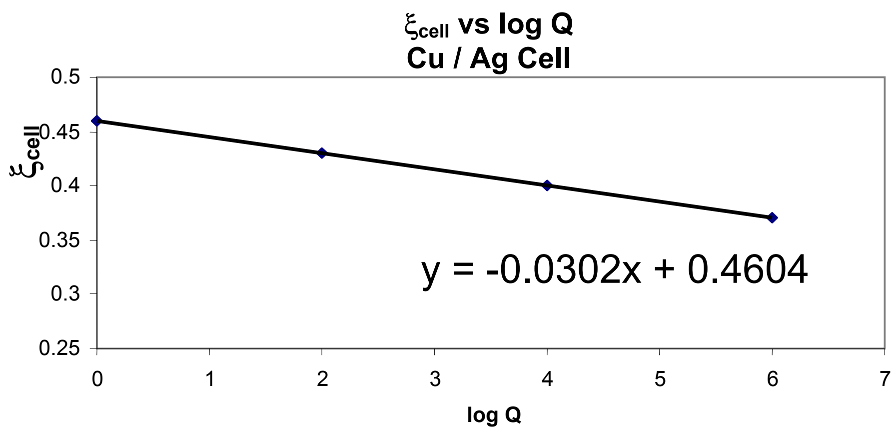


Figure 2.11. Snapshot of cell constructed to investigate concentration effects obtained from http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/electroChem/voltaicCellEMF.html

Students must use their data to construct a graph of cell potential vs. log Q. (The reaction quotient, Q, is discussed in an earlier chapter.) The data is linear so students use graphing software to graph the data and determine an equation for the line. With the equation of the line in hand, students are introduced to the Nernst relationship, which they have already observed from data collected during the simulation. A parallel is drawn between the Nernst equation and the equation of a line. See Figure 2.12 for an example graph with data and corresponding Nernst equation.

Data for Cu/Ag cell.

$[Ag^{+}]$ (M)	$[Cu^{2+}]$ (M)	log Q	ξ (V)
2.0	1.0	-0.6	0.47
1.0	1.0	0	0.46
0.1	1.0	2	0.43
0.01	1.0	4	0.40
0.001	1.0	6	0.37



$$\xi_{cell} = \xi^{o} - \frac{0.05916}{\eta}\log Q$$

y = b + m x

$y \rightarrow$ how potential varies with conc.

$x \rightarrow$ varying concentrations

$m \rightarrow$ get the # of electrons

$b \rightarrow \xi^{o}_{cell}$

$y = -0.0302x + 0.4604$

$m = 0.05916 / \eta = 0.0302$

$b = \xi^{o} = 0.4604$

$\eta =$ 1.96 ~ 2 electrons transferred

Figure 2.12. Example graph and data obtained from "Classic Concentration" activity and corresponding discussion of the Nernst Equation.

Once students have completed the "Classic Concentration" activity they are given two group problems to work. The group problems were designed to challenge students and to encourage them to use the concepts that have been presented in class. The problems are presented in Figures 2.13 and 2.14. Further practice is provided through homework.

An unknown ore was removed from an archeological digging site. It was taken to a chemistry lab that used electrochemical methods to determine its identity. Gold is often used as a reference in electrochemistry. The ore was compared to gold in an electrochemical cell with varying concentrations. The data are shown in the plot.

Identify the unknown ore and determine the number of electrons transferred.

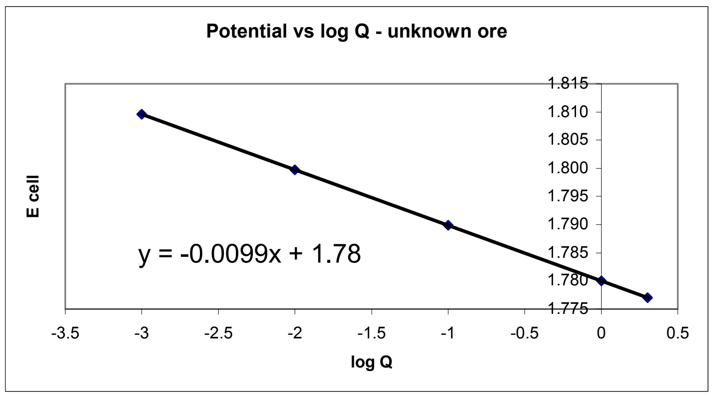


Figure 2.13. Group problem given to students after completing "Classic Concentration" Activity.

The figure below shows two electrochemical cells joined together in a common circuit (*47*).

1. Indicate whether a net flow of electrons occurs in the direction of the red arrows or the blue arrows.
2. Indicate the type of cells A and B are.

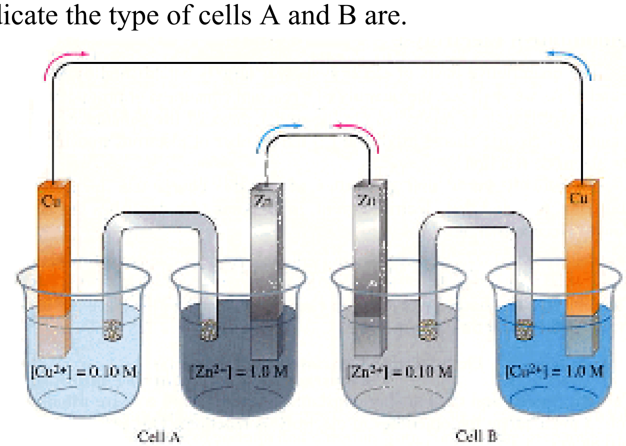


Figure 2.14. Group problem given to students after completing discussing the Nernst relationship.

The unit on electrochemistry is wrapped up by discussing and applying Faraday's Law. Examples of group problems given are provided in Table 2.8.

Table 2.7. Problem Session on Faraday's Law.

1)	Calculate the mass of Cu produced by the reduction of Cu^{2+} ion at the cathode during the passage of 1.600 ampere of current through a solution of $CuSO_4$ for 1.0 hour. (1A = 1C/s)
2)	What volume of O_2 (at STP) is produced by the oxidation of water in the electrolysis of $CuSO_4$ during the passage of 2.50 A of current for 50.0 min.?
3)	An aqueous solution of an unknown salt of Pd is electrolyzed by a current of 3.00A for 1.0 hr. This produces 2.977g of Pd metal at the cathode. What is the oxidation state of Pd in this solution?
4)	Very large currents are used in many industrial electrolytic cells. How much time is required to produce exactly 1000 kg of Mg by passage of 150,000A through the molten $MgCl_2$? Assume 100% yield.

The activities developed for $cAcL_2$ are designed to provide a challenging chemistry experience for students that builds successively upon material learned throughout the semester. In these activities students are exposed to chemical concepts in a hands-on format that allows them to actively construct their own understanding. Students observe the microscopic behavior of chemical systems through various simulations and animations, while modified demonstrations and lab activities provide correlation to macroscopic observations of the same chemical systems. Experiencing both the macroscopic and the microscopic views aims at developing a comprehensive picture of chemical concepts. Students in $cAcL_2$ are also exposed to real-world problems and investigations in addition to traditional problems and homework. Each component of the $cAcL_2$ curriculum is designed to support a highly integrated environment in which students can actively participate in the learning process.

2.6 ADAPTATION

The dynamic nature of each activity allows for simple adoption of the $cAcL_2$ active classroom environment. The activity curriculum was specifically designed to compliment the general chemistry program at NCSU where chemical concepts are discussed the first semester and revisited with emphasis on quantitative relationships during the second semester. Although this program is very different than that of most institutions, these activities can be readily adapted into existing programs. Each activity includes a listing of major topics covered in that activity. Therefore, both CH101 and CH201 activities can be implemented to cover a specific topic in another program. For instance, any general chemistry class covering electrochemistry can incorporate the activities described above in accordance to its program of study.

The activities themselves are also easily modified to fit into other programs. The activity tables are guides that provide an outline of the dynamic between activity and discussion for a particular topic. However, the activities can be applied and discussed in the ways most beneficial to a particular program. In that case, the activity sheets serve as a resource describing hands-on procedures that can be implemented in any chemistry classroom.

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CHAPTER 3

CLASSROOM MECHANICS

3.1 DYNAMICS

Establishing a highly collaborative environment is an important goal in $cAcL_2$. Various researchers have reported the necessity and success of cooperative grouping in the classroom (*1,2,3*), and specifically in the chemistry classroom (*4*). This environment is important in the development of teamwork and communication skills for practical use in the chemistry profession (*5*).

In order to create a collaborative environment in $cAcL_2$, students are placed in teams of three and each team is part of a larger group of nine students, or three teams total (*6,7,8*). Cooperative grouping techniques researched by Rich Felder (NCSU) have also been incorporated - groups are formed by the instructor to ensure heterogeneous ability and at least two women or minorities are placed in the same group (*9*). Grouping arrangements are closely monitored for effectiveness. Teams are evaluated for effectiveness and possibly reassigned once during the semester based on peer evaluations and test grades. Several actions are taken to promote successful collaboration among teams. For example, bonus points are added to the exam scores when teams average above a specified minimum on an exam. This seems to encourage better students to help group members that may be struggling with the material, while slower students tend to show a deeper sense of responsibility (*7*).

3.2 DESIGN

A special room houses SCALE-UP courses at NCSU. The room holds 99 students that are divided into 33 teams seated among 11 round tables (three teams at each table). Round tables were chosen to promote collaboration among team members as well as among the group of three teams. A laptop with Internet access is provided for every team. Laptop computers are preferred because desktops physically hinder student interaction. White boards surrounding the entire room are readily accessible for all teams to allow communication of data or problem solutions throughout the room.

The instructor station, located in the middle of the room, is equipped with a networked computer, a document display camera (ELMO or NAVITAR), and connections to LCD projectors. This computer and multimedia technology in conjunction with screens at both ends of the room are used to ensure visibility for all students. A picture of the current room design with the integrated technology is shown in Figure 3.1.

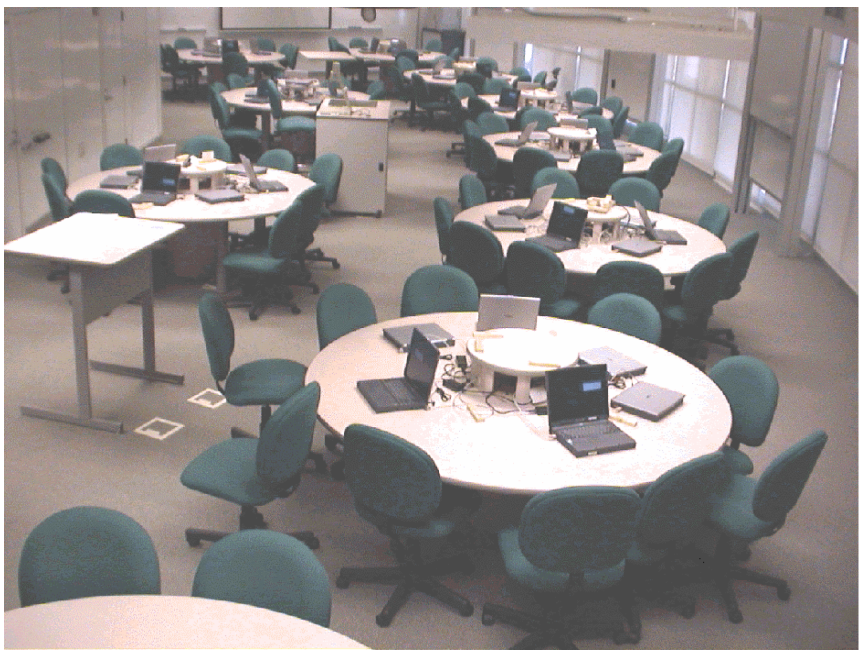

Figure 3.1. The SCALE-UP Room (NCSU Harrelson G108).

3.3 MANAGEMENT

In order to manage an active class of 99 students effectively, certain classroom management techniques are essential. First, all students have name cards placed in front of them to help both instructors and students establish a sense of community. Students do much of the work in teams which reduces grading by one-third. In addition to electronic homework, other group or individual assignments can be collected by the roll of a die. A special 12-sided die is used to determine which table(s) will hand in their assignment. This requires all 99 students to be responsible for doing their assignments but grading is reduced to a fraction of the student population. Papers are easily collected and distributed by table. A quick evaluation of team comprehension is indicated by scanning answers that teams are asked to put on the white boards. The aforementioned techniques encourage individual accountability, positive interdependence, development of interpersonal skills, and communication as well as effective use of time to make an active class of 99 students relatively easy to manage.

3.4 DISSEMINATION

Dissemination of the program has been initiated at multiple institutions. Classroom dynamics are the most important component of the dissemination. It is crucial to have a classroom that supports cooperative grouping. Round tables (6-7' diameter) are the preferred method of seating because it allows face-to-face interaction with students (*10*). The classroom described above and shown in Figure 3-1 was designed specifically for SCALE-UP physics at NCSU and seats 99 students. However, the room has also been used for SCALE-UP chemistry ($cAcL_2$) and engineering classes. Several variations of this type of room have been designed and used. For instance, pilot SCALE-UP courses were taught in a classroom seating 54 students. This room was initially a traditional classroom seating 55 students at individual desks. The room was remodeled to incorporate round tables, white boards, and networked technology. Figure 3.2 shows before and after pictures of the room.

Figure 3.2. 54-Student Room (NCSU Cox 209). The picture on the left shows the layout of the room prior to renovation, which is shown on the right.

This renovation allowed for effective use of space since the new design holds a comparable number of students.

Similar renovations have already taken place at other institutions. The Massachusetts Institute of Technology has designed and implemented a room that seats 117 students. The University of Central Florida has built a room to seat 80 students. The rooms at both of these schools, as well as several others, resemble the layout of the room at NCSU (*11*) (Figure 3.1). However, the University of New Hampshire and the University of Alabama have made use of alternate table designs to suit their available space and resources. All of these designs are shown in Figure 3.3.

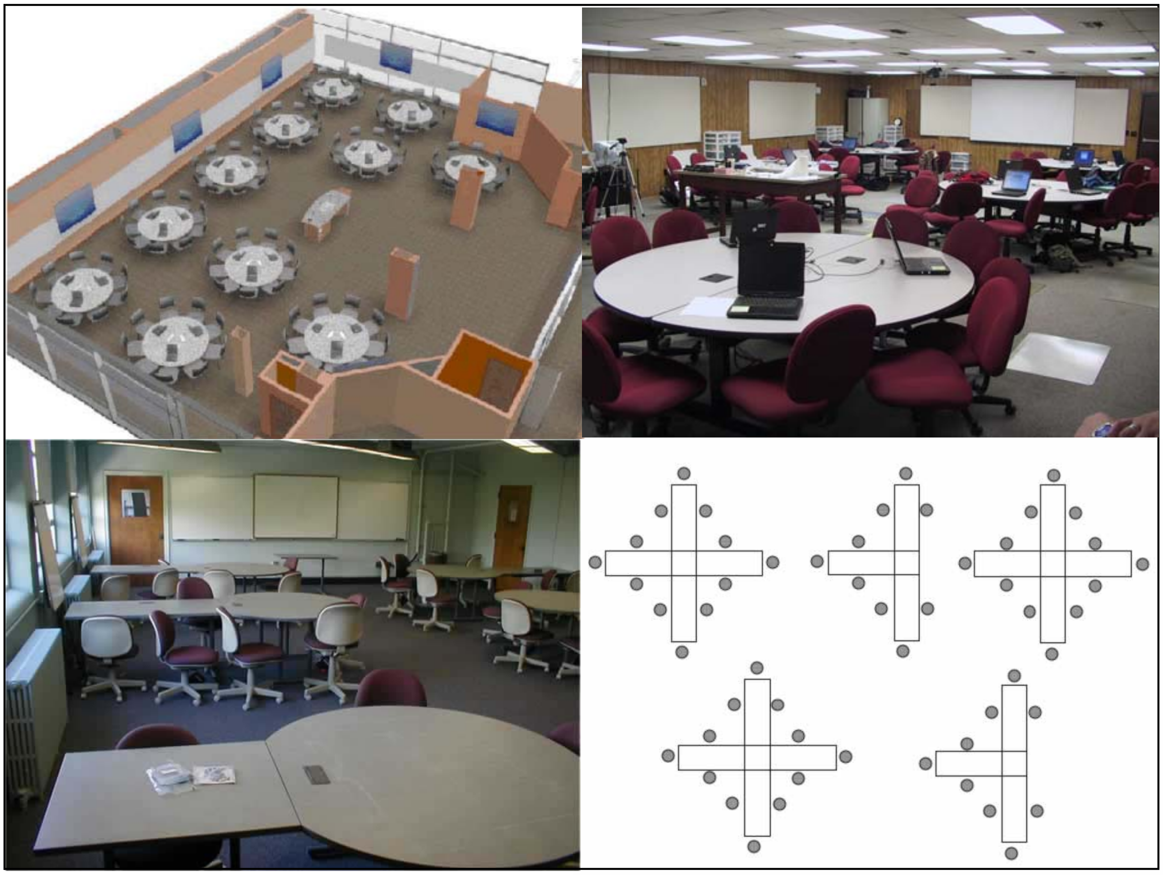

Figure 3.3. Rooms designed for use at other institutions. Clockwise from upper left: Massachusetts Institute of Technology, University of Central Florida, University of New Hampshire, and University of Alabama. More pictures can be found at the following link: http://www.ncsu.edu/per/SCALEUP/Classrooms.html.

The classroom mechanics and instructional philosophies of the physics program have been disseminated to several other institutions besides NCSU, thus establishing adequate resources to further disseminate the program into other disciplines. The program at NCSU is the only one to fully disseminate these practices into existing chemistry courses. By combining these classroom mechanics with the effective incorporation of the activity-based curriculum discussed in Chapter 2, the chemistry version of SCALE-UP, $cAcL_2$, can be disseminated and adapted, as well.

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CHAPTER 4

IMPLEMENTATION

& RESEARCH DESIGN

4.1 IMPLEMENTATION

Activities for the first semester of $cAcL_2$ were developed during the summer and fall of 2000. The activities were then implemented in the spring of 2001 during a pilot course in which students continued to attend a separate lab section. Activities for the second semester of $cAcL_2$ were developed during the summer and fall of 2001 and then implemented during a pilot course taught in the spring of 2002.

The pilot course implementation was necessary to ensure logical progression within each activity. The time requirements for each activity were also checked and recorded for instructor reference. Any other inconsistencies (unlisted materials or skipped steps) were also made note of in modifying the activity. The number of available activities and their corresponding topics were also evaluated so that more opportunities for activities could be identified. The materials for the first semester were completed in the summer and fall of 2001, while those for the second semester were completed in the summer and fall of 2002. A total of 93 activities were developed for $cAcL_2$.

4.2 RESEARCH DESIGN

Although, much background research and work went into the development and planning of the $cAcL_2$ curriculum, it does not guarantee that the new instructional method will have an impact on students. In order to determine the effects of the $cAcL_2$ instructional method, experimental courses were implemented in the fall of 2001 and the fall of 2002 for CH101 and CH201, respectively. Both quantitative and qualitative research approaches were taken in order to develop a full picture of the impact of $cAcL_2$.

Quantitative research methods are used to show results. The collected data can reveal the overall effects of a treatment and the extent to which that treatment is significant.

However, quantitative data may give no insight on how and why those results are obtained. Qualitative research must be used to investigate the reasons and/or processes leading to certain results (*1*).

The first semester of $cAcL_2$ (CH101) focused primarily on chemistry concepts. Therefore, the first study employed quantitative research methods to determine the effects on student understanding of basic chemical concepts and development of higher order cognitive skills. Student attitudes toward chemistry were also investigated. Two classes of CH101 were taught by the same instructor. The control section was taught using a traditional lecture method with a separate laboratory assignment. The experimental section was taught using the active approach of $cAcL_2$. Data were collected on exam performance over four exams and through surveys administered at the beginning and ending of the semester. Statistical methods were used to compare the two classes for any difference in student performance resulting from the two different instructional approaches (*2*). Residualized gain analysis was used to compare attitudes between both classes (*3*).

The second semester of $cAcL_2$ (CH201) focused primarily on a more mathematical treatment of general chemistry topics. Therefore, a more qualitative research approach was taken to delve into more specific areas of learning. Data were collected through surveys, interviews, exams, homework assignments, and reflective journals. The data were qualitatively analyzed to investigate how students solve problems, how students construct, manipulate and interpret graphs ([4]), and what perceptions students hold toward chemistry.

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CHAPTER 5

QUANTITATIVE STUDY

5.1 EXPERIMENTAL DESIGN

A quantitative comparative design was implemented for the first semester study of $cAcL_2$. One instructor taught two sections of the same course (CH101) consisting primarily of freshmen students (89.1% and 91.7%). This course is conceptually driven where no algorithmic problems are assigned. One class section was conducted in a traditional large lecture setting following a primarily passive format. The second class section was taught in the SCALE-UP classroom using the $cAcL_2$ active format. Students in both classes signed consent forms, agreeing to participate in the research study and to allow all materials and results of the study to be disseminated.

Both sections were taught during the fall of 2001 and both met during mid-afternoon hours. The passive traditional lecture met twice a week for 75 minutes per lecture (T &Th from 4:05 - 5:20 p.m.). Students also enrolled in a separate lab (3 hours/lab) and separate problem session (1 hour/session) that met once a week on alternating weeks. The lecture had seven corresponding lab sections and problem sessions with the same TA conducting a particular section. The active $cAcL_2$ class met three times a week for 100 minutes at a time (M, W, & F from 3:40 - 5:25 p.m.). No separate lab or problem session was required. One TA was assigned to $cAcL_2$, who was available during each class. A second TA helped with activity preparation and grading. The instructor spent a maximum of three hours per week in the SCALE-UP room so that the contact hours between instructor and students were comparable in both classes.

Since the same instructor taught the two sections, both content knowledge and time on task were carefully controlled. The instructional materials used in class covered the same topics with the same perspective and emphasis given to each topic. The difference lay in the delivery format. For example, demonstrations of chemical phenomena shown and explained by the instructor in the passive format were part of the hands-on curriculum for students in $cAcL_2$.

Time spent on each topic in class was also carefully monitored. In developing the topic schedule, the time spent in each topic during lecture time, lab experiment time and problem sessions were added to determine the allowable time on task dedicated to the same topic in the active format. During the entire semester, the $cAcL_2$ class met for 73.3 hours while the traditional class met for 65.5 hours including lecture, lab, and problem sessions. The time difference was spent mostly at the beginning of the semester in organizational issues like orientation to collaborative techniques, familiarization with the technology to be used in class, and student evaluation of group members.

Data were collected through surveys and exams. A pre-survey was created and administered electronically to both sections during the first two weeks of classes. The pre-survey addressed student background, expectations, study habits, computer skills, and anxiety towards chemistry classes, evaluations, and laboratories. The background information on the student population was used to categorize class sections for statistical purposes. During the last two weeks of classes students were given the opportunity to fill-out a post-survey that followed up on the questions given in the pre-survey. The follow-up questions were specifically directed to record changes in attitude brought about by student participation in the course. The demographic and attitudinal portions of the surveys were adapted from surveys used to compare a modular teaching approach to a traditional lecture approach at Grinnell College and U.C. Berkeley (*1*). The anxiety portion of the survey was adapted from the Derived Chemistry Anxiety Rating Scale (DCARS) (*2*).

5.2 ASSESSMENT METHODS

One objective of this study was to compare student performance in terms of improvements in understanding of basic chemical concepts and effective use of higher order cognitive skills. Attitudes and anxiety of students in both classes were also analyzed and compared. The traditional lecture class was used as the control and the $cAcL_2$ class served as the treatment, or experimental, section. A description of the analyses follows.

Student Performance

Exam questions were used to assess objectives on student performance. Exams were very similar in format, length, and amount of material covered per exam. They were also graded according to the same guidelines. A selected group of identical exam questions from both classes was analyzed. These questions were carefully chosen and/or constructed to satisfy the use of higher-order skills such as application, analysis, synthesis, and evaluation (*3*). These questions cannot be answered by plugging values into an equation. Students have to understand basic chemical concepts in order to answer them. Students must show their work and be explicit in the answers to these specific questions to receive credit. Collections of ConcepTests or similar conceptual questions are available from various resources (*4*). A total of 64 identical questions was given over the course of the semester. All of these conceptual questions are provided in Appendix B.

Student Attitudes

Attitudinal analysis was accomplished by comparing pre- and post-survey responses. Both surveys included questions designed to monitor attitudes toward learning science (14 questions), and chemistry anxiety in learning, evaluation, and chemical handling (25 questions). Students chose the option that best matched their feelings toward specific questions (attitudes: strongly disagree, disagree, neutral, agree, and strongly agree)(anxiety: not at all, a little, moderately, quite a bit, and extremely). These answers were converted to numerical values with a scale ranging from 1 to 5.

Reliability coefficients were reported for questions evaluating student attitudes toward learning and chemistry anxiety. Scores were computed for attitudinal data and averages were tabulated for anxiety questions. Raw attitude scores are obtained by adding the numerical values (from 1 to 5) assigned to each of the 14 questions to obtain a total score ranging from 14 to 70. These scores were used to compute residualized gains in learning attitude. Residualized gains are further discussed in the student attitudes section (5.4). A t-test was used to identify and analyze changes in student anxiety.

In addition, all students filled out a standard departmental evaluation that contained specific questions about the course and the instructor in both close-ended and open-ended formats. Scale means and standards deviations are reported for the close-ended questions. A summary of the most popular answers from the open-ended questions is also included in the results section.

5.3 STUDENT PERFORMANCE

Two objectives of the quantitative study were to compare improvements in student understanding of basic chemical concepts and effective use of higher order cognitive skills by students exposed to the two different formats, passive lecture and active $cAcL_2$. Identical exam questions were used to assess these objectives. A total of 64 identical questions was administered to both classes throughout four exams given during the semester. The specific set of challenging questions given to both classes was used to obtain adjusted exam scores for each student. Adjusted scores were obtained by calculating the percentage of points earned on the identical higher-order questions. The statistical analysis of adjusted scores for students in the control versus the experimental classes is discussed.

Four criteria must be met for statistical results to be valid. The first criterion is a sound experimental design with controlled variables, which has already been discussed (Section 5.1). The second criterion is complete data sets. The data were screened to compile data sets where students had taken all four tests and completed both surveys. Out of an enrollment of 51 students for $cAcL_2$ and 151 for the traditional section, 48 students in the $cAcL_2$ section and 119 students in the traditional section met the completed data criteria.

The third criterion is that the classes represent a random sample. CH101 is a requisite for all science majors. The class enrollment consists mostly of freshmen. During fall semesters, incoming freshmen receive a pre-determined schedule from the registrar. Changes are allowed but rarely pursued. Furthermore, incoming freshmen are generally unaware of the differences between their scheduled SCALE-UP section and the traditional lecture sections. These conditions suggest that the two classes represent random samples because the students have not self-selected themselves in favor of one instructional method over another.

The final criterion is establishing that comparison groups are equivalent in order to minimize the possibility that a random unidentifiable variable has dictated the effects observed in these groups (*5*). Academic major was the measure of choice since student attitudes toward science, average college entrance scores and mathematical aptitudes are implicit in this categorization. A second measure used for comparison was number of previous chemistry courses taken, including high school courses. Equivalency between the two comparison groups in this study is reflected in the distribution of students in each class per category. Figures 5.1 and 5.2 show categorization by these two measures.

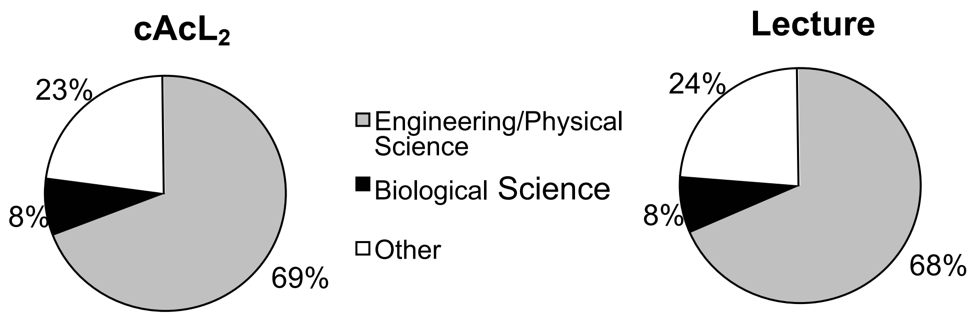

Figure 5.1. Equivalency of Comparison Groups by Academic Majors.

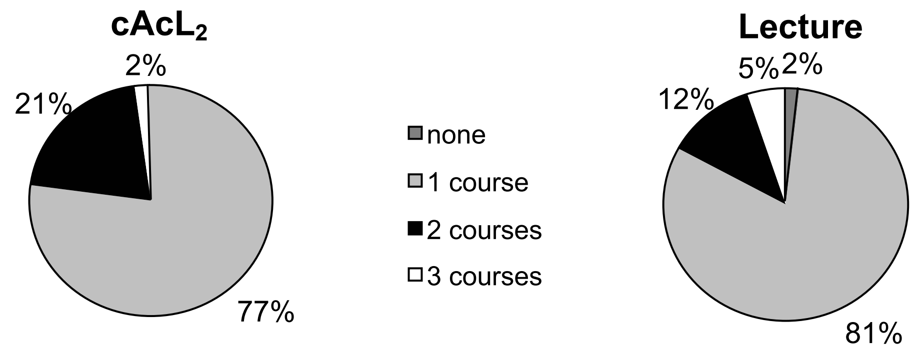

Figure 5.2. Equivalency of Groups by # of Previous Chemistry.

The demographic pie charts for each class were almost identical; the percentages of each academic major group were within 1 %. The percentages reflecting previous chemistry courses were within 4%. This indicates that there is no confounding effect between field of study / previous experience and instructional method and that the two class populations are similar. If all of the biological science majors are in one section while all of the engineering majors are in the other, determining whether the difference in performance of the classes is due to student major or due to the instructional method would be statistically impossible.

Analysis of variance (ANOVA) was used to determine whether instructional method affects overall student performance. The ANOVA allows us to take into account other sources of variation besides instructional method (class) such as student major, exam, and any two and three way interactions when testing for the class effect. An interaction between class and major exists if the performance of students across the various majors in the traditional instruction differs from the performance of students across the various majors in the $cAcL_2$ section. The analyses consider scores for each student based on the adjusted exam scores.

Preliminary analysis began with a 3-way ANOVA that included terms for class, major, exam, and all two and three way interactions. These three factors are considered to be the major sources of possible variation in overall student performance. For this model to be valid, exam scores across individuals must be statistically independent, exam scores within each individual must be statistically independent, and the samples must represent random samples of the student population. These assumptions are considered valid with a high degree of confidence. This is referred to as Model 1 as shown in Table 5.1.

Table 5.1. ANOVA Model 1.

$y_{ijkl} = \mu + C_i + M_j + E_k + (C{*}M)_{ij} + (C{*}E)_{ik} + (M{*}E)_{jk} + (C{*}M{*}E)_{ijk} + \varepsilon_{ijkl}$	
$i = 1, 2$	Passive or active class
$j = 1, 2, 3$	Classification of scores by majors
$k = 1, 2, 3, 4$	Classification of scores by exam
y_{ijkl}	Responses – total proportion of similar questions on exams; 4 per student
C_i	Effect of i^{th} class (passive instruction or active instruction)
M_j	Effect of j^{th} major (phys. science/engineering, bio. science, or other)
E_k	Effect of k^{th} exam (exam 1, 2, 3, or 4)
$(C{*}M)_{ij}$	Interaction between i^{th} class and j^{th} major
$(C{*}E)_{ik}$	Interaction between i^{th} class and k^{th} exam
$(M{*}E)_{jk}$	Interaction between j^{th} major and k^{th} exam
$(C{*}M{*}E)_{ijk}$	Interaction between i^{th} class, j^{th} major, and k^{th} exam
ε_{ijkl}	Random error

Before conducting any tests to determine if students in the $cAcL_2$ section perform better than students in the traditional section, any insignificant terms from Model 1 must be eliminated. For example, if there is no significant interaction between major and exam, then the interaction term is not a significant source of variation and can be eliminated from Model 1. Table 5.2 presents the ANOVA results for Model 1.

Table 5.2. Statistical Analysis System (SAS) (*6*) Output of Model 1.

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	23	29270.0390	1272.6104	4.14	<.0001
Error	639	196358.1921	307.2898		
Corrected Total	662	225628.2312			

R-Square	Coeff Var	Root MSE	score Mean
0.129727	28.47352	17.52968	61.56486

Source	DF	Type III SS	Mean Square	F Value	p-value
exam	3	9351.42128	3117.14043	10.14	<.0001
major	2	10426.42790	5213.21395	16.97	<.0001
class	1	808.79390	808.79390	2.63	0.1052
major*exam	6	614.14311	102.35718	0.33	0.9195
exam*class	3	6079.65053	2026.55018	6.59	0.0002
major*class	2	1923.64515	961.82257	3.13	0.0444
class*major*exam	6	973.14147	162.19024	0.53	0.7874

The F statistics given in Table 5.2 are testing the following hypothesis:

H_o: There is no effect due to term *X; X* is not significant

H_a: Term X does have an effect on the response

Using an $\alpha = 0.05$ significance level, a p-value < 0.05 indicates that the null hypothesis (H_o) is rejected and *X* is significant. Notice that the terms M*E and C*M*E are not significant. Therefore, these terms can be removed to create a reduced model, Model 2. The SAS output for Model 2 is given in Table 5.3.

Table 5.3. Statistical Analysis System (SAS) Output of Model 2.

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	11	27687.5473	2517.0498	8.28	<.0001
Error	651	197940.6839	304.0564		
Corrected Total	662	225628.2312			

R-Square	Coeff Var	Root MSE	score Mean
0.122713	28.32332	17.43721	61.56486

Source	DF	Type III SS	Mean Square	F Value	p-value
exam	3	9878.49469	3292.83156	10.83	<.0001
major	2	10458.92996	5229.46498	17.20	<.0001
class	1	819.22303	819.22303	2.69	0.1012
major*class	2	1925.68958	962.84479	3.17	0.0428
exam*class	3	5317.80720	1772.60240	5.83	0.0006

To compare Model 1 to Model 2, a full versus reduced model F-test was performed.

$$F = \frac{(197940.6839 - 196358.1921)/(651 - 639)}{307.2898} = 0.42915 \qquad [1]$$

Since $0.42915 = F < F_{\alpha=0.05,\ 12,\ 639} = 1.76742$, there is confidence in concluding that the terms M*E and C*M*E are not significant sources of variation in the student exam scores and can be excluded from the model. Thus, Model 2 is used to analyze whether students in $cAcL_2$ performed better than students in traditional lecture. The p-values of interest obtained from Model 2 are presented in Table 5.4.

Table 5.4. Results of Model 2.

Parameter	F statistic	p-value
Class	2.69	0.1012
Exam*Class	5.83	0.0006

At an $\alpha = 0.05$ significance level, class is not significant. This test is performed by taking averages across exam scores for each class. However, the Exam*Class term is highly significant, strongly suggesting that we need to compare class performances for each exam instead of across all exams. Note that these same results were also obtained in Model 1. For each exam we want to test the hypothesis that the average performance of the $cAcL_2$ section (μ_2) is higher than the average performance of the traditional section (μ_1):

$$H_o: \mu_1 = \mu_2 \qquad [2]$$
$$H_a: \mu_2 > \mu_1 \qquad [3]$$

We reject the null hypothesis if $t > t_{crit}$ where the critical t value is 1.645. See Table 5.5.

Table 5.5. Average Performance for Each Class Per Exam.

	$\overline{x}_1$ (Lecture)	$\overline{x}_2$ ($cAcL_2$)	$\overline{x}_1 - \overline{x}_2$	t
Exam 1	63.4068	57.5917	-5.8151	-1.9480
Exam 2	65.3916	71.9938	6.6022	2.2117
Exam 3	58.4564	55.6271	-2.8293	-0.9478
Exam 4	56.9664	66.1426	9.1762	3.0739

Thus, we can conclude at an $\alpha = 0.05$ significance level that the students in the $cAcL_2$ section performed significantly better on Exams 2 and 4 while there was no significant difference in their performance on Exams 1 and 3.

Visualization of the above data is easily achieved by representing the data using boxplots (Figure 5.3). Schematic boxplots show percentiles, mean (+), and median values (horizontal line). The "body" of the boxplot represents the interquartile range (IQR) which comprises the 25th to 75th percentile data values. The top 25th percentile extends through a line up to the maximum observation (upper bar) and the lower 25th percentile extends to the minimum observation (lower bar). Outliers are represented by "O".

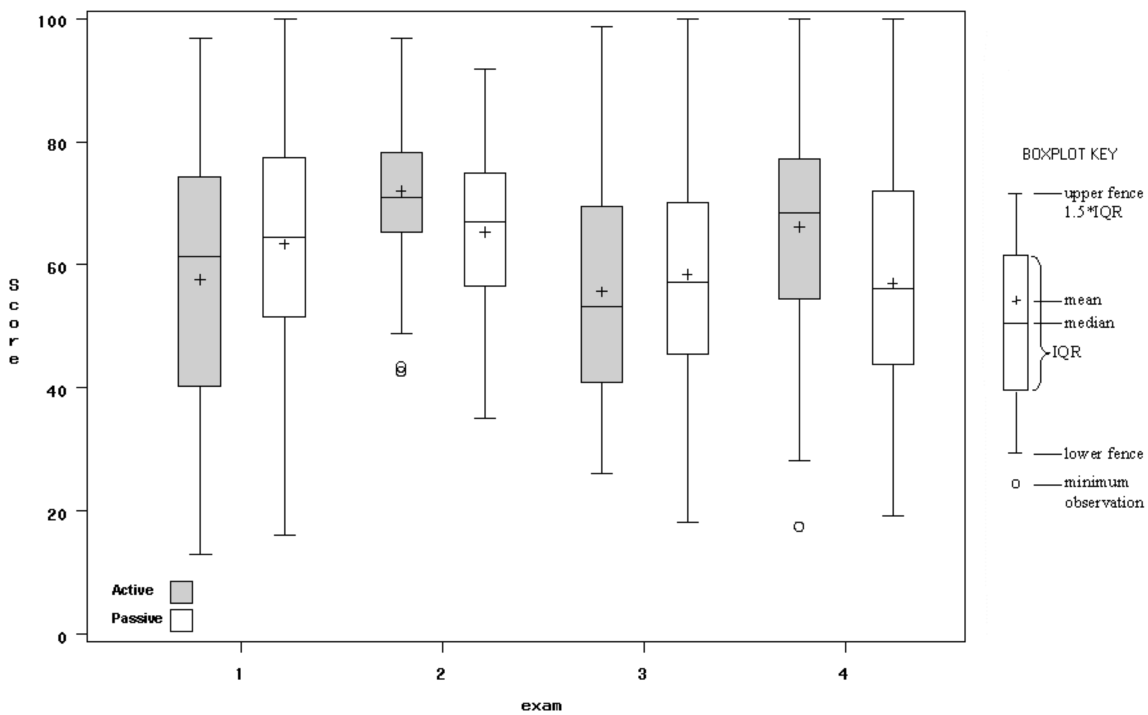

Figure 5.3. Boxplots for the Four Exams - $cAcL_2$ (Active) and Lecture (Passive) Formats.

As seen in Figure 5.3, Exam 1 is the only exam in which the passive format class shows higher scores across the board (the lower 25% of the student population, the higher

25% of the student population, higher average and median). The IQR is also wider and lower among the active students than the passive students. These results came as no surprise due primarily to the exposure to a completely different format during the first few weeks of classes. Adjustments to this class format were obvious as results for Exam 2 show. For Exam 2, the $cAcL_2$ class outperformed the passive class in the top and bottom 25%, average and median values as well as in the IQR. By the end of the semester, $cAcL_2$ achieved significantly higher median and average values, as well as a better IQR with the lower 25% of the students attaining higher scores (as seen on Exam 4).

Exclusion of Exam 3 was considered due to the fact that this was the only exam that did not follow the same scheduling guidelines as all other tests due to university holidays and breaks. The traditional passive format class took Exam 3 one week after all material was covered in class, while the $cAcL_2$ class had their third exam two weeks after the material was discussed in class. Due to a scheduling mismatch for both classes for Exam 3, the analysis excluding this exam was also performed. If Exam 3 is excluded from Model 2 the following results are obtained:

Table 5.6. Results of Model 2 excluding Exam 3.

Parameter	F statistic	p-value
Class	5.33	0.0214
Exam*Class	7.39	0.0007

Both p-values are less than 0.05 indicating that class and the exam by class interaction are significant. Furthermore, the performance of the students in the $cAcL_2$ section is significantly different from the performance of the students in the traditional lecture averaging across all exams.

Conclusions

The statistical analyses reveals significant statistical differences between the two sections exposed to the two different instructional formats. These significant differences demonstrate that the $cAcL_2$ active environment positively influenced student performance in an introductory chemistry course.

5.4 STUDENT ATTITUDES AND ANXIETY

The importance of attitudes toward science has risen from widely accepted assumptions that achievement and attitude are positively interdependent (*7*) and that affective variables are as important as cognitive variables in molding student learning (*8*). Research studies have investigated the attitudinal aspects of chemistry instruction in two realms - lecture and laboratory. Both are potential grounds to excite students into the wonders of chemistry. Studies show that exclusive use of lecture methods fails to sustain student interest in the sciences (*9*) and tends to decrease student interest, attendance, and motivation as students feel little sense of responsibility or accountability (*10*). Adding aspects of cooperative learning to a lecture course showed a strong positive effect on student retention, however, better attitude toward science, and greater enjoyment of science were attributed to individual instructors and not to cooperative techniques (*11*). On the other hand, active involvement might be the reason why students enjoy the laboratory component of chemistry more than any other part of their chemistry instruction (*12*). Studies have looked at the use of hands-on laboratory instruction as a means of improving student attitude toward science (*13*). Laboratory instruction seems to influence student attitudes consistently in a positive way (*13,14,15,16*).

The $cAcL_2$ program has incorporated elements believed to positively influence student performance and attitudes toward science including cooperative learning, hands-on activities, real-world applications and engaging technology (*17*). The effect of the active $cAcL_2$ learning environment on attitude and anxiety has been investigated.

Instruments

Pre- and post-surveys were administered electronically to students during the first and last two weeks of classes. Both surveys included questions designed to monitor attitudes toward learning science (14 questions), and chemistry anxiety in learning, evaluation, and chemical handling (25 questions). The attitudinal portion of the surveys was adapted from surveys used to compare a modular teaching approach to a traditional lecture approach at Grinnell College and U.C. Berkeley (*18*). The anxiety portion of the survey was adapted from the Derived Chemistry Anxiety Rating Scale (DCARS) (*2*). See Appendix C.

Students chose the option that best matched their feelings toward specific questions. These options included "strongly disagree", "disagree", "neutral", "agree", and "strongly agree" for the attitude questions. These answers were converted to numerical values with a scale ranging from 1 (strongly disagree) to 5 (strongly agree). Questions were in an affirmative positive mode so that the higher the values the better the attitude toward learning in science. On the other hand, the chemistry anxiety options included "not at all", "a little", "moderately", "quite a bit", and "extremely" which were also converted to a scale of 1 (not at all) to 5 (extremely). Lower numbers in this scale represent less anxiety.

Reliability coefficients are reported for questions evaluating student attitudes toward learning and chemistry anxiety. Scores are computed and reported for attitudinal data while numerical results of the means were tabulated for anxiety questions. Raw attitude scores are obtained by adding the numerical values (from 1 to 5) assigned to each of the 14 questions to obtain a total score ranging from 14 to 70. These scores were used to compute residualized gains in learning attitude. A t-test was used to analyze change in student anxiety.

In addition, all students filled out a standard departmental evaluation that contained specific questions about the course and the instructor in both close-ended and open-ended formats. Scale means and standards deviations are reported for the close-ended questions. A summary of the most popular answers from the open-ended questions is also included in the results section.

Results and Discussion

Common factor: Instructor

Instructors can dramatically influence student performance and attitudes in the classroom (*19,20*). Therefore, departmental evaluations were used to compare student perceptions of the instructor in order to monitor discrepancies that could jeopardize findings in the attitudinal and anxiety surveys. A total of 161 surveys were collected from the two class sections. A scale of 1 (strongly disagree) to 5 (strongly agree) was used. The averages with accompanying standard deviations are included in Table 5.7.

Table 5.7. Student Evaluations of Instructor in CH101.

Question	**$cAcL_2$ n = 48**	**Lecture n = 113**
Instructor demonstrates enthusiasm for teaching.	4.6 (0.5)	4.8 (0.4)
Instructor is well prepared for lecture.	4.5 (0.7)	4.8 (0.4)
Instructor writes legibly.	4.4 (0.6)	4.6 (0.6)
Instructor speaks clearly.	3.7 (1.1)	4.1 (0.8)
Instructor is receptive to questions and comments.	4.1 (1.1)	4.6 (0.6)
Instructor is available during posted office hours.	4.4 (0.7)	4.3 (0.8)
Instructor is knowledgeable of subject material.	4.6 (0.7)	4.8 (0.4)
I would recommend this instructor to other students.	3.7 (1.2)	3.8 (1.1)
The overall effectiveness of this instructor as a teacher is: (1) poor, (2) fair, (3) good, (4) very good, or (5) excellent	3.8 (1.0)	4.0 (0.9)

Student evaluations of the same instructor in the two different formats reflect that there is no significant difference in the two classes, even though the $cAcL_2$ class gave consistently lower markings to the same questions. This is a common finding when implementing innovative approaches especially when students become more responsible for their own learning (*21*). The instructor is an important source of variation and if it were the only variable taken into consideration we could predict that parallel results would occur on student attitudes since the instructor was perceived comparably in both sections.

Reliability of survey questions: Cronbach alpha

Since instruments used in this study were adaptations of survey tools used at other institutions, Cronbach alphas were calculated for both sets of questions, attitudinal and chemistry anxiety. Cronbach alpha measures how well scale items correlate with each other (*22*). Values for the chemistry anxiety correlate closely to previously reported values of the DCARS instrument (*2*). The results are given in Table 5.8.

Table 5.8. Internal Consistency of Survey Questions.

Rating	**Cronbach alpha**	
$cAcL_2$	Pre-Survey	Post-Survey
Derived Chemistry Anxiety Rating Scale	0.96	0.93
Factor 1, Learning-Chemistry Anxiety	0.93	0.91
Factor 2, Chemistry-Evaluation Anxiety	0.90	0.83
Factor 3, Handling-Chemicals Anxiety	0.95	0.89
Attitudinal Scale*	0.73	0.82
Lecture	Pre-Survey	Post-Survey
Derived Chemistry Anxiety Rating Scale	0.94	0.93
Factor 1, Learning-Chemistry Anxiety	0.92	0.91
Factor 2, Chemistry-Evaluation Anxiety	0.84	0.82
Factor 3, Handling-Chemicals Anxiety	0.90	0.92
Attitudinal Scale*	0.72	0.70

*14 questions dealing with student attitude towards learning in science

Analysis of Data: Residualized Gain Scores

Due to the complexity of factors affecting attitudinal responses (scores) the use of raw difference scores raises validity concerns. Some argue that raw difference scores are inherently unreliable especially when considering the measurement of attitudes on different occasions that may influence student responses (*23*). Residualized gain scores, RGS, tend to attenuate some of the difficulties associated with comparison of raw scores (*23,24*). In RGS analysis post- versus pre-survey scores for each student in the lecture section (the control group) are plotted. A regression line is obtained from this pre/post-survey scatter plot. Its positive slope indicates positive attitudinal change for students in the control group. This regression line, or baseline, is used to compute predicted post-survey scores for each student in $cAcL_2$ (the experimental group). The residualized gain is the difference between each predicted value and the actual post-survey value for each student, which measures real change relative to predicted change. These residualized gains are considered good estimates of the treatment effects. Figures 5.4 and 5.5 show the pre/post-survey scatter plot and the RGS graph respectively for all students completing both pre- and post-surveys ($cAcL_2$ $n = 48$, lecture $n = 119$). Positive gains were reflected by 77.1% of the student population in $cAcL_2$. These changes are above the baseline constructed from responses of the lecture section.

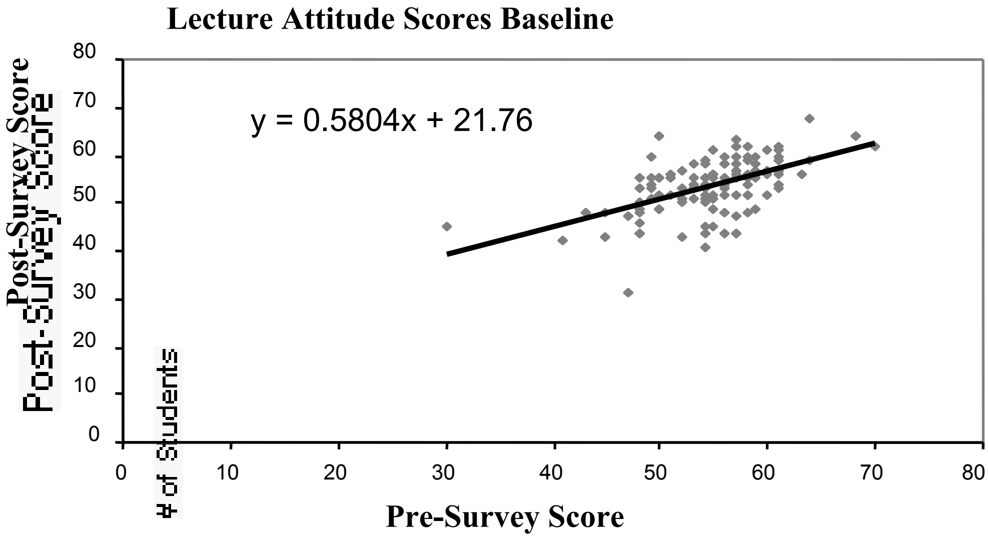

Figure 5.4. Pre- Post-Survey Scatter Plot.

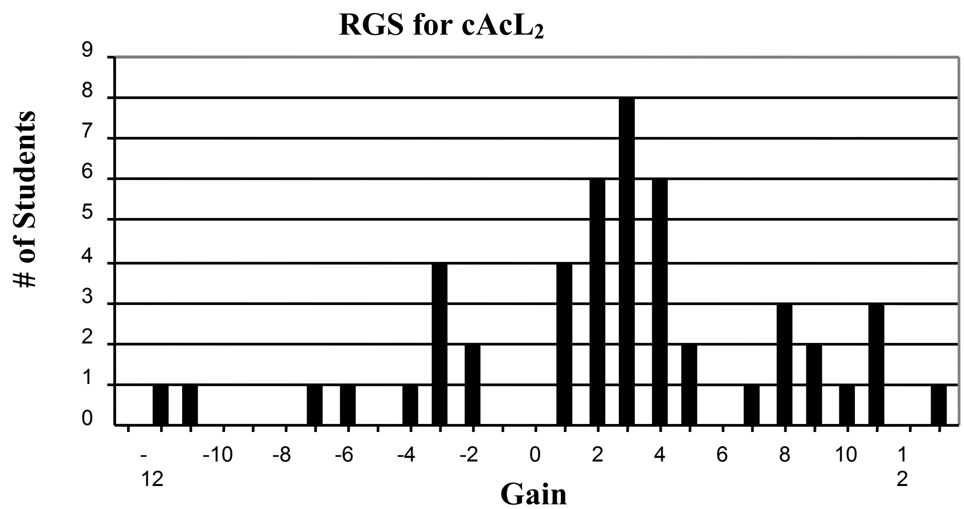

Figure 5.5. Residualized Gain.

RGS values for the active class as a whole were dissected to investigate if some academic groups benefited more than others. When academic groups were compared separately to the pre- post-scatter plot, positive RGS were attained by 76.9% of the physical/engineering majors, 81.8% of the biology majors, and 72.7% of the majors grouped under "other." These results are shown in Figure 5.6. When majors are compared to their counterparts in the control group, the percentage of students experiencing positive gain above the baseline of their counterparts remains the same as when compared to the control group as a whole (Figure 5.4).

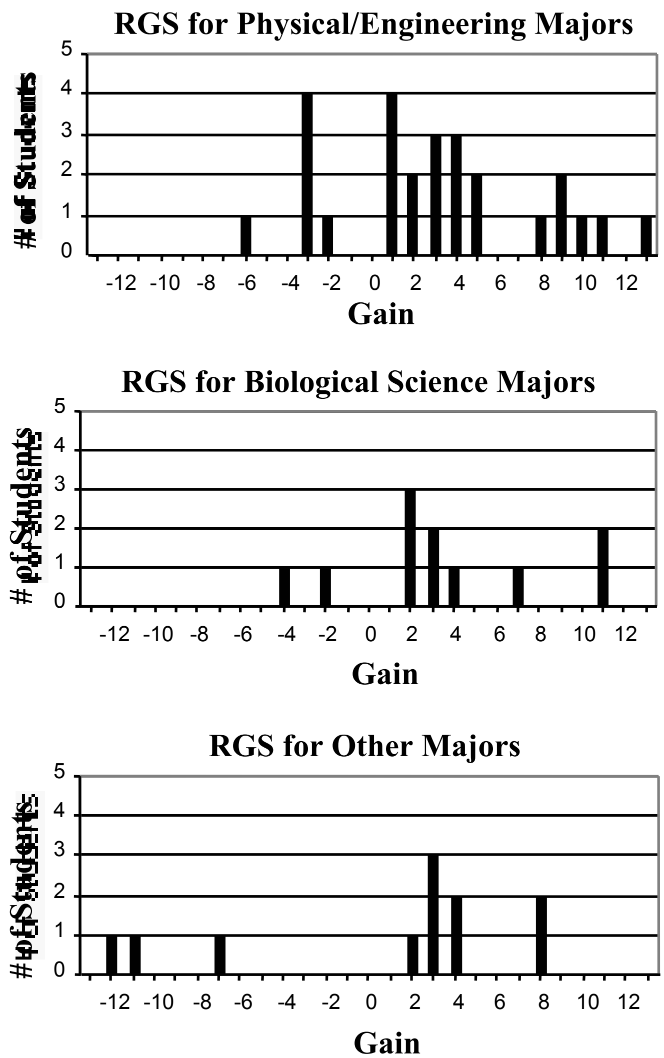

Figure 5.6. Residualized Gains by Academic Groups.

Chemistry Anxiety

Research on chemistry anxiety is at an early stage but the existence of it among chemistry students is palpable. Changes in student anxiety levels from both classroom environments were monitored. Table 5.9 includes the pre- and post-survey results with corresponding net changes (Δ = post - pre) to each specific question as well as to the three factors, learning-chemistry, chemistry-evaluation and chemical handling. A negative net change indicates a decrease in average anxiety, while a positive net change indicates an increase in average anxiety.

Responses are designated for the question "Please indicate 'how stressed you would become' when doing the following activities" in terms of the following: 1 - not at all, 2 - a little, 3 - moderately, 4 - quite a bit, 5 - extremely. A t-test was used to compare the anxiety level of students in both classes. Pre-survey responses from students in both classes were first compared for each question to determine if the two classes had similar levels of anxiety, initially. A significant difference is indicated when p is less than 0.05. The results of these t-tests reveal that, overall, there is no significant difference in anxiety between the students in $cAcL_2$ and lecture. Only two anxiety statements, out of 25, indicated a significant difference between the classes: "spilling a chemical" ($p = 0.01$) and "working with a chemical whose identity you don't know" ($p = 0.05$). A t-test was then used to compare pre and post responses within a class in order to look for significant changes occurring over the course of the semester. Significant differences are denoted by an asterisk (*) in the net change (Δ) column in Table 5.9.

Table 5.9. Chemistry Anxiety for CH101.

	$cAcL_2$			Lecture		
Learning-Chemistry	**Pre**	**Post**	**Δ**	**Pre**	**Post**	**Δ**
Signing up for a chemistry course	1.98 (1.08)	1.96 (1.07)	-0.02	1.97 (0.98)	2.19 (1.20)	0.23
Reading the word "chemistry".	1.81 (1.08)	1.77 (1.08)	-0.04	1.70 (0.93)	1.9 (1.12)	0.26*
Walking into a chemistry class.	1.92 (1.01)	2.04 (1.07)	0.13	1.98 (1.05)	2.18 (1.15)	0.19
Looking through the pages in a chemistry text.	2.15 (1.29)	2.23 (1.21)	0.08	2.34 (1.08)	2.57 (1.18)	0.23
Reading a formula in chemistry.	2.27 (1.18)	2.23 (1.31)	-0.04	2.32 (1.13)	2.51 (1.16)	0.19
Picking up a chemistry textbook to begin working on a homework assignment	2.44(1.15)	2.35 (1.16)	-0.08	2.43 (1.03)	2.58 (1.12)	0.15
Having to use the tables in a chemistry book.	2.06 (1.10)	2.06 (0.95)	0.00	1.99 (0.91)	2.09 (1.07)	0.10
Reading/interpreting graphs or charts that show the results of chemistry experiments.	2.15 (1.03)	2.19 (1.12)	0.04	2.21 (0.90)	2.24 (1.01)	0.03
Listening to another student explain a chemical reaction.	2.08 (1.15)	1.94 (1.00)	-0.15	2.27 (1.12)	2.28 (1.16)	0.01
Listening to a lecture in a chemistry class.	2.15 (1.27)	2.33 (1.28)	0.19	2.04 (1.08)	2.43 (1.24)	0.39*
Total Learning Chemistry Score	**21.0 (8.93)**	**21.1 (8.30)**	**0.10**	**21.3 (7.73)**	**23.0 (8.53)**	**1.70***
Chemistry Evaluation						
Working on an abstract chemistry problem, such as "If x = grams of hydrogen and y = total grams of water produced, calculate the number of grams of oxygen that reacted with the hydrogen.	2.75 (1.23)	2.50 (1.19)	-0.25	2.71 (1.15)	2.71 (1.19)	-0.01
Waiting to get a chemistry test returned.	3.10 (1.34)	3.63 (1.25)	0.52*	3.29 (1.22)	3.50 (1.25)	0.22
Taking a test or examination in a chemistry class.	3.56 (1.24)	3.65 (1.19)	0.08	3.42 (1.13)	3.56 (1.14)	0.14
Being given a homework assignment that is due the next chemistry class.	2.60 (1.14)	2.56 (1.22)	-0.04	2.59 (1.05)	2.61 (1.20)	0.03
Thinking about a chemistry test one day before.	3.15 (1.38)	3.52 (1.27)	0.38	3.29 (1.19)	3.40 (1.18)	0.12
Taking a final in chemistry.	3.90 (1.17)	4.06 (1.28)	0.17	4.14 (1.05)	4.04 (1.16)	-0.10
Total Chemistry Evaluation Score	**19.1 (6.19)**	**19.9 (5.41)**	**0.80**	**19.4 (5.11)**	**19.8 (5.16)**	**0.40**

*A significant result was obtained during a t-test ($p<0.05$).

Table 5.9. (continued)

	$cAcL_2$			Lecture		
Chemical Handling	Pre	Post	Δ	Pre	Post	Δ
Walking into a chemistry laboratory.	1.81 (0.98)	1.83 (0.95)	0.02	1.92 (0.94)	1.77 (0.94)	-0.14
Spilling a chemical.	2.65 (1.23)	1.98 (1.08)	-0.67*	3.13 (1.22)	2.51 (1.29)	-0.61*
Listening to another student describe an accident in the chemistry lab.	1.83 (1.12)	2.69 (1.29)	0.85*	1.88 (1.11)	1.92 (1.11)	0.04
Being told how to handle the chemicals for the laboratory experiment.	1.69 (0.90)	1.75 (0.93)	0.06	1.80 (0.93)	1.76 (0.98)	-0.04
Working with acids in the lab.	2.08 (1.20)	1.38 (0.64)	-0.71*	2.13 (1.07)	1.92 (1.08)	-0.20
Getting chemicals on your hands during the experiment.	2.44 (1.27)	1.75 (0.84)	-0.69*	2.69 (1.21)	2.45 (1.21)	-0.24
Working with a chemical whose identity you don't know.	2.27 (1.27)	2.29 (1.20)	0.02	2.61 (1.14)	2.22 (1.14)	-0.39
Mixing chemical reagents in the laboratory.	2.04 (1.18)	2.27 (1.36)	0.23	2.15 (1.12)	1.93 (1.03)	-0.22*
Heating a chemical in the Bunsen Burner flame.	2.08 (1.18)	1.83 (1.12)	-0.25	1.97 (1.04)	1.97 (1.12)	0.00
Total Chemical Handling Score	**18.9 (8.84)**	**17.8 (7.01)**	**-1.10**	**20.3 (7.33)**	**18.5 (7.81)**	**-1.80***
Overall Score	**59.0 (20.6)**	**58.8 (17.0)**	**-0.20**	**61.0 (17.0)**	**61.3 (17.3)**	**0.30**

*A significant result was obtained during a t-test ($p<0.05$).

The tests reveal that overall anxiety for $cAcL_2$ students was lowered in three areas of the chemical handling section: “spilling a chemical”, “working with acids in the lab”, and “getting chemicals on your hands during the experiment.” Anxiety for students in the lecture section was also lowered in the area of “spilling a chemical”, as well as in “working with a chemical whose identity you don’t know.” Significant decreases or improvement in anxiety levels were only observed for the chemical handling factor for both classes.

Total scores for each factor in the anxiety rating scale were computed by adding a student’s responses over all questions for that factor. An overall score was also computed using all questions on the anxiety rating scale. When t-tests were used to compare these total scores, significant changes were only noted for the lecture section. Anxiety significantly decreased for chemical handling, while anxiety significantly increased for learning chemistry. Although, there were no significant changes for $cAcL_2$ in learning chemistry, the averages for each area in this factor show a consistent decrease in anxiety of learning chemistry, while those in the lecture show a consistent increase in anxiety.

Although students in $cAcL_2$ completed the same labs as the lecture students, $cAcL_2$ labs involved microscale techniques only. Additional activities conducted by the $cAcL_2$ students also used microscale techniques and non-hazardous materials. This may explain the significant overall decrease in chemical handling anxiety for the lecture students while students in $cAcL_2$ experienced only a slight overall decrease.

It is also of interest to observe anxiety in terms of various academic groups. Therefore, anxiety data was dissected according to academic major. The averages are reported in Table 5.10.

Table 5.10. Chemistry Anxiety Ratings by Majors for CH101.

	Rating	Pre-Survey			Post-Survey		
		P	B	O	P	B	O
$cAcL_2$	Derived Chemistry Anxiety Rating Scale	2.06	2.83	2.59	2.13	2.76	2.47
	Factor 1, Learning-Chemistry Anxiety	1.71	2.81	2.31	1.82	2.74	2.18
	Factor 2, Chemistry-Evaluation Anxiety	2.78	3.79	3.50	3.00	3.97	3.42
	Factor 3, Handling-Chemicals Anxiety	1.97	2.21	2.29	1.89	1.99	2.15
Lecture	Derived Chemistry Anxiety Rating Scale	2.45	2.39	2.46	2.44	2.42	2.53
	Factor 1, Learning-Chemistry Anxiety	2.10	2.09	2.23	2.26	2.25	2.46
	Factor 2, Chemistry-Evaluation Anxiety	3.34	3.13	3.10	3.31	3.22	3.36
	Factor 3, Handling-Chemicals Anxiety	2.24	2.24	2.29	2.05	2.06	2.04

P = Physical/Engineering Science, B = Biological Sciences, O = Other majors
No significant changes indicated by $p < 0.05$.

Dissecting this information into the three academic majors revealed that physical/engineering (P) students had repeatedly higher levels of anxiety in the lecture setting while the biology (B) majors showed consistently more anxiety in the active environment. When comparing changes of these two majors within each class setting there were no significant differences on pre- and post-survey results. The academic grouping of all other sciences (O) did not show a consistent pattern when comparing passive lecture to active environment. However, this group (O) showed a decrease in anxiety levels on all three factors for the active environment and only a decrease in the laboratory factor in the lecture setting. Table 5.10 includes these results.

Student opinions

Departmental evaluation questions that refer specifically to the course do not show differences between the lecture and $cAcL_2$ settings. These results are shown in Table 5.11.

Table 5.11. Course Specific Questions for CH101.

Question	$cAcL_2$ n = 48	Lecture n = 113
The course is challenging and stimulates independent thinking.	4.5 (0.6)	4.7 (0.7)
The knowledge gained in previous courses prepared me sufficiently for this one.	3.4 (1.1)	3.4 (1.1)
The degree of difficulty associated with this course is: very difficult (5), difficult, average, easy, trivial (1)	4.2 (0.7)	4.3 (0.8)
The numbers of hours required outside of class per week is: <2 (5), 2-5, 5-8, 8-12, >12 (1).	3.4 (0.8)	3.4 (0.8)

The neutrality shown in these quantitative results does not match the strong opinionated responses given to the open-ended questions that asked, "How would you describe this course?" and "Elaborate on any other aspects of this course, especially those rated very positively or negatively in the multiple-choice section." Both classes felt they had to work hard but the active class use adjectives like "in-depth", and " stimulating" more often than the lecture setting class. In almost every instance that the active class referred to the course as "hard" it was accompanied by words like "rewarding", "worth it", "better" and "teaches you a lot" or "you get more out of it". That was not the case in the lecture setting where "hard" was often accompanied by adjectives like "extremely", and "too" or phrases like "too much work", "must put lots of effort", and "requires too much time". In the active class words like "fun" and "interesting" were used more often.

A phenomena not encountered with the lecture class was the aftermath of emails expressing gratitude for the opportunity to learn chemistry. The reason for this effect might lie in the fact that students in the active section are familiar with the lecture format but not vice-versa. Students in the active class consistently referred to their active class as a better way to learn and they recognized their roles and responsibilities in learning. In the lecture setting the "responsibility" for doing well in class was more often blamed on the instructor rather than the student.

Conclusions

The active environment integrated four elements believed to positively influence student attitudes. It was expected that the synergy of these elements would show markedly positive changes on students exposed to this format. Clear changes were recorded during this quantitative study, while an analysis of open-ended responses reinforced the same observations and provided more insight into the effect of $cAcL_2$ on student attitudes. In addition, the chemistry anxiety results are shared in the hopes they will contribute to a better understanding of anxiety in chemistry. The findings can be summarized as follows:

- Evaluations by students on the instructor's performance and capability showed comparable perceptions from both classes but the $cAcL_2$ class evaluation was a bit lower in every survey question. Instructors need to be aware that this is a real effect encountered in implementation of new approaches.

- Positive changes were markedly obtained in student attitude toward learning as 77.1% of the student population in $cAcL_2$ showed positive RGS. These changes represent gains above projected changes in the lecture section.

- The active environment promoted positive attitudinal changes in different types of students. Positive gains among the three academic groups were as follows: 76.9% of physical/engineering majors, 81.8% of the biology majors, and 72.7% of the majors grouped under "other."

- T- tests reveal that overall anxiety for SCALE-UP students was lowered in three areas of the chemical handling section: “spilling a chemical”, “working with acids in the lab”, and “getting chemicals on your hands during the experiment.” Anxiety for students in the lecture section was also lowered in the area of “spilling a chemical”, and in “working with a chemical whose identity you don’t know.” Significant decreases or improvement in anxiety levels were only observed for the chemical handling factor for both classes.

- No significant changes were obtained for $cAcL_2$ in the learning chemistry factor. However, the averages for each question in this factor show a consistent decrease in anxiety of learning chemistry, while those in the lecture show a consistent increase in anxiety.

- The academic group of "other" majors consistently decreased in all three anxiety factors for $cAcL_2$. This group seemed to benefit more than other academic groups.

- Quantitative results of student opinions from departmental evaluation surveys were comparable for both classes. However, the feedback received by instructors in the active environment was numerous, positive and inspiring.

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CHAPTER 6

QUALITATIVE STUDY

6.1 EXPERIMENTAL DESIGN

A one-class experimental design employing qualitative research methods (*1,2*) was implemented for the second semester study of $cAcL_2$. A one-class model was used to remove any variability that arises in a two-class comparative model. The same instructor that taught CH101 in the quantitative study taught one section of CH201 for the qualitative study. The class was taught in the SCALE-UP classroom using the $cAcL_2$ active format. All students signed consent forms agreeing to participate in the research study and allow all materials and results of the study to be disseminated.

The section was taught during the fall 2002 semester and met twice a week for 100 minutes (M & W from 3:40 - 5:30 p.m.). Students did not attend a separate problem session for this course; it was included as part of class time. Students were enrolled in a separate lab that met every week for three hours in order to familiarize themselves with specific laboratory techniques and handling of equipment. The lab sections for CH201 are not linked with specific lecture sections of CH201; therefore, $cAcL_2$ students attended lab with students taking other sections of CH201 taught by different instructors.

Data were collected through surveys, journals, interviews, and copies of student work on exams, in-class work, and homework. Pre- and post-surveys similar to the ones used for the quantitative study were administered the first and last two weeks of classes to collect data on student background, expectations, study habits, and chemistry anxiety (see Appendix C). Reflective journals were implemented to collect samples of student problem solving approaches as well as attitudes toward chemistry and $cAcL_2$. Copies of student work were used to collect data and look for trends in problem solving and graphing skills.

Interviews were used to collect and confirm data on all facets of the study. The first interview took place during the second week of class. This interview was not conducted on an individual basis, but was given to the entire class to obtain an initial evaluation of attitudes, problem solving skills and graphing skills. This first segment of data collection is referred to as an interview because it serves as part of a series of questions in subsequent interviews. Three other interviews were conducted throughout the course of the semester with individual students outside of class. During each interview students were given a problem to solve and a set of data to graph. They were asked questions concerning their problem solving methods, study habits, attitudes towards chemistry, and graph interpretation. See Appendix D for interview templates.

Students were systematically chosen in a random fashion in order to obtain a representative, or stratified, sample for interviews #2, #3, and #4. A representative sample is a sample that reflects the characteristics of the population. In this case the population was the $cAcL_2$ section of CH201. Student major, gender, and ethnicity were used as categories in the stratification of the sample. Stratification ensures that a sample is representative of a population based on certain categories. For instance, if a population is 50% physical science majors then 50% of the students randomly chosen to participate in a particular interview sample should be physical science majors. The samples for interviews had to be chosen within the first few weeks of class in order to give an interview schedule to students. Therefore, the categorization for interview groups was based on the initial make-up of the class, prior to drop and withdrawal dates. The percentages for initial make-up are given in Table 6.1.

Table 6.1. Initial Make-up of Class by Category.

Category		Percentage of Total Enrollment
Major		
	Physical Sci. & Engineering	51
	Biological Sciences	25
	Other	24
Gender		
	Female	22
	Male	78
Ethnicity		
	Asian	7
	Black	5
	Hispanic	4
	Indian	2
	White	82

In the randomization process students were separated by major first. Half of the necessary sample for each major was randomly selected. The selections were then evaluated based on gender and ethnicity requirements for the sample. If the selections were consistent with stratification requirements then the selection process continued for half of the remaining sample. When selections appeared to be deviating from the necessary stratification then the sample was evaluated to see what type of student would be needed to complete the sample. Successive selections were made until a student matched the requirements. The three interview samples were made as homogeneous as possible with each student scheduled for only one interview. Note that all students were assigned to one interview, not just a sample of the $cAcL_2$ population. Therefore, the stratification process made it possible to divide students into three comparable groups based on major, gender, and race.

Students were required to attend these interviews and received three extra credit points on an exam grade in return for their participation. Students were also given the opportunity to sign-up for one additional interview, and the extra three bonus points. This would allow some students to be interviewed twice so that comparisons of observations could be made over the course of the semester. A total of 39 people out of the final enrollment of 45 participated in an interview and 15 of those students participated in two interviews.

6.2 ASSESSMENT METHODS

Two objectives of this study were to observe problem-solving skills and graphing skills of students over the course of the semester. Student attitudes were also monitored. A description of the analyses follows.

Problem-Solving Analysis

Students were exposed to a problem-solving protocol known as GOAL the third week of class. GOAL is an acronym for the steps in the scheme - *Gather-Organize-Analyze-Learn* (*3*). Copies of student work from quizzes, exams, interviews, and journals were used to determine how students solve chemistry problems and whether they chose to use the GOAL method. The copies are generally referred to as samples in this work. Each student sample was analyzed to determine whether students specifically indicated the use of GOAL or whether they used steps similar to the GOAL process.

Chi-square (χ^2) analyses were performed on the data collected from the nine questions used in this study in order to determine whether there is a relationship between organizing, gathering, and success on a problem. The tests were run according to procedures laid out by Bruning and Kintz (*4*). The results are presented in section 6.3.

Graphing Skills Analysis

No specific guidance in constructing graphs was given to students during the course of the semester unless students specifically sought assistance. Data on graphing skills was collected during each of the four interviews and through two separate homework assignments. Copies of student work were maintained for evaluation purposes. Each piece of student work was quantified in terms of the presence of various graph components -- scale, title, choice of axes, labels, and units. Ability in using Excel to generate graphs and edit existing graphs was also monitored. Class percentage data and key observations are summarized and reported for each category. All results and observations are presented in section 6.4.

Attitudinal Analysis

Pre- and post-surveys were administered electronically to students during the first and last two weeks of classes. A total of 18 questions were used to measure student attitudes about learning in general, 5 questions were used to indicate how $cAcL_2$ affected student interest in science, 14 questions were used to gather information on student perceptions of $cAcL_2$, and 25 questions were given to measure student anxiety levels for the areas of chemistry learning, chemistry evaluation, and chemical handling. Reliability coefficients, or Cronbach alpha values, are also computed to confirm the internal consistency of the survey questions in the qualitative CH201 study. Class averages and standard deviations for each question are tabulated and discussed.

A t-tests was used to compare pre- and post-survey responses. Net changes (Δ = post - pre) are reported to indicate an overall increase or decrease in student averages for each question. The t-tests indicate whether or not those changes are considered significant at an $\alpha = 0.05$ significance level ($p < 0.05$). Significant changes are indicated by an asterisk (*).

During this qualitative study interviews and journal entries served as additional forums through which to collect data on student attitudes. Students were asked questions designed to gather data on attitudes toward group work and the structure of $cAcL_2$. Results from interviews and journals are discussed qualitatively. All results and observations on student attitudes are presented in section 6.5.

Data Collection Time-Table

Data was collected through surveys, journals, interviews, and copies of student work on exams, in-class work, and homework. Each data collection procedure served to gather data on student attitudes, anxiety, problem solving skills, or graphing skills. A timetable is provided to indicate when data was collected and for what area of study that data would pertain (attitude, anxiety, background, problem-solving, or graphing).

Table 6.2. Data Collection Time-Table.

Type of Sample	Date	Type of Data	Notes
Pre-survey	Aug. 19	AXB	electronic survey given during first two weeks
Interview #1	Aug. 28	PAG	students had not yet been exposed to GOAL
Journal #1	Sep. 4	P	students had not yet been exposed to GOAL
Quiz #1	Sep. 9	P	students introduced to GOAL in previous class
Exam #1	Oct. 7	P	one problem chosen for analysis
Interview #2	Oct. 8	PAG	individual student interviews
Journal #2	Oct. 16	A	students described benefits of the class structure
Homework #1	Oct. 23	G	students graphed three sets of titration data
Quiz #2	Oct. 30	P	one problem chosen for analysis
Interview #3	Nov. 4	PAG	individual student interviews
Homework #2	Nov. 11	G	students graphed E_{cell} vs Log Q from class data
Exam #2	Nov. 18	P	one problem chosen for analysis
Post-survey	Nov. 25	AX	electronic survey given during last two weeks
Interview #4	Dec. 3	PAG	individual student interviews
Exam #3	Dec. 16	P	one problem chosen for analysis

A=attitude, X=anxiety, B=background, P=problem-solving, G=graphing

6.3 PROBLEM SOLVING

The problem solving skills of chemistry students have been a research topic for the past 20 years. Information on how students solve problems is important for two reasons. The first reason is to identify the common strategies employed by students and the typical mistakes and obstacles encountered. The second reason is its implication in developing instructional problem solving strategies that cater specifically to students. This section provides an overview and comparison of various problem solving strategies, research findings based on the use of a specific problem solving strategy, and the results and conclusions reached when analyzing problem solving skills of students in the CH201 $cAcL_2$ class.

Overview of Problem Solving Strategies

Chemical education research has pointed out that quantitative problem solving ability does not necessarily imply conceptual understanding (*5,6,7,8*). Therefore, more meaningful approaches to teaching problem solving skills have been developed to foster logical application of concepts to solve quantitative problems. Most of these methods are based upon the universal problem solving principles described by Polya (*9*). Polya describes four steps essential for solving problems: 1) understand the problem, 2) devise a plan, 3) execute the plan, and 4) look back to review the results. A short review is provided on how these principles have been integrated into specific cognitive steps that students can follow when solving problems.

Bunce and Heikkinen (*10*) studied the effect of an explicit approach. The approach included the following steps: a) statement of problem in words, b) sketch of the situation described, c) recall of necessary content knowledge needed to solve problem, d) solution diagram that identifies given information, lists the recalled information, and outlines steps in solving the problem, e) mathematical solution, and f) review of problem statement and solution diagram. No significant effect was observed for the treatment group although some evidence suggested that the method might prove to be useful if implemented fully by students. In a subsequent study Bunce, Gabel and Samuel (*11*) provided specific instruction to students in problem categorization while incorporating the use of the explicit method for problem solving, also known as EMPS. Significant effects were observed in student achievement when using problem categorization with EMPS on problems requiring the use of more than one chemical concept as well as on unannounced tests. These two studies considered only effect on achievement and give no details on the implementation of EMPS by students.

McCalla (*12*) presents a similar strategy based on the EMPS model that includes the elements of *Objective*, *Given*, *Pathway*, and *Answer*. The Objective and Given steps serve to summarize the problem and given information. The Answer step is simply the application of mathematics to solve for a specific answer. The Pathway step is what distinguishes this strategy. McCalla uses "pathways" to construct a solution by linking logical paths from the objective to the information given in the problem by building on key definitions and concepts one step at a time. In essence, McCalla methodically works backwards from the objective of the problem by building a concept map-like structure until the information in the problem can be used. A suggested advantage of using a pathway is that a wrong turn in the solution can be easily backtracked and corrected. A study of the method suggests that the use of pathways may be associated with greater success on difficult problems. Data were not available on student use of the other steps in this problem solving procedure.

Another specific method applied in chemistry is described by Asieba and Egbugara (*13*). This method incorporates detailed instructions on how to read a problem carefully, make a plan, combine separate pieces of information, write down relevant information, answer the question in the problem, and evaluate the answer in terms of the goal and given information from the problem. A study implementing this method indicated that providing orientation, practice, and feedback for mastery in using the method in addition to instruction for content mastery, develops important problem solving skills in students. Data was collected through pre- and post-tests measuring problem solving ability. No specific data on student use of the problem solving method was reported.

In contrast to these methodical problem solving schemes, some educators have focused more heavily on basic mathematical reasoning. For instance, efforts have been made to connect concepts using the popular factor-label, or dimensional analysis, approach (*14,15,16*). In this approach concepts are linked using a series of conversion factors. Other educators have argued that ratio reasoning procedures provide a more meaningful mathematical approach because students must reason through relationships step-by-step (*17,18,19*) or apply equations and relationships appropriately to concepts (*20,21*).

All of these methods contribute to the literature base advocating that specific instruction in problem solving leads to the development of certain problem solving skills and possibly greater success on advanced problems. However, there is no information about how students implemented each step of the methods. Either overall achievement results were investigated or only one part of the method was discussed. There is not sufficient evidence to suggest that one method is superior, but based on the research results they all have advantageous qualities derived from Polya's principles. The following promotion of the GOAL problem solving protocol, which stands for *Gather*, *Organize*, *Analyze*, and *Learn*, is an attempt to integrate Polya's principles in a streamlined mnemonic form.

GOAL Problem Solving Protocol

The GOAL protocol is a problem solving strategy developed by the NCSU Physics Education & Research group for use in introductory physics courses, specifically SCALE-UP courses (*3,22*). Like other methods this approach was also developed from the universal problem solving principles described by Polya. The GOAL protocol promotes use of the four primary steps in a simple mnemonic form. Students *gather* given information and the specific question being asked in a problem. Students then *organize* a solution to the problem calling on concepts, definitions, and important equations. Once the solution is organized, students *analyze* the problem by solving it mathematically for the desired answer. Then students *learn* by stepping back, reviewing their work, and asking what they have learned by working the problem. GOAL is discussed in more detail in Appendix E.

There are two distinguishing features of the GOAL protocol. The first is that it is easy for students to remember, G-O-A-L. It does not involve cumbersome checklists or specially designed worksheets to frame the use of GOAL. The second distinguishing feature is the *Learn* step. Most problem solving strategies include steps for reviewing solutions and answers to be sure that the problem has been solved correctly. The *Learn* step does include the reviewing process but it also asks students to evaluate the reasonableness of an answer and to ask themselves what was learned by solving the problem or why the problem was given. Ideally, student refection upon their answers is more conducive to learning when solving a problem using GOAL than when only an answer is obtained from a mathematical calculation.

Design

Problem solving methods of students enrolled in a CH201 $cAcL_2$ section were observed throughout the course of the fall semester of 2002. The GOAL protocol was adapted for chemistry and presented to students. GOAL was chosen for two reasons: 1) the *Learn* step differentiates it from its counterparts, and 2) the connection in instructional strategy between SCALE-UP and $cAcL_2$. The GOAL problem solving protocol was presented as an optional approach to problem solving. Problems done by instructors during class and keys posted for exams and quizzes were done explicitly using the GOAL protocol. Instructors also used GOAL during office hours when helping students. However, students were not required to use (or graded on the use of) GOAL on any given problem, assignment, exam or quiz.

Data on student problem solving methods were collected during four separate interviews, three exams, and two quizzes. One question was chosen for each collection sample for a total of nine questions, included in the Sample Collection section. Copies of student work were kept for purposes of this study. Student work is referred to as samples. Students journal entries made periodically throughout the semester were also available to observe problem solving skills.

During interviews #2-4 students were also asked questions about their use of GOAL and their opinions about the problem solving protocol. The responses were qualitatively analyzed and have been summarized in the results section.

Goals

- To analyze student samples gathered during a second semester $cAcL_2$ chemistry class in order to gather meaningful data on student problem solving methods

- To determine how students respond to explicit problem solving procedures like GOAL
- To develop a meaningful approach to teaching problem solving skills that fosters logical application of concepts
- To develop problem solving strategies for classroom implementation based on student problem solving methods and preference

Sample Collection

The following questions were used to analyze student problem solving strategies among chemistry students participating in this study. Each question was specifically chosen from various resources to evaluate knowledge of a certain topic presented in class. Students worked example problems during class and completed homework assignments relating to the topics covered in class. However, the questions used for data collection were new to students, as they did not previously work problems requiring similar solutions. A total of 307 samples were collected from students on nine questions over the course of the semester.

Question #1 (Interview # 1)

> The concentration of grain alcohol (C_2H_5OH) in whisky is given in 'proof', which is twice the percent alcohol by volume (v/v). What are the mole fraction and molality of C_2H_5OH in 90 proof vodka? Assume that vodka is a solution of C_2H_5OH and water only and that the volumes are additive. The density of C_2H_5OH is 0.79 g/mL.

Question #2 (Quiz # 1)

> Vitamin K is involved in normal blood clotting. When 1.00 g of vitamin K is dissolved in 20.0 g of camphor, (k_f = 40.0°C/m) the freezing point of the solution is lowered by 4.43°C. What is the molar mass of vitamin K?

Question #3 (Exam #1)

> The following reaction rarely occurs under standard state conditions. Calculate ΔG for this reaction at 25°C <u>when the pressure of SO_3 is 0.16 atm</u>.

Substance	ΔG^o_f (kJ/mol)
$CaO_{(s)}$	-604.0
$SO_{3\,(g)}$	-371.1
$CaSO_{4\,(s)}$	-1321.8

$$CaO_{(s)} + SO_{3\,(g)} \Leftrightarrow CaSO_{4\,(s)}$$

Question #4 (Interview #2)

Consider the following equilibrium at 400 K: $Br_{2\,(g)} + Cl_{2\,(g)} \Leftrightarrow 2\ BrCl_{(g)}$ K = 7.0

A mixture contains 2.10 mol BrCl, 0.80 mol of Br_2, and 0.56 mol Cl_2 in a 4.26-L container. How many moles of Cl_2 must be removed to obtain an equilibrium mixture that contains 1.00 mol Br_2?

Question #5 (Quiz #2)

A chemistry student needs 250 mL of a solution buffered at pH 9.00. How many grams of ammonium chloride have to be added to 250 mL of 0.200 M ammonia to make such a buffer? Assume that no change in volume occurs by the addition of this solid salt. $K_{bNH3} = 1.8 \times 10^{-5}$.

Question #6 (Interview #3)

At 25°C, a 0.100M aqueous solution of the base methylamine (CH_3NH_2) is 6.8% ionized. Calculate the K_b for methylamine.

Question # 7 (Exam #2)

What are the concentrations of all the ions in solution after 100.0 mL of 0.020 M $Pb(NO_3)_2$ and 100.0 mL of 0.020 M Na_2SO_4 are mixed? (K_{sp} $PbSO_4 = 1.7 \times 10^{-5}$) (solubility rules also given)

Question #8 (Interview #4)

The following data was collected when butadiene reacts to form its dimer according to the equation at 30°C.

$$2\ C_4H_{6\,(g)} \rightarrow C_8H_{12\,(g)}$$

[C_4H_6]	**Time (s)**
0.01000	0
0.00625	1000
0.00476	1800
0.00370	2800
0.00313	3600
0.00270	4400
0.00241	5200
0.00208	6200

What is the rate constant of C_8H_{12} at 30°C?

Question #9 (Exam #3)

The carbon in a sample of wood found in an Egyptian pyramid has an activity of 8.5 grams of carbon per cm^3. Carbon-14 decomposes with first order kinetics. The wood from a recently cut tree has a concentration of 14.9 grams of carbon per cm^3. If the half-life of carbon-14 is 5715 years, how old is the wood from the Egyptian pyramid?

Results and Discussion

The GOAL problem solving protocol was presented to students the second week of class and used explicitly by instructors during class and office hours and also for exam and quiz keys. It was expected that students would incorporate the use of GOAL for problem solving. However, extensive use of GOAL was not obvious for this group of students. Out of 269 samples, explicit use of GOAL was only observed in 2 samples. (Question #1 samples were excluded because students had not yet been exposed to the GOAL protocol.) Explicit use of GOAL is identified when students label steps in solving a problem with *Gather*, *Organize*, *Analyze*, *Learn*, and/or G, O, A, or L. This result is consistent with observations in other studies (*10,11,3,23*). It is very difficult to get students to change their method or follow explicit guidelines to solve problems. Since GOAL was not required students did not make an effort to use it. For this reason, GOAL itself could not be directly evaluated in this study. However, evidence of using unspecified steps similar to those in GOAL was investigated.

A) Gather & Organize

Although explicit use of GOAL was not largely observed, many students included steps resembling the *Gather* and *Organize* steps of GOAL. In analyzing student samples, notes were made when students showed evidence of gathering important information and organizing their approach. Gathering was indicated when a student showed evidence of extracting at least one important piece of information from the problem before beginning to solve it. The piece of information could be listed separately or visually marked in the text of the problem. Organizing was indicated when a student wrote down an equation, in variable form, or set up a reaction table for use in solving the problem. Students were considered successful in solving the problem if they obtained the right answer, made only minor mathematical mistakes, or missed only a minor step in the calculation such as miscalculating a molar mass. Table 6.3 below shows the frequency of students showing evidence of gathering and organizing prior to attempting a calculation and the frequency of success observed for each question.

Table 6.3. Observations of Gathering, Organizing, and Success.

Question #	Total # of Students	Gathering	Organizing	Successful
1	38	16	24	9
2	45	15	33	31
3	42	10	30	19
4	16	10	12	0
5	44	28	33	35
6	21	6	15	8
7	40	15	35	17
8	17	1	10	11
9	44	12	29	33
Total	307	113	221	163

A chi-square (χ^2) analysis is useful when determining whether various groups have an effect on a variable. Frequency counts for the various groups and variables are made and summarized in contingency tables. Using the values in the contingency table a chi-square value (χ^2_{calc}) is computed and compared to a table of critical chi-square values (χ^2_{crit}) at an $\alpha = 0.05$ significance level to determine if the difference among the different groups has a high probability of being real. If $\chi^2_{calc} > \chi^2_{crit}$ then the difference is significant and has at least a 95% probability of being real.

In this study the variable is a successful or unsuccessful attempt at solving a problem. In order to determine whether gathering and organizing data prior to attempting to solve a problem has any effect on student success, students were broken into the following subgroups based on observations of their methods: gather only, organize only, both gather and organize, or neither. The use of a chi-square analysis is only appropriate when frequency counts are greater than or equal to 1 and the percentage of cells with a frequency less than 5 is less than 20%. The frequency counts for individual questions do not meet this requirement and were therefore excluded from the analysis. However, a combined analysis for all questions can be performed in order to obtain an overall assessment on the effect of gathering and organizing on problem solving success. See the table below.

Table 6.4. Contingency Table for χ^2 tests.

All Questions	**Successful**	**Unsuccessful**	TOTAL
Gather only	9	14	23
Organize only	73	58	131
Both	56	34	90
Neither	25	38	63
TOTAL	163	144	307
χ^2_{calc}	9.726		

$df = 3$, $\alpha = 0.05$, $\chi^2_{critical} = 7.815$

The chi-square analysis reveals that gathering and organizing methods do significantly affect student success in problem solving ($\chi^2_{calc} = 9.726$). In order to describe the effect, consider the frequency counts in the contingency table above. Notice that approximately half of all student attempts at problem solving were observed to be successful, but more responses were found to be successful when students organized an approach or used both gathering and organizing approaches. For those students that used neither gathering nor organizing methods their responses were more unsuccessful. The data suggest that gathering and organizing may lead to more successful problem solving.

These relationships were further broken down to investigate which factor, if any, has the greatest effect on success - gathering, organizing, or both. In order to determine this effect the contingency table above was broken down into four relationships: Gather only vs. Organize only, Both vs. Neither, Gather only vs. Neither, and Organize only vs. Neither. The results are given in Table 6.5.

Table 6.5. Comparison between different groups.

All Questions	Successful	Unsuccessful	χ^2_{calc}
Gather only	9	14	2.164
Organize only	73	58	
Both	56	34	6.595
Neither	25	38	
Gather only	9	14	0.024
Neither	25	38	
Organize only	73	58	3.619
Neither	25	38	

$df = 1$, $\alpha = 0.05$, $\chi^2_{critical} = 3.841$

When gathering and organizing were compared no significant relationship was found (Gather Only vs. Organize Only, $\chi^2_{calc} = 2.164$). The only significant relationship indicated by this data is that both gathering and organizing, together, affect the success rate for a student solving a problem (Both vs. Neither, $\chi^2_{calc} = 6.595$). The other relationships indicate a varying effect on success rate, but are not found to be significant. Values reported in Table 6.6 indicate the probability that any difference between factors is real based on the α-level at which χ^2_{calc} becomes significant.

Table 6.6. Significance Level Distinguishing between Gather and Organize.

Comparison	χ^2_{calc}	Significance level*	Probability difference is real
Gather only vs. Organize only	2.164	0.14	86 %
Both vs. Neither	6.595	0.01	99 %
Gather only vs. Neither	0.024	0.88	12 %
Organize only vs. Neither	3.619	0.06	94 %

*significance level obtained from http://quantrm2.psy.ohio-state.edu/kris/chisq/chisq.htm
$df = 1$, $\alpha = 0.05$, $\chi^2_{critical} = 3.841$

When students that both gathered and organized are compared to students that did neither, a significant difference was found ($\chi^2_{calc} = 6.595$) and the probability that that difference is real is 99%. When students that only organized are compared to students that did neither the difference was not significant at the $\alpha = 0.05$ level. However, the value is significant at an $\alpha = 0.06$ level. All of the data provides strong evidence that the first two steps of the GOAL protocol - Gather and Organize - are valuable as steps to solve a problem. The analysis also strongly suggests that organizing may play a more important role in problem solving than gathering.

B) Analyze

The *Analyze* step of GOAL is part of the problem solving protocol most familiar to students. *Analyze* requires students to mathematically work through the problem. Students would include this section whether or not they followed a specific problem solving scheme. Even strictly algorithmic approaches would be considered a parallel to the *Analyze* step of GOAL. Since successful and unsuccessful students were considered in the gather/organize analysis, no analysis was done on whether students included an "analyze" step in their problem solving.

C) Learn

Indication of students including a *Learn* step in their problem solving was mostly nonexistent; it was observed only twice in all of the 307 samples. The *Learn* step makes the GOAL protocol unique. Not only does it require students to double-check their calculations, but it also requires them to review their answer and its units, decide if it is reasonable within the context of the problem, and discuss the significance of the problem and what was learned by solving it. It is this step, or analogs of this step, that students were least likely to include, explicitly, in their problem solving procedure.

One possible explanation for why there is very little indication of a *Learn* step is that students have very little chemical intuition, or experience with chemistry, which limits them in evaluating their answers for reasonableness. As expressed by students early in the semester, students feel inept at using the *Learn* step of the problem solving protocol. This sentiment was observed while helping students during office hours. However, it was also observed that a few persistent students that attended office hours regularly would verbally evaluate their answers without coaxing by the end of the course. When commenting on this ability, students expressed that they had developed the skill over the course of the semester as they gained more experience with the material. However, this was still not a step that was explicitly included, in writing, when solving a problem.

Although, students were not likely to include a step in their problem solving procedure related to the *Learn* step of GOAL, there was one example in which students showed more prevalent evidence of evaluating their answers. Students were often asked to answer various questions in their journals. One journal question, given prior to the first presentation of the GOAL protocol included a practical evaluation question as part of the question statement. See the question below.

Journal Question

As a very rough general rule, increasing the temperature of a reaction by $10^{o}C$ doubles the rate of reaction. Approximately how many grams of salt should be added to 1.5 liters of water to increase the temperature of the boiling water by $10^{o}C$? Would this be a satisfactory way in which to reduce the time required to make "boiled potatoes"?

This question was obtained from Wertz, Dennis W. *Chemistry: A Quantitative Science*; Prentice Hall: New Jersey, 2002.

For this question, it was observed that some students did try to evaluate their answers. Only 20 students out of 42 obtained an answer to the numerical question of "how many grams of salt should be added?" Of those 20 students, only 12 responded to the question "Would this be a satisfactory way in which to reduce the time required to make 'boiled potatoes'?" The remaining 8 students out of these 20 neglected to respond to this evaluation question at all. There were 7 other students that responded to this evaluation question that provided reasoning only, but did not provide a numerical answer. The typical response of these 7 students was that it would take longer because it would take longer to reach the boiling point when salt is added.

As indicated by the data collected from this journal question, students are more likely to include a "Learn" step in their thinking process if the question statement includes some sort of practical evaluation. This makes sense because students are required to give a response based on that evaluation. However, as noted above, even when the evaluation response is required some students either choose not to respond or overlook that part of the question focusing only on the mathematical solution. It is possible that by regularly building such evaluation statements into questions, students will develop chemical intuition, or those skills necessary to judge the reasonableness of the answers.

Student Comments on GOAL

Student opinions and reactions for the GOAL problem solving protocol were gathered from three interviews. The results for the 39 students that participated in the interviews are summarized on the following page.

In response to the question "Do you use GOAL?" the following results were obtained:

- 15% - Yes
- 33% - No
- 13% - Sometimes
- 13% - Use at least one step of GOAL
- 8% - Try to use GOAL
- 18% - Use own variation that is similar to GOAL (not as formal)

The advantages of GOAL as listed by students include:

- 69% - more organized/neater/pattern to follow
- 15% - aids thinking process
- Other comments include:
  - less mistakes
  - breaks down problem
  - makes problem easier
  - can backtrack mistakes
  - learn more
  - prevents wrong answer

The major disadvantages of GOAL as listed by students include:

- 56% - takes too long
- 18% - no disadvantages
- 8% - too much unnecessary work
- Other comments include:
  - confusing
  - not sure about what goes in what step
  - problem with Learn step
  - have to know how to solve problem before you can use it
  - very structured
  - don't understand
  - focus more on method than problem

Although students did not use GOAL they were aware that using GOAL had notable advantages. The organization of the approach was listed as an advantage by 69% of the students interviewed and 15% said that it aided the thinking process. In fact, when asked to list disadvantages 18% of the interviewees stated that GOAL had no disadvantages. So students do see the potential of the GOAL protocol, but as stated previously, students in the CH201 cAcL$_2$ class did not make extensive use of the GOAL problem solving protocol. The most likely reason this was observed is revealed by the number one disadvantage cited by students - it takes too long. Other studies have also found this to be a major complaint of students (*10,11,3,23*). It is very difficult to get students to change their method or follow explicit guidelines to solve problems. A majority of students are also not willing to spend time planning a solution before jumping directly into calculations. Therefore, the disadvantages cited by students are not surprising. Based on this research it is apparent that an organized problem solving approach is needed, but it must require less written work and it must appeal to students in order for them to make use of it.

Review of Significant Problem Solving Components

Students recognized the possible usefulness of GOAL, but chose not to use it primarily because that felt that it took too long and added unnecessary work to the problem solving process. However, chi-square tests indicated that including gathering and organizing steps could significantly and positively affect student success in problem solving. This is consistent with observations in other studies of student problem solving methods. For instance, Gabel, Sherwood, and Enochs examined the problem solving skills of high school chemistry students (*24*). Their study found that students solving problems correctly used a more organized approach than those students who did not solve problems correctly. Students relied heavily upon algorithmic methods and did not use evaluation methods that aid in problem solving. In many cases it appeared that algorithms were a substitute for conceptual understanding. The researchers make two suggestions: 1) present chemical concepts qualitatively prior to introducing more quantitative descriptions, and 2) teach students how to solve problems in a more organized fashion.

Heyworth conducted a study examining expert and novice problem solving characteristics of high school chemistry students (*25*). He examined the strategies that students employed in solving a volumetric analysis problem and how students represented the problem with their conceptual knowledge. He found that both expert-ability and novice-ability students formed initial representations of problems based on keywords identified in the problem statement. However, expert-ability students used a forward working logical strategy, while novice-ability students used a means-ends analysis that often failed because students were unable to use a formula to link the concept to the data given.

Bunce, Gabel and Samuel, provided specific instruction to students in problem categorization while incorporating the use of EMPS, (*11*). EMPS was discussed previously as a specific problem solving strategy. Significant effects were observed in student achievement when using problem categorization with EMPS on problems requiring the use of more than one chemical concept as well as on unannounced tests. Interview transcripts revealed that students accessed what was identified as a "Rolodex" of equations organized primarily by the units involved. However, there were gaps, or the absence of appropriate links, between chemical concepts and the skills necessary to solve a problem.

The literature provides overwhelming evidence that instruction in explicit problem solving approaches develops more advanced problem solving skills in students (*26,27,28*). One of the primary conclusions of all these studies is that organizing an approach to solving the problem or generating a representation of the problem, centered around concepts, provides the greatest benefit in problem solving. Based on studies specifically comparing the methods of expert and novice problem solvers, it is this organization of thought around specific concepts that separates the ability of expert and novice problem solvers

(*26,29,30,31*). Therefore, any problem solving strategy that is to be effective in developing expert-like ability in students must link an organization process to the main concepts necessary to solve a problem.

Proposed Problem Solving Strategy

The GOAL protocol provides a framework in which to cultivate the research findings presented above. A modified GOAL approach is suggested in which more emphasis is placed on the cognitive connection between concepts and mathematical relationships while less emphasis is placed on the explicit writing of each step deemed unnecessary by students. This shift affects the *Gather* and *Organize* steps of GOAL. By combining the concepts of keyword identification, problem identification (or categorization), and organization, the focus in problem solving is shifted to triggering important relationships between concepts and equations. "Triggers" can be used to initiate the problem solving process.

For this modified approach to GOAL, the trigger is defined as the phrase or relationship that identifies the important concepts for solving a problem. This trigger will serve as the breaking point that allows students to access various patterns associated with solving chemistry problems. These patterns are known as schema (*32*), or chunks (*33*), that exist as recognizable units of conceptual knowledge resulting from repeated exposure to those concepts. This is the most difficult step for students because they do not recognize varying patterns for solving a problem due to a lack of experience (*32*). A meta-analysis/review of studies on problem solving reveals that instruction in this area will help students to become better problem solvers (*34*). By emphasizing the effectual connection of concepts and mathematical procedures, expert-like problem solving ability should be developed and fostered in students.

Implementation

An important issue with which to contend is the fact that students feel that GOAL and other explicit problem solving approaches are too time-consuming. Many students want to advance quickly to the mathematical portion of the problem solving process. Consider a compromise between what is beneficial for the student and what the student actually wants to do. Much of the formal writing involved in following an explicit problem solving approach can be eliminated. Therefore, in accordance with student comments on using the GOAL approach, much of the formal strategy can be converted into mental steps.

Gathering can be accomplished by having students to simply underline or circle keywords and information in the problem statement. It is important for students to complete the gathering portion because cognitive science teaches us that introductory students can handle only 5-7 cognitive tasks at a time (*35*). Therefore it is important for a student to be organized and efficient in their problem solving approach. Marking or writing the given information eliminates the task of juggling multiple facts and values in the working memory.

Once the important information from the problem has been gathered, the trigger can be identified. The trigger is the key word or phrase that will prompt cognitive relationships between chemical concepts and mathematical relationships. Once the students have identified a trigger, they can begin accessing the "rolodex" of equations discussed by Bunce, Gabel and Samuel (*11*). These steps can be done mentally or students may still choose to record the process in writing. Although much of the gathering and organizing can be done mentally students should be encouraged to write all equations that are being used in order to clearly identify how they are categorizing the problem and the mathematical context they intend to use.

The *Analyze* and *Learn* steps would then be very much the same as before with the exception that students will solve for unknowns using substituted values rather than working completely through the problem prior to any mathematical procedures. A check (√) may be incorporated to indicate that students have evaluated their answer and obtained the appropriate units. This would eliminate writing that students might consider unnecessary.

It is recommended that students be required to write out all steps of GOAL during initial stages of instruction in problem solving. This will help students to learn the method and begin developing problem solving patterns. As students become more experienced in using the approach they should be permitted to begin using a more implicit application of GOAL. Follow the steps in the flowchart (Figure 6.1) to see how "trigger theory" could contribute to successful problem solving when implementing a modified GOAL protocol. Compare the trigger/GOAL method to the original GOAL method for *Questions #2, #6, and #9* in Figures 6.2 through 6.4.

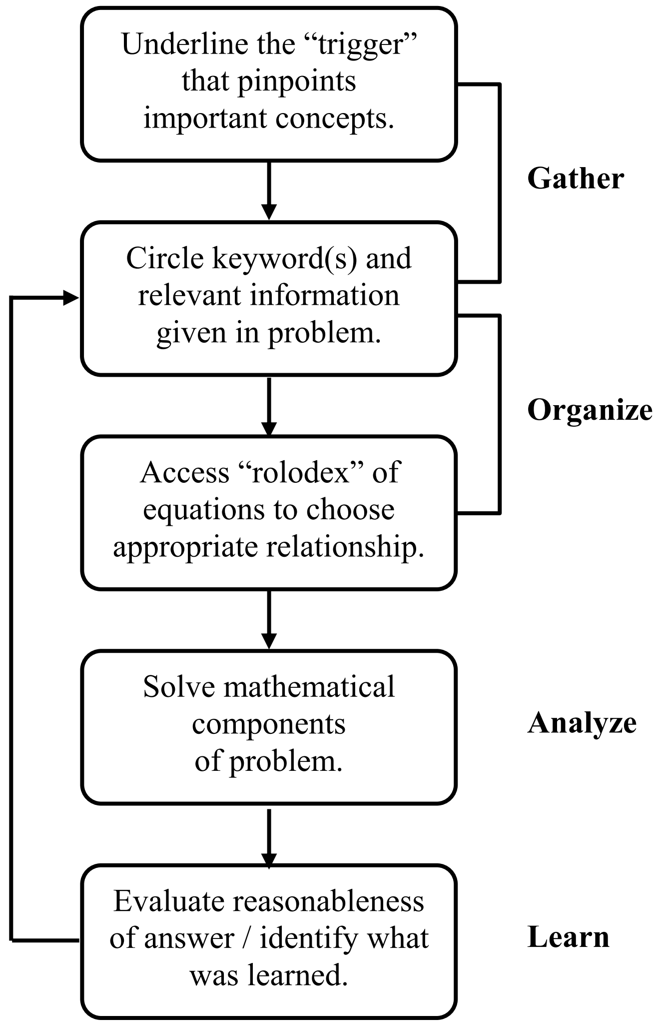

Figure 6.1. GOAL / Trigger Theory Flowchart.

Original GOAL Solution

Vitamin K is involved in normal blood clotting. When 1.00 g of vitamin K is dissolved in 20.0 g of camphor, ($k_f = 40.0^oC/m$) the freezing point of the solution is lowered by 4.43^oC. What is the molar mass of vitamin K?

Gather: 1.00g vitamin K
20.0 g camphor
$k_f = 40.0^oC/m$
$\Delta T = 4.43^oC$
molar mass = ?

Organize: Freezing point depression $\Delta T = imk_f$
solution concentration $\text{molality} = m = \dfrac{\text{moles solute}}{\text{kg solvent}}$

Have the grams of solute and kg of solvent so plug in x for molar mass to convert grams of solute to moles of solute

$$\Delta T = i\,\frac{(\text{grams solute / molar mass})}{\text{kg solvent}}\,k_f$$

$$4.43^oC = (1)\frac{(1.00g / x)}{0.0200\text{ kg}}(40.0^oC/\text{molal})$$

Solve for x.

Analyze: $x = \dfrac{1.00g\ (40.0)\text{ kg}}{4.43\ (0.0200\text{ kg})\text{ mol}} = 451\text{ g/mol}$

Learn: Reasonable answer because units are correct and Vitamin K is probably a large molecule. Molar mass can be determined from freezing point depression.

Trigger GOAL Solution

Vitamin K is involved in normal blood clotting. When 1.00 g of vitamin K is dissolved in 20.0 g of camphor, ($k_f = 40.0^oC/m$) the <u>freezing point of the solution is lowered</u> by 4.43^oC. What is the molar mass of vitamin K?

G: trigger → freezing point is lowered due to solute; Circle given info; find molar mass

F.P. depression and molality

Organize: $\Delta T = imk_f$
$\text{molality} = m = \dfrac{\text{moles solute}}{\text{kg solvent}}$

$4.43^oC = (1)(m)(40.0^oC/\text{molal})$

Analyze: $m = 0.11075\ \dfrac{\text{moles solute}}{\text{kg camphor}}$

$0.11075\ \dfrac{\text{moles}}{\text{kg}} \times 0.0200\text{ kg} = 0.002215\text{ moles}$

have grams of solute; use molar mass to find moles

$\text{molar mass} = \dfrac{1.00g}{0.002215\text{ mol}} = 451\text{ g/mol}$

Learn: √ Molar mass can be determined from freezing point depression.

Figure 6.2. Trigger/GOAL comparison for *Question #2*.

<table>
<tr><th>Original GOAL Solution</th><th>Trigger GOAL Solution</th></tr>
<tr><td>
At 25°C, a 0.100M aqueous solution of the base methylamine (CH_3NH_2) is 6.8% ionized. Calculate the K_b for methylamine.

Gather: 0.100 M CH_3NH_2
6.8% ionized
K_b = ?

Organize: Equilibrium reaction $CH_3NH_2 + H_2O \Leftrightarrow CH_3NH_3^+ + OH^-$
K_b expression $\frac{[CH_3NH_3^+][OH^-]}{[CH_3NH_2]}$

Reaction table $CH_3NH_2 + H_2O \Leftrightarrow CH_3NH_3^+ + OH^-$
I 0.100
Δ - x + x + x
F 0.100 - x x x

At equilibrium CH_3NH_2 is 6.8% ionized
Determine how much has ionized and plug in for x in K_b

Analyze: x = 0.100 (0.068) = 0.0068

$K_b = \frac{(0.0068)(0.0068)}{(0.100 - 0.0068)} = 4.96 \times 10^{-4} = 5.0 \times 10^{-4}$

Learn: Reasonable answer because methylamine is only 6.8% ionized and would therefore expect K_b to be small. K_b can be determine from a percent ionization.
</td><td>
At 25°C, a 0.100 M aqueous solution of the base methylamine (CH_3NH_2) is 6.8% ionized. Calculate the K_b for methylamine.

G: trigger → 6.8% ionized / K_b - equilibrium; Circle given info; find K_b

equilibrium and K_b expression
Organize: $CH_3NH_2 + H_2O \Leftrightarrow CH_3NH_3^+ + OH^-$
I 0.100
Δ - x + x + x
F 0.100 - x x x

$\frac{[CH_3NH_3^+][OH^-]}{[CH_3NH_2]}$

find 6.8% of 0.100 then plug in for x in

Analyze: : x = 0.100 (0.068) = 0.0068

$K_b = \frac{(0.0068)(0.0068)}{(0.100 - 0.0068)} = 4.96 \times 10^{-4} = 5.0 \times 10^{-4}$

Learn: √ K_b can be determine from a percent ionization.
</td></tr>
</table>

Figure 6.3. Trigger/GOAL comparison for *Question #6*.

Original GOAL Solution	Trigger GOAL Solution
The carbon in a sample of wood found in an Egyptian pyramid has an activity of 8.5 grams of carbon per cm^3. Carbon-14 decomposes with first order kinetics. The wood from a recently cut tree has a concentration of 14.9 grams of carbon per cm^3. If the half-life of carbon-14 is 5715 years, how old is the wood from the Egyptian pyramid? Gather: old wood 8.5 g/cm^3 new wood 14.9 g/cm^3 $t_{1/2} = 5715$ age = ? Organize: First order kinetics $\ln [A] = \ln [A_o] - k\,t$ Half-life $t_{1/2} = 0.693 / k$ Use half-life to determine k and then plug in to first order eq'n $k = 0.693 / t_{1/2}$ $\ln [A] = \ln [A_o] - (0.693 / t_{1/2})t$ Solve for t Analyze: $t = \dfrac{\ln [A] - \ln [A_o]}{-(0.693 / t_{1/2})} = \dfrac{\ln (8.5\ g/cm^3) - \ln (14.9\ g/cm^3)}{-(0.693 / 5715\ yrs)}$ t = 4628 years = 4600 years Learn: Reasonable answer because units are correct and Egyptian pyramids are very old. Decay of carbon-14 is first order and can be used to date artifacts.	The carbon in ~~a sample of wood~~ found in an Egyptian pyramid has an activity of 8.5 grams of carbon per cm^3. Carbon-14 decomposes with first order kinetics. The wood from a recently cut tree has a concentration of 14.9 grams of carbon per cm^3. If the half-life of carbon-14 is 5715 years, how old is the wood from the Egyptian pyramid? G: trigger $\rightarrow$ first order kinetics; Circle given info; find age Organize: : $\ln [A] = \ln [A_o] - k\,t$ $t_{1/2} = 0.693 / k$ first order and half-life relationship Analyze: $k = 0.693 / 5715\ yrs = 1.21 \times 10^{-4}$ determine k then plug into equation $\ln [8.5\ g/cm^3] = \ln [14.9\ g/cm^3] - (1.21 \times 10^{-4})\,t$ $t = \dfrac{\ln (8.5\ g/cm^3) - \ln (14.9\ g/cm^3)}{-(1.21 \times 10^{-4})}$ t = 4638 years = 4600 years Learn: √ Decay of carbon-14 is first order and can be used to date artifacts.

Figure 6.4. Trigger/GOAL comparison for *Question #9*.

The steps shown in the Trigger/GOAL protocol more effectively resemble how a student might approach a problem while still involving the gathering and organizational components necessary for successful problem solving. The GOAL approach outlined on the left side of Figures 6.2 through 6.4 requires students to fully plan their solutions before manipulating any equations. This approach does not work well for students due to their lack of experience with solving this type of problem. As a student gains more experience their thought process will begin to resemble that of an “expert”.

As noted previously, students do not adopt explicit protocols for problem solving because, according to students, the protocols are too time-consuming and require too much writing. In this form of GOAL the gather and organize steps are closely associated and streamlined to allow students to spend more time thinking about the relationships in the problem in proportion to time spent writing what some students feel is unnecessary information. Students can also do more of the gathering and organizing mentally. Therefore, since the process is more streamlined, saving time and energy, students may be more inclined to use the modified GOAL method. This method, in turn, will help students to identify “triggers” that will develop important linkages between a problem, concept, equation, and a solution.

Conclusions

The original plan to evaluate GOAL was not possible due to the following reasons: 1) most students did not explicitly use it and 2) the students who do report using the GOAL protocol do not show evidence of it primarily because they use it to do their homework, for which answers are submitted electronically. Therefore, it was not possible to monitor the explicit use of GOAL. However, the extensive collection of student problem solving samples through interviews, journals, quizzes and exams provided substantial insight into the problem solving practices of students. This data was categorized and compiled according to components of the GOAL protocol. Chi-square tests reveal that, although students do not specifically implement the GOAL protocol, there are great advantages to gathering and organizing data to solve a problem.

Based on this analysis, GOAL was modified to specifically appeal to student preference in problem solving methods by eliminating unnecessary writing and placing emphasis on identification of important concepts in the problem. The modified approach involves "triggering" cognitive recognition of the relationships between the problem and chemical concepts learned in class. The steps in the Trigger/GOAL protocol now more effectively resemble how a student might approach a problem while still involving the gathering and organizational components necessary for successful problem solving.

The *Learn* step involves reviewing the solution to a problem, evaluating the reasonableness of an answer, and asking what was learned by solving the problem. However, evidence for the inclusion of a *Learn* step by students was not observed unless specific questions were built into the problem requiring students to evaluate their answers. Therefore, in order to develop meaningful problem solving that fosters the logical application of concepts these statements should be included in the original problem.

6.4 GRAPHING ABILITY

Expert chemists possess the necessary linguistic skills and experience required to coherently construct, describe and relate graphs to chemical principles and concepts (*36*). Students tend to focus only on the surface features of the representation - letters, numbers, and lines - and are less able to interpret chemical concepts from the representations (*37*).

Therefore, the use of graphs in the classroom has little meaning unless students are adequately prepared to understand the representations (*38*).

Several studies have focused on the cognitive abilities that enable students to read and interpret graphs (*39,40,41*), that is, the theory that certain learning aptitudes are required to comprehend graphs. However, Roth et al. have suggested that deficiencies in graph construction and interpretation could be overcome by "increasing participation in purposeful and competent graphing practices" (*42,43*). They have reported that the social practice of allowing a novice to interact with peers and with experts will develop the necessary understanding that the novice needs in order to fully participate in a given practice (*44,45,46*). Therefore, the implications for a chemistry curriculum include the demand for a more purposeful implementation of construction, description, and relation of graphs.

As some researchers have noted, much of the research on graphing skills has focused on the K-12 student population (*47,48,49*). Although, many examples of graphical approaches to learning and analyzing chemical phenomena have been reported (*50*), extensive research on the graphing skills of college chemistry students has not been conducted. In this portion of the cAcL$_2$ study, the graphing ability of students is considered.

Design

Graphing skills of students in the fall 2002 (CH201) cAcL$_2$ section were observed throughout the course of the semester. No specific guidance in constructing graphs was given to students. Instructors gave help only when students sought assistance. The data collected were used to determine the skills that students already possessed and then developed over the course of the semester.

Data on graphing skills were collected during four interviews and through two separate homework assignments over the course of the semester. During the interviews students graphed data using Microsoft Excel. During the first two interviews students also generated graphs manually with pen and paper. Copies of student work were kept for purposes of this study. A timeline for all data collection is given in Table 6.2 in the Assessment Methods section.

Goals

- To observe student ability in constructing graphs, incorporating specific components, and monitor these skills over the course of the semester.
- To evaluate student perception of their graphing abilities over the course of the semester.
- To summarize and interpret results and suggest relevant implications for chemical education.

Sample Collection

Interview #1 (referred to as #1)

The first interview was conducted the second week of class during a pre-testing session. Students were asked to graph a set of data both by hand (manual) and using computer software, more specifically, Excel. Students were then asked to respond to a few questions about the graphs. The students were also given a separate file for another Excel graph and asked to insert a best-fit line and equation and perform various editing tasks using the program. The artificial set of data provided to students to graph during Interview #1 is given in Table 6.7 in its original format.

Table 6.7. Graphing Assignment for Interview #1.

Assignment: Construct a formal graph of the following data and hand in when you have completed it.								
Time (s)	1	2	3	4	5	6	7	8
Temperature (^oC)	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0

This artificial data set was constructed to represent a simple linear relationship between two variables, since students had not yet covered material that would require graphing. Therefore, this data set was used to measure baseline graphing construction skills.

Interview #2 (referred to as #2)

The graphing tasks performed during the second interview paralleled those of Interview #1. Students generated a manual graph, an Excel graph, edited a separate Excel graph and responded to questions about the graphs. Students also answered questions asking them to assess their graphing abilities. Table 6.8 shows the artificial data provided to students to graph. The topic of equilibrium was covered prior to this interview and students were exposed to concentration vs. time graphs in class.

Table 6.8. Graphing Assignment for Interview #2.

Assignment: Construct a formal graph of the following data with the graph paper provided.

Time (s)	**[Cu^{2+}] mol/L**
0	24
1	12
2	9
3	8
4	8
5	8

Interview #3 (referred to as #3)

During interview #3 students were not asked to generate a manual graph because all students were able to construct some sort of graph by hand. Therefore, students were only asked to construct graphs using Excel and to edit separate graphs already constructed using

Excel. Students also responded to questions about the graphs and again assessed their graphing abilities. Prior to this interview students had completed an activity on titrations in which they constructed titration curves during a group activity. The artificial titration data in Table 6.9 was given to students to graph during the interview.

Table 6.9. Artificial Data and Graphing Assignment for Interview #3.

Assignment: 0.8 *M* NaOH was used to titrate a 15-mL sample of a weak monoprotic acid. The data are given below. Construct a formal graph of the following data in Excel.	
Volume (mL)	**pH**
0	3.27
2	4.09
6	4.69
8	4.92
12	5.55
14	7.64
16	11.65
20	12.12
22	12.22

Interview #4 (referred to as #4)

Interview #4 followed the same format as interview #3. During this interview students were asked to graph artificial rate data already manipulated to produce a linear relationship. They had previously covered integrated rate laws in class and constructed the corresponding graphs. Data were collected using the same procedures as previous interviews. It was observed that all previous data that had been given to students to graph in previous interviews was given in order of the variable that should go on the x-axis and then the y-axis. Therefore, the order of the variables in the artificial data in Table 6.10 was reversed to specifically examine whether students consciously choose appropriate axes designations based on the dependent and independent variables.

Table 6.10. Graphing Assignment for Interview #4.

Assignment: Construct a formal graph of the following data.	
1 / [C_4H_6]	**Time (s)**
100.0	0
160.0	1000
210.1	1800
270.3	2800
319.5	3600
370.4	4400
414.9	5200
480.8	6200

Homework

The nature of the interviews allowed the graphing procedures to be monitored directly, but two other samples were collected in addition to the interview samples. The two other samples were gathered from student homework assignments that required the graphing of data collected during a lab activity. Students were required to use a computer to generate the graphs. The first assignment was to graph three sets of titration data collected during a group titration activity. Students were asked to construct graphs for each titration (strong acid/strong base, strong base/strong acid, weak acid/strong base) as a group and submit them via email. The second assignment was a graph of E_{cell} vs Log Q. Students were given the option to use any available graphing software for this assignment. The data for this graph were collected during a lab that was used to introduce the Nernst equation. These two homework samples were graded graphing assignments. It is possible that students may perform differently on graded work than on the interview work.

Results and Interpretations

The total enrollment of the class was 45 students; however, participation in data collection varies with each sample. For instance, a total of 39 samples were collected from the students during interview #1 and only 21 during interview #3. (Refer to the first section in this chapter for how students were selected for interviews.) Due to technical difficulties experienced during the first interview, only 8-10 computer-generated samples were collected (some graphed the data, some submitted only the editing file, and others did both). The sample size for computer-generated graphs for interview #1 is considered small; however, it is included in the discussion below in order to show all results obtained. Table 6.11 details the number of students providing samples.

Table 6.11. # of Students Represented in Data Collection Samples.

Sample	**# of Students Participating**
#1 manual	39
#1 computer	8-10
#2 manual	16
#2 computer	16
#3 computer	21
#4 computer	17
Titration	15*
E_{cell} vs. Log Q	17

*Titration assignment was completed in groups not by individual students.

In order to appropriately interpret observations on graphing it is necessary to know how many students were able to submit a graph, even if incorrect, vs. no graph at all. For instance, it was observed whether or not students included a title on their graphs. If students could not generate a graph then obviously they included no title. All students were able to generate some sort of manual graph. Students encountered more problems when using software to generate a graph. Percentages of students able to generate a graph using Excel, even if incorrect, are given in the table below. The first interview is not included because only students that got a graph submitted it and some students that did get a graph may have had trouble submitting it electronically. Homework is not included because it could only be submitted if students were successful with generating the plots; therefore, all students submitting a homework assignment were able to generate some sort of graph. As Table 6.12 shows, most students were able to create some sort of graph using Excel.

Table 6.12. Students Able to Create a Graph in Excel even if Incorrect.

Sample	**Students Creating Graphs using Excel (%)**
#2 computer	93.8
#3 computer	90.5
#4 computer	94.1

Several physical characteristics of a scientific plot were considered: scaling, title, labels, axis choice, and units. Characteristics of graphs constructed using computer software also include these components as well as type of plot, best-fit line and equation generation, and editing abilities. A discussion of the observations for each characteristic is presented below with interpretations denoted by bullets.

Scaling

When evaluating the scaling component of the students' graphs, the ranges of both axes were considered. Did students adequately scale both axes so that the data would fill the plot area? The scaling component is only an issue on manual graphs because most computer software scales graphs automatically. The results observed in the manual graphs collected in sample #1 and #2 are given below.

Table 6.13. Observations of Appropriate Scaling Characteristics.

Sample	**Appropriate Scaling (%)**
#1 manual	46.1
#2 manual	12.5

- The data indicate that most students did not appropriately scale their graphs.

Title

The inclusion of a title was evaluated based on two factors. First, was any title at all included on the graph? Secondly, did students use a Y vs. X descriptive title or the reverse, X vs. Y title? Student graphs were evaluated and the results are presented in Table 6.14.

Table 6.14. Observations of Title Characteristics.

Sample	**Any title given (%)**	**Y vs. X format (%)**	**Reversed Title (%)**
#1 manual	10.3	2.6	-
#1 computer	50.0	12.5	12.5
#2 manual	31.3	25.0	-
#2 computer	56.3	31.3	6.3
#3 computer	52.4	14.3	4.8
#4 computer	64.7	23.5	5.9
Titration HW	93.3	20.0	-
E_{cell} vs. Log Q HW	94.1	52.9	17.6

Most students did not include any title on the manual graphs and very few used a Y vs. X descriptive title for any of the graphs. More students included a title on the computer-generated graphs. There were four occurrences in which a student entitled their graph using an X vs.Y format. Three of the occurrences were the same student.

The titration assignment required the graphing of three sets of data collected during different titrations (a group assignment). Each group constructed their three graphs using a consistent format, therefore, the three graphs were considered as only one sample for each group. As seen in the data above, most groups included a title (93.3%). The title is very important in this sample because the three graphs were of different titrations. When presenting multiple graphs of similar data, the graphs should be distinguishable. For this assignment, 66.7% provided titles that distinguished between the three graphs. Only one group distinguished between the graphs using a Y vs. X format. Most of the students submitting the E_{cell} vs. Log Q assignment also included a title (94.1%). This title, in Y vs. X format, was explicitly stated when the assignment was given, although, only 52.9% chose to use it as the title and 17.6% had a reversed format.

- More students included a title on the computer-generated graphs. This may be attributed to automatic features of computer software that ask for, but do not require, a title.
- Students do not typically use the Y vs. X convention when naming a graph. Other students think the convention is X vs. Y, which could cause confusion when trying to present or interpret a plot.
- More students included a title when the graphs were collected for a grade as part of the class. Students were not graded on interview graphs #1 - 4 and therefore, may have been less meticulous in the construction of the graphs both by hand and using computer software.

Choice of Axes

When choosing how to graph a set of data it is standard convention to place the independent variable on the x-axis. Interviews #1, #2, and #4 involved time while #3 involved addition of volume increments during a titration. The data are presented in Table 6.15.

Table 6.15. Observations Conventional Axes Choice.

Sample	Conventional Choice (%)
#1 manual	92.3
#1 computer	90.0
#2 manual	81.3
#2 computer	93.8
#3 computer	81.0
#4 computer	41.2
Titration	100.0
E_{cell} vs. Log Q	70.6

Most students make the appropriate choice for placement of the data. For interviews #1-3 the data was given in the order x then y. When the order of the given data was reversed in #4, 41.2% of the 17-student sample chose to place time on the x-axis. As for the homework assignments, all students used the conventional pH vs volume format for the titration assignment. Most students correctly plotted the E_{cell} vs Log Q data on the appropriate axes (70.6%). One student intended to graph it correctly, as noted by the labels, but the data was reversed. Four other students reversed the order of the axes, two of which used E_{cell} vs Log Q as the title.

- Even though most students choose axes appropriately, some students may not intentionally choose their axes when using computer software. Graphing conventions vary from program to program and students may not fully understand how the software uses the data that has been placed into a spreadsheet.
- In interviews #1-3 the data was given in the order that it should be placed in Excel for appropriate graphing, so students just had to type it in as given. This order was intentionally reversed for #4, and, as the data shows, only 41.2% chose to place time on the x-axis. That is, more than half of the students did not consciously choose axes designations. They just plotted the given data.
- In a similar fashion, students are generally familiar with the shape of a titration curve and would quickly notice if they had graphed it incorrectly, thus explaining the 100% appropriate choice of axes for the titration assignment.

Labels

Axis labels are important in clarifying how data has been graphed. The data below distinguishes between students that labeled both axes, only labeled one axis, those students that reversed their labels with respect to the data graphed, and those that included no labels at all.

Table 6.16. Observations of Label Characteristics.

Sample	**X and Y labels (%)**	**One axis only (%)**	**Reversed Labels (%)**	**No Labels (%)**
#1 manual	71.8	2.6	-	25.6
#1 computer	50.0	10.0	-	40.0
#2 manual	81.3	6.3	-	12.4
#2 computer	68.8	6.3	-	24.9
#3 computer	66.7	-	9.5	33.3
#4 computer	70.6	-	5.9	29.4
Titration	93.3	-	-	6.7
E_{cell} vs Log Q	100	-	5.9	-

In most cases students correctly provided axes labels. However, it seems that labels were more commonly found on the manual graphs than on the computer graphs. Excel has a chart wizard that helps to create various graphs. The wizard asks for a title and x and y labels; however, it was observed, during interviews, that many students skip the step of filling in requested axes label information when using the computer. As found for the title component, more students included axes labels for the graded assignments.

- Labels were placed with the correct axis more frequently when graphing by hand.
- Students may have been less meticulous in the construction of graphs #1-4 than in graded homework.

Units

Units define the relevancy and extent of relationships illustrated through graphical representation. Without units the plotted values are meaningless. Table 6.17 describes how often students included units on their graphs.

Table 6.17. Observations of Unit Inclusion Characteristics.

Sample	X and Y Units (%)	Units One Axis Only (%)
#1 manual	66.7	7.7
#1 computer	40.0	10.0
#2 manual	81.3	6.3
#2 computer	68.8	6.3
#3 computer	23.8	-
#4 computer	52.9	5.9
Titration	N/A	93.3
E_{cell} vs Log Q	N/A	41.2

The data show variability in students' use of units. There is no speculation as to why students include or do not include units. The two homework assignments required units on only one axis because pH and Log Q are unitless quantities. The titration assignment is much higher in presence of units than any other sample.

- The data show that students are more likely to include axis labels than units. In the case of the titration assignment the unit of measure was typically used for the axis label. Students performed the titrations by drops and therefore the units would be drops. In every instance that students included an x-axis label, it was denoted in some variation as "# of drops". However, they do not indicate what substance is being measured in drops. Only 7 groups (46.7%) indicated what substance had been added during the titration.

XY-Scatter

When using computer software to graph scientific data, a scatter type plot is preferred. Many programs offer various types of graphs (bar, line, pie, scatter, etc). The type of graph that students choose to use affects the display of their data. Consider the observations in Table 6.18 below. Note that the homework assignments are not included in this discussion because direct observations could not be made on how students graphed the data.

Table 6.18. Observations on the Use of XY-Scatter in Excel.

Sample	Used xy-scatter (%)	Observations
#1 computer	30.0	5 students correctly used line type, while 2 students chose to use bar graph.
#2 computer	75.0	3 students that used line type correctly for #1 could not generate a proper graph for #2 or #3.
#3 computer	42.9	7 students tried used line type incorrectly, 1 student used line type appropriately but labeled data inaccurately for x-axis
#4 computer	88.2	1 student correctly used scatter twice previously, but could not get a graph for #4

Many students could not construct an accurate plot because they attempted to use the line plot option instead of scatter plot. A line plot, in Excel, automatically plots the data columns as lines with the x-axis points as 1, 2, 3, 4, 5, etc. Sample plots for the data given for interview #3 are in Figure 6.5 below using both scatter type and line type.

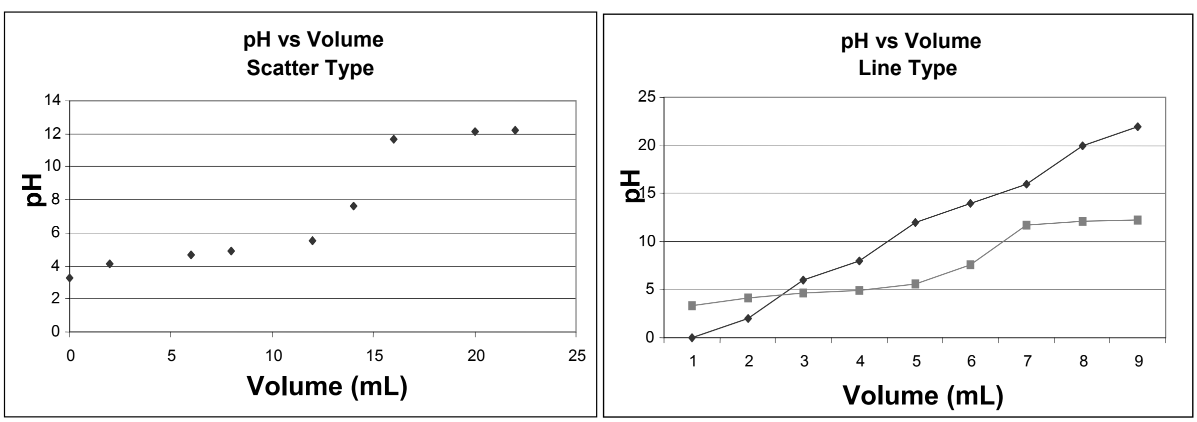

Figure 6.5. Difference between xy-scatter and line type graph functions in Excel.

The same spreadsheet data were used to construct both graphs. Notice the x-axis on the line type graph (1, 2, 3, 4, 5…). Instead of plotting the two columns as nine (x, y) points, both columns are plotted separately against points 1-9. Many students constructed line plots resembling the one in Figure 6.5. It was observed during the interview that students tried deleting the top line, which yields a graph that resembles a typical titration curve; however, this does not correct the problem with the x-axis. Although, it is possible to use the line type plot to get an appropriate graph, it is much more complex and involves changing many parameters. Computer-generated graph samples were collected from a total of 41 students over the course of the semester. Out of 39 students interviewed, at least 18 (46.2%) encountered problems with trying to use the line type graph, rather than an xy-scatter, at some point during an interview.

- Line-type versus scatter-type is the major problem that students encountered when using Excel to construct graphs. This may only be a problem specific to using Excel. However, this issue and similar ones for other programs should be pointed out to students.

Best-Fit Line

Scientists typically look for linearity when analyzing relationships because a straight line is the simplest form of graphical representation. The linearity of many relationships has been exploited to study numerous chemical phenomena like gas behavior (ideal gas law), absorbance and concentration (Beer's Law), and kinetics (integrated rate laws). Therefore, generating best-fit lines and equations of the lines are important skills in chemistry. Best-fit lines and equations are easily found using most graphing software packages as well as spreadsheet programs like Excel. During the interviews students were asked to use Excel to generate lines and equations for model graphs that had obvious linear relationships. The results are reported in table 6.19.

Table 6.19. Observations on Generating Lines and Equations using Excel.

Sample	Line & Equation (%)	Line only (%)
#1 computer	30.0	-
#2 computer	50.0	12.5
#3 computer	23.8	-
#4 computer	52.9	-

- Some students were able to use Excel to determine an equation of the line, but no trend is observed in the data.

Editing

Formatting a computer-generated graph may be required to clarify or highlight certain features of the graph or to comply with specific requirements for publication in scientific literature. In order to observe this "editing" ability, students were asked to perform editing tasks on model graphs. The tasks included changing the title, adjusting the format of the scale for the y-axis, and changing the color of the plot area. The results are presented in Table 6.20 below.

Table 6.20. Observations of Editing Ability in Excel.

Sample	Edited Title %	Edit Plot Area %	Edited Scale Appropriately %
#1 computer	100	90.0	20.0
#2 computer	100	93.8	43.8
#3 computer	95.2	85.7	76.2
#4 computer	94.1	82.4	70.6

Almost all students were able to edit the titles of the graphs. Most students also had success in changing the color of the plot area. Some students encountered trouble because they changed the color corresponding to the border of the plot rather than the plot area, but the problem was usually corrected quickly by the student. The numbers dropped considerably for formatting the scale on the y-axis. In observing the ability of students to edit graphs in Excel it was found that many students used a seek-and-click method. Three observations relating to this seek-and-click method are given below.

I. Even if students did not specifically know how to perform an editing task, they would keep searching until they found it. For most students the seek-and-click method generally took very little time. A few students attempted for several minutes and were still unsuccessful.

II. The seek-and click method works well for formatting the title and the plot area. The title of a graph is easily formatted in Excel because it can be accomplished simply by clicking on the title as well as through other methods. Changing the color of the plot area is also easily accomplished because students can either double-click on the plot area or use right-click options (on a PC) to access the color pallet.

III. The seek-and-click method works to find the screen for formatting the scale of the y-axis, but many students did not know what parameters to change to get the desired effect. Some understanding of the various parameters is required.

Discussion

Out of the 39 students that submitted a manual graph for interview #1, 37 (94.9%) obtained an accurate plot of the points even if all the components of the graph were not fully correct. This is consistent with student perceptions observed in interview #2. See the summary of student responses in table 6.21. These perceptions change over the course of the semester as students gain more graphing experience.

Table 6.21. Student Responses to Questions about Graphing Abilities

Interview	Question	Yes (%)	Somewhat (%)	No (%)
#2 (n = 16)	Can you graph a set of data?	100	0	0
	Can you read and interpret graphs well?	100	0	0
	Can you graph in Excel?	63	31	6
#3 (n = 21)	Has your graphing ability improved as a result of taking this class? *	0	5	90
	Has your ability to read and interpret graphs improved?	19	5	76
	Has this class helped you feel more comfortable using Excel?	29	9	62
#4 (n = 17)	Has your graphing ability improved as a result of taking this class?	41	18	41
	Has your ability to read and interpret graphs improved?	35	6	59
	Has this class helped you feel more comfortable using Excel?	59	23	18

* The other 5% could not make any judgement.

At the beginning of the semester, students felt they could graph a set of data as well as read and interpret graphs. A majority of students also felt they could graph in Excel, although, student samples show that many students did not pay close attention to detailed labeling and some encountered trouble in using Excel to generate graphs. However, students did seem to pay closer attention to detail on graphs turned in for a grade. It is interesting to note the changes that took place over the course of the semester. Although 100% of the students interviewed at the beginning of the semester felt confident in their graphing abilities, interview #4 reveals that 59% of students perceive that taking the $cAcL_2$ class improved their graphing ability (yes + somewhat responses) and 82% felt the class increased their comfort level in using Excel (yes + somewhat responses).

These results are consistent with post-survey responses. Out of a total enrollment of 45 students, 43 students completed the survey and of those 43, 51.2 % agreed that the course gave them more confidence in preparing graphs. Only the responses of the 36 students that completed both surveys were compared in measuring anxiety levels. As measured on the pre- and post-surveys it was found that 38.9% of the students showed a decrease in level of stress in reading and interpreting graphs or charts that show the results of chemistry experiments. 22.2% had no anxiety to begin with and continued to show no anxiety at the end of the semester. 13.9% did not change in level of anxiety and the remaining 25% increased in level of anxiety by one or two points.

As previously stated, no specific instruction was given on graphical representation. Graphing was implemented intermittently for most of the semester. In fact, only three graphs were required during classroom activities prior to the end of the semester when kinetics was covered. The kinetics unit provided numerous opportunities for students to implement graphing. This unit was covered between Interviews #3 and #4 and graphing was done exclusively with Excel during class. At this time many students sought help either from instructors outside of class or obtained help from group members during class. As seen in the data above, students felt more capable of constructing and interpreting graphs after having more experience using them in class. This was especially true for using Excel to construct graphs. This observation comes as no surprise because students learn and develop skills as they gain more experience.

Conclusions and Implications

Students initially showed varying skill levels in constructing graphs and including important components. However, skill levels improved just by requiring students to construct and use graphs for class. Therefore, the incorporation of a graphing skills component in a general chemistry curriculum is expected to improve graphing skill and confidence levels among students. A systematic implementation of the recommendations listed below is suggested in introducing graphing to students. Once graphing has been carefully and purposefully incorporated into the curriculum a valid assessment will be necessary to show the full effect of the integration.

- Briefly introduce each component of a graph either through in-class instruction, on-line tutorials, or handouts that provide sample graphs with labeled components. Software of choice can be used as the medium.
- Discuss the importance of more subtle points in graphing such as scale, choice of axes, and identification of units.

Graphing applications should be incorporated as frequently as the material permits in order to make graphing a common tool used by students in the class. Discussion of graphs by both instructor and students should be integrated into class time. It is not suggested that great amounts of class time be spent on graphing instruction; if the conscious effort is made to include it, students will develop valuable skills.

6.5 STUDENT ATTITUDES

The importance of attitudinal data was discussed in the attitudinal section (5.4) of the quantitative study presented previously. The same elements regarding attitudes toward learning and the prevalence of chemistry anxiety were evaluated for the $cAcL_2$ CH201 class. An additional set of questions monitored student perception of the $cAcL_2$ format. More specific attitudes toward cooperative grouping and the structure of $cAcL_2$ were obtained from interviews and reflective journals.

Instruments

Pre- and post-surveys were administered electronically to students during the first and last two weeks of classes. The CH101 surveys were modified (see Appendix C) to include a total of 18 questions to measure student attitudes about learning in general, 5 questions to indicate how $cAcL_2$ affected student interest in science, and 14 questions to gather information on student perceptions of $cAcL_2$. A total of 25 questions were given to measure student anxiety levels for chemistry. These 25 questions are the same as those given to students during the CH101 quantitative study (Appendix C). Results for each question are included and discussed.

Reliability coefficients (Cronbach alpha values) are again computed to confirm internal consistency of the survey questions in the qualitative CH201 study. Cronbach alpha is also reported for the 14 additional questions pertaining to student perception of $cAcL_2$. A t-test was used to compare pre- and post-survey responses. Net changes for each question (Δ = post - pre) are reported to indicate an overall increase or decrease in student averages. The t-tests indicate whether or not those changes are considered significant at an $\alpha = 0.05$ significance level.

During this qualitative study interviews and journal entries served as additional forums through which to collect data on student attitudes toward group work and the structure of $cAcL_2$. Information gathered from interviews and journals are discussed qualitatively.

Sample

A total of 38 students filled out the pre-survey and 43 students filled out the post-survey. Only those students filling out both a pre- and post-survey were considered in pre/post comparisons (36 students) where t-tests were used. All responses on post-surveys were considered when analyzing course specific questions found only on the post survey. All 39 students participating in interviews and the forty-two providing journal entries were included in the qualitative discussion.

Results and Discussion

Reliability of Surveys

Values for Cronbach alpha are reported in Table 6.22. These values indicate that the questions for each part of the survey are consistent in measuring a specific factor. The values are comparable to values reported previously in Section 5.4. Therefore, these surveys are considered valid tools.

Table 6.22. Internal Consistency of Survey Questions given in CH201.

Rating (# of questions)	**Cronbach alpha**	
	Pre-Survey	Post-Survey
Derived Chemistry Anxiety Rating Scale (25)	0.92	0.93
Factor 1, Learning-Chemistry Anxiety (10)	0.89	0.93
Factor 2, Chemistry-Evaluation Anxiety (6)	0.87	0.81
Factor 3, Handling-Chemicals Anxiety (9)	0.84	0.89
Learning Attitudes (18)	0.75	0.81
Student Perceptions of $cAcL_2$ (14)	--	0.87

Learning Attitude

Students were asked a series of questions pertaining to attitudes about learning. The questions are given in Table 6.23. Higher values represent more positive attitudes. Therefore, positive net changes are viewed favorably. Net changes in average for each question are also reported (Δ = post - pre). A t-test was used to indicate significant differences between pre- and post-survey averages. Significant changes ($p < 0.05$) are indicated by an asterisk (*) in the net change column (Δ).

Table 6.23. Attitudes Toward Learning - Averages (standard deviations).

	Pre	Post	Δ
It is important to me that a course provide time for discussing ideas.	3.94 (0.92)	4.33 (0.59)	0.39*
I like courses that encourage me to discover some of the ideas for myself.	3.83 (0.91)	3.75 (0.84)	-0.08
I prefer problems that are open-ended to problems that have one right answer.	3.00 (0.93)	2.92 (1.05)	-0.08
I value being able to apply chemistry ideas to everyday situations.	3.97 (0.70)	3.94 (0.83)	-0.03
I learn well by ...			
doing homework assignments.	3.94 (0.83)	3.92 (0.94)	-0.03
using diagrams and other visual media.	4.17 (0.77)	3.50 (0.88)	-0.67*
using computer-based materials.	3.42 (1.00)	3.44 (0.94)	0.03
reading a (good) textbook.	3.56 (1.05)	3.67 (0.93)	0.11
doing hands-on activities.	4.39 (0.69)	3.97 (0.88)	-0.42*
listening to lecture.	3.72 (0.85)	3.81 (0.75)	0.08
explaining concepts to others.	4.00 (0.99)	4.11 (0.82)	0.11
doing in-class exercises.	3.94 (0.83)	3.81 (1.01)	-0.14
working in a group.	3.53 (0.94)	3.56 (1.05)	0.03
I know I understand when…			
I can work problems in the book.	3.83 (0.82)	3.83 (0.70)	0.00
I can apply ideas to new situations.	4.37 (0.73)	4.06 (0.79)	-0.32*
I get a good grade on an exam.	3.92 (0.73)	4.08 (0.87)	0.17
I can explain the ideas to someone else.	4.47 (0.65)	4.47 (0.65)	0.00
I can see how concepts relate to one another.	4.28 (0.57)	4.31 (0.62)	0.03

*Significant result indicated by $p < 0.05$.

These results reveal eight positive changes in student attitudes toward learning (only one significant), eight negative changes (three significant), and two with no net change ($\Delta = 0$). The only significant positive change observed was for “it is important to me that a course provide time for discussing ideas”. Although all other positive changes were not significant, information gathered from interviews and journals is quite revealing. In regards to “working in a group”, 41% of the students interviewed at the end of the semester (interview #4) indicated that it helped them learn, 71% indicated that they liked working in a group, and 67% of the students mentioned group work when responding in their journals to the question "How does the structure of this class benefit your chemistry learning experience?" This was the number one cited benefit of $cAcL_2$ by the students. During interviews students admitted to having negative perceptions of group work prior to taking the $cAcL_2$ class, but that $cAcL_2$ helped them realize that group work can be beneficial to their learning. Therefore, the structure of $cAcL_2$ significantly improved student attitudes toward group work and related activities.

The students in this section of $cAcL_2$ showed a significant decline in attitude toward "using diagrams and other visual media", "doing hands-on activities", and "applying ideas to new situations". Using diagrams and other visual media may encompass many areas: graphs and charts, computer simulations and animations, transparencies, etc. Therefore, it is not clear exactly what the students are evaluating. This question should be clarified in future studies.

Activities in $cAcL_2$ were used to introduce concepts to students in a discovery-based, hands-on format. Although the survey data does not indicate a positive response towards activities, the interviews and journals reveal contradictory results. When asked "How does the structure of this class benefit your chemistry learning experience?" 36% of students specifically mentioned, in their journals, that the activities were a benefit to their chemistry learning experience. During interview #4, 71% of the students interviewed gave an overwhelming positive response to the question "Do you like the use of hands-on activities in this class?" Students indicated that the activities allow them to apply the material and see and grasp what they are learning. Only two students out of the 17 interviewed, felt that the activities did not contribute to their learning.

It comes as no surprise that the survey data contradicts the information gathered from journals and interviews. Students generally give low scores to new instructional approaches in which they are required to become more responsible for their own learning (*51*). Therefore, it is important to triangulate the data from surveys, journals, and interviews in order to develop a full picture of student attitudes about $cAcL_2$.

Chemistry Anxiety

Changes in student anxiety levels were monitored using pre- and post-surveys. Table 6.24 includes the averages, standard deviation, and net change (Δ = post - pre) for each anxiety question on the pre- and post-surveys. Questions corresponded to three areas: learning-chemistry, chemistry-evaluation, and chemical handling. A negative net change indicates a decrease in average anxiety, while a positive net change indicates an increase in average anxiety.

A t-test was used to compare pre and post anxiety levels of students in the CH201 $cAcL_2$ class. A significant difference is indicated at the $\alpha = 0.05$ level ($p < 0.05$). Significant changes over the course of the semester are indicated in Table 6.24 by an asterisk (*).

Table 6.24. Chemistry Anxiety for CH201.

Learning-Chemistry	Pre	Post	Δ
Signing up for a chemistry course	2.17 (1.40)	1.97 (0.97)	-0.20
Reading the word "chemistry".	1.63 (1.09)	1.58 (1.05)	-0.05
Walking into a chemistry class.	2.00 (1.12)	1.94 (0.98)	-0.06
Looking through the pages in a chemistry text.	2.33 (1.26)	2.14 (0.97)	-0.19
Reading a formula in chemistry.	2.08 (0.97)	2.25 (1.16)	0.17
Picking up a chemistry textbook to begin working on a homework assignment	2.19 (0.89)	2.33 (1.10)	0.14
Having to use the tables in a chemistry book.	1.83 (1.00)	1.92 (0.94)	0.08
Reading and interpreting graphs or charts that show the results of chemistry experiments.	2.08 (1.11)	1.97 (1.03)	-0.11
Listening to another student explain a chemical reaction.	1.89 (0.82)	1.94 (0.92)	0.06
Listening to a lecture in a chemistry class.	1.78 (0.87)	2.14 (1.07)	0.36*
Total Learning-Chemistry Score	**19.94 (7.59)**	**20.17 (7.86)**	**0.23**

Chemistry Evaluation			
Working on an abstract chemistry problem, such as "If x = grams of hydrogen and y = total grams of water produced, calculate the number of grams of oxygen that reacted with the hydrogen.	2.40 (1.03)	2.19 (1.06)	-0.21
Waiting to get a chemistry test returned.	2.92 (1.11)	3.06 (1.24)	0.14
Taking a test or examination in a chemistry class.	3.39 (1.10)	3.53 (1.25)	0.14
Being given a homework assignment that is due the next chemistry class.	2.75 (1.18)	2.64 (1.07)	-0.11
Thinking about a chemistry test one day before.	3.42 (1.16)	3.47 (1.13)	0.06
Taking a final in chemistry.	4.00 (1.12)	3.78 (1.29)	-0.22
Total Chemistry Evaluation Score	**18.83 (5.30)**	**18.67 (4.99)**	**-0.16**

*Significant result indicated by $p < 0.05$.

Table 6.24 continued

Chemical Handling			
Walking into a chemistry laboratory.	1.67 (0.89)	1.78 (0.87)	0.11
Spilling a chemical.	2.64 (1.15)	2.11 (1.14)	-0.53*
Listening to another student describe an accident in the chemistry lab.	1.67 (0.93)	1.58 (0.77)	-0.08
Being told how to handle the chemicals for the laboratory experiment.	1.42 (0.69)	1.33 (0.68)	-0.08
Working with acids in the lab.	1.78 (1.05)	1.72 (0.74)	-0.06
Getting chemicals on your hands during the experiment.	2.50 (1.03)	2.31 (1.12)	-0.19
Working with a chemical whose identity you don't know.	2.63 (1.29)	2.06 (1.19)	-0.57*
Mixing chemical reagents in the laboratory.	1.94 (0.94)	1.67 (0.83)	-0.28
Heating a chemical in the Bunsen Burner flame.	1.57 (0.74)	1.71 (0.80)	0.13
Total Chemical Handling Score	**17.72 (5.90)**	**16.22 (5.95)**	**-1.50**
Total Anxiety Score	**40.50 (15.56)**	**55.06 (13.62)**	**14.56**

*Significant result indicated by $p < 0.05$.

There were no significant decreases in anxiety observed for the learning chemistry factor. However, there was a significant increase observed for “listening to a lecture in a chemistry class”. This increase in anxiety could be viewed positively in light of $cAcL_2$ teaching methods. Lecturing is a teacher-centered approach that does not actively involve students in the learning process. In $cAcL_2$, a student-centered approach is taken in which students actively participate in the learning process.

No significant decreases or increases in anxiety were observed for the chemistry evaluation factor. Therefore, the $cAcL_2$ course structure did not decrease previously existing student anxiety towards chemistry evaluation nor did it increase student anxiety in this area. These results are also consistent with those observed for the CH101 $cAcL_2$ class.

Decreases in chemical handling anxiety were observed for 7 out of 9 questions, two of which were significant decreases: “spilling a chemical” and “working with a chemical whose identity you don't know”. This can be attributed to the fact that students gain experience working with chemicals during class. However, students would also gain this same experience during a traditional laboratory class. The data may be interpreted as evidence of comparable instruction in chemical use and handling in $cAcL_2$, just as in traditional laboratory sections.

Student anxiety scores were also grouped by major (engineering/physical science, biological, other) in order to determine whether the anxiety of various groups differed. Figure 6.6 shows the break down of majors for students completing the pre- and post surveys. The averages according to major are reported in Table 6.25.

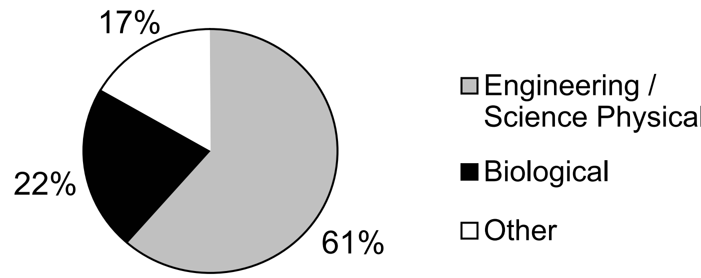

Figure 6.6. CH201 Students Grouped by Academic Majors.

Table 6.25. Chemistry Anxiety Ratings by Majors for CH201.

Rating	Pre-Survey			Post-Survey		
	P	**B**	**O**	**P**	**B**	**O**
Derived Chemistry Anxiety Rating Scale	2.12	1.06	3.09	2.13	2.19	2.51*
Factor 1, Learning-Chemistry Anxiety	1.90	1.73	2.73	1.95	2.01*	2.28*
Factor 2, Chemistry-Evaluation Anxiety	2.96	2.96	4.08	2.95	3.40*	3.33*
Factor 3, Handling-Chemicals Anxiety	1.81	1.85	2.81	1.78*	1.58*	2.20*

P = Physical/Engineering Science, B = Biological Sciences, O = Other majors
* Significant result indicated by $p < 0.05$.

These results show an extremely varied anxiety response in the different majors. The engineering/physical science majors show a significant decrease in chemical handling anxiety and no significant differences for chemistry learning and chemistry evaluation. A significant increase in chemistry learning and chemical evaluation anxiety was observed for biological science majors, while a significant decrease in the chemical handling anxiety was observed. The only group with an overall significant decrease in anxiety was the group of majors combined under "other". A significant decrease in each of the three anxiety factors was observed for this group.

Interest in Science and Chemistry

Increasing interest in the sciences and specifically in chemistry was a specific goal of the $cAcL_2$ program. Effects on student interest in science and chemistry were gauged using five questions on the post-survey. The average and standard deviation for all responses are reported in Table 6.26 below. The percentage of students indicating an increase in interest by choosing "agree" or "strongly agree" on the survey are reported as well.

Table 6.26. $cAcL_2$ Effects on Interest in Science and Chemistry (n = 43).

Taking this course has increased my interest in…	Average	% Agree
science in general.	3.53 (0.81)	51.2
chemistry in general.	3.50 (1.03)	48.8
taking more chemistry.	3.19 (1.12)	32.6
pursuing a chemistry-related major.	2.78 (1.24)	27.9
pursuing a science-related field.	3.81 (0.82)	58.1

Approximately half of the students in $cAcL_2$ feel that the course has increased their interest in science, chemistry, and pursuing a science-related field. Approximately a third of the students feel that the course has increased their interest in taking more chemistry and pursuing a chemistry-related major. Since CH201 is a chemistry course for non-majors, the percentages reported in Table 6.26 may be interpreted as an achievement.

Perceptions and Opinions of $cAcL_2$

Although it has been shown that $cAcL_2$ can improve student understanding of chemistry (section 5.3), it is important to acknowledge the perceptions that students have toward this instructional approach. A series of questions was asked on the post-survey to gauge student attitudes toward the structure of $cAcL_2$. Class averages and standard deviations are reported in Table 6.27 along with the total percentage of students choosing agree or strongly agree. Note that higher values correspond to more positive student attitudes toward the $cAcL_2$ instructional environment.

Table 6.27. Student Perceptions of $cAcL_2$ (n = 43).

Evaluating this course.	**Average**	**% Agree**
This course was organized so that we were encouraged to discuss ideas.	3.79 (0.89)	69.8
The structure of this course enabled me to discover some of the ideas of chemistry for myself.	3.77 (0.84)	69.8
It was clear how the activities fit into this course.	3.95 (0.62)	83.7
This course helped me feel more comfortable with the idea that some questions have no single right answer.	3.44 (0.88)	48.8
I understood most of the ideas presented in this course.	3.86 (0.77)	67.4
This course increased my understanding of chemistry.	4.09 (0.78)	83.7
The computer simulations in this course helped me to learn the chemistry.	3.79 (0.89)	69.8
This course caused me to think about chemistry in the world around me (outside of class).	3.51 (0.91)	60.5
This course has given me more confidence in preparing graphs and tables.	3.53 (0.93)	51.2
This course has given me more confidence in interpreting/explaining scientific graphs.	3.42 (0.82)	44.2
This class has helped me gain more confidence in using computer technology.	3.37 (0.79)	41.9
I liked the format of this class.	3.79 (0.86)	67.4
I would recommend this class to others.	3.58 (0.93)	60.5
Overall this course was a good experience for me.	3.60 (1.09)	63.1

As seen from the high percentage of agreeable responses in Table 6.27, students hold very positive perceptions of the $cAcL_2$ instructional approach. An average of 63.0% of the students indicated an agreeable response for the questions in Table 6.27. The students especially perceive the purpose of the class activities and feel the course increased their understanding of chemistry (both were 83.7% agree). It is also notable to point out that only an average of 9.1% of students indicated disagree or strongly disagree for this group of questions. In fact, no students marked strongly disagree for 8 out of the 14 questions. Over 60% of the students agreed that they liked the format of the class and that they would recommend it to others.

Students were given the opportunity to respond to the open-ended question “How would you describe this course to other students?” A total of 35 students responded to this question. 51% of these students described the $cAcL_2$ course as challenging. Although some students commented on the large amount of work required for the class, most students described $cAcL_2$ in a positive tone. Students used phrases like “practical”, interesting”, “stimulating”, and “worth it”. Students also reported that $cAcL_2$ was a “good course” that gave an “opportunity to grasp chemical concepts” in an environment that “is more conducive to learning”. Some students also included favorable remarks about the “group learning environment” and said that $cAcL_2$ was “better than lecture”.

Conclusions

The quantitative study clearly pointed out that $cAcL_2$ has added benefits in improving student attitudes in CH101 when compared to a traditional lecture class. However, a more detailed analysis in this qualitative study on CH201 provides more insight into the effect of $cAcL_2$ on student attitudes and anxiety. The data collected through surveys, interviews, and reflective journals provides overwhelming evidence that the $cAcL_2$ instructional method is positively received and favored by students. The findings can be summarized as follows:

- Hands-on activities are the driving force of the $cAcL_2$ curriculum. It is evident from the data collected in this study that students in $cAcL_2$ recognized the purpose of activities and how activities contributed to their learning.

- Cooperative grouping is a major physical component of classroom dynamics in $cAcL_2$. Students responded positively to working in groups and in some cases, as indicated in interviews, changed their attitudes toward group work. Students that once considered it an obstacle viewed it as a necessary and important part of their $cAcL_2$ experience.
- The $cAcL_2$ course did not indicate significant effects in anxiety for the class as a whole. However, when students were categorized by major it was observed that each major group (physical/engineering, biological, other) experienced a significant decrease in chemical handling anxiety. It was also shown that $cAcL_2$ proved to be more effective at decreasing the anxiety of majors grouped under "other" than for physical/engineering and biological science majors. This result was indicated by t-tests that revealed significant decrease ($p < 0.05$) for each factor as well as for the overall anxiety rating scale.
- The $cAcL_2$ instructional method serves to improve student interest in chemistry and general science as indicated by approximately half of the students agreeing that the course has increased their interest in science, chemistry, and pursuing a science-related field and a third of the students agreeing that the course has increased their interest in taking more chemistry and pursuing a chemistry-related major.
- Students indicated positive attitudes toward the class and its structure. An average of 63.0% of the students indicated an agreeable response for questions specifically designed to measure student attitudes toward $cAcL_2$. This is contrasted by the fact that only an average of 9.1% of the students indicated disagree or strongly disagree for each question.

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CHAPTER 7

SUMMARY & CONCLUSION

Concept Advancement through Chemistry Laboratory-Lecture, or $cAcL_2$, has been presented as a new instructional format that combines both laboratory and lecture components of a general chemistry program into one integrated environment. The primary features of this integrated environment include cooperative learning, hands-on activities, real-world applications, and technology applications. An active learning environment is promoted by shifting from traditional modes of lecture instruction to more student-centered instructional methods. The effective use of these elements allows students to experience chemistry in an active setting that fosters understanding of chemistry concepts and relationships. This new format had the following objectives:

- Improve student understanding of basic chemical concepts through an integrated lab-lecture format.
- Improve the higher order cognitive skills of students through "real world" problems and applications.
- Improve graph construction, manipulation, and interpretation skills.
- Increase student interest and improve student attitudes toward chemistry.

In order to determine the effects of the $cAcL_2$ instructional method, pilot sections were implemented in the fall of 2001 and the fall of 2002 for CH101 and CH201, respectively. Both quantitative and qualitative research approaches were taken in order to develop a full picture of the impact of $cAcL_2$. The first study employed quantitative research methods to determine the effects on student understanding of basic chemical concepts and development of higher order cognitive skills as well student attitudes toward chemistry. In this study the experimental course was compared to a traditional lecture section. Data was collected through exams and pre- and post-surveys. Statistical methods were used to compare the two classes for any difference in student performance and attitudes resulting from the two different instructional approaches.

The second study employed a more qualitative research approach in order to delve into more specific areas of learning. Data was collected through interviews, surveys, reflective journals, exams, quizzes and homework assignments. The data was qualitatively analyzed to investigate how students solve problems, how students construct, manipulate and interpret graphs, and how student attitudes toward chemistry are affected.

A summary of the results of the quantitative and qualitative studies is presented below.

- Student understanding of basic chemical concepts and the development of higher-order cognitive skills were improved as shown by performance on conceptual questions when compared to student performance in a traditional lecture section. The statistical analysis revealed that there was either no significant statistical difference between the two sections exposed to the two different instructional formats or that positive significant results were achieved by the $cAcL_2$ section.
- Clear changes were recorded in student attitudes and anxiety as demonstrated by the results of statistical t-tests on student survey data. It was shown that $cAcL_2$ students achieved greater attitudinal change as indicated by residualized gains above projected changes from the lecture section. Data collected from student interviews, journals, and survey responses revealed that students responded positively to $cAcL_2$ instructional strategies, including hands-on activities and cooperative grouping. Students also indicated more interest in science and chemistry as a result of taking the $cAcL_2$ course.

- Problem solving skills were not affected by the use of an explicit problem solving protocol. Students chose not to use the method primarily because the protocol was presented in a detailed manor that students found to be too time-consuming. However, an analysis of actual student problem solving practices revealed that students using gathering and organizing methods were more successful than those that did not. These results were combined to propose a modified Trigger/GOAL problem solving approach to appeal to student use in solving chemistry problems.
- Graph construction, manipulation, and interpretation skills were monitored over the course of a semester. Requiring students to construct and use graphs for class resulted in improved skill level in students initially demonstrating varying graphing skill levels. Therefore, the incorporation of a graphing component in a general chemistry curriculum is expected to improve graphing skills and confidence levels among students. Based on the examination of student data it is recommended that students be briefly introduced to each component of a graph and that the importance of more subtle points of graphing be discussed.

The $cAcL_2$ project has demonstrated that an activity-driven curriculum designed to a) physically combine laboratory and lecture, b) incorporate discovery- and inquiry-based learning methods, c) capitalize on cooperative grouping, and d) foster the active engagement of students, can effectively cover content material in a time frame comparable to traditional formats while improving student attitudes and maintaining student performance levels that are comparable to or better than the performance of traditional lecture students. Historical accounts of education in chemistry tell us that it is experimentation that gives us understanding of chemical concepts. Therefore, lab and lecture should not be stand-alone realms that are treated separately; lab and lecture should be a contiguous experience that seamlessly integrates the positive aspects of both lab and lecture in order to foster the scientific growth and development of students.

A few programs have attempted to deal with the disconnection of lab and lecture. The primary reform efforts can be grouped into two categories that can be considered a progression of connection along a continuum: 1) better correlation of lecture and laboratory topics and 2) physical integration erasing the boundaries between lab and lecture.

The simplest and most cost-effective approach to dealing with the disconnect is to better correlate lecture and laboratory topics. At smaller institutions this may be a viable approach due to the involvement of professors in both laboratory and lecture. However, at larger institutions several challenges arise: a) professors are removed from the laboratory, b) there may be a significant amount of turnaround in general chemistry instructors, and c) turnaround makes difficult the task of developing a consistent curriculum in which laboratory and lecture are effectively correlated.

The effective connection between laboratory and lecture, in $cAcL_2$, is dependent upon the integrated activity curriculum introduced in a physically integrated environment. The $cAcL_2$ curriculum establishes a logical progression in which each activity builds upon the last in order to reinforce important chemical concepts. Discovery- and inquiry-based techniques are used to promote concept develop in students. However, the body of work presented in this dissertation represents a very small sample of the population of students that could potentially benefit from the active $cAcL_2$ learning environment.

As the $cAcL_2$ approach continues to be implemented, both short and long-term effects of $cAcL_2$ instruction may be realized by a more encompassing body of research that demonstrates a level of success not attainable by the methods and sample sizes employed during the initial stages of development and implementation. Once a large population of students have passed through the $cAcL_2$ course then longitudinal studies can be conducted. One longitudinal study could compare the success of $cAcL_2$ students to that of traditional students in subsequent classes. Another option could include giving post-tests several semesters later and comparing scores of $cAcL_2$ and traditional students for retention of general chemistry material.

Further assessment involving new and effective approaches is needed to fully understand and realize the effects to reform on learning. Based on the results of the $cAcL_2$ study it is strongly recommended that survey data be used with caution. The use of surveys is a strongly favored method of assessment to indicate student perceptions. Although, student perceptions indicated in post-survey type evaluations can reveal a great deal about students attitudes in a course, it is extremely difficult to use the data in a pre/post analysis or to compare the experimental instruction to other modes of instruction as demonstrated in this work. It is important to have one-on-one contact with students at multiple points throughout the semester in order to gather more detailed information on student perceptions and performance. For this reason, interviews and journals provide extremely useful opportunities for collecting data. It is recommended that this type of detailed qualitative data be collected in both experimental and traditional formats in order to make a stronger comparison of students and to provide internal checks for validating results of an educational study.

The cumulative materials and results of the $cAcL_2$ project embody the initial stages of development and successful implementation for a combined lab-lecture experience and contribute important assessment data to the literature in this area. The groundwork has been laid to allow other chemistry programs to adopt the student-centered approach by adapting the existing curriculum for their program needs. The general chemistry curriculum also serves as a model for the adoption of $cAcL_2$ instructional strategies into upper level courses where student maturity in scientific thinking becomes more and more reliant upon laboratory experiences. Further review of the $cAcL_2$ project and the development of innovative assessment protocols are needed in order to build and expand upon the initial success observed in this body of research.

Appendices

Appendix A - Sampler of Activities

[1] Allen, DeeDee; Oliver-Hoyo, Maria T. *J. Chem. Educ.* **2002**, *79*, 459-461.

Fingerprinting

Time: 45 - 60 minutes
Topic: Emission Spectra, bar codes
Type: Probe
Level: Intermediate

Overview: Students will see how an element can be identified by its emission spectra just like a consumer product can be identified by its bar code.

Equipment and Materials
Bar codes with and without corresponding reflectance pattern, computers with Internet access, several emission spectra with corresponding absorbance spectra including hydrogen, and energy level diagram of hydrogen.

Learning Objective(s):
Students will relate the microscopic emission spectra to a macroscopic bar code.
Students will be able to interpret bar code patterns.
Students will use bar code properties (line width, positions, reflectance patterns) to identify the properties of an emission spectra.
Students will discover that simple lines can be used to identify elements.
Students will relate the gaps in absorbance spectra to emission lines.

Student Misconceptions:
1) An emission spectrum is not unique to an element.
2) Bar codes do not have wave patterns.

Other Student Difficulties: Extrapolating information contained in a "line."

Prerequisites: Electromagnetic radiation

Activity Table

Task	Reason
Put up a bar code without the printed numbers and begin a question series about what is it and how does it work.	Students will have to think about something they see everyday, but may not understand.
Put up a bar code with its corresponding reflectance pattern. Ask students to write down how the pattern arises.*****	Students will classify the white space as a peak and the black space as nothing. Students should distinguish between line widths.
Show a diagram of how a scanner reads the bar code.	Students will observe that the scanner detects reflected light.
Give students another barcode reflectance pattern and ask them to predict the bar code based on the explicit reflectance peaks.	To test student understanding of whether light is reflected or absorbed.

Activity Table continued

Have students draw what the pattern would look like if it were in terms of absorbance.	Relates the bar codes to another chemistry concept that is relevant to ems spectra.
Show and explain the diagram of a barcode and the bar patterns for coding each number.	To show students how to obtain information from a barcode.
Have students decode several bar codes using the UPC-A pattern that is provided. Go over the codes that some groups obtained.	Students will see that each line represents a number, which also corresponds to information about the product. Note: Students may need a little background info in order to understand how to read the bar code.
Show several emission spectra and ask students to compare them to barcodes.	Students will relate the microscopic emission spectra to a macroscopic bar code. Both use line widths, positions, and reflectance patterns as means for identification.
Discuss how lines arise in emission spectra. Show and discuss the features of the energy level diagram of hydrogen.	Students will identify characteristics of spectra and relate lines to numbers in chemistry (ΔE, λ, and ν).
Ask students to compare and contrast the emission and absorption spectra of one element on University of Oregon web page.	Further develops a relationship between emission and absorption.
Show transparency of a bar code and then overlay the reflectance pattern. Then do the same with an absorption and emission spectra.	Emphasizes the inverse nature of the relationship between emission and absorption.
Have students answer comprehension question provided in Supplementary Material.	Reviews emission and applies the characteristics to absorption spectra.

***** If students have a difficult time recognizing how the reflectance pattern of the barcode arises, then ask them why we do not wear dark clothes in the summer time. This clues them in that the black bars will absorb light.

Related Activities:

Hydrogen Atom Spectrum

References:

Palmer, Roger C. *The Bar Code Book: Reading, Printing, Specification, and Application of Bar Code and Other Machine Readable Symbols*; Helmers Publishing: Peterborough, NH, 1995.

Erdei, William H. *Bar Codes: Design, Printing & Quality Control*; McGraw-Hill: Mexico,1993.

Absorbance and Emission Spectra at the University of Oregon: *http://javalab.uoregon.edu/dcaley/elements/Elements.html*

Bar Code Decoding: *http://www.deBarcode.com/deBarcode/html/index.html*

Discussion and Supplementary Material:

Barcodes contain information about an object and most consumer products, as well as many non-consumer products, have barcodes. There are many types of barcodes (UPC-A, UPC-E, EAN-13, Code 39 and many more). UPC symbols are very common. UPC stands for Universal Product Code and you can find them on almost every product you purchase. Here is a sample UPC symbol with and without numbers:

Figure 1. UPC symbols with and without the numbers
(obtained from *http://www.deBarcode.com/deBarcode/html/index.html)*

The UPC symbol is a special kind of barcode that contains the following information:

Table 1. Information from character numbers. There are 12 characters found on the UPC symbol numbered from right to left.

Character	Corresponding Information
12	Number System Character
11, 10, 9, 8, 7	Manufacturer ID
6, 5, 4, 3, 2	Item ID
1	Check Digit (ensures a valid UPC symbol)

Table 2. Number System Character (12) defines UPC symbol type.

Number	**System Type**
0	Regular UPC
2	Random Weight Items (meat and produce)
3	National Drug Code & National Health Related
4	In Store Marking of Non-food Items
5	Coupons
6, 7	Regular UPC Codes
1, 8, 9	Reserved for Unidentified Uses

The above information was obtained from Erdei, William H. *Bar Codes: Design, Printing & Quality Control*; McGraw-Hill: Mexico, 1993.

In the sample UPC symbol in Figure 1, 0 is the Number System Character, which corresponds to a regular UPC product, and 7 is the check digit. The check digit is the result of a mathematical computation of the characters in the bar code. This digit confirms the validity of a UPC symbol. The first two lines in every barcode are called the left guard pattern. The last two lines are the right guard pattern and there is also a two-line center guard pattern. Every number is encoded by two lines of varying width with relative spacing. Numbers to the left of the center guard pattern are referred to as "left digits" and those to the right as "right digits." The pattern for each number differs depending on its location. The line widths and spacing can be used to identify an item. (See Figures 2 and 3).

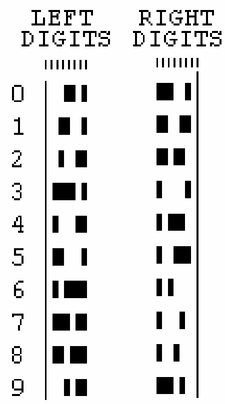


Figure 2. Encoding Pattern for UPC-A barcodes.
(Obtained from http://educ.queensu.ca/~compsci/units/encoding/barcodes/undrstnd.html)

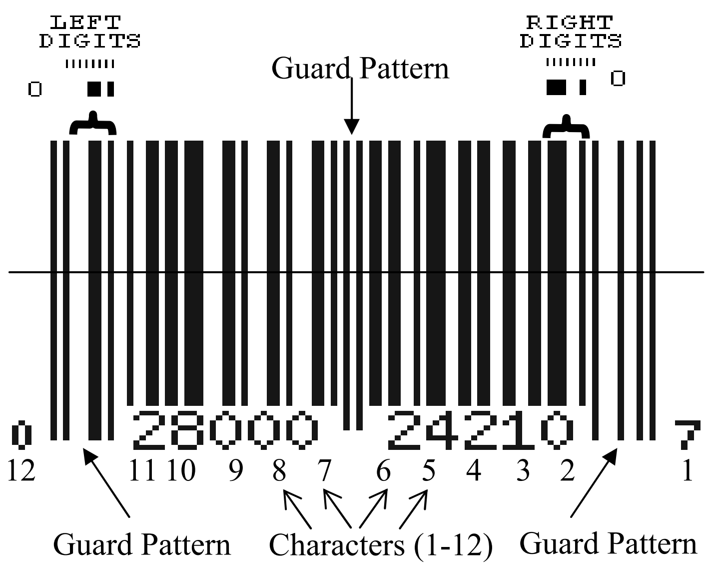


Figure 3. Diagram of the parts of a UPC-A

Barcodes are most commonly read by computerized scanners, which obtain a reflectance pattern from the line widths of a barcode. Examples are provided. An absorbance pattern would be the inverse of the wave pattern.

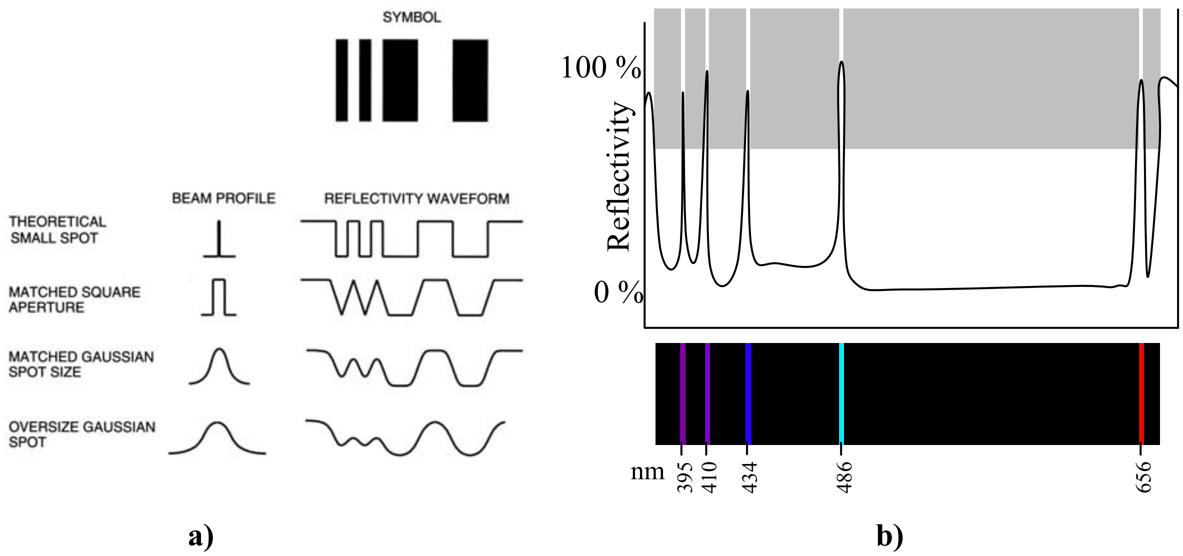


Figure 4. a) Barcode with corresponding reflectance patterns and waveforms obtained from various sources. (Obtained from Palmer, Roger C. *The Bar Code Book: Reading, Printing, Specification, and Application of Bar Code and Other Machine Readable Symbols*; Helmers Publishing: Peterborough, NH, 1995 (p. 168-179).

b) Diagram generated by author to explicitly illustrate the significant relationships.

A schematic of how the scanner obtains the reflectance pattern provided in Figure 5 below.

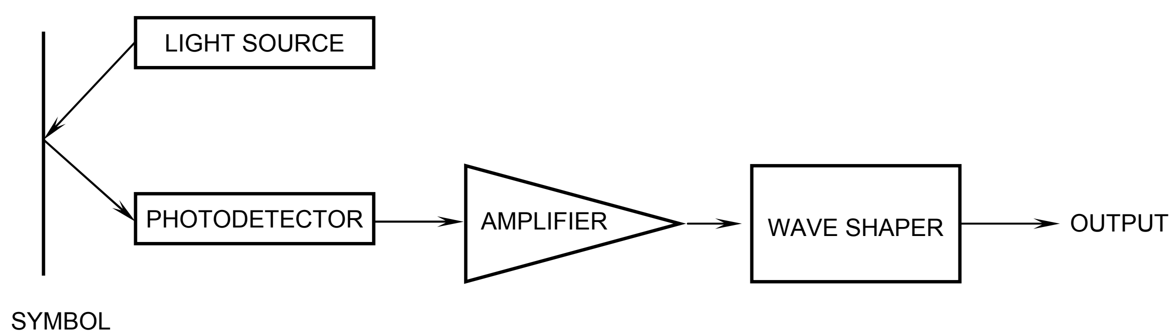


Figure 5. How a scanner works. (Adapted from Palmer, Roger C. *The Bar Code Book: Reading, Printing, Specification, and Application of Bar Code and Other Machine Readable Symbols*; Helmers Publishing: Peterborough, NH, 1995 (p 88).

Relationship to Emission Spectra

Emission spectra are spectra in which lines provide information about the energy levels of an atom. Emission spectra are often referred to as fingerprints for elements since they are unique for every element. This is also the case for barcodes. Every product has it's own barcode and the information is contained in lines. Emission spectra are the inverse of absorbance spectra. Therefore, emission spectra are similar to reflectance patterns obtained from barcodes.

Each line of an emission spectrum contains information about the energy levels of an atom. Consider the simplest case of Hydrogen.

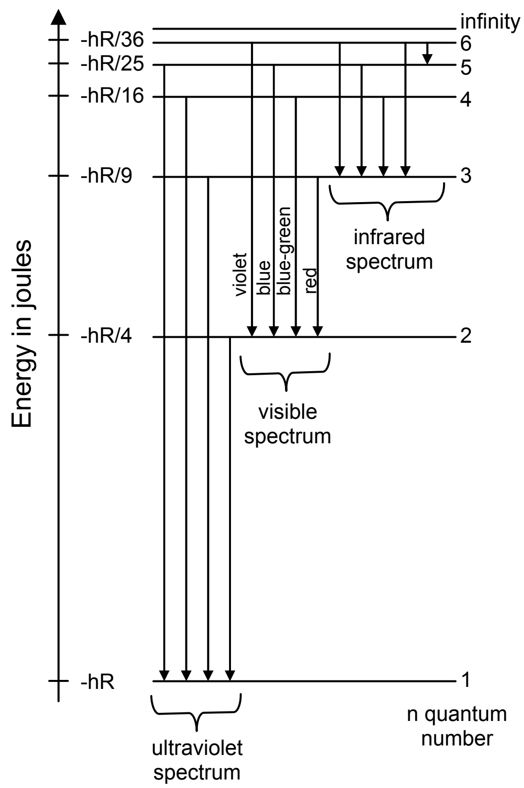


Figure 6. Energy level diagram of Hydrogen. (Adapted from Wertz, Dennis W. *Chemistry: A Molecular Science*; Patterson Jones Interactive: Cary, NC, 1999 (page 2- 9).

The lines that appear in the visible region correspond to electron transitions from n = 6, 5, 4, and 3 down to n = 2. The respective colors are violet, blue, blue-green, and red. The relationship between energy, color, absorbance, and reflection can be drawn.

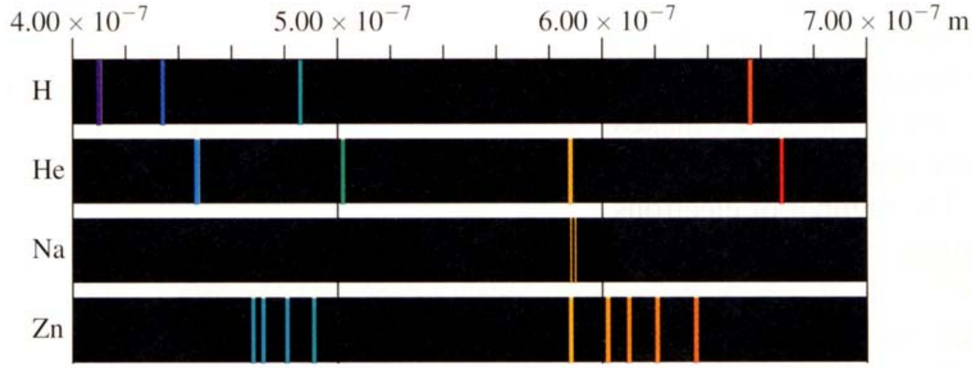


Figure 7. Line spectra of H, He, Na, Zn. (Obtained from Umland, Jean B.; Bellama, Jon M. *General Chemistry, 2nd Ed.*; West Publishing: St. Paul, MN, 1996, p. 230.) There are many examples also available on the World Wide Web.

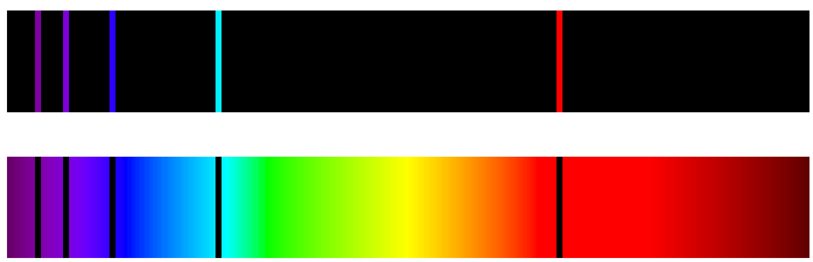


Figure 8. Corresponding Emission and Absorption Spectra of Hydrogen (375-775 nm). (Obtained from http://www.physics.sfasu.edu/astro/color.html).

Note: Absorbance and emission spectra can be viewed on the University of Oregon webpage at *http://javalab.uoregon.edu/dcaley/elements/Elements.html*

Comprehension Question: The absorption spectrum of sunlight shows a pair of dark lines at 589.0 nm and 589.6 nm, whereas the emission spectrum of sodium has bright yellow lines at these same wavelengths. Explain how the dark lines might arise. (Hill, John W.; Petrucci, Ralph H. *General Chemistry*; Prentice Hall: Upper Saddle River, NJ, 1996, page 235.)

> Absorbance and emission spectra are inverses of each other. Therefore, if the dark lines in an absorption spectrum correspond to the bright lines in an emission spectrum, then both spectra are of the same element. In this case the spectra are evidence that the sun may contain sodium.

See http://www.harmsy.freeuk.com/fraunhofer.html for spectrum of sunlight and identification of lines.

Counting Equilibrium

Time: 30 minutes
Topic: Equilibrium and intro to Le Châtelier's Principle
Type: Probe
Level: Introductory

Overview: Students will determine when a "penny reaction" reaches equilibrium.

Equipment and Materials: 30 pennies per group

Objective(s):
Students will observe how a reaction comes to equilibrium.
Students will be able to define equilibrium.
Students will be able to explain a graph of concentration vs. time.
Students will be able to define k_f and k_r for a reaction.
Students will be able to write equilibrium constant expressions.
Students will be able to determine the effect of a perturbation on the reaction (Le Châtelier's Principle).

Misconceptions: Equilibrium is in effect when [reactants]=[products].
Other Student Difficulties: Reading graphs of concentration vs. time for equilibrium reactions.

Prerequisites: chemical equations

Activity Table

Task	Reason	Notes
Demonstrate how the simulation will work at t = 0, t = 1 min, and t = 2 min.	To clear up any confusion about the procedure.	Use this reaction $A \underset{1/4\ \text{min}^{-1}}{\overset{1/3\ \text{min}^{-1}}{\Leftrightarrow}} B$
Give each group 24 pennies and the reaction with $k_{forward}$ and $k_{reverse}$.	To spark interest of the students.	$A \underset{1/4\ \text{min}^{-1}}{\overset{1/2\ \text{min}^{-1}}{\Leftrightarrow}} B$
Ask students to collect data on the reaction at 1-minute intervals starting at zero.	To have students determine how the k_f and k_r work in the reaction.	Students will probably stop when they see the numbers don't change anymore.
Ask students how long it took the reaction to reach "equilibrium".	To define equilibrium as when the concentrations are not changing.	The reaction reaches equilibrium after 3 minutes.
Have students graph concentration of A and B vs time on the same plot.	To visualize and explain what is happening to the [ ]'s of reactants and products.	See data and plot in Supplementary Material.
Discuss what k_f and k_r mean?	To define k_f and k_r.	
Introduce the equilibrium constant, K_c.	To define the equilibrium constant.	$K_c = k_f / k_r$ = [products]/[reactants]

Activity Table continued

Give each group 6 more pennies and ask them what happens when you add more of a reactant to a reaction at equilibrium.	To illustrate the shift to products.	
Ask students how long it took to reestablish equilibrium.	To determine the effect of a perturbation.	It takes 3 minutes. See data in Supplementary Material.
Have students graph this second data set.	To practice graphing.	
Have students determine whether the reaction "shifted" to the left or right.	To have them interpret the graphical data.	This is a prelude to teaching Le Châtelier's Principle.
Use the new equilibrium concentrations to calculate K_c for comparison.	To show that K_c remains the same.	
Give students problems to write equilibrium expressions.	To practice.	

Related Activities: Shifting Reactions

References: Harrison, John A.; Buckley, Paul D. *J. Chem. Educ.* **2000**, *77*, 1013-1014.

Discussion and Supplementary Material:

Many students have a difficult time understanding dynamic equilibrium in a conceptual manner. This probe will allow students to visualize what goes on in an equilibrium reaction. Use the following reaction.

$$A \underset{\frac{1}{4}\,\text{min}^{-1}}{\overset{\frac{1}{2}\,\text{min}^{-1}}{\Leftrightarrow}} B$$

Start with 24 pennies representing reactant A at time zero. ½ of reactant A, 12 pennies, is lost in the forward reaction in the first minute. During the second minute ½ of A and ¼ of B, 6 and 3 respectively, are lost to the opposite sides leaving 9 A and 15 B (sum must always equal 24). During the next minute values must be rounded down because pennies cannot be divided. See the reference for discussion of this issue. After three minutes the reaction reaches equilibrium. The data and graph of concentration vs. time are provided below.

Table 1. Concentration Data.

Time	[A]	[B]
0	24	0
1	12	12
2	9	15
3	8	16
4	8	16
5	8	16

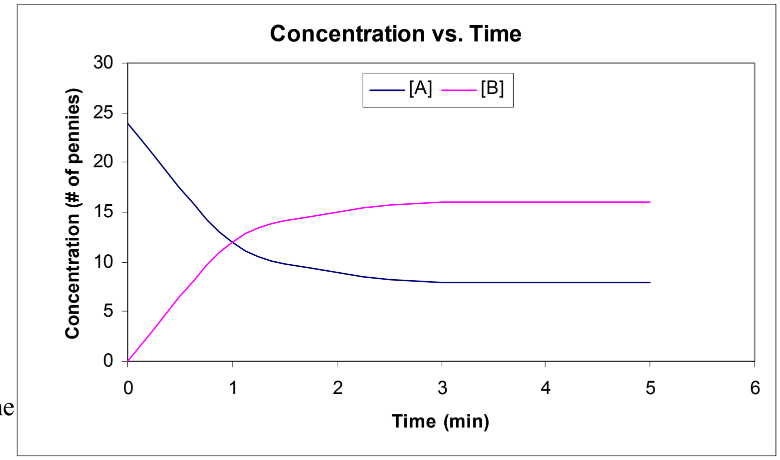


Figure 1. Plot of Concentration vs. Time

Table 2. Concentration Data before and after Perturbation.

Time	[A]	[B]
0	24	0
1	12	12
2	9	15
3	8	16
4	8	16
5	8	16
6	14	16
7	11	19
8	9	21
9	10	20
10	10	20
11	10	20

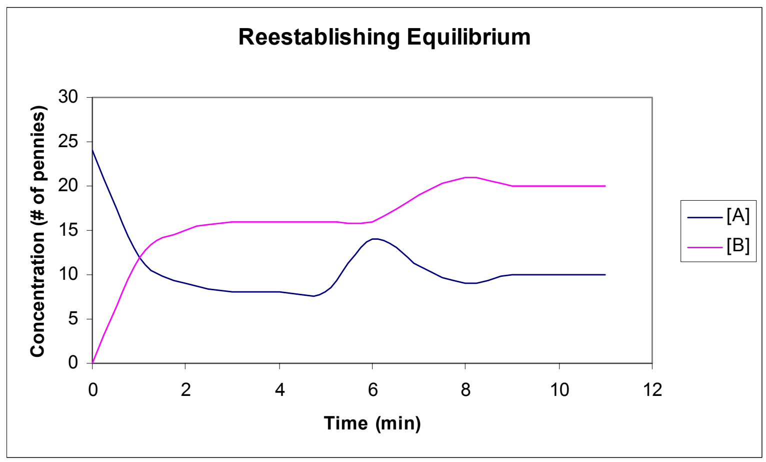


Figure 1. Plot of Concentration vs. Time after perturbation.

There is an overall shift to the product side of the reaction after more reactant is added.

Conceptual Question:

Equilibrium is defined as the point in a reaction when

a) concentration of products equals the concentration of reactants.
b) there is not net change in concentrations of products or reactants.
c) there is no more reactant left to continue the reaction.
d) both a & b

Shifting Reactions

Time: 45 minutes
Topic: Le Châtelier's Principle
Type: Probe
Level: Intermediate

Overview: Students will predict the shift in a reaction based on their observations.

Equipment and Materials:
0.1 M $CoCl_2$, 0.1 M $AgNO_3$, 50-ml beakers, well plates, hot plate, ice,
optional: 20 ml 0.2 M $Fe(NO_3)_3$, 20 ml 0.2 M KSCN, 1-L beaker, 5 400-ml beakers.

Objective(s):
Students will be able to predict the shift in a reaction based only on their observations.

Student Misconceptions: Reactions cannot be reversed easily.
Other Student Difficulties: Relating the change in color to a shift in reaction

Prerequisites: Chemical reactions, writing equations, thermodynamics

Activity Table

Task	Reason	Notes
[1]Show a demo that has visible equilibrium like Fe^{3+}/SCN^-. Have students take notes.	To grab the students attention for the probe.	Be sure that demo is clearly visible to all students.
Discuss the cobalt equilibrium (see Supp. Mat.), but do not discuss how the color changes will occur.	To be sure that students understand the reaction	Provide students with the reaction.
Have students design a data table to record observations when HCl, water, and $AgNO_3$ are added, as well as when it is heated and cooled.	To have students organize the procedures they will be performing.	
[2]Have students test effects of HCl, water, and $AgNO_3$, on the cobalt equilibrium.	Students will see equilibrium in action.	Encourage students to combine different "stresses" (ie solution will turn blue with addition of HCl, and back to pink with addition of water.)
Have students test the effect of temperature. Students should place solutions in small beakers to heat and cool.	Students will see equilibrium in action.	Better results may be obtained if HCl is added until the solution is purple before heating and cooling.

Activity Table continued

Students should answer a series of questions relating to their observations. Questions are provided in Supp. Mat.	Students will postulate Le Châtelier's Principle.	Students may wish to make more observations in order to answer questions.
Allow students to work in groups on the conceptual problem supplied in the Supplemental Material.	Develops critical thinking skills and applies the concepts presented in this probe.	
Have students explain observations of initial demo.	To review.	

Related Activities: Counting Equilibrium

References:

[1]Last, Arthur M. and Peter W. Slade. "A Colorful Demonstration of Le Châtelier's Principle: Observing the Effect of Stress on a Solution Containing Iron (III) and Thiocyanate Ions." November 1997 JCST pages 143-145.

[2]*North Carolina State University CH 102 Laboratory Manual*. Department of Chemistry, Fall 2000, 37.

[3]Wertz, Dennis W. *Chemistry: A Molecular Science*; Patterson Jones Interactive: Cary, NC, 1999 (page 9-21).

[4]Ophardt, Charles E. *J. Chem. Educ.* **1980**, 57, 453.

Discussion and Supplementary Material:

Le Châtelier's Principle states that a system at equilibrium will respond to a stress in such a way as to minimize the effect of the stress. Primarily, when a substance is added to a reaction at equilibrium, then the reaction equilibrium shifts to reduce the amount of the added substance; when a substance is removed, then the reaction equilibrium shifts to replace the removed substance[3]. In this activity students will postulate Le Châtelier's Principle.

<u>The Demo – Iron(III) thiocyanate</u>[1]

Show students the clear solutions of $Fe(NO_3)_3$ and KSCN. Then mix 10 ml of each of the solutions to show the formation of a dark red complex.

$$Fe^{3+} + SCN^{-} \Leftrightarrow \underset{\textbf{\textit{deep red}}}{Fe(SCN)^{2+}}$$

Dilute this mixture to 1 liter to clearly demonstrate color changes in later steps. Separate this solution into five 200-ml aliquots. Set one aliquot aside to use as a color comparison and use the other four aliquots in the following demonstrations.

Change in Temperature
The formation of $Fe(SCN)^{2+}$ is an exothermic reaction. Therefore, when the reaction is heated the complex dissociates into Fe^{3+} and SCN^{-}, thus decreasing the intensity of the deep red color. Begin heating one aliquot on a hot plate and move on to the rest of the demo while it is heating.

Addition of Reactant
Adding one of the reactants will cause the equilibrium to shift in favor of the $Fe(SCN)^{2+}$ complex. Add the remaining 10 ml of KSCN to one the aliquots and the remaining $Fe(NO_3)_3$ to another aliquot. The intensity of the red color should increase.

Removal of Reactant
Removing one of the reactants will cause the equilibrium to shift in favor of the reactants. In other words, the $Fe(SCN)^{2+}$ complex will dissociate, thus, decreasing the intensity of the red color. SCN- is removed from the reaction by precipitation with Ag^{+}. Add 10 ml of $AgNO_3$ to the remaining aliquot. AgSCN will precipitate and the color intensity should decrease indicating the dissociation of $Fe(SCN)^{2+}$.

The Probe – Cobalt Equilibrium

The cobalt equilibrium provides an excellent illustration of Le Châtelier's Principle due to the drastic color change between reactants and products[4]:

$$\underset{\textbf{\textit{blue}}}{CoCl_4^{2-}} + 6\ H_2O \Leftrightarrow \underset{\textbf{\textit{pink}}}{Co(H_2O)_6^{2+}} + 4\ Cl^{1-}$$

Using well plates, students should be able to see the effects of adding HCl, water, and $AgNO_3$ to the cobalt equilibrium. The original cobalt solution is pink. Students can add HCl to 3 drops of cobalt solution and observe a color change to blue. Students can then add water to change it back to pink. The addition of $AgNO_3$ will cause precipitation of AgCl, which should shift reaction equilibrium to the right (pink). *This observation is often overlooked because the precipitate is so predominate.

To test the effect of temperature, better results are obtained when starting with a purple solution. HCl can be added to ~10ml of cobalt solution until it is purple. Then half of the solution can be heated and the other half cooled. This reaction is exothermic, therefore, heating causing the equilibrium to shift to the higher energy side, which is reactants, and the solution turns blue. The opposite occurs when cooling the solution in an ice bath.

PLACE ALL WASTE IN A WASTE CONTAINER!

To avoid student use of 12 M HCl the solutions can be pre-mixed to obtain blue and purple solutions for the students to add water and $AgNO_3$ and to heat and cool. Test tubes may also be used in place of the beakers.

Questions

Using your observations and the chemical equation that you were given answer the following questions. As the reaction is written, you can refer to the left side as the side that should be blue and the right side as the side that should be pink.

$$\underset{\textit{\textbf{blue}}}{CoCl_4^{2-}} + 6\ H_2O \Leftrightarrow \underset{\textit{\textbf{pink}}}{Co(H_2O)_6^{2+}} + 4\ Cl^{1-}$$

1. When adding HCl to the cobalt solution…

   a) The concentration of which ion (found in the reaction) caused a change in the equilibrium?

   b) Did the reaction shift to the left or to the right?

   c) When a reaction shifts, the concentrations of the component ions change. Based on your observations did the concentration of $CoCl_4^{2-}$ increase or decrease?

   d) Did the concentration of $Co(H_2O)_6^{2+}$ increase or decrease?

2. When adding water to the reaction…

   a) Did the reaction shift to the left or to the right?

   b) Did the concentration of $CoCl_4^{2-}$ increase or decrease?

   c) Did the concentration of $Co(H_2O)_6^{2+}$ increase or decrease?

3. Based on your observations what is a general rule for an equilibrium system when adding an ion or complex that is part of the equilibrium reaction?

4. When $AgNO_3$ was added, a solid precipitate, AgCl, was formed. The precipitation of AgCl removed Cl^- ions from the reaction.

   a) The concentration of which ion (found in the reaction) caused a change in the equilibrium?

   b) Did the reaction shift to the left or to the right?

   c) Did the concentration of $CoCl_4^{2-}$ increase or decrease?

   d) Did the concentration of $Co(H_2O)_6^{2+}$ increase or decrease?

5. Based on your observations what is a general rule for an equilibrium system when removing
   an ion or complex that is part of the equilibrium reaction?

6. When heating the solution did the reaction shift to the left or to the right?

7. When cooling the solution did the reaction shift to the left or to the right?

8. Adding energy to a system at equilibrium tends to shift the equilibrium to the higher energy side of the reaction. Would heat be considered a reactant or a product? Is this reaction endothermic or exothermic?

Conceptual Problems:

1. (i) Methanol can be prepared from water, gas and additional hydrogen at high temperature and pressure in the presence of a suitable catalyst. Write the expression for the equilibrium constant for the reversible reaction.

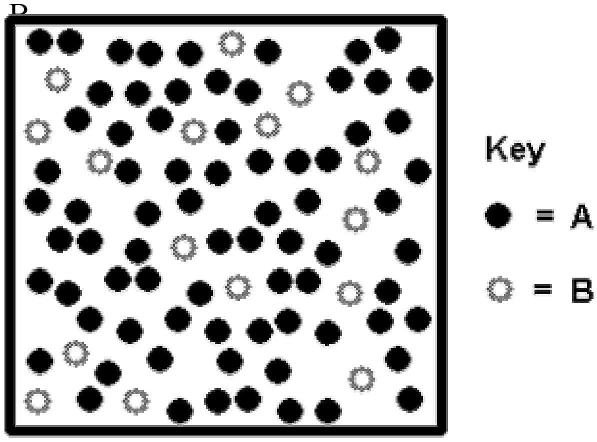
$$2\ H_2(g) + CO(g) \rightarrow CH_3OH(g) \qquad \Delta H = -90.2\ kJ$$

   (ii) If a mixture of H_2, CO, and CH_3OH is at equilibrium, how will the concentrations of H_2, CO, and CH_3OH at a new equilibrium differ from their original concentrations when

   a. more H_2 is added?
   b. CO is removed?
   c. CH_3OH is added?
   d. the pressure on the system is increased?
   e. the temperature of the system is increased?
   f. more catalyst is added?

Reference: http://jchemed.chem.wisc.edu/JCEWWW/Features/CQandChP/ CQs/LibraryCQ/ EquilibriumCQ.html

2. The figure represents a portion of an equilibrium mixture of two compounds related by the reaction 2 A → B.



Which of the following must be true of this equilibrium?
(a) $K > 1$
(b) $K = 1$
(c) $K < 1$
(d) $K = 0$
(e) $K < 0$

Reference: http://jchemed.chem.wisc.edu/JCEWWW/Features/CQandChP/ CQs/LibraryCQ/EquilibriumCQ.html

3. (knowledge of solubility is required)

In order to obtain x-rays of the digestive tract patients must drink $BaSO_4$ (s) in Na_2SO_4 (aq). $BaSO_4$ (s) is opaque and can be seen easily in the x-ray. Note that Ba^{2+} is very poisonous, but the solubility of $BaSO_4$ (s) in Na_2SO_4 (aq) is low enough to prevent high levels of Ba^{2+} in the body. The equilibrium showing the solubility of $BaSO_4$ (s) is given below. Why is the solubility of $BaSO_4$ (s) so low in Na_2SO_4 (aq) solution? (Na_2SO_4 is a soluble salt.)

$$BaSO_4\ (s) \Leftrightarrow Ba^{2+}\ (aq) + SO_4^{2-}\ (aq)$$

ANSWER: Since Na_2SO_4 is soluble then you have Na^+ and SO_4^{2-} in solution. The excess SO_4^{2-} suppresses the solubility of $BaSO_4$ (s) by shifting the equilibrium to the left.

Reference: Umland, Jean B. & Jon M. Bellama. General Chemistry, 2nd Ed. West Pub.: 1996, p 631.

Reviewing Thermodynamics

Time: 15 minutes
Topic: Thermo, Equilibrium
Type: Demo
Level: Intermediate

Overview: Students will discuss the thermodynamics of the $NO_{2\,(g)}$ equilibrium and predict equilibrium shifts the system undergoes temperature changes.

Equipment and Materials:
Two sealed tubes containing $NO_{2\,(g)}$, two large beakers, hotplate, stir bar, ice, two ring stands

Objective(s):
Students will review energy vs reaction coordinate diagrams.
Students will review ΔH_{rxn}.
Students will review activation energy.
Students will describe the function of a catalysts using words and pictures.
Students will apply Le Châtelier's principle to a chemical reaction.

Misconceptions: Increasing the temperature causes product to be formed faster.
Other Student Difficulties: Determining whether a reaction is endo- or exothermic.

Prerequisites: Thermodynamics, Le Châtelier's Principle

Activity Table

Task	Reason
Provide students with the ΔHs for bond making and breaking for the NO_2 rxn. Ask them to draw and energy vs rxn coordinate diagram.	To review thermodynamics.
Ask students to report ΔH for this reaction.	To review ΔH_{rxn}.
Ask students to report the activation energy.	To review activation energy.
Ask students to describe the effect of a catalyst on this reaction with pictures and words.	To describe function of a catalyst using pictures and words.
Ask students to determine if this is an endo- or exothermic reaction.	To practice determining if a reaction is endo- or exothermic.
Ask students to predict what would happen if the reaction were cooled down (or heated up).	To apply Le Châtelier's principle.
Perform the demo and have students make observations.	To observe the NO_2 equilibrium.
Have students determine which gas is brown, NO_2 or N_2O_4.	To conclude the activity with a conceptual question on which way the reaction shifts.

Related Activities: Shifting Reactions, Counting Equilibrium
References: NCSU Demo Room

Discussion and Supplementary Material:

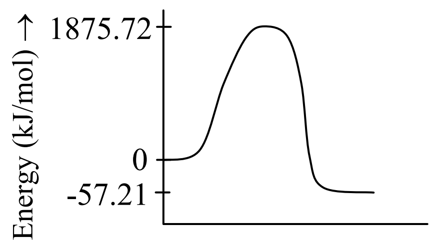
The equilibrium between NO_2 and N_2O_4 is given below.

$$2\ NO_2\ (g) \rightleftharpoons N_2O_4\ (g)$$

Some thermodynamic data is also given along with specific diagrams.

Bond breaking:	$2\ NO_2\ (g) \rightarrow 2\ N\ (g) + 4\ O\ (g)$	$\Delta H = 1875.72$ kJ/mol
Bond making:	$2\ N\ (g) + 4\ O \rightarrow N_2O_4\ (g)$	$\Delta H = -1932.93$ kJ/mol

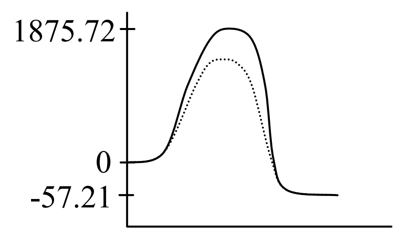
Reaction Coordinate Diagram



$\Delta H = -57.21$ kJ/mol

$E_a = 1875.72$ kJ/mol

Effect of a Catalyst



Lowers the E_a!

Demonstration

After students have made their predictions of equilibrium shift perform the demo.

Begin heating water in one large beaker at the beginning of class. The other large beaker should contain ice water. Place one tube in each beaker. The tubes should be secured by clamping them to a ring stand. It may take several minutes to notice the change in color of the gases.

Equilibrium shifts

This is an endothermic reaction because ΔH is negative; therefore heat is released.

Cooled down $\rightarrow$ shifts to the right to form more N_2O_4.

Observations: gas in tube gets lighter in color.

Warmed up $\rightarrow$ shifts to the left to form more NO_2.

Observations: gas in tube gets darker in color.

Final Conclusion: NO_2 is a brown gas.

WARNING: These gases are very toxic. Extreme caution should be used when handling the sealed tubes. Avoid use of dry ice, acetone mix, and liquid N_2. N_2O_4 liquefies at -10^o C and could cause the tube to implode if cooled excessively.

Reviewing Equilibrium

Time: 5-10 minutes
Topic: Equilibrium
Type: Probe
Level: Introductory

Overview:
Students will review equilibrium concepts using concentration vs. time plots for a reaction.

Equipment and Materials: computer with internet access

Objective(s):
Students will observe, graph, and interpret graphical representations of concentration vs. time in order to review or be introduced to equilibrium concepts.

Misconceptions: All reactions go to completion.

Other Student Difficulties: Calculating acid concentrations.

Prerequisites: none

Activity Table

Task	Reason	Notes
Give students the picture of the H_2/I_2 reaction set-up and the description. Have them predict what will happen.	To think about the how concentration varies with respect to time or to recall concepts of equilibrium.	The optional activity can be done in place of the "wet" activity if the appropriate materials are not available or vice versa.
(Optional) Send students to the given website to observe the reaction and plot.	To observe concentration change with respect to time.	http://www.chm.davidson.edu/ChemistryApplets/equilibria/BasicConcepts.html

Related Activities: Counting Equilibrium, Shifting Reactions

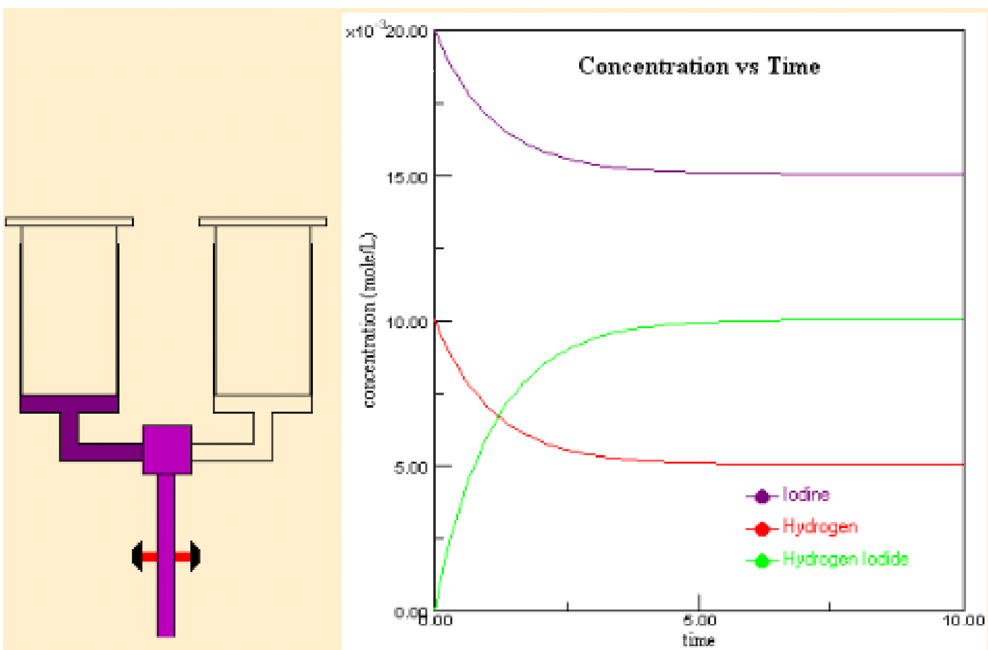
References: http://www.chm.davidson.edu/ChemistryApplets/equilibria/BasicConcepts.html

Discussion and Supplementary Material:

This simulation can be used to simulate the change in concentration of reactants and products over time. This relationship is easily seen in a generated graph. This simulation can be combined with the above "wet" activity in order to incorporate concepts of stoichiometry in the reaction. The description is provided below.

Consider the following gas-phase chemical reaction: $H_2 + I_2$ *f* $2\ HI$

Suppose you have a dual syringe in which one half contains 0.02 mole/L I_2 gas and the other half contains 0.01 mole/L H_2 gas. When the two syringes are depressed, the two gases are mixed and the above reaction occurs. Predict how the concentrations of H_2, I_2, and HI will vary as a function of time.



K

Time: 20 minutes
Topic: Equilibrium constants
Type: Probe
Level: Introductory

Overview: Students will use an internet simulation to measure pressure in a system in order to determine K_c and K_p.

Equipment and Materials: Computer with Internet connection

Objective(s):
Students will write equilibrium expressions in terms of concentration and partial pressure.
Students will use experimental data to calculate equilibrium constants.

Misconceptions: K_c and K_p are the same.
Other Student Difficulties: Converting between K_c and K_p.

Prerequisites: Equilibrium reactions

Activity Table

Task	Reason
Review equilibrium reactions.	To establish foundation for activity.
Derive expressions for equilibrium constants.	To write expressions for equilibrium.
Have students work through experiments on website.	To use experimental data to calculate equilibrium constants.
Give students other exercises.	To use new concepts.

Related Activities: Determining Dissociation Constants

References:
http://www.chm.davidson.edu/ChemistryApplets/equilibria/EquilibriumConstant.html

Discussion and Supplementary Material:

Equilibrium Constants

For: $aA + bB \Leftrightarrow cC + dD$ $\qquad K_c = \dfrac{[C]^c [D]^d}{[A]^a [B]^b}$

Derivation $\qquad 2A + B \leftrightarrow A_2B$

rate $_{forward} = k_f [A]^2 [B]$ $\qquad$ rate $_{reverse} = k_r [A_2B]$

At equilibrium: $\qquad$ rate $_{forward}$ = rate $_{reverse}$

$$k_f [A]^2 [B] = k_r [A_2B]$$

$$\frac{k_f}{k_r} = \frac{[A_2B]}{[A]^2 [B]} = K_c$$

About K_c:

-Its numerical value can only come from experiments.
-Varies only with temperature.
-It is independent of the initial [ ]'s.
-Its magnitude measures the extent to which a reaction occurs.
-It varies with the form of the balanced equation.

Examples:

1) $2SO_2 + O_2 \Leftrightarrow 2SO_3$ $\qquad K_{c1} = \dfrac{[SO_3]^2}{[SO_2]^2[O_2]}$

2) $2SO_3 \Leftrightarrow 2SO_2 + O_2$ $\qquad K_{c2} = \dfrac{[SO_2]^2[O_2]}{[SO_3]^2}$

3) $SO_3 \Leftrightarrow SO_2 + 1/2O_2$ $\qquad K_{c3} = \dfrac{[SO_2]\,[O_2]^{1/2}}{[SO_3]}$

Relationship between K_p and K_c

For gases molar [ ]'s may be used and K_c obtained, but it is more convenient to measure pressures than concentrations.

$P = \dfrac{n}{V} R T$ $\qquad \therefore$ P is α to concentration= n/V

[ ] = P/RT $\qquad K_c = K_p(RT)^{-\Delta n}$ or $K_c = K_p(RT)^{\Delta n}$

Problems:

1. In an equilibrium mixture, we find
   P_{NH3} = 0.147 atm
   P_{N2} = 1.41 atm **K_p = 7.1 x 10^{-5}**
   P_{H2} = 6.00 atm **K_c = 0.285**
   Evaluate Kp and Kc at 500°C

2. At very high temperature, K_c = 1.0 X 10^{-13} for the following reaction:

   $$2\ HF_{(g)} \leftrightarrow H_{2(g)} + F_{2(g)}$$

   At a certain time the following concentrations were detected:

   [HF] = 0.500M [H_2] = 1.00 x 10^{-3} [F_2] = 4.00 x 10^{-3}

   Is the system at equilibrium?

   Q = 1.6 x 10^{-5}
   Q>K Therefore, reaction will shift to left to establish equilibrium.

6. 1.00 mole of bromine is placed in a 1.00 liter flask and heated to 1756K at which the halogen molecules dissociate to bromine atoms. If bromine is 1.0% dissociated at this temperature, calculate K_c.
   $K_c = (0.02)^2 / (0.99) = 4.04 \times 10^{-4}$

7. At a given temperature the equilibrium constant is 5.0 for:

   $$CO_{(g)} + H_2O_{(g)} \leftrightarrow CO_{2(g)} + H_{2(g)}$$

   Analysis showed that an equilibrium mixture at this temperature contained 0.90 mole of CO, 0.25 mole of water, and 0.50 mole of hydrogen in a 5.0 L. How many moles of CO_2 were there in the equilibrium mixture?

   5 = (0.5) (x) / (0.9) (0.25) **Volumes cancel in this calculations**
   x = 2.25

Activity Series

Time: 1.5 hours
Topic: activity series, electrochemistry
Type: Demo / Probe
Level: Introductory

Overview:
The class will construct a small portion of the activity series based on chemical observations.

Equipment and Materials:
Metals → iron (nails or wire), copper, copper wire, magnesium, zinc (mossy), zinc strip, silver, tin (mossy) 0.1M $SnCl_2$ in 3M HCl, 0.1-1.0M $AgNO_3$, 0.7M $Fe(NO_3)_3$ $9H_2O$, 2 M HCl, conc. HCl, 0.1M CuSO4, 0.1M $Pb(C_2H_3O_2)_2$, 12 50-mL beakers

Objective(s):
Students will be able to order metals according to reactivity based on chemical observations.
Students will be able to identify oxidation and reduction processes in a reaction.

Misconceptions: Reduced means lost electrons.
Other Student Difficulties: Students cannot distinguish between the properties of a solid metal and its ion.

Prerequisites: Oxidation states, nomenclature, balancing chemical equations

Activity Table

Task	Reason	Notes
Optional: Have students use the simulations at the provided Website to determine the order of reactivity for several metals.	To introduce students to reactivity of metals.	http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/redox/home.html
Review some of the properties of metals and the common oxidation states of metals.	To remind students of the properties of metals and that metals like to lose electrons.	Students may not be able to differentiate between properties of solid metals and their ions.
Begin discussing reactivity and ask students how can we compare the reactivity of metals.	To have students think about to determine reactivity.	The first answer to this is comparing to something set as a standard → hydrogen.
Demo Series: Comparing various metals to H^+.	To make observations of reactivity.	See Supplementary Material. Do NOT show complete rxn.
Ask students how they would determine overall activity of the metals (Mg vs. Zn, etc.)	Again, to have students think about how to determine reactivity.	

Activity Table continued

One way is observation.	Students observed that Mg had a more vigorous reaction so it more reactive than Zn or Fe.	
Another way is by testing the metals against each other. Perform Zn + $FeSO_4$ demo.	Students observe that Zn is more reactive than Fe.	See Supplementary Material. Fill in the order on a reactivity chart as you go.
Ask student what should happen if Fe + $ZnSO_4$ were mixed.	To show students that they can predict reactions based on reactivity.	No reaction here!
Next, test the reactivity between Cu/$AgNO_3$.	More observations to construct the series.	See Supplementary Material.
Ask students what they would do if they wanted to add in another metal.	To see if they think back through the same steps.	1. React with HCl 2. React against other metals.
Repeat these steps for Sn.	To show students it works.	See Supplementary Mat.
Give an expanded version of the activity series.	To provide a resource showing reactivity of common metals.	
Ask what will happen with iron and $CuSO_4$.	To use the activity series to predict reactions.	$\rightarrow Cu_{(s)} + FeSO_{4\,(aq)}$
Ask what will happen with zinc and $Pb(C_2H_3O_2)_2$.	To use the activity series to predict reactions.	$\rightarrow Pb_{(s)} + Zn(C_2H_3O_2)_{2\,(aq)}$
Go back to the reactions of the first demo and have students determine ox. states for all of the elements and then ask them if they notice anything in common among the reactions.	To get students to notice the change in oxidation states of the elements	
Ask students whether hydrogen is gaining or losing electrons.	To remind them that positive ox. states indicate loss of e^-'s, and negative is gaining.	
Begin to introduce redox terms. H^+ is reduced and the metals are oxidized.	To allow students to identify oxidation and reduction processes with e-transfer	
Relate the activity series to oxidation.	To clarify that the solid metals are being oxidized.	
Give students a few redox equations.	To practice classifying oxidation/reduction processes.	

Related Activities: Electron Hopping, Batteries, Electrolysis, The Silver Cell
References: NCSU Demonstration Room
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/redox/home.html

Discussion and Supplementary Material:

Electrochemistry is often hard for students to grasp right away. Even when students began to get an understanding of the vocabulary they may not understand the actual concepts involved in redox reactions. Therefore, by constructing a small portion of the activity series, students can gain a better understanding of the reactivity of metals and how that relates to electrochemistry.

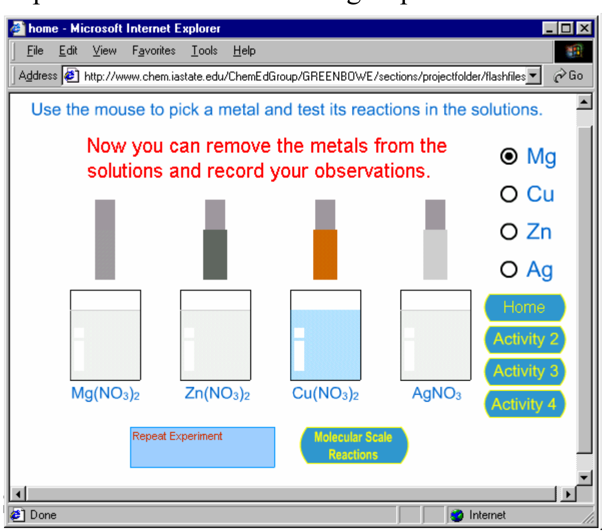
Many of the demos here can be scaled down for students to do themselves and make observations of the reactions. Use slightly less concentrated chemicals and tiny pieces of metal. Observation of bubbles, dissolving a metal, or plating a metal usually indicates a reaction.

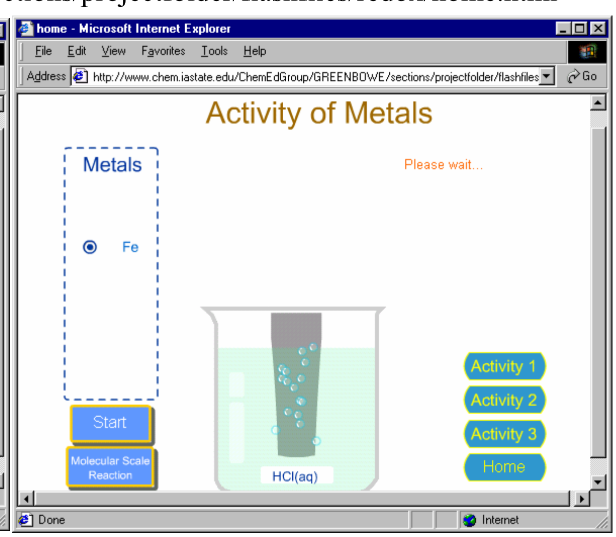
Simulation:
The following simulated activities will allow you to determine the reactivity of various metals. If a metal reacts with a solution, then that metal is more reactive than the metal that is in the solution.

For example: if metal A is placed into a solution of $Cu(NO_3)_2$ and a reaction is observed (copper is plated onto metal A) then A is a more reactive metal than copper.

Go through the four activities and make a list of the metals. When you are done the metals should be in order from the most reactive to the least reactive.

Go to the following Website:
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/redox/home.html





Activity 1: Mg > Zn > Cu > Ag
Activity 2: Zn > Fe > Pb > Cu
Activity 3: Fe > Ni > Sn > Pb
Activity 4: (Qualitative evaluation of bubbles.) Shows that copper and silver do not react with hydrochloric acid.

Overall reactivity for these metals:

Mg > Zn > Fe > Ni > Sn > Pb > Cu > Ag

Comparing Metals to H^+ (using 2 M HCl)

$Fe_{(s)}$ + HCl → reaction
$Cu_{(s)}$ + HCl → no reaction
$Zn_{(s)}$ + HCl → reaction
$Mg_{(s)}$ + HCl → reaction (obviously a much more vigorous reaction)
$Ag_{(s)}$ + HCl → no reaction

From this we gather:

Zn, Mg, Fe	↑ More reactive
Hydrogen	
Cu, Ag	Less reactive

Determining overall reactivity (use 1 - 2 M solutions for all reagents)

Observation: Mg obviously produced a much more vigorous reaction and students should conclude that it is more reactive than Zn or Fe.

Comparatively: React the metals and ions against each other. See below.

$3\ Zn_{(s)} + 2\ Fe(NO_3)_{3\ (aq)} \rightarrow 3\ Zn(NO_3)_{2\ (aq)} + 2\ Fe_{(s)}$
$Fe_{(s)} + ZnSO_{4\ (aq)} \rightarrow$ no reaction

$Ag_{(s)} + CuNO_{3\ (aq)} \rightarrow$ no reaction
$Cu_{(s)} + AgNO_{3\ (aq)} \rightarrow CuNO_{3\ (aq)} + Ag_{(s)}$

Mg	More reactive ↑
Zn	
Fe	
Hydrogen	
Cu	
Ag	Less reactive

Adding another metal

Sn + HCl(conc.) → reaction (above hydrogen in the series,but not vigorous like Mg)
$Zn_{(s)} + SnCl_{2\ (aq)} \rightarrow$ Sn solid forms on zinc metal (Zn is more reactive than Sn)
$Sn_{(s)} + FeSO_{4\ (aq)} \rightarrow$ no reaction (Sn fits between Fe and Hydrogen)

Activity Series

Cesium — Most reactive
Rubidium
Potassium
Barium
Strontium
Calcium
Sodium
Magnesium
Aluminum
Zinc
Chromium
Iron
Cadmium
Cobalt
Tin
Lead
HYDROGEN
Copper
Silver
Mercury
Gold — Least reactive

Oxidation States

$Fe_{(s)} + H^+ \rightarrow Fe^{2+} + H_2$	$Fe^0_{(s)} + H^{1+} \rightarrow Fe^{2+} + H_2^0$
$Zn_{(s)} + H^+ \rightarrow Zn^{2+} + H_2$	$Zn^0_{(s)} + H^{1+} \rightarrow Zn^{2+} + H_2^0$
$Mg_{(s)} + H^+ \rightarrow Mg^{2+} + H_2$	$Mg^0_{(s)} + H^{1+} \rightarrow Mg^{2+} + H_2^0$

Hydrogen is gaining electrons, therefore it is being reduced.

Reactions

$Zn_{(s)} + Cu(NO_3)_{2\,(aq)} \rightarrow Cu_{(s)} + Zn^{2+}_{(aq)} + 2\ NO_3^{1-}{}_{(aq)}$
zinc solid gets oxidized - copper(II) gets reduced

$CoCl_{2\,(aq)} + Cd_{(s)} \rightarrow Cd^{2+}_{(aq)} + Co_{(s)} + 2\ Cl^{1-}_{(aq)}$
cobalt(II) gets reduced - cadmium solid gets oxidized

$AgCl_{(s)} + H_2C_2O_{4(aq)} \rightarrow Ag_{(s)} + 2\ CO_{2\,(g)} + Cl^{1-}_{(aq)} + 2\ H^{1+}_{(aq)}$
silver ion gets reduced - carbon gets oxidized from +3 to +4

$3\ F_{2\,(g)} + 2\ Fe_{(s)} \rightarrow 2\ FeF_{3\,(s)}$
fluorine gets reduced - iron solid gets oxidized

$MgI_{2\,(aq)} + Ag_2CrO_{4\,(s)} \rightarrow I_{2\,(s)} + 2\ Ag_{(s)} + Mg^{2+}_{(aq)} + CrO_4^{2-}{}_{(aq)}$
iodide gets oxidized - silver ion gets reduced

Electron Hopping

Time: 1 hour
Topic: Redox reactions
Type: Demo/Probe
Level: Intermediate

Overview:
Students will observe demonstrations of redox reactions, learn about the microscopic nature of electron transfer, and analyze chemical equations for redox behavior.

Equipment and Materials:
Aluminum can, $CuCl_2$ solution, penny (made before 1980), conc. HNO_3, petri dish (top & bottom)

Objective(s):
Students will be able to explain what is happening microscopically.
Students will be able to determine if a substance will behave as an oxidant or reductant.
Students will be able to use a table of standard reduction potentials effectively.
Students will be able to write and balance simple redox reactions.
Students will be able to distinguish between spontaneous and non-spontaneous processes.

Other Student Difficulties:
Determining oxidation numbers for oxygen containing compounds.
Knowing the difference between oxidation and reduction.

Prerequisites: Activity Series, nomenclature, oxidation states, balancing chemical equations

Activity Table

Task	Reason	Notes
"Can Ripper" demo. Scratch a circle around the inside of an aluminum can, then pour in some $CuCl_2$ and the can will rip in half easily.	Grabs students' attention.	Scratch the can before coming to class. The copper oxidizes the aluminum.
Describe the $CuCl_2$ as an oxidant and the aluminum as a reductant. Briefly define.	Introduce new terms.	
Discuss the microscopic phenomena of redox rxns.	To show students why elements gain / lose electrons.	See energy level diagrams in Supplementary Material.
Ask students to work the problems provided.	To see if they understand redox conceptually.	

Activity Table continued

Go back to the activity series and ask student to draw orbital representations of what happens when Zinc and Sn^{2+} are mixed.	To help students visualize the microscopic nature of metal reactivity.	Remember that "more reactive" is easily oxidized
Introduce the table of standard reduction potentials and explain how it relates to activity series.	To introduce a new reference that relates to something the students are already familiar with.	This is the "quantitative" comparison of reactivity.
Teach students how to use the table to calculate cell potentials and write and balance simple redox equations.	To teach students how to use the table and the mechanics of writing and balancing redox reactions.	
Describe the spontaneity of a redox rxn in terms of sign of E^{o}_{cell}.	To allow students to distinguish between sp and non-sp reactions.	
Ask students about the sign of ΔG for sp and non-sp rxns.	To review a familiar thermodynamic property.	
Introduce the equation $\Delta G = -\eta \Im E^{o}$.	To relate E^{o} to ΔG.	
Give students the rest of the provided questions.	To practice using the table of standard reduction potentials.	
Perform the "Penny Demo" and have students write reactions describing the oxidation and reduction processes.	To review and present students with a challenging question.	

Related Activities: Activity Series

References:

UW Card Catalog
http://genchem.chem.wisc.edu/demonstrations/Gen_Chem_Pages/17electropage/electromain.htm
NCSU Demonstration Room
Example Questions and Extra Practice developed by Edward Bowden (NCSU)

Discussion and Supplementary Material:

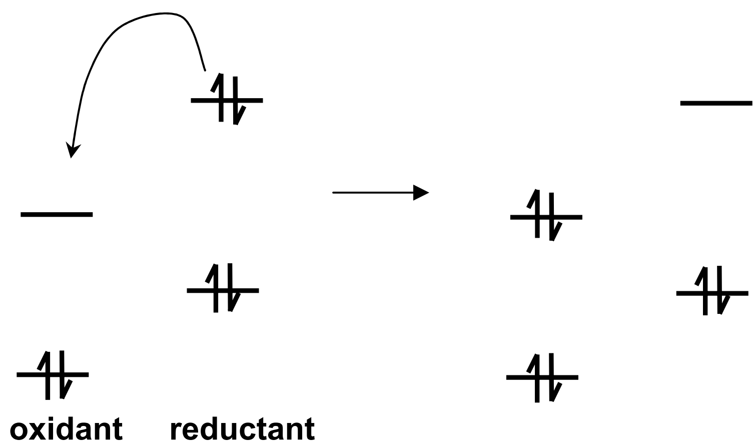
Can Ripper Demo

See http://genchem.chem.wisc.edu/demonstrations/Gen_Chem_Pages/17electropage/electromain.htm

Microscopic Nature of Redox Reactions

Students are usually able to learn how to work redox problems without knowing what happens conceptually. For example, the questions on the following page are very conceptual because students can use only the nature of the chemicals and not standard reduction potentials.

Electrons want to be in lower energy orbitals. This is simply stated for general chemistry students to understand why some elements will gain electrons and some will lose electrons. Once students grasp this concept they can predict which elements will be oxidants or reductants.



Penny Demo

Place the penny into the top portion of a petri dish. Add nitric acid and immediately place the smaller bottom dish over it to contain the gas evolved. The penny will dissolve.

WARNING: the gas is NO_2, which is poisonous.

Here is the reaction: $Cu_{(s)} + H^{+}_{(aq)} + 2NO_3{}^{1-}{}_{(aq)} \rightarrow 2NO_{2\,(g)} + Cu^{2+}_{(aq)} + 2H_2O_{(l)}$

Oxidation: $Cu_{(s)} \rightarrow Cu^{2+}_{(aq)} + 2e^-$

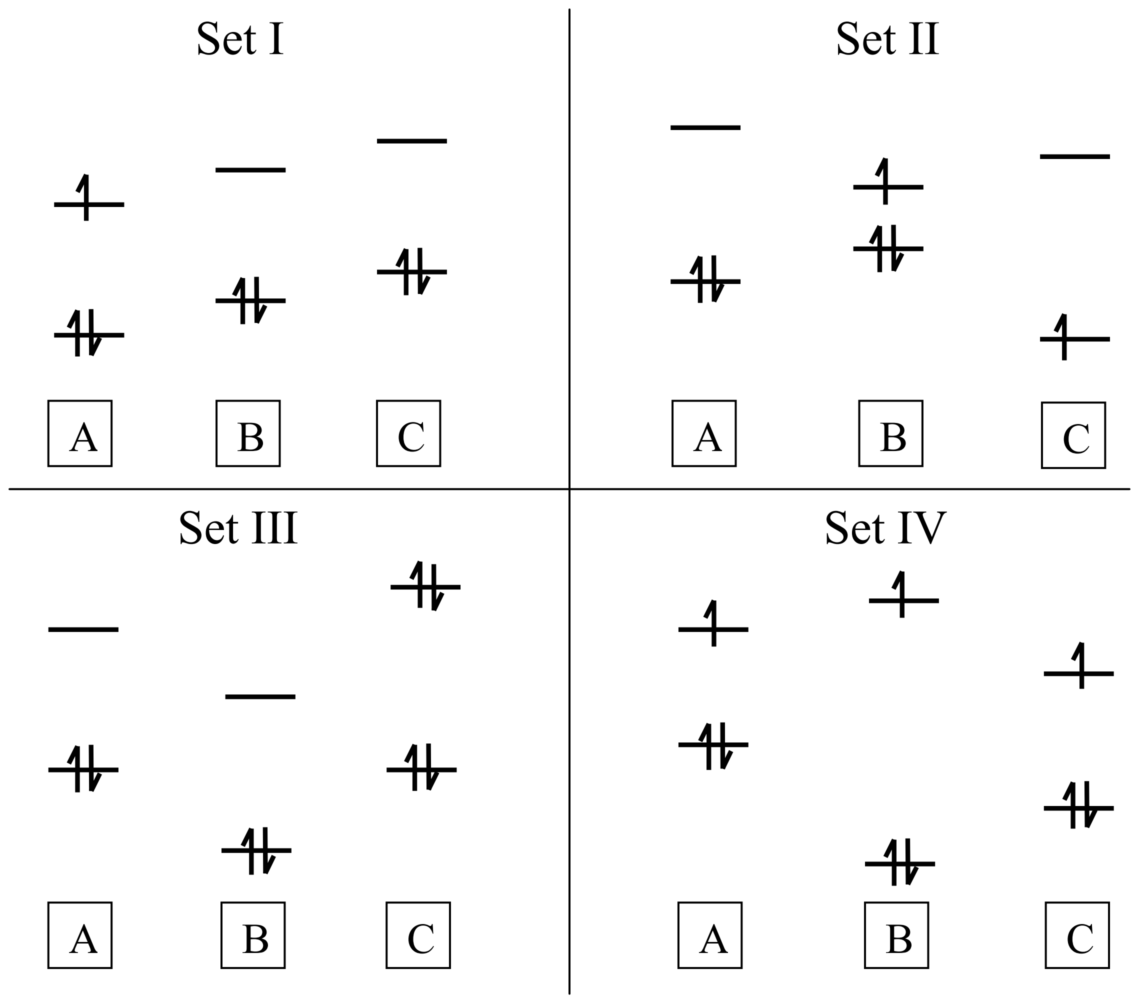
Reduction: $\underset{(5+)}{NO_3{}^{1-}} + 1e^- \rightarrow \underset{(4+)}{NO_2}$ (simplified)

Example Questions

Below are four sets of valence orbital energy diagrams, with 3 redox species per set. For each set answer the following questions. Assume that no other free energy terms are important other than the orbital energy levels.

		I	II	III	IV
a)	Which would be the best oxidant?				
b)	Which would be the best reductant?				
c)	Is A capable of oxidizing B?				
d)	Is C capable of reducing A?				

In each set, three species are labeled A, B, and C. All orbitals not shown are either <u>lower energy and filled</u> or <u>higher energy and empty</u>.



Extra Practice

1. For these reactions, identify the oxidant, the reductant, and the number of electrons transferred between the two reactants in the balanced reaction:

	oxidant	reductant	# e^-'s transferred
a) $2Fe^{2+} + F_2 \rightarrow 2Fe^{3+} + 2F^{1-}$	________	________	________
b) $2Al + 3Pb^{2+} \rightarrow 3Pb + 2Al^{3+}$	________	________	________

2. Use Table 11.1 to write net redox reactions for the following processes. One of the five will not result in a redox reaction because the oxidant or reductant is absent; identify this one with NRR (no redox reaction). For the other four, specify whether the reaction occurs spontaneously or not. The following are the "spectator ions": Cl^{1-} in parts b & d; SO_4^{2-} in part c; NO_3^{1-} in part e.

	net reaction or NRR	spontaneous?
a) immersing tin in nitric acid	________________________	________
b) mixing $ZnCl_{2(aq)}$ and $FeCl_{3(aq)}$	________________________	________
c) mixing $FeSO_{4(aq)}$ and Cl_2-sat'd water	________________________	________
d) immersing lead in a $ZnCl_{2(aq)}$ sol'n	________________________	________
e) immersing Zn in $AgNO_{3(aq)}$ sol'n	________________________	________

3. Consider the reaction: $Pb + 2Ag^{1+} \rightarrow Pb^{2+} + 2Ag$

   a) Would this represent the reaction of a galvanic or an electrolytic cell? _________

   b) What change in potential will transferred electrons feel? _________ V

4. Circle the <u>strongest oxidant</u> among these species: $\mathbf{I^{1-}}$ $\mathbf{Cl_2}$ $\mathbf{O_2}$ $\mathbf{F^{1-}}$ $\mathbf{K^{1+}}$ $\mathbf{Cu^{2+}}$

5. Circle the <u>strongest reductant</u> among these species: $\mathbf{Al^{3+}}$ **Pb** **Ag** $\mathbf{F_2}$ $\mathbf{I_2}$ $\mathbf{Na^{1+}}$

Batteries

Time: 15 minutes
Topic: Batteries, electrodes, salt bridge
Type: Probe
Level: Introductory

Overview: Students will observe electrochemical animations and describe the redox chemistry involved.

Equipment and Materials: none

Objective(s):
Students will be able to describe how a galvanic cell works.
Students will be able to identify anodes and cathodes.
Students will be able to explain why a salt bridge is needed.
Students will be able to identify and write half reactions for oxidation and reduction.
Students will be able to write and balance simple redox reactions.

Misconceptions: Electrons flow through the electrolyte solution and the salt bridge in order to complete the "circuit". Electrons move by attaching to ions. Anions and cations in the salt bridge and electrolyte transfer electrons between electrodes. Consult the reference for other common misconceptions about electrochemistry.[1]

Other Student Difficulties: Correct use of terminology.

Prerequisites: Using a Standard Reduction Potential Table, writing redox reactions

Activity Table

Task	Reason	Notes
Have students watch a computer animation and make detailed observations.	To see how a battery works.	Watch "Copper, Silver Cell". Watch the "closer looks" as well.
Define anode and cathode.	To introduce new terms.	
Ask students to identify the anode and cathode in the animation.	Students will be able to identify anodes and cathodes.	anode $Zn_{(s)} / Zn^{2+}_{(aq)}$ cathode $Cu_{(s)}/Cu^{+2}_{(aq)}$
Have students list ALL ions present in the animation.	To check observation skills.	Cu^{2+}, Zn^{2+}, K^{1+}, NO_3^{1-}
Have students write equations describing what is happening at each electrode.	To practice writing half reaction for reduction and oxidation.	$Zn_{(s)} \Leftrightarrow Zn^{2+}_{(aq)} + 2e-$ $Cu^{+2}_{(aq)} + 2e- \Leftrightarrow Cu_{(s)}$
Have them determine the potential (E^o) for each ½ cell.	To review using table of standard reduction potentials.	anode +0.76 V cathode +0.34 V

Activity Table continued

Have students write overall reaction and determine the overall cell potential.	To practice writing redox reactions and determining cell potentials.	$Zn_{(s)} + Cu^{2+}_{(aq)} \Leftrightarrow Zn^{2+}_{(aq)} + Cu_{(s)}$ +1.10 V
Ask students what the salt bridge is composed of and what role it plays in the battery.	To have students use their observations to explain the role of the salt bridge.	
Using observations and what they have learned, have students describe in detail what is happening when the wires are connected.	To describe how an electrochemical cell works. Review.	
Give students the electroquiz[1].	To test understanding.	Quiz found in Sanger ref.

Related Activities: Activity Series, Electron Hopping, Electrolysis, Constructing a Battery

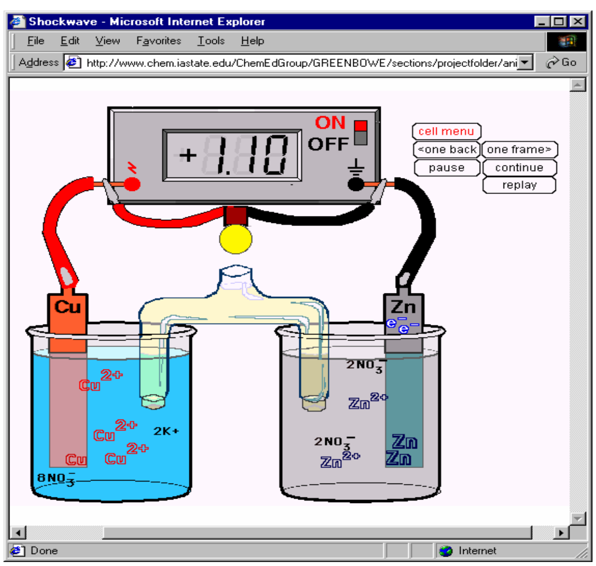
References: [1]Sanger, Michael J.; Greenbowe, Thomas J. *J. Chem. Educ.* **1997**, *74*, 819-823.

http://www.chem.iastate.edu/ChemEdGroup/GREENBOWE/sections/projectfolder/animations/CuZncell.html

Discussion and Supplementary Material:

The animations developed by Thomas J. Greenbowe and co-workers are very detailed. Students can observe reactions on the microscopic level in order to prevent or correct misconceptions that students have about batteries. A picture of the "Copper, Silver Cell" is shown below. The reactions are also provided for your convenience.

anode	$Zn_{(s)} \Leftrightarrow Zn^{2+}_{(aq)} + 2e-$	+0.76 V
cathode	$Cu^{+2}_{(aq)} + 2e- \Leftrightarrow Cu_{(s)}$	+0.34 V
	$Zn_{(s)} + Cu^{2+}_{(aq)} \Leftrightarrow Zn^{2+}_{(aq)} + Cu_{(s)}$	+1.10 V



Electrolysis

Time: 15 minutes
Topic: Electrolysis
Type: Demo / Probe
Level: Introductory

Overview:
Students will observe the process of electrolysis and write equations to describe the process.

Equipment and Materials:
Electrolysis apparatus, food coloring, computer with Internet connection.

Objective(s):
Students will be able to describe an electrolytic process.
Students will be able to write equations for an electrolytic process.
Students will be able to observe the microscopic nature of an electrolytic process.
Students will be able to distinguish between spontaneous and non-spontaneous processes.

Misconceptions: Cell potential should always be positive.
Prerequisites: Electrochemistry

Activity Table

Task	Reason	Notes
Review galvanic cells.	To review.	
Give students the equation showing the electrolysis of water. Have them find the two half reactions.	To review using the table of standard reduction potentials to write equations.	$2\ H_2O \rightarrow 2\ H_2 + O_2$ This can be tricky because many equations involve H_2, O_2, and water.
Ask them if this is a spontaneous reaction.	To review E^o_{cell} calculations.	E^o_{cell} = -1.29 Volts (non-spontaneous)
Set up the electrolysis apparatus and describe how one column will collect the H_2 and the other O_2.	To explain how the apparatus is set-up.	
Perform the demo.[1]	To allow students to make observations.	
Ask students what their observations are.	To see if they notice the 2:1 ratio of gas forming.	This shows how the equation is balanced.
Have students watch the animation of "NaI (molten) Electrolysis".[2]	To observe microscopic nature of electrolysis.	See website in reference 2. Picture is provided if animation is not available.
Ask students to write the chemical equation that represents the reaction that is occurring.	To tie the process to a chemical equation.	$2Na^+ + 2I^- \rightarrow 2Na + I_2$

Activity Table continued

Ask students to write the half reactions and determine the E^o_{cell}.	To practice writing chemical equations and using table of reduction potentials.	$2(Na^+ + 1e^- \rightarrow Na)$ -2.71V $2I^- \rightarrow I_2 + 2e^-$ -0.54V $E^o_{cell} = -3.25$ V
Ask students if this reaction is spontaneous.	To see if they can distinguish between sp. and non-sp.	
Ask students what the sign of ΔG is.	To relate this to a familiar thermodynamic term.	ΔG is (+) $\Delta G = -\eta\Im E^o$
Ask students to define an electrolytic cell in their own words.	To have students describe an electrolytic process and conclude the activity.	

Related Activities: Activity Series, Batteries, Electron Hopping, Constructing a Battery

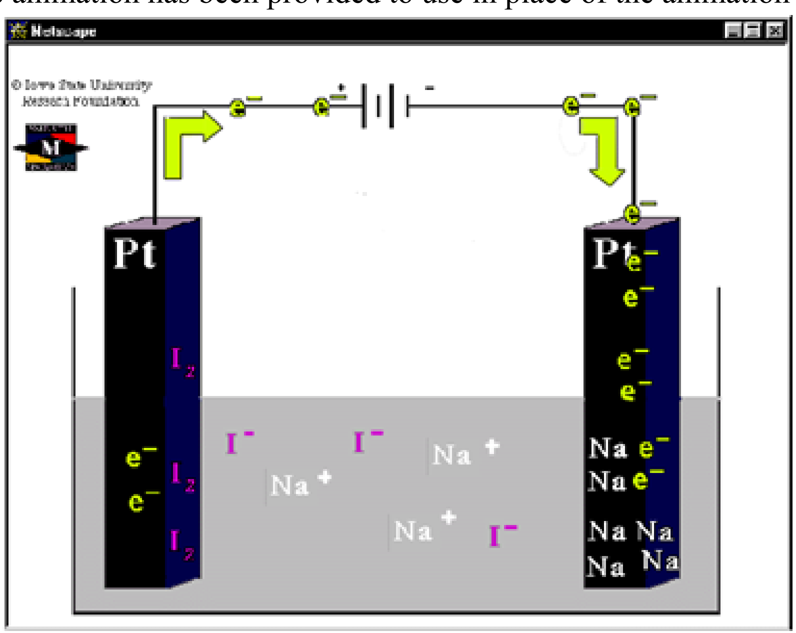
References:

[1]Shakhashiri, B.Z. *Chemical Demonstrations: A Handbook for Teachers of Chemistry Vol. 4,* page 156. (http://genchem.chem.wisc.edu/demonstrations/General_Chemistry_Demos.html)

[2]http://www.public.iastate.edu/~iachemed/FIPSE/MULTIMEDIA/DIRECTOR/homepage.html This link was outdated as of November 2001 check the following website for updates and other animations:

http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/animationsindex.htm

A picture of the animation has been provided to use in place of the animation if desired.



Discussion and Supplementary Material:

The electrolysis of water is an example of an electrolytic cell. There are many variations of this demonstration. The standard demo uses a Hoffman apparatus in which a voltage can be applied to break down water into hydrogen and oxygen gas. Bromothymol blue indicator can be used to show that the side of the reaction creating hydrogen is basic (blue) and the side creating oxygen is acidic (yellow).[1] If bromothymol blue is not available, then food coloring can be used to make the water more visible.

A 2:1 ratio of the gases will be visible just as the equation stoichiometry indicates.

$$2\ H_2O_{(l)} \rightarrow 2\ H_{2\,(g)} + O_{2\,(g)}$$

Reduction:	$2\ (\ 2\ H_2O_{(l)} + 2e- \rightarrow H_{2\,(g)} + 2\ OH^{1-}\ )$	-0.41 V
Oxidation:	$2\ H_2O_{(l)} \rightarrow O_{2\,(g)} + 4\ H^+_{(aq)} + 4e-$	-0.88 V
	$6H_2O_{(l)} \rightarrow 2H_{2\,(g)} + O_{2\,(g)} + \underbrace{4OH- + 4H^+_{(aq)}}_{4H_2O\text{ (cancels with 4 waters on other side)}}$	-1.29 V

<u>NaI (molten) Electrolysis</u> (a picture of the animation is provided below[2])

$2(Na^+ + 1e- \rightarrow Na)$	-2.71 V
$2I^- \rightarrow I_2 + 2e-$	-0.54 V
$2Na^+ + 2I^- \rightarrow 2Na + I_2$	-3.25 V

This is a non-spontaneous reaction, therefore, ΔG is positive (+) and this is an electrolytic cell.

$\Delta G = -\eta \Im E^o$

KI Electrolysis

Time: 15 minutes
Topic: Electrochemistry
Type: Demo / Investigation
Level: Advanced

Overview:
Students will explain and will write half reactions for what occurs in the demonstration.

Equipment and Materials:
50 ml 1 M Potassium iodide, 1 ml phenolphthalein indicator, two 4-in pieces of silver or platinum wire, petri dish, dropper, 6-V lantern battery

Objective(s):
Students will use the table of standard reduction potentials.
Students will use observations to determine reactions.
Student will write redox reactions.

Misconceptions: The components of a solution used in an electrolytic cell are always the substances oxidized or reduced.

Prerequisites: Electrochemistry

Activity Table

Task	Reason	Notes
Perform demo and have students make observations.	To collect data to answer questions.	See Supp. Mat. for instructions on demo.
Ask students to write the half reactions for the demo.	To apply electrochemistry.	Most students will write reactions using K^{1+} and I^{1-}.
Ask students to share their reactions. Discuss the reactions as a class.	To show students answers are reasonable.	
Point out that hydroxide is produced in the reaction and ask students to rethink their half reactions.	To combine observation with applying electrochemistry.	
Ask students to share their reactions again. Discuss as a class.	To provide the correct reactions describing the demo.	
Ask students to explain why potassium is not generated.	To engage students in explanation.	

Related Activities: Batteries, Electrolysis

References: NCSU Demo Room

Discussion and Supplementary Material:

Current is passed an aqueous solution of 1 M potassium iodide. Iodide ions are oxidized to Iodine at the anode as noted by the brown color observed around this electrode in the colorless solution. Water is reduced to hydrogen gas at the cathode. The production of hydroxide is noted by adding phenolphthalein. The solution will turn pink around this electrode

Procedure:
Connect the two wires to the battery terminals. Fill the petri dish 3/4 full with 1M KI solution. Add 1 ml of phenolphthalein. Place the ends of the electrodes into the solution. DO NOT let the two electrodes touch. The solution near the cathode (positive terminal) will turn yellow-brown while the solution near the anode (negative terminal) will turn pink.

Discussion:
Students will typically assume that the iodide is being oxidized and the potassium is being reduced in this electrolytic cell. This answer should be acknowledged because the reactions would be correct; they just do not match the observations from the demo. In most cases students have not been exposed to indicators extensively and will not know that hydroxide is being produced. Therefore, this demo provides good points for discussion. Both expected responses are provided below. The reason that water is reduced rather than potassium is because it takes significantly less voltage to reduce the water than the potassium.

Expected Response:

Anode: $2\ I^{1-}_{(aq)} \rightarrow I_{2\ (s)} + 2e-$

Cathode: $K^{1+}_{(aq)} + e- \rightarrow K_{(s)}$

Correct Response:

Anode: $2\ I^{1-}_{(aq)} \rightarrow I_{2\ (s)} + 2e-$

Cathode: $2\ H_2O + 2e- \rightarrow H_{2\ (g)} + 2\ OH^{1-}_{(aq)}$

The Silver Cell

Time: 45 minutes
Topic: Electrolysis and Reduction Potentials
Type: Investigation
Level: Intermediate

Overview: Students will construct a silver-silver chloride reference electrode and use it to determine potentials of other metals and construct a reduction potential table.

Equipment and Materials: A 9-Volt Battery, electrical wires, a pH meter with alligator clips, 3 cm Ag wire, 3 cm Fe wire, 3 cm Cu wire, 3 cm Zn wire, 0.1 M $AgNO_3$, 0.1 M $CuCl_2$, 0.1 M $ZnCl_2$, 0.1 M $Fe(NH_4)_2(SO_4)_2$, 0.1 M NaCl, saturated KCl solution, filter paper, and five 10-mL beakers, steel wool

Objective(s):
Students will plate silver chloride on a silver wire using an electrolytic process.
Students will use a reference electrode to determine potentials of various metals.
Students will construct a reduction potential table using the data they collect.
Students will evaluate the reliability of these tables.

Misconceptions: The hydrogen reference electrode is the only electrode that can be used to create standard reduction potential tables.

Prerequisites: Electrolysis

Activity Table

Task	Reason	Notes
Have students set up the electrolysis apparatus or have students dip a piece of silver metal in saturated KCl and then $AgNO_3$ several times.	To create the silver-silver chloride reference electrode.	Better results are yielded using the electrolysis method.
Have students set up the battery using the reference electrode and one of the Cu, Fe, and Zn metal wires and corresponding solutions.	To enable students to measure the potential for different metals.	The instrument may have some fluctuations when measuring voltage.
Measure potentials for all available metals.	To compare different metals.	Be sure that students keep the black wire attached to the Ag/AgCl electrode.
Have students use the data to create a qualitative standard reduction potential table for Cu, Fe, and Zn.	To illustrate how reduction potential tables are created.	Zn metal should have the greatest negative potential and Cu metal should have the only positive potential.

Activity Table continued

Give students the standard potential for the Ag/AgCl reference electrode and have them to calculate the actual potentials.	To prove that the qualitative table is correct.	The numerical values may not exactly match but the location of the metals will.
Have students to identify the cathode and anode in each reaction.	To illustrate how these terms are used in electrochemistry.	The iron and zinc metals will be anodes and the copper will be the cathode.
Conclude by discussing the students' results and observations.	To re-emphasize concepts of electrolysis and standard reduction potential tables.	

References: Thomas, J.M., *J. Chem. Educ.* **1999,** 76, 97.

Discussion and Supplementary Material:

The purpose of the experiment is to create and use a silver-silver chloride reference electrode. This electrode can be created in two different ways. The first method is an electrolytic method that requires using current to force the non-spontaneous reaction. A piece of silver wire 3-cm long is connected to a 1.5 kΩ resistor in series with the positive terminal of a 9-Volt battery. A 3-cm piece of copper wire is connected to the negative terminal of the 9-Volt battery. Both wires should be lowered into the same beaker of 0.1 M NaCl. The reaction should continue until a black residue is noted on the silver metal (continue for two minutes). Remove the silver metal from the solution and rinse with distilled water. Electrodes that begin to form a white precipitate of AgCl may not work as well.

Alternatively, the electrode can be made by immersing the silver wire into a saturated KCl solution and then immersing it into a 0.1 M $AgNO_3$ solution. This should be repeated until a fine white coating is noted on the metal. After the metal is coated, allow it to dry. The electrolytic method yields better results than the dipping method because the silver chloride that accumulates on the silver remains more intact during use. However, with the non-electrolytic method, the silver chloride comes off easily.

All metals used for the experiment came from Alfa Aesar. Table 1 specifically lists pertinent information concerning the metals:

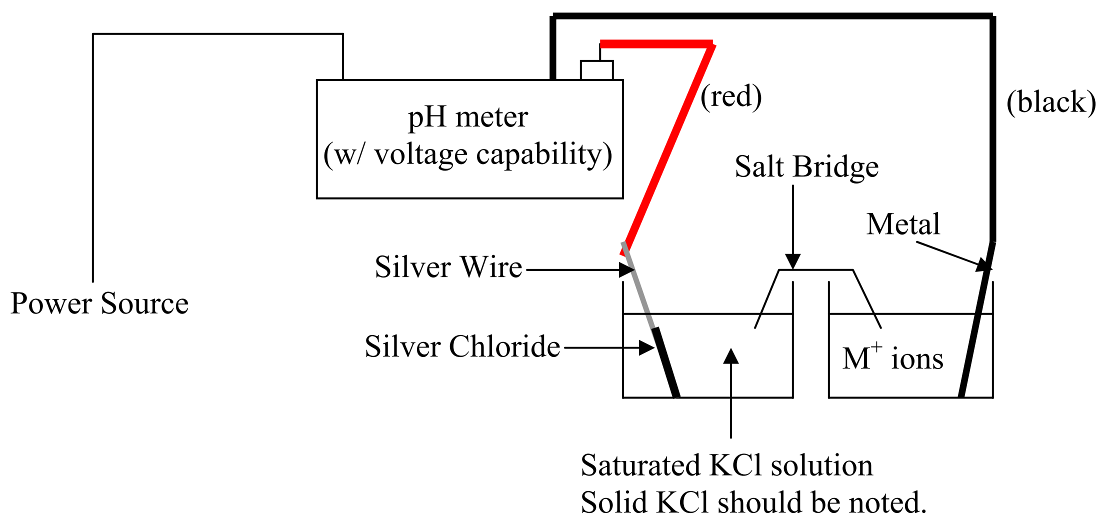
Table 1: Description of Metals Used

Metal	Diameter	Length	Description	Stock Number
Copper	1.0 mm	25 m	99.9% metal basis	10782
Iron	1.2 mm	100 m	99+% metal basis	14147
Silver	1.0 mm	1 m	99.9% metal basis	41456
Zinc	1.0 mm	1 m	99.95% metal basis	42705

Steel wool can be used to clean any of the wires. This cleaning will allow for better electrical connections and reactions.

When setting up the cell, the red wire is connected to the silver-silver chloride reference electrode. The black wire is connected to the other metal electrode. This is important because the sign of the voltage will depend upon how these wires are connected. If the wires are connected in a reverse manner, the results would be incorrect. Strips of filter paper soaked in 0.1 M NaCl were used for the salt bridges. Figure 1 illustrates how the apparatus was set up:

Figure 1: The Apparatus Used for the Experiment



When recording the potential, one will probably have to make an approximation. Most instruments oscillate between a range of potentials. Therefore, an approximation can only be determined. For the particular metals Cu, Fe, and Zn, there should not be any difficulties determining the order in which each should appear on the reduction potential table. Negative potentials result when the metal is more easily reduced than the reference electrode. Alternatively, positive potentials result when the metal is more easily oxidized than the reference electrode. Hence, copper is more easily reduced than the silver-silver chloride reference electrode. Iron and zinc are more easily oxidized than the silver-silver chloride reference. Sample results are listed in Table 2. The reading for the copper was less than one might expect, but the order can still be interpreted easily. Other metals can be used, but the method should be tested prior to classroom activity. Using electrolyte solutions of concentration less than 1 M may result in inaccurate experimental potentials, but they yield the same qualitative results.

Table 2: Sample Results

Metal Reaction	Potential
$Zn^{2+} + 2e^{-} \Leftrightarrow Zn(s)$	-950 mV
$Fe^{2+} + 2e^{-} \Leftrightarrow Fe(s)$	-648 mV
$AgCl(s) + e^{-} \Leftrightarrow Ag(s) + Cl^{-}$	0 mV
$Cu^{2+} + 2e^{-} \Leftrightarrow Cu(s)$	25 mV

Cathode and anode are commonly used terms in electrochemistry. Cathode is used for the cell that is reduced, and anode is used for the cell that is oxidized. Therefore, the copper cell is the cathode and the iron and zinc cells are anodes when reacting the silver-silver chloride reference electrode.

Classic Concentration

Time: 15 minutes
Topic: Nernst Equation
Type: Probe
Level: Intermediate

Overview: Students will build virtual cells and observe the effect of concentration on potential.

Equipment and Materials: computer with internet connection

Objective(s):
Students will review electrochemical concepts.
Students will build representations of electrochemical cells.
Students will observe how concentration affects potential.
Students will be introduced to the Nernst equation.
Students will construct graphical displays of data to examine linear relationships.
Students will apply the Nernst equation.

Misconceptions: Potential does not depend on concentration.
Other Student Difficulties: Expressing Q (reaction quotient) accurately.

Prerequisites: basic redox electrochemistry

Activity Table

Task	Reason	Notes
Assign two metals to each group (Ag, Cu, Zn) and have them determine anode, cathode, net reaction, and write cell notation and calculate standard potential.	To review basic electrochemical concepts.	See solutions for each combination in Supplementary Material.
Have students check their work by building a virtual cell.	To build representations of electrochemical cells.	http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/electroChem/voltaicCell20.html
Have students build the same cell and collect data at various concentrations.	To observe how concentration affects potential.	http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/electroChem/voltaicCellEMF.html
Have students describe in writing how potential varies when the concentration of anode and cathode electrolytes are varied.	To study the relationship.	

Activity Table continued

Introduce the Nernst equation.	To introduce the Nernst equation.	
Have students do a practice problem using this equation.	To practice applying a new concept.	
Have students graph E vs log Q.	To examine graphical relationships.	
Define the graphical relationships.	To examine graphical relationships.	
Give a challenging group problem.	To wrap up the activity by applying the concepts.	See Supplementary Material.

References:

http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/electroChem/voltaicCell20.html

http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/electroChem/voltaicCellEMF.html

Discussion and Supplementary Material:

The various combinations of cells that can be constructed with Ag, Cu, and Zn are given below.

$Cu \mid Cu^{2+}$ (__M) $\parallel$ Ag^{+} (__M) $\mid Ag$

Red (cathode): $Ag^{+}_{(aq)} + 1e^{-} \Leftrightarrow Ag_{(s)}$ +0.80
Black (anode): $Cu_{(s)} \Leftrightarrow Cu^{2+}_{(aq)} + 2e^{-}$ -0.34

$\mathbf{2Ag^{+}_{(aq)} + Cu_{(s)} \Leftrightarrow 2Ag_{(s)} + Cu^{2+}_{(aq)}}$ **+0.46**

$Zn \mid Zn^{2+}$ (__M) $\parallel$ Ag^{+} (__M) $\mid Ag$

Red (cathode): $Ag^{+}_{(aq)} + 1e^{-} \Leftrightarrow Ag_{(s)}$ +0.80
Black (anode): $Zn_{(s)} \Leftrightarrow Zn^{2+}_{(aq)} + 2e^{-}$ +0.76

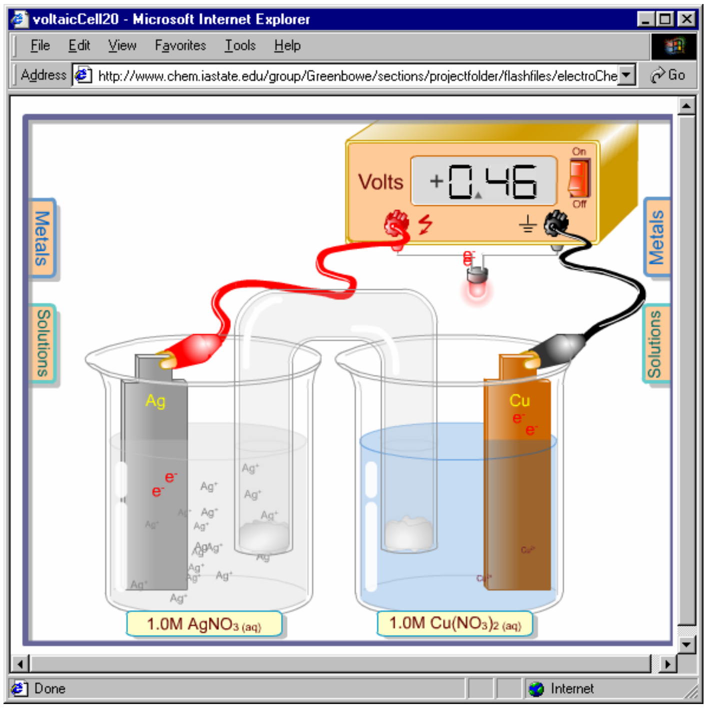
$\mathbf{2Ag^{+}_{(aq)} + Zn_{(s)} \Leftrightarrow 2Ag_{(s)} + Zn^{2+}_{(aq)}}$ **+1.56**

$Zn \mid Zn^{2+}$ (__M) $\parallel$ Cu^{2+} (__M) $\mid Cu$

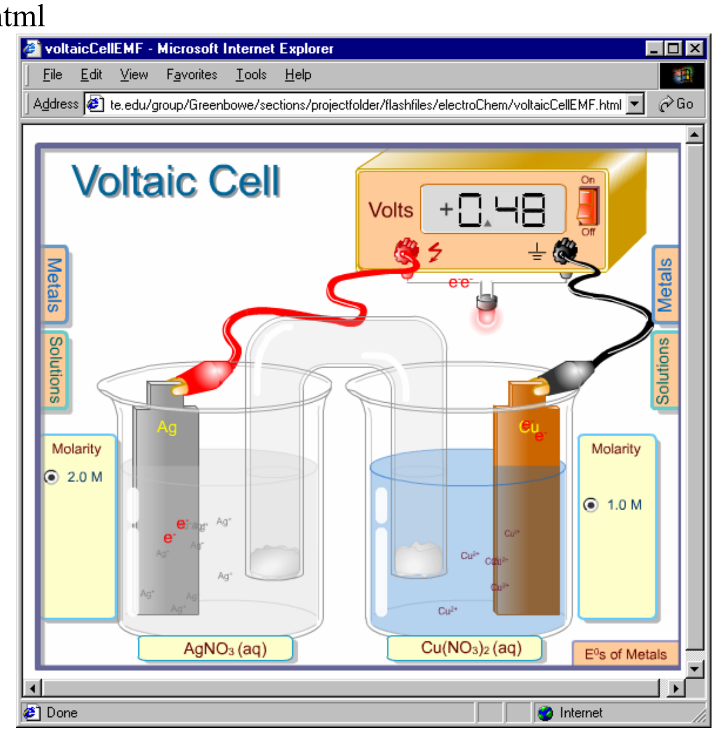
Red (cathode): $Cu^{2+}_{(aq)} + 2e^{-} \Leftrightarrow Cu_{(s)}$ +0.34
Black (anode): $Zn_{(s)} \Leftrightarrow Zn^{2+}_{(aq)} + 2e^{-}$ +0.76

$\mathbf{Cu^{2+}_{(aq)} + Zn_{(s)} \Leftrightarrow Cu_{(s)} + Zn^{2+}_{(aq)}}$ **+1.10**

Building a Virtual Cell:
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/electroChem/voltaicCell20.html



Varying Concentration:
http://www.chem.iastate.edu/group/Greenbowe/sections/projectfolder/flashfiles/electroChem/voltaicCellEMF.html



Nernst Equation

$$E_{cell} = E°_{cell} - \frac{0.02569}{\eta} \ln Q$$

$$E_{cell} = E°_{cell} - \frac{0.05916}{\eta} \log Q$$

Calculate the cell potential at 25°C of a cell in which the concentration of Zn^{2+} ions is 0.10 M and that of the Cu^{2+} ions is 0.0010M. ANS: 1.04 V

What is the potential of a spontaneous cell that contains a 0.1-M solution of Sn^{2+} ions and a 0.5 M solution of Al^{3+} ions with the appropriate corresponding electrodes? ANS: 1.5 V

Graphing

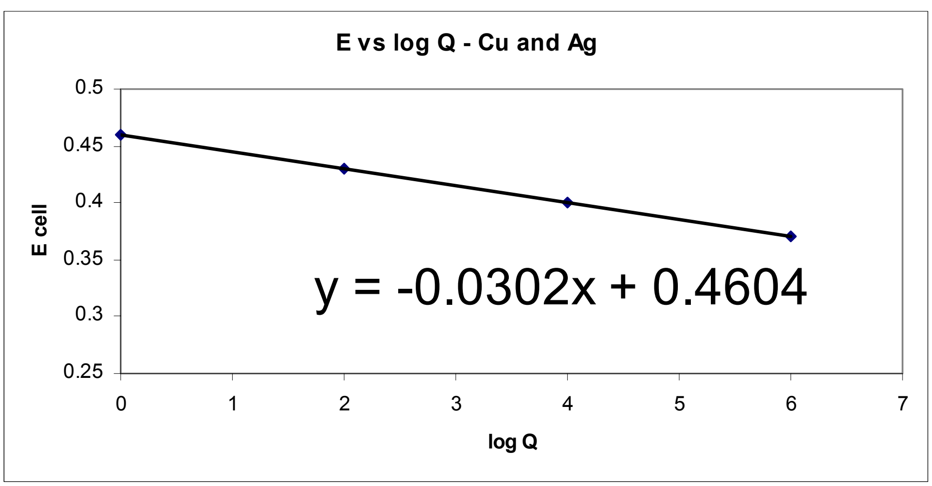
$$E_{cell} = E°_{cell} - \frac{0.05916}{\eta} \log Q$$

$$y = b + m \quad x$$

$y \rightarrow$ how potential varies with varying concentrations
$x \rightarrow$ varying concentrations
$m \rightarrow$ get the # of electrons
$b \rightarrow E°_{cell}$

Data as the concentration is varied for silver ion for Cu/Ag cell.

$[Ag^+]$ (M)	$[Cu^{2+}]$ (M)	log Q	ξ (V)
2.0	1.0	-0.6	0.47
1.0	1.0	0	0.46
0.1	1.0	2	0.43
0.01	1.0	4	0.40
0.001	1.0	6	0.37



Determine $E°_{cell}$ and the # of e- transferred from the following equation

$$y = -0.0302x + 0.4604$$

$$b = E^o = 0.4604$$
$$m = 0.05916 / \eta$$
$$\eta = 0.05916 / m$$

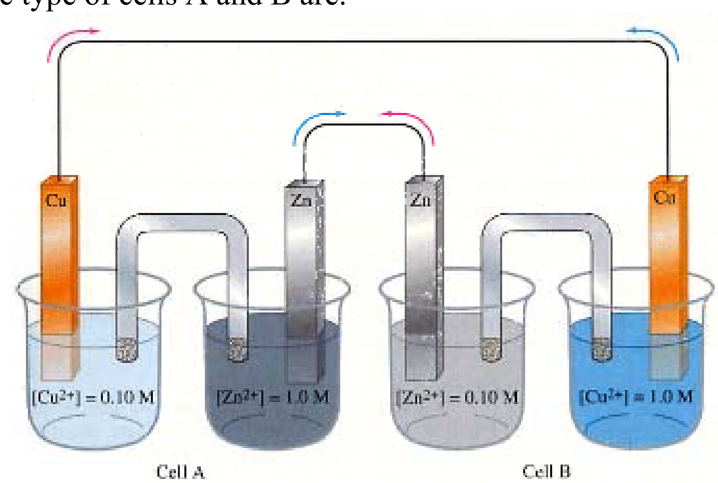
$$= 0.05916 / 0.0302 = 1.96 \sim 2\ e^{-}s$$

Group Problem

The figure below shows two electrochemical cells joined together in a common circuit.

1. Indicate whether a net flow of electrons occurs in the direction of the red arrows or the blue arrows.

2. Indicate the type of cells A and B are.



Note that the two cells have the same electrodes in the same solutions, but that the solution concentrations differ. Also, the cells are joined in such a way that the cells oppose one another. The cell exerting the greater emf as a voltaic cell is the one that will establish the direction of electron flow. The two cells have the same E^o_{cell} value.

Reduction (cathode):	$Cu^{2+}(1M) + 2e^- \rightarrow Cu_{(s)}$	$E^o_{red} = 0.337$ V
Oxidation (anode):	$Zn_{(s)} \rightarrow Zn^{2+}(1M) + 2e^-$	$E^o_{ox} = 0.763$ V
Net:	$Zn_{(s)} + Cu^{2+}(1M) \rightarrow Zn^{2+}(1M) + Cu_{(s)}$	$E^o_{cell} = 1.100$ V

Cell A: $E_{cell} = 1.1V - \frac{0.005916\ V}{2} \log (1.0 / 0.1) = 1.07$ V

Cell B: $E_{cell} = 1.1V - \frac{0.005916V}{2} \log (0.1 / 1.0) = 1.13$ V

Cell B > Cell A Therefore, Cell B will determine the flow of electrons (**Red arrows**)

Unknown Ore

Time: 10 minutes
Topic: Nernst equation
Type: Real World Problem
Level: Intermediate

Overview:
Students will apply concepts of the Nernst Equation to a real world problem.

Equipment and Materials:
none

Objective(s):
Students will apply concepts of the Nernst Equation to a real world problem.

Student Difficulties:
Finding the metal corresponding to the correct potential (+ or -).

Prerequisites:
Electrochemistry and Nernst equation

Activity Table

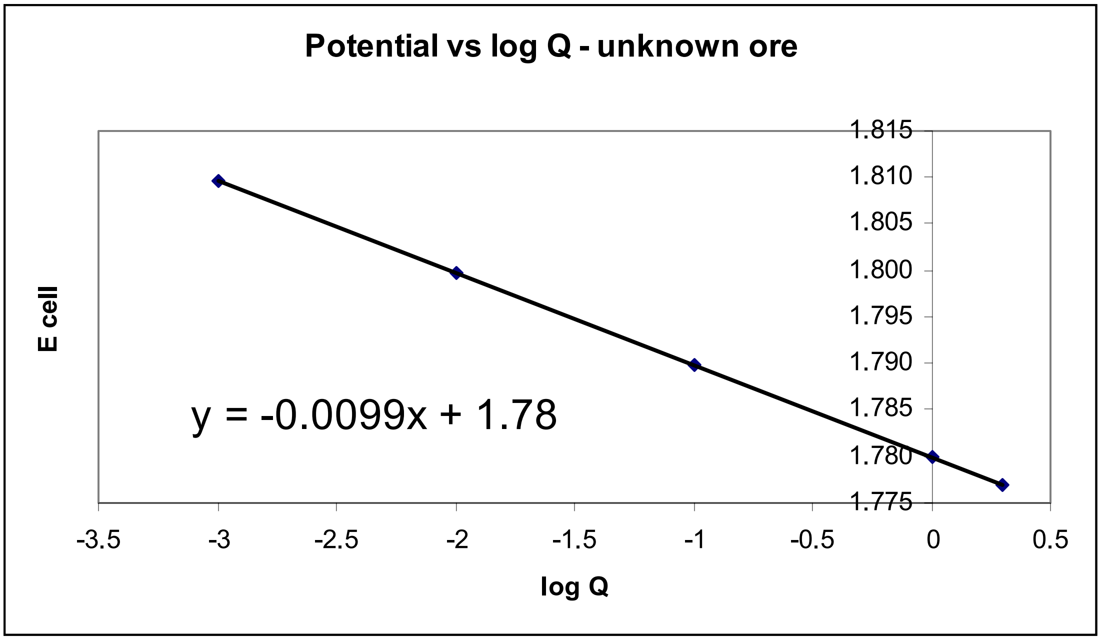
Task	Reason	Notes
Give students the r7eal world problem to work on.	To apply concepts of the Nernst Equation to a real world problem.	See Supplementary Material.

Related Activities: Classic Concentration

References: none

Discussion and Supplementary Material:

An unknown ore was removed from an archeological digging site. It was taken to a chemistry lab that used electrochemical methods to determine its identity. Gold is often used as a reference in electrochemistry. The ore was compared to gold in an electrochemical cell with varying concentrations. The data is shown in the plot below.



Identify the unknown ore and determine the number of electrons transferred.

Solution:

$$E_{cell} = E°_{cell} - \frac{0.05916}{\eta} \log Q$$

$y = 1.78 - 0.0099\ x$

$E^o = 1.78 = \text{cathode} - \text{anode}$

Gold most likely serves as the cathode due to its highly positive potential.

$1.78 = 1.5 - x$

$x = -0.28$

This potential corresponds to **cobalt**.

Appendix B - Conceptual Questions

The questions found on the following pages represent a conglomerate of questions found in the literature, in the public domain, obtained from various instructors, and some original questions. The following work is not claimed as work of the author. Some of the most common resources used for many of the questions include: http://jchemed.chem.wisc.edu/JCEWWW/Features/CQandChP/index.html, http://people.brandeis.edu/~herzfeld/alphabetical.html, and http://www.chem.wisc.edu/%7Econcept/.

Table B.1 List of Conceptual Questions used in Quantitative Study

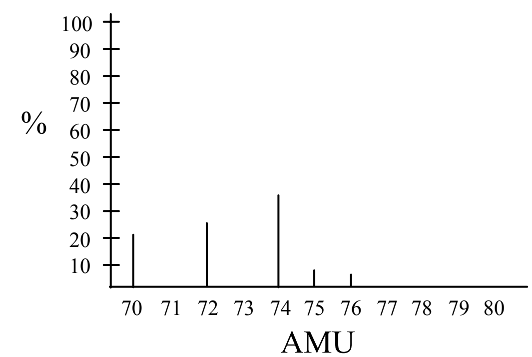
#	**Question**
1.	The early alchemists used to do an experiment in which water was boiled for several days in a sealed glass container. Eventually, some solid residue would appear in the bottom of the flask, which was interpreted to mean that some of the water in the flask had been converted into "earth". When Lavoisier repeated this experiment, he found that the water weighted the same before and after heating and the mass of the flask plus the solid residue equaled the original mass of the flask. Were the alchemists correct? Explain what really happened.
2.	Assuming that an electron's mass is negligible compared to protons and neutrons. A mass spectrometer separates atoms and molecules based on atomic mass. When a sample of magnesium, Mg, is passed through a mass spectrometer the following graph is obtained. Why does this graph have three lines? What is the atomic number of this element?_________ 
3.	Which of the following samples could be methane, CH_4? *Circle the letter to all that apply.* (a) 0.40 moles H_2 molecules and 0.10 moles C atoms (d) 8 mol H atoms and 2 moles C atoms (b) 4.0 moles H atoms and 6.022×10^{23} C atoms (e) 1.0 g of H atoms and 12.0 g of C atoms (c) 4.0 g of H atoms and 1.0 g of C atoms (f) none of these could be methane

Table B.1 (continued)

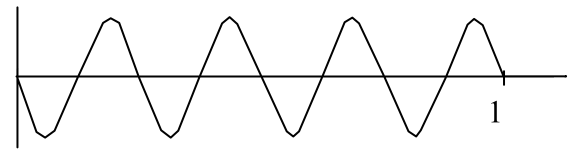
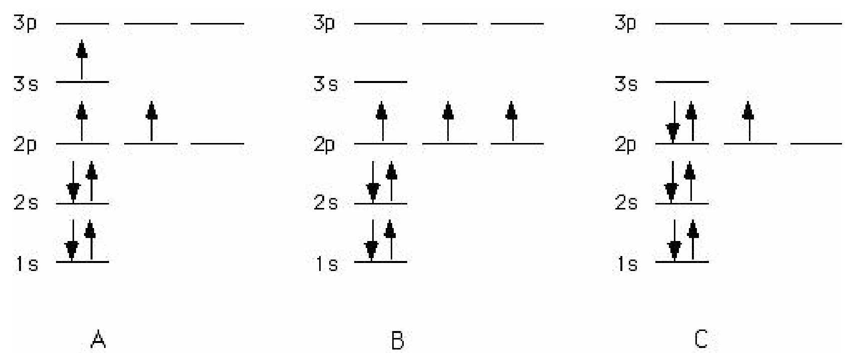
4.	What is the frequency of the following wave? Answer ________ 
5.	*Circle the answer*. When a chromium plate is irradiated with blue light, no electrons are released. To release electrons (a) the intensity of the light should be increased. (b) red light should be tried. (c) either of the above. (d) neither of the above. Explain your answer!
6.	Which of the following electron diagrams represents a correct ground state? _______ Which diagram or diagrams do not follow Hund's rule? _______ 

Table B.1 (continued)

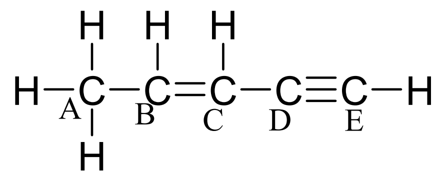
7.	The unstable fulminate ion (CNO-) has two possible resonance structures. a) Circle the best structure and explain your reasoning for that choice. [:C=N=O:] $^-$ Answer the following questions for the structure chosen in part a. [:C≡N–O:] $^-$ b) What is the hybridization of the N? ________ c) Is this molecule polar or non-polar? ________ d) What is the molecular shape of this ion? ________
8.	In the following molecule, identify the carbon or carbons that:  a) use sp^2 hybrid orbitals in bonding. ________ b) conforms to a tetrahedral arrangement ________ c) are involved in pi bonds ________ d) carbons with angles of 120° ________
9.	Show the Lewis structure (4pts) for the ion $SbBr_4^-$ and answer the following questions a) Electronic geometry ________ b) Molecular geometry ________ c) Hybridization of Sb ________ d) Is the molecule polar or non-polar? ________
10.	Draw using valence bond theory the molecular arrangement of C_2H_2 (2nd Version C_2H_4). **Show orbital arrangement including orbital overlap**. Indicate any σ and π bonds in the structure.

Table B.1 (continued)

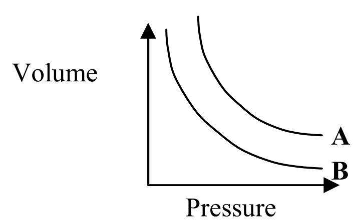
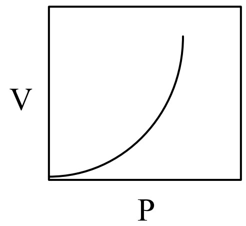
11.	Which will always decrease the volume of a sample of methane gas which occupies a volume of 2.4 L at 25°C? ________ (a) An increase in pressure and an increase in temperature. (b) A decrease in pressure and a decrease in temperature. (c) An increase in pressure and a decrease in temperature. (d) A decrease in pressure and an increase in temperature
12.	To convert a sample of air into a liquid, you would probably have to_______. (a) increase temperature and increase pressure (b) decrease temperature and increase pressure (c) decrease temperature and decrease pressure (d) increase temperature and decrease pressure (e) air cannot be converted into a liquid
13.	Consider all relationships among ideal gas law variables. **Demonstration:** What will happen to each gas law variable when an inflated balloon is placed in liquid nitrogen? a) number of gas moles: goes up, goes down, stays constant ___________ b) temperature: goes up, goes down, stays constant ___________ c) volume of trapped gas: goes up, goes down, stays constant ___________ d) value of the gas constant: goes up, goes down, stays constant ___________
14.	The following PV curves were obtained at different constant temperatures. Which plot, A or B, represents the lower temperature? 

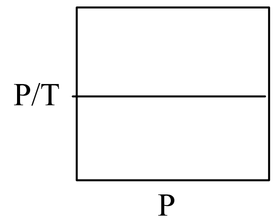
Table B.1 (continued)

15. State which gas behaves significantly <u>different</u> from that expected for an ideal gas.

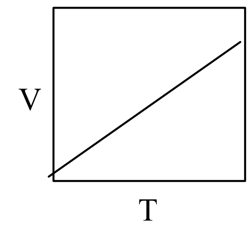
Gas A



Gas B



Gas C



16-18) Using the following table, classify the substances in questions 16 through 18.

Substance	**melting pt (°C)**	**boiling pt (°C)**	**Electrical conductor?**	
			solid state	**liquid state**
Ti	1675	3260	yes	yes
BN	3000 (sublimes)	-----	no	no

16. Titanium can be classified as a(n) __________ solid.
a) ionic b) molecular c) metallic d) covalent

17. Boron nitride can be classified as a(n) ___________solid.
a) ionic b) molecular c) metallic d) covalent

18. Osmium forms an oxide with formula OsO_4. The soft crystals of OsO_4 melt at 40°C and the resulting liquid does not conduct electricity. What type of solid would OsO_4 forms?
a) ionic b) molecular c) metallic d) covalent

19. A scientist measures the conductivity of solid beryllium (Be) and boron (B). The scientist finds that Be is the best conductor while B conducts electricity slightly. In two sentences or less explain the observed differences in conductivity in terms of band theory and the movement of electrons. Diagrams are required!

Table B.1 (continued)

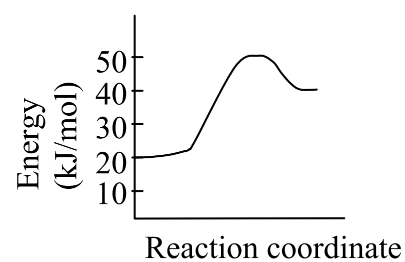
20.	Graphite is a very interesting covalent solid. From the facts explained in class about its structure choose the statement(s) that is correct: a) its flat sheets of sp^2 carbon atoms give it a slipperiness that defines its use as a lubricant. b) the electrical conductivity of graphite parallel to its planes is different from that perpendicular to them. c) is the only non-metal used as an electrical conductor. d) only statements a and b are correct. e) statements a, b, and c are correct.
21.	Explain the difference between an n-type and a p-type semiconductor.
22.	Account for the following observations **in terms of the type of intermolecular forces** that exist in the following compounds: a) Boiling point of NH_3 is –33°C and that of PH_3 is –87°C b) The boiling point of octane, C_8H_{18} is 125.6°C and that of decane, $C_{10}H_{22}$, is 174.1°C.
23.	If water and ammonia molecules interact, what type of forces exists between these two molecules? a) hydrogen bonding b) dipole-dipole forces c) only London forces d) electrostatic forces e) dipole-induced dipole forces and hydrogen bonding. Explain your reasoning.
24.	Consider the following diagram: ________ a) What is ΔH for this reaction? ________ b) Is this reaction endothermic or exothermic? ________ c) What is E_a for the **forward** reaction? ________ d) What is E_a for the **reverse** reaction? 

Table B.1 (continued)

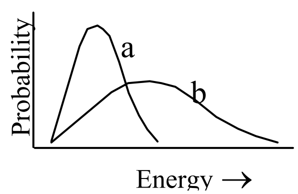
25.	Some early organisms are presumed to have lived by fermenting organic molecules, for example the fermentation of ribose to acetic acid (the distinctive component of vinegar). Use the fermentation reaction below to answer the following questions. $3\ C_5H_{10}O_{5\ (aq)} + 5\ H_2O_{(l)} \rightarrow 5\ CH_3COOH_{(aq)} + 5\ CO_{2\ (g)} + 10\ H_{2\ (g)}$ _____ i) ΔS for this reaction is expected to be (a) positive (b) negative (c) zero _____ ii) Since fermentation releases heat, ΔH is (a) positive (b) negative (c) zero _____ iii) ΔG is (a) positive at high T, negative at low T (b) negative at high T, positive at low T (c) negative at all T (d) positive at all T
26.	_____ Which of the following energy distributions corresponds to the gas with the higher temperature? 
27.	Why will a spark ignite a coal dust explosion in a mine and not cause charcoal to react explosively in a barbecue? Give a one sentence response.
28.	Consider the equilibrium: $2\ BrF_{5\ (aq)} \Leftrightarrow Br_{2\ (g)} + 5\ F_{2\ (g)}$ At equilibrium the expression for K_c is:

Table B.1 (continued)

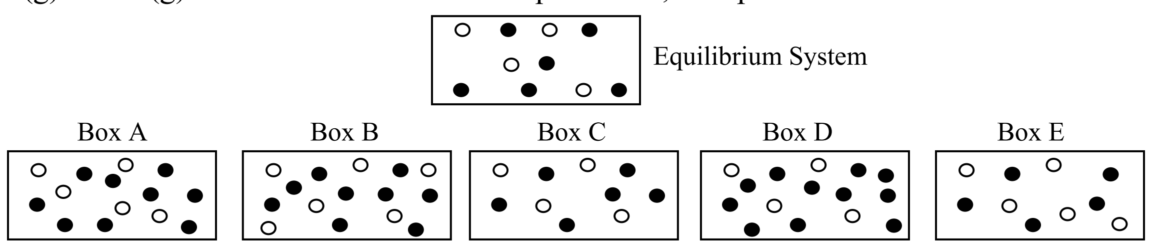
29.	The reaction $Cu^{2+}_{(aq)} + 4\ Br^{1-}_{(aq)} \Leftrightarrow [CuBr_4]^{2-}_{(aq)}$ is endothermic. *blue* *green* ______ To push the reaction to produce more Cu^{2+}, the solution should be (a) warmed (b) cooled (c) not enough information
30.	Consider a mixture of A, B, C & D in which the following reaction is at equilibrium. $A + B \Leftrightarrow C + D$ _____ i) Adding some extra C will initially (a) increase the forward rate (b) increase the backward rate (c) decrease the forward rate (d) decrease the backward rate _____ ii) The amount of D will (a) increase (b) decrease (c) remain the same _____ iii) The amount of A and B will (a) increase (b) decrease (c) remain the same
31.	The reaction ○ (g) ⇔ ● (g) was allowed to come to equilibrium, as represented in the box below.  ____ Some ● was added to the system at equilibrium. Which box (A-E) best represents the new position of equilibrium? Explain your answer.

Table B.1 (continued)

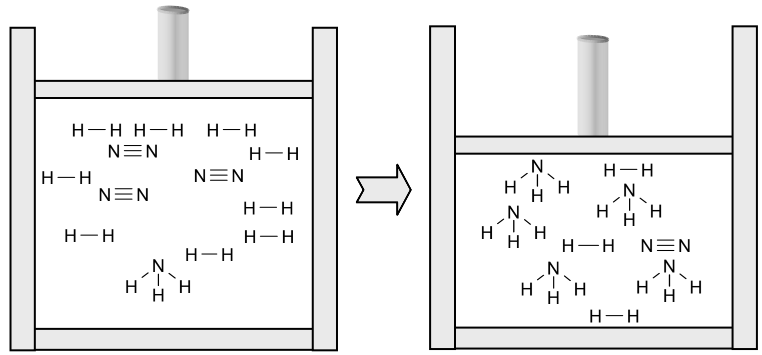
32.	Use Le Châtelier's Principle to describe what is occurring in the following picture. Be concise in your answer. $3\ H_{2\,(g)} + N_{2\,(g)} \Leftrightarrow 2\ NH_{3\,(g)}$ 
33.	Write the equilibrium reaction **and** Ksp expression for $PbCl_{2(s)}$.
34.	Write the net reaction when mixing: a) ammonium sulfate and calcium perchlorate b) potassium nitrate and silver sulfate
35.	A grandmother lived in a rural area of the country noted for its limestone deposits (limestone is $CaCO_3$). She often commented about the "hard" water" that she got from her well as a result of the limestone (hard water contains the positive ions Ca^{2+}, Mg^{2+}, and Fe^{2+}.) She suffered from swollen ankles and would often soak her feet in Epsom salts (Epsom salts contain $MgSO_4$). One day her granddaughter came to visit her. The grandmother asked the granddaughter to fix a solution of soaking salts so she could soak her swollen feet. The granddaughter was quick to help her grandmother out, but the granddaughter mistakenly poured NaCl instead of $MgSO_4$ in the pan of water assuming that was the "soaking salts" her grandmother requested. After 10 minutes the grandmother was ready for the soaking, but as soon as she saw the solution in the pan she knew her granddaughter had made a mistake. Since Epsom salts and table salt are both soluble in water, how did the grandmother know?
36.	The following ions are all in one solution: Ca^{2+}, Pb^{2+}, Ni^{2+}. The following solutions are available to separate these ions through precipitation one ion at a time: NaCl, $Na_2Cr_2O_7$, Na_2SO_4. What order must each of the solutions be added to precipitate the ions one at a time? 1) ______________ 2) ______________ 3) ______________

Table B.1 (continued)

37.	When CCl_4 and water are poured into the same dish, they will (a) mix (b) separate (c) either mix or separate depending on the order in which they are put in the dish
38.	Which of the following is expected to be the most soluble in benzene (C_6H_6)? (a) HC_3-$(CH_2)_3$-F (b) HC_3-$(CH_2)_3$-OH (c) HC_3-$(CH_2)_3$-CH_3 (d) NaCl
39.	Grape Kool-Aid® is dissolved in water and flushed through a powder that is made of non-polar material. The liquid that comes through the powder is colorless. We can conclude that the color in Grape Kool-Aid® comes from (a) polar molecules (b) non-polar molecules
40.	Mark with an XX those compounds that are strong electrolytes, and with one X those that are weak electrolytes. Any others that do not fit these two categories are left blank. ________barium sulfate ________deionized water ________hydrochloric acid ________sodium hydroxide ________$NaCl_{(s)}$ ________sugar
41.	Circle all of the following compounds that could be used to make a solution of Zn^{2+}: $Zn(ClO_4)_2$ $ZnCl_2$ $ZnCrO_4$ ZnCO ZnS
42.	In balancing the half reaction $CO_{(g)} \rightarrow CO_{2\,(s)}$ the number of electrons that must be added is (a) 2 on the left (b) 2 on the right (c) 4 on the left (d) 4 on the right

Table B.1 (continued)

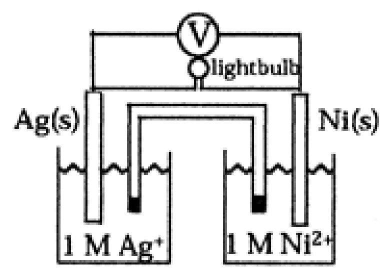
43.	When a voltaic cell is running, cations in the salt bridge (a) move into the cathode compartment (b) move into the anode compartment (c) stay put
44.	Circle the metals that will react with 1 M $HCl_{(aq)}$ to liberate $H_{2\,(g)}$: Co Cu Fe Mg Ag
45.	Circle the metals that will displace Co^{2+} from aqueous solution: Pb Zn Ag Al
46.	For the reaction: $2Fe^{2+} + F_2 \rightarrow 2Fe^{3+} + 2F^{1-}$ Identify: Oxidizing agent ____________ Reducing agent ____________ # of e^-'s transferred ____________
47.	Consider the reaction: $Pb + 2Ag^{1+} \rightarrow Pb^{2+} + 2Ag$ Would this represent a galvanic or an electrolytic cell? ____________________
48.	Electrons in the cell flow through the _____ toward the _____. (a) wire, silver electrode (b) wire, nickel electrode (c) salt bridge, nickel electrode (d) salt bridge, silver electrode  What is the potential of this cell? __________

Table B.1 (continued)

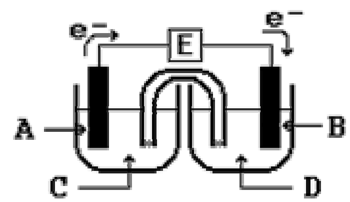
49.	If the reduction of mercury (I) in a galvanic cell is desired, the half reaction is: $Hg_2^{2+}{}_{(aq)} + 2e^- \Leftrightarrow 2\ Hg_{(l)}$ $E° = 0.80\ V$ Circle the reaction that could be used as the anode from the following: $Zn^{2+} + 2e^- \Leftrightarrow Zn_{(s)}$ $E° = -0.76\ V$ $Br_{2(l)} + 2e^- \Leftrightarrow 2Br^-_{(aq)}$ $E° = 1.07\ V$
50.	Write the cell reaction for a galvanic cell based on the following half-reactions and calculate the potential of the cell. $HClO_{2\,(aq)} + 2H_3O^+ + 2e^- \rightarrow HClO_{(aq)} + 3H_2O$ $E^o_{red} = 1.64\ V$ $ClO_3^{1-}{}_{(aq)} + 3H_3O^+ + 2e^- \rightarrow HClO_{2\,(aq)} + 4H_2O$ $E^o_{red} = 1.21\ V$ Cell Reaction: ____ Potential of the cell: ____
51.	In the diagram, identify the materials needed to make the anode and the cathode in a galvanic cell based on the chemical reaction between aluminum metal and silver ions. $Al_{(s)} + 3\ Ag^+_{(aq)} \leftrightarrow Al^{3+}_{(aq)} + 3\ Ag_{(s)}$  Metal A is _______________. Metal B is _______________. Solution C contains _______________. Solution D contains _______________.

Table B.1 (continued)

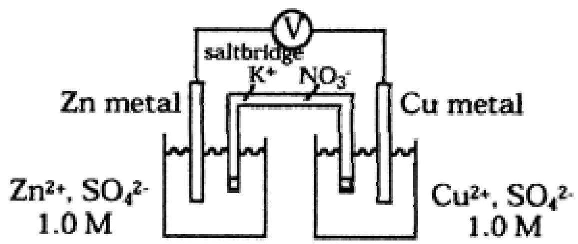
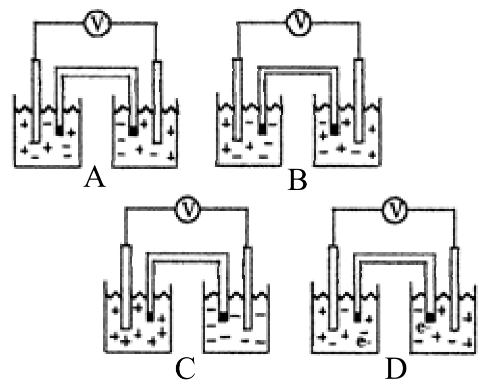
52.	If the electrodes (Ni^{2+}/Ni) and (Zn^{2+}/Zn) are used to construct a galvanic (voltaic) cell it is expected that: (a) Ni will reduce Zn^{2+} to Zn (b) Zn will reduce Ni^{2+} to Ni (c) Neither of the above
53.	The electrochemical cell shown below has 1.10 volts for its emf. There is an oxidation reaction and a reduction reaction.  Which one(s) of the diagrams below depict each half-cell as the reactions proceed? Note: In the following diagrams, cations are symbolized as + and anions as -. An electron is symbolized as e-. (a) B only (b) C only (c) A only (d) either A or B (e) D only  Explain your reasoning:

Table B.1 (continued)

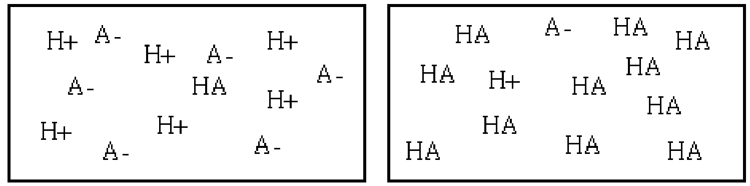
54.	Which of the following "molecular" pictures best represents a concentrated solution of the weak acid HA with $K_a = 10^{-10}$? Answer: ______________  **A** **B**
55.	Using the equation below as it is written you may conclude ________. $NH_2^{1-} + H_2O \rightarrow NH_3 + OH^{1-}$ a) NH_2^{1-} is a stronger base than OH^{1-} b) water acts as an acid c) NH_3 is the strongest base d) There is only one conjugate pair e) choices a & b are correct
56.	The K_a for hydrogen sulfide ion, HS^{1-}, is 1.3 x 10^{-13} and the K_a for formic acid, $HCHO_2$, is 1.8 x 10^{-4}. a) What specie has the highest pK_a? ____________ b) The conjugate base for hydrogen sulfide ion is ____________ while that for formic acid is ____________. c) Which one is the stronger acid? ____________. d) Write the chemical equation for the equilibrium of formic acid in water. e) Write the corresponding equilibrium expression (K_a) for formic acid in water.
57.	Indicate whether each of the following solutions is acidic, basic, or neutral: __________ a solution in which $[H_3O^+] = 10^{-2}$ __________ a solution in which $[OH^-] = 10^{-10}$

Table B.1 (continued)

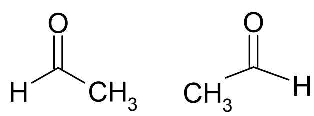
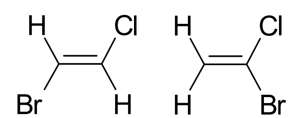
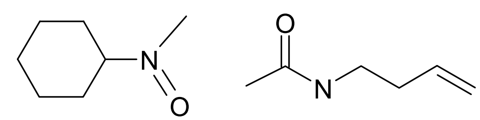
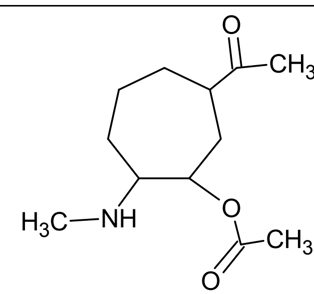
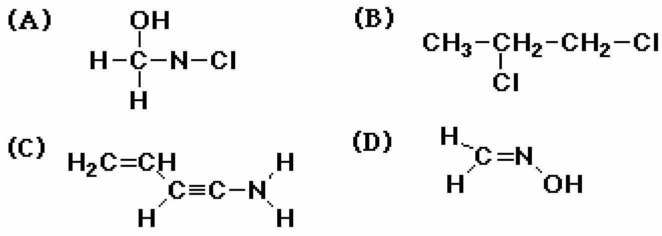
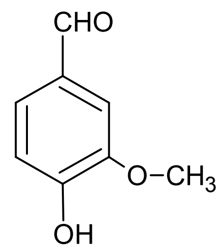
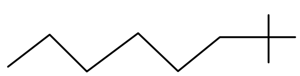
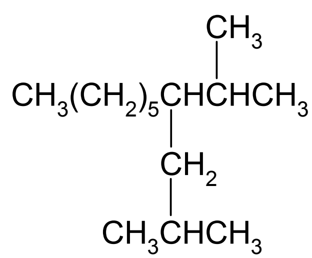
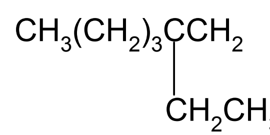
58.	The equilibrium constant for the reaction below is 1.1 x 10^6 M. ***This value indicates that*** ________. $HONO_{(aq)} + CN^{1-}_{(aq)} \rightarrow HCN_{(aq)} + ONO^{1-}_{(aq)}$ (a) CN^{1-} is a stronger base than ONO^{1-}. (b) HCN is a stronger acid than HONO. (c) HONO dissociates completely. (d) HCN dissociates completely. (e) both a & c
59.	The equilibrium constant for which of the following reactions in water is a K_a? ________ (a) $HCOOH + H_2O \rightarrow HCOO^- + H_3O^+$ (b) $CN^- + H_2O \rightarrow HCN + OH^-$ (c) $HCOO^- + H_3O^+ \rightarrow HCOOH + H_2O$ (d) $HCN + OH^- \rightarrow CN^- + H_2O$
60.	State whether the following pairs are identical, unrelated, structural (constitutional) isomers, or geometric isomers.    $CH_3-O-CH_2-CH_2-CH_3$ $CH_3CH_2CH_2CH_2-O-CH_3$
61.	Mark **all** <u>stereocenters with an asterisk (*)</u> in the following compound: 

Table B.1 (continued)

62.	The only structure that does NOT have an error is ___________ 
63.	Name three functional groups found in Cortisone (shown below). Do <u>not</u> count cycloalkane groups! (List of functional group names provided.) 
64.	Name the following compounds:   

Appendix C - Surveys[1]

CH101 PRE-SURVEY

Background Information

Which of the following categories represents your age?
- 19 years or under
- 20 years
- over 40
- 21 years
- 22 years
- 23-29 years
- 30-40 years

Which of the following represents your year in college?
- First year
- Senior
- Sophomore
- Senior +1
- Junior

What is your gender?
- Female
- Male

What is your intended major?
- Chemistry / Chemical engineering
- Biological sciences
- Pre-Med / Pre-Vet / Pre-Health Profession
- Other science / Engineering
- None of the above
- Social sciences
- Business / Policy
- Humanities / Arts
- Mathematics
- Computer Science
- Pulp and Paper Science
- Food Science
- Environmental Sciences
- None of the above

Why did you enroll in this **section** of general chemistry? (Choose the most important factor)
- Scheduling constraints / meets at a convenient time
- Liked the course description
- Recommended by other students
- No specific reason
- Other

How many high school chemistry courses did you complete including AP courses?
none 1 2 3 4 or more

How many previous college chemistry <u>courses</u> have you taken (semesters)?
none 1 course 2 courses 3 courses 4 or more courses

How many more chemistry courses do you plan to take?
none 1 2 3 4 or more

How many more courses do you plan to take in math and science (excluding chemistry)?
none 1 2 3 4 or more

---

[1] Survey questions used for the $cAcL_2$ studies were adapted from a) Gutwill-Wise, Joshua P. *J. Chem. Educ.* **2001**, *78*, 684-690, b) Eddy, Roberta M. *J. Chem. Educ.* **2000**, *77*, 514-517, and c) questions developed specifically for $cAcL_2$.

Based on past experience, what grade do you expect to receive in this class?

A to A–	C+ to C–
B+ to B–	D to F

What is your ethnicity? Please select only **one** category.

Mixed/multi-ethnic (See next question)	Black/African-American
Latino or other Hispanic	Native American/Alaskan
Chinese	Japanese
Korean	Other Asian
Pacific Islander	White/Caucasian
European	Pakistani or East Indian
None of the above (See next question)	

If mixed/multi-ethnic or none of the above was chosen then please type your answer here _______. [If an ethnicity was chosen in the previous question then type NA]

Expectations and Class Experiences

Please use the 5-point scale to indicate your agreement or disagreement with each statement. Use the SCANTRON form to record your answers. Note that 1 corresponds to Strongly Disagree and 5 corresponds to Strongly Agree.	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
It is important to me that a course provide time for discussing ideas.	1	2	3	4	5
I like courses that encourage me to discover some of the ideas for myself.	1	2	3	4	5
I prefer problems that have one right answer to problems that are open-ended.	1	2	3	4	5
Assuming that all the following activities are equally well-implemented, I learn well by …					
doing homework assignments.	1	2	3	4	5
using diagrams and other visual media.	1	2	3	4	5
using computer-based materials.	1	2	3	4	5
reading a (good) textbook.	1	2	3	4	5
doing hands-on activities.	1	2	3	4	5
listening to lecture.	1	2	3	4	5
explaining concepts to others.	1	2	3	4	5
doing in-class exercises.	1	2	3	4	5
working in a group.	1	2	3	4	5
I know I understand when…					
I can work problems in the book.	1	2	3	4	5
I can apply ideas to new situations.	1	2	3	4	5
I get a good grade on an exam.	1	2	3	4	5
I can explain the ideas to someone else.	1	2	3	4	5
I can see how concepts relate to one another.	1	2	3	4	5

Chemistry Anxiety

Please indicate "how stressed you would become" when doing the following activities. Use the code provided below to fill in the SCANTRON form.

1 not at all
2 a little
3 moderately
4 quite a bit
5 extremely

THE CLASS					
Signing up for a chemistry course	1	2	3	4	5
Reading the word "chemistry".	1	2	3	4	5
Walking into a chemistry class.	1	2	3	4	5
Looking through the pages in a chemistry text.	1	2	3	4	5
Reading a formula in chemistry.	1	2	3	4	5
Picking up a chemistry textbook to begin working on a homework assignment	1	2	3	4	5
Having to use the tables in a chemistry book.	1	2	3	4	5
Reading and interpreting graphs or charts that show the results of chemistry experiments.	1	2	3	4	5
Listening to another student explain a chemical reaction.	1	2	3	4	5
Listening to a lecture in a chemistry class.	1	2	3	4	5
EVALUATION					
Working on an abstract chemistry problem, such as "If x = grams of hydrogen and y = total grams of water produced, calculate the number of grams of oxygen that reacted with the hydrogen.	1	2	3	4	5
Waiting to get a chemistry test returned.	1	2	3	4	5
Taking a test or examination in a chemistry class.	1	2	3	4	5
Being given a homework assignment that is due the next chemistry class.	1	2	3	4	5
Thinking about a chemistry test one day before.	1	2	3	4	5
Taking a final in chemistry.	1	2	3	4	5
THE LAB					
Walking into a chemistry laboratory.	1	2	3	4	5
Spilling a chemical.	1	2	3	4	5
Listening to another student describe an accident in the chemistry lab.	1	2	3	4	5
Being told how to handle the chemicals for the laboratory experiment.	1	2	3	4	5
Working with acids in the lab.	1	2	3	4	5
Getting chemicals on your hands during the experiment.	1	2	3	4	5
Working with a chemical whose identity you don't know.	1	2	3	4	5
Mixing chemical reagents in the laboratory.	1	2	3	4	5
Heating a chemical in the Bunsen Burner flame.	1	2	3	4	5

CH101 POST-SURVEY

Expectations and Class Experiences

Please use the 5-point scale to indicate your agreement or disagreement with each statement. Use the SCANTRON form to record your answers. Note that 1 corresponds to Strongly Disagree and 5 corresponds to Strongly Agree.	**Strongly Disagree**	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
It is important to me that a course provide time for discussing ideas.	1	2	3	4	5
This course was organized so that we were encouraged to discuss ideas.	1	2	3	4	5
I like courses that encourage me to discover some of the ideas for myself.	1	2	3	4	5
The structure of this course enabled me to discover some of the ideas of chemistry for myself.	1	2	3	4	5
In this course I was encouraged to participate in hands-on activities.	1	2	3	4	5
It was clear how the activities fit into this course.	1	2	3	4	5
I prefer problems that have one right answer to problems that are open-ended.	1	2	3	4	5
I value being able to apply chemistry ideas to everyday situations.	1	2	3	4	5
This course has helped me realize that I learn well by ...					
doing homework assignments.	1	2	3	4	5
using diagrams and other visual media.	1	2	3	4	5
using computer-based materials.	1	2	3	4	5
reading a (good) textbook.	1	2	3	4	5
doing hands-on activities.	1	2	3	4	5
listening to lecture.	1	2	3	4	5
explaining concepts to others.	1	2	3	4	5
doing in-class exercises.	1	2	3	4	5
working in a group.	1	2	3	4	5
I know I understand when…					
I can work problems in the book.	1	2	3	4	5
I can apply ideas to new situations.	1	2	3	4	5
I get a good grade on an exam.	1	2	3	4	5
I can explain the ideas to someone else.	1	2	3	4	5
I can see how concepts relate to one another.	1	2	3	4	5
Taking this course has increased my interest in…					
science in general.	1	2	3	4	5
chemistry in general.	1	2	3	4	5
taking more chemistry.	1	2	3	4	5
pursuing a chemistry-related major.	1	2	3	4	5
pursuing a science-related field.	1	2	3	4	5

Complexity and Understanding

This course helped me feel more comfortable with the idea that some questions have no single right answer.	1	2	3	4	5
I understood most of the ideas presented in this course.	1	2	3	4	5
The computer assignments in this course (if any) helped me to learn the chemistry.	1	2	3	4	5
By the end of this course, I felt able to apply the concepts presented.	1	2	3	4	5

Chemistry Anxiety

Please indicate "how stressed you would become" when doing the following activities. Use the code provided below to fill in the SCANTRON form.

1 not at all
2 a little
3 moderately
4 quite a bit
5 extremely

THE CLASS					
Signing up for a chemistry course	1	2	3	4	5
Reading the word "chemistry".	1	2	3	4	5
Walking into a chemistry class.	1	2	3	4	5
Looking through the pages in a chemistry text.	1	2	3	4	5
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Picking up a chemistry textbook to begin working on a homework assignment	1	2	3	4	5
Having to use the tables in a chemistry book.	1	2	3	4	5
Reading and interpreting graphs or charts that show the results of chemistry experiments.	1	2	3	4	5
Listening to another student explain a chemical reaction.	1	2	3	4	5
Listening to a lecture in a chemistry class.	1	2	3	4	5
EVALUATION					
Working on an abstract chemistry problem, such as "If x = grams of hydrogen and y = total grams of water produced, calculate the number of grams of oxygen that reacted with the hydrogen.	1	2	3	4	5
Waiting to get a chemistry test returned.	1	2	3	4	5
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Thinking about a chemistry test one day before.	1	2	3	4	5
Taking a final in chemistry.	1	2	3	4	5
THE LAB					
Walking into a chemistry laboratory.	1	2	3	4	5
Spilling a chemical.	1	2	3	4	5
Listening to another student describe an accident in the chemistry lab.	1	2	3	4	5
Being told how to handle the chemicals for the laboratory experiment.	1	2	3	4	5
Working with acids in the lab.	1	2	3	4	5
Getting chemicals on your hands during the experiment.	1	2	3	4	5
Working with a chemical whose identity you don't know.	1	2	3	4	5
Mixing chemical reagents in the laboratory.	1	2	3	4	5
Heating a chemical in the Bunsen Burner flame.	1	2	3	4	5

CH201 PRE-SURVEY

Background Information

Which of the following categories represents your age?

19 years or under	20 years
21 years	22 years
23-29 years	30-40 years
over 40	

Which of the following represents your year in college?

First year	Senior
Sophomore	Senior +1
Junior	

What is your gender?

Female
Male

What is your intended major?

Chemistry / Chemical engineering	Biological sciences
Pre-Med / Pre-Vet / Pre-Health Profession	Other science / Engineering
None of the above	Social sciences
Business / Policy	Humanities / Arts
Mathematics	Computer Science
Pulp and Paper Science	Food Science
Environmental Sciences	None of the above

Why did you enroll in this **section** of general chemistry? (Choose the most important factor)

Scheduling constraints / meets at a convenient time	Liked the course description
Recommended by other students	No specific reason
Other	

How many total chemistry courses have you completed (and passed) including high school and college.

none	3
1	4 or more
2	

What is your ethnicity? Please select only **one** category.

Mixed/multi-ethnic (See next question)	Black/African-American
Latino or other Hispanic	Native American/Alaskan
Chinese	Japanese
Korean	Other Asian
Pacific Islander	White/Caucasian
European	Pakistani or East Indian
None of the above (See next question)	

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I like courses that encourage me to discover some of the ideas for myself.	1	2	3	4	5
I prefer problems that are open-ended to problems that have one right answer.	1	2	3	4	5
I value being able to apply chemistry ideas to everyday situations	1	2	3	4	5
Assuming that all the following activities are equally well-implemented, I learn well by ...					
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using computer-based materials.	1	2	3	4	5
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doing hands-on activities.	1	2	3	4	5
listening to lecture.	1	2	3	4	5
explaining concepts to others.	1	2	3	4	5
doing in-class exercises.	1	2	3	4	5
working in a group.	1	2	3	4	5
I know I understand when…					
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I can apply ideas to new situations.	1	2	3	4	5
I get a good grade on an exam.	1	2	3	4	5
I can explain the ideas to someone else.	1	2	3	4	5
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Chemistry Anxiety

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5 extremely

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Reading the word "chemistry".	1	2	3	4	5
Walking into a chemistry class.	1	2	3	4	5
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Picking up a chemistry textbook to begin working on a homework assignment	1	2	3	4	5
Having to use the tables in a chemistry book.	1	2	3	4	5
Reading and interpreting graphs or charts that show the results of chemistry experiments.	1	2	3	4	5
Listening to another student explain a chemical reaction.	1	2	3	4	5
Listening to a lecture in a chemistry class.	1	2	3	4	5
EVALUATION					
Working on an abstract chemistry problem, such as "If x = grams of hydrogen and y = total grams of water produced, calculate the number of grams of oxygen that reacted with the hydrogen.	1	2	3	4	5
Waiting to get a chemistry test returned.	1	2	3	4	5
Taking a test or examination in a chemistry class.	1	2	3	4	5
Being given a homework assignment that is due the next chemistry class.	1	2	3	4	5
Thinking about a chemistry test one day before.	1	2	3	4	5
Taking a final in chemistry.	1	2	3	4	5
THE LAB					
Walking into a chemistry laboratory.	1	2	3	4	5
Spilling a chemical.	1	2	3	4	5
Listening to another student describe an accident in the chemistry lab.	1	2	3	4	5
Being told how to handle the chemicals for the laboratory experiment.	1	2	3	4	5
Working with acids in the lab.	1	2	3	4	5
Getting chemicals on your hands during the experiment.	1	2	3	4	5
Working with a chemical whose identity you don't know.	1	2	3	4	5
Mixing chemical reagents in the laboratory.	1	2	3	4	5
Heating a chemical in the Bunsen Burner flame.	1	2	3	4	5

CH201 POST-SURVEY

Expectations and Class Experiences

Please use the 5-point scale to indicate your agreement or disagreement with each statement. Use the SCANTRON form to record your answers. Note that 1 corresponds to Strongly Disagree and 5 corresponds to Strongly Agree.	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
It is important to me that a course provides time for discussing ideas.	1	2	3	4	5
I like courses that encourage me to discover some of the ideas for myself.	1	2	3	4	5
I prefer problems that are open-ended to problems that have one right answer.	1	2	3	4	5
I value being able to apply chemistry ideas to everyday situations.	1	2	3	4	5
This course has helped me realize that I learn well by ...					
doing homework assignments.	1	2	3	4	5
using diagrams and other visual media.	1	2	3	4	5
using computer-based materials.	1	2	3	4	5
reading a (good) textbook.	1	2	3	4	5
doing hands-on activities.	1	2	3	4	5
listening to lecture.	1	2	3	4	5
explaining concepts to others.	1	2	3	4	5
doing in-class exercises.	1	2	3	4	5
working in a group.	1	2	3	4	5
I know I understand when…					
I can work problems in the book.	1	2	3	4	5
I can apply ideas to new situations.	1	2	3	4	5
I get a good grade on an exam.	1	2	3	4	5
I can explain the ideas to someone else.	1	2	3	4	5
I can see how concepts relate to one another.	1	2	3	4	5
Taking this course has increased my interest in…					
science in general.	1	2	3	4	5
chemistry in general.	1	2	3	4	5
taking more chemistry.	1	2	3	4	5
pursuing a chemistry-related major.	1	2	3	4	5
pursuing a science-related field.	1	2	3	4	5

Evaluating this course.

This course was organized so that we were encouraged to discuss ideas.	1	2	3	4	5
The structure of this course enabled me to discover some of the ideas of chemistry for myself.	1	2	3	4	5
It was clear how the activities fit into this course.	1	2	3	4	5
This course helped me feel more comfortable with the idea that some questions have no single right answer.	1	2	3	4	5
I understood most of the ideas presented in this course.	1	2	3	4	5
This course increased my understanding of chemistry.	1	2	3	4	5
The computer simulations in this course helped me to learn the chemistry.	1	2	3	4	5
This course caused me to think about chemistry in the world around me (outside of class).	1	2	3	4	5
This course has given me more confidence in preparing graphs and tables.	1	2	3	4	5
This course has given me more confidence in interpreting/explaining scientific graphs.	1	2	3	4	5
This class has helped me gain more confidence in using computer technology.	1	2	3	4	5
I liked the format of this class.	1	2	3	4	5
I would recommend this class to others.	1	2	3	4	5
Overall this course was a good experience for me.	1	2	3	4	5

CHEMISTRY ANXIETY

Please indicate "how stressed you would become" when doing the following activities. Use the code provided below to fill in the SCANTRON form.

1 not at all
2 a little
3 moderately
4 quite a bit
5 extremely

THE CLASS

Signing up for a chemistry course	1	2	3	4	5
Reading the word "chemistry".	1	2	3	4	5
Walking into a chemistry class.	1	2	3	4	5
Looking through the pages in a chemistry text.	1	2	3	4	5
Reading a formula in chemistry.	1	2	3	4	5
Picking up a chemistry textbook to begin working on a homework assignment	1	2	3	4	5
Having to use the tables in a chemistry book.	1	2	3	4	5
Reading and interpreting graphs or charts that show the results of chemistry experiments.	1	2	3	4	5
Listening to another student explain a chemical reaction.	1	2	3	4	5
Listening to a lecture in a chemistry class.	1	2	3	4	5

EVALUATION					
Working on an abstract chemistry problem, such as "If x = grams of hydrogen and y = total grams of water produced, calculate the number of grams of oxygen that reacted with the hydrogen.	1	2	3	4	5
Waiting to get a chemistry test returned.	1	2	3	4	5
Taking a test or examination in a chemistry class.	1	2	3	4	5
Being given a homework assignment that is due the next chemistry class.	1	2	3	4	5
Thinking about a chemistry test one day before.	1	2	3	4	5
Taking a final in chemistry.	1	2	3	4	5
THE LAB					
Walking into a chemistry laboratory.	1	2	3	4	5
Spilling a chemical.	1	2	3	4	5
Listening to another student describe an accident in the chemistry lab.	1	2	3	4	5
Being told how to handle the chemicals for the laboratory experiment.	1	2	3	4	5
Working with acids in the lab.	1	2	3	4	5
Getting chemicals on your hands during the experiment.	1	2	3	4	5
Working with a chemical whose identity you don't know.	1	2	3	4	5
Mixing chemical reagents in the laboratory.	1	2	3	4	5
Heating a chemical in the Bunsen Burner flame.	1	2	3	4	5

Appendix D - Interviews

INTERVIEW #1

(Interview #1 was not given individually. It was given as a handout to the entire class. It is labeled as an interview because it is part of a series of questions asked in other interviews.)

Name ____

Overview: Data is being collected in order to establish a baseline of basic problem-solving and graphical skills as well as attitudes toward chemistry and learning. You will be asked a series of questions. Please respond open and honestly to the best of your ability. Please don't shade your answers with what you think we want to hear. We want to create a better learning environment for chemistry students and your honesty will help us do that.

Please work the following problem to the best of your ability. Show ALL work and briefly explain your solution.

The concentration of grain alcohol (C_2H_5OH) in whisky is given in 'proof', which is twice the percent alcohol by volume (v/v). What are the mole fraction and molality of C_2H_5OH in 90 proof vodka? Assume that vodka is a solution of C_2H_5OH and water only and that the volumes are additive. The density of C_2H_5OH is 0.79 g/mL.

Construct a formal graph of the following data and hand in when you have completed it.

Time (s)	1	2	3	4	5	6	7	8
Temperature (^{o}C)	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0

Use Excel to construct a graph of the same data. Save the graph to your k-drive. Save as firstname_lastname.

Time (s)	1	2	3	4	5	6	7	8
Temperature (^{o}C)	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0

Goto Interview #1 link in WebCT. Open the spreadsheet. Perform the following tasks and save the spreadsheet to your k-drive under a new title called firstname_lastname2. Also include your answers to the five questions in the spreadsheet.

Perform the following tasks. If you are unable to do one of the tasks then skip it.

Report an equation for the line and a measure of "goodness of fit".
Change the title on the Excel graph to Apples.
Change the background in the plot area so that it's white instead of gray.
Change the scale so that every number is shown on the Y-axis (1, 2, 3…).

1. Based on this graph how would you describe the relationship between pressure and temperature?

2. Suppose the equation of this line were given as y = 6.23x + 0.33. Rewrite this equation in terms of the chemistry terms or variables.

3. What does the slope represent?

4. What does the y-intercept represent?

5. Why would this graph be significant?

<u>SEND BOTH FILES IN AN EMAIL ATTACHMENT TO dabelche@unity.ncsu.edu</u>

There is a WebAssign entitled "Making Chemistry Work for You". Please respond to all questions open and honestly. You will receive full credit just by answering each question.

Thank you for your response ☺

Making Chemistry Work For You (Part of Interview #1)

Please elaborate on your responses to the following questions. You will get full credit by providing answers for each question. You have two submissions. Thank you for all your help!

---

1. What learning method(s) helps you to learn in most situations? Check all that apply.
   ___ doing homework
   ___ using diagrams or visual aids
   ___ using computer-based materials
   ___ reading a good textbook
   ___ hands-on activities
   ___ listening to lecture
   ___ explaining concepts to others
   ___ doing in-class exercises
   ___ working in a group

   What is it about these learning methods that help you to learn better?

2. How do you prepare for chemistry class?

3. What do you think would be the best way to prepare for an exam in chemistry?

4. How do you know when you have learned the material or how do you decide that you are well prepared for an exam?

5. Why did you choose this section of CH201?

6. What are your opinions about the structure of the class so far?

7. In general, do you like working in a group?
   yes
   no
   sometimes

   Why or why not?

8. Do you think the computers will be helpful in learning chemistry?

9. Do you think the use of hands-on activities in this class will help you learn?
   yes
   no
   maybe

   Why or why not?

10. How do you expect this class to compare to a regular large lecture class?

11. Do you have any other comments or remarks about the class?

12. How is chemistry related to your life and the world around you if at all?

13. Do you like chemistry?
    yes
    no
    sort of

    Why or why not?

14. Do you think the concepts you learn in chemistry are or will be relevant to other classes you take?

15. Do you think the skills you learn in this class will be important in the future?
    yes
    no
    I don't know

    Describe the skills and why they would be important. Or, discuss why you think skills learned in this class will not be important.

16. How important is chemistry in the life of an average person involved in their community and briefly describe why?

INTERVIEW #2

Overview: This is the second interview in a series of four being conducted to follow basic problem-solving and graphical skills as well as attitudes toward chemistry and learning. You will be asked a series of questions. Please respond open and honestly to the best of your ability. It is important that you do not try to tell us what you think we want to hear.

Do you have any questions before we begin?

PROBLEM SOLVING

Please read the following problem as though you were reading it on a test.

Given enough time, do you think you could solve this problem?

If yes → Please work out the problem carefully on paper and please try to think out loud. Even if some steps seem very simple please try to let me know what you are thinking -- sort of like talking to yourself while you're solving the problem.

If no (or maybe) → Why not?

How confident are you in your answer?

How hard would you rate this problem on a scale of 1-5 with 5 being the hardest?

Do you have any comments or questions about the problem (positive or negative)?

GOAL

Why did/didn't you use the GOAL protocol?

[If used GOAL] Could you have solved the problem had you not used GOAL?
How did GOAL help you solve the problem?

Can you point out elements of GOAL in your solution [use coding sheet]?
[If student had difficulty] How could the use of GOAL have helped you solved the problem more easily?

What are the advantages of using the GOAL protocol?

What are the disadvantages of using the GOAL protocol?

Learning

What do you do to prepare for chemistry class when there is not an exam?

How did you study or prepare for your first exam in this chemistry class?

How do you know when you have learned the material or how do you decide that you are well prepared for an exam?

Do you feel that your current study habits and methods are working for you?

Describe how you know whether or not your methods are working [self-evaluation].

The Class

What are your opinions about the structure of this class?

How does it compare with other sections of chemistry?

Do you like working in a group in this class? Why or why not?

Is your group contributing to your learning? How?

Describe how computers are used in class?

Do you like the use of computers in this class? Why or why not?

Are you learning useful computer skills in this class? Describe them.

Any other comments or remarks about the class?

Chemistry

Do you like chemistry?

Has this class affected how you feel about chemistry in any way?

GRAPHING

Can you graph a set of data?
Can you read and interpret graphs well?

Construct a formal graph of the following data with the graph paper provided.

Time (s)	**[Cu^{2+}] mol/L**
0	24
1	12
2	9
3	8
4	8
5	8

Identify the y-axis.
Identify the x-axis.

Can you graph in Excel?

Use Excel to construct a graph of the data.

Based on this graph how would you describe the relationship between time and concentration of copper(II)? [provide a graph if the graph could not be constructed]

What is the significance of this plot? Why would we graph it?

If the student could construct the graph in Excel then ask the following questions:

Here is a graph of the natural log of dinitrogen pentoxide concentration vs. time. [open in Excel]

> Report an equation for the line and a measure of "goodness of fit".
> Change the title on the Excel graph to Apples.
> Change the background in the plot area so that it's white instead of gray.
> Change the scale so that every number is shown on the Y-axis (1, 2, 3…).

The equation is given in terms of x and y [give equation if student could not generate it]. Rewrite the equation in terms of the chemistry terms or variables.

What does the slope represent?

What does the y-intercept represent?

Why would this graph be significant?

INTERVIEW #3

Overview: This is the third interview in a series of four being conducted to follow problem-solving and graphical skills as well as attitudes toward chemistry and learning. You will be asked a series of questions. Please respond open and honestly to the best of your ability. Remember, your open and honest answers will help us develop a better learning environment.

Do you have any questions before we begin?

PROBLEM SOLVING

Please read the following problem as though you were reading it on a test.

Given enough time, do you think you could solve this problem?

If yes → Please work out the problem carefully on paper.

If no (or maybe) → Why not?

How confident are you in your answer?

How hard would you rate this problem on a scale of 1-5 with 5 being the hardest?

GOAL

Do you use GOAL?

Why did/didn't you use the GOAL protocol?

How could/did GOAL help you solve the problem?

What are the advantages of using the GOAL protocol?

What are the disadvantages of using the GOAL protocol?

Learning

Do you feel that your current study habits and methods are working for you?

Describe how you know whether or not your methods are working [self-evaluation].

The Class

What are your opinions about the structure of SCALE-UP?

Do you like working in a group? Why?

Describe how computers are used in the class? Do you like it?

Do you have any comments or remarks about the class?

Chemistry

What do you think about chemistry as a subject at this point in the semester?

How does chemistry relate to your everyday life?

Graphing

Has your graphing ability improved as a result of taking this class?
Has your ability to read and interpret graphs improved?

Has this class helped you feel more comfortable using Excel?

Use Excel to construct a graph of the data.

> 0.8M NaOH was used to titrate a 15-mL sample of a weak monoprotic acid. The data is given in the table below. Construct a formal graph of pH vs volume of NaOH.

Volume (mL)	**pH**
0	3.27
2	4.09
6	4.69
8	4.92
12	5.55
14	7.64
16	11.65
20	12.12
22	12.22

Describe the relationship between the volume of NaOH and the pH.

Why is this type of plot significant? (list info that you can determine from this graph)

Here is another graph:

> Report an equation for the line and a measure of "goodness of fit".
> Change the title on the Excel graph to Apples.
> Change the background in the plot area so that it's white instead of gray.
> Change the scale so that every number is shown on the Y-axis (1, 2, 3…).

Here is the equation:

> Identify the term that represents pH.
> Identify the term that represents volume NaOH.
> Identify the slope.
> Identify the y-intercept.

INTERVIEW #4

Overview: This is the final interview of the semester being conducted to follow problem-solving and graphical skills as well as attitudes toward chemistry and learning. We appreciate your dedication in participating in the interviews for this research. You will be asked a series of questions. Please respond open and honestly to the best of your ability.

Do you have any questions before we begin?

PROBLEM SOLVING

Please read the following problem as though you were reading it on a test.

Given enough time, do you think you could solve this problem?

If yes → Please work out the problem carefully on paper.

If no (or maybe) → Why not?

How confident are you in your answer?

How hard would you rate this problem on a scale of 1-5 with 5 being the hardest?

GOAL

Do you use GOAL?

Why did/didn't you use the GOAL protocol?

How could/did GOAL help you solve the problem?

What are the advantages of using the GOAL protocol?

What are the disadvantages of using the GOAL protocol?

LEARNING

What learning method(s) helps you to learn in most situations?

doing homework, using diagrams or visual aids, using computer-based materials, reading a good textbook, hands-on activities, listening to lecture, explaining concepts to others, doing in-class exercises, working in a group

What is it about ________ that helps you to learn better?

Has this class helped you discover anything new about the way you learn? If so, how?

THE CLASS

Consider lecture-only methods of teaching compared to this class.

What makes this class worse than lecture-only?

What makes this class better than lecture-only?

Do you like working in a group? Why?

Do you like the use of hands-on activities in this class? Why or why not?

Are you learning chemistry as a result of the hands-on activities in this class?

Describe the activities that you have learned the most from.

Do you like the use of computers in this class? Why or why not?

What advice would you give students that take this class in the future?

Any other comments or remarks about the class?

CHEMISTRY

Is chemistry a required course for you? If chemistry were not a requirement would you take it anyway?

Are the concepts you learn in chemistry relevant to other classes you take or will take?

Do you notice chemistry in the world around you? Can you point out examples?
Has your view of chemistry [as a subject] changed since enrolling in this class? In what way?

If time permitted and no grades were involved would you like to learn more about chemistry?

What topics would you especially like to learn about?

GRAPHING

Has your graphing ability improved as a result of taking this class?

Has your ability to read and interpret graphs improved?

Has this class helped you feel more comfortable using Excel?

Use Excel to construct a graph of the data.

Time (s)	1 / [C_4H_6]
0	100.0
1000	160.0
1800	210.1
2800	270.3
3600	319.5
4400	370.4
5200	414.9
6200	480.8

Describe the relationship between time and [C_4H_6].

Why is this type of plot significant?

Here is another graph.

> Report an equation for the line and a measure of "goodness of fit".
> Change the title on the Excel graph to Apples.
> Change the background in the plot area so that it's white instead of gray.
> Change the scale so that every number is shown on the Y-axis (1, 2, 3…).

Here is the equation:

> Identify the term that represents 1 / [ ].
>
> Identify the term that represents time.
>
> Identify the slope.
>
> Identify the y-intercept.

Appendix E - GOAL Protocol

GOAL is a problem solving strategy developed by the NCSU Physics Education and research group for use in introductory physics courses, specifically SCALE-UP courses ([1]). The approach was developed from the universal problem solving principles described by Polya ([2]). GOAL encourages students to *Gather*, *Organize*, *Analyze*, and *Learn* with each Problem solving task. This method was adapted for chemistry and presented to students in the CH201 section of $cAcL_2$ in the fall of 2002. The information given below was provided to students on using the GOAL method.

Gather information
The first thing to do when approaching a problem is to understand the situation. Carefully read the problem statement, looking for key phrases like "at equilibrium," or "standard conditions." What information is given? Exactly what is the question asking? Don't forget to gather information from your own experience and common sense. What should a reasonable answer look like? You wouldn't expect to calculate the concentration of a solution to be 5×10^{26} M. Do you know what units to expect? Are there any limiting cases you can consider? What happens when a concentration or a mass gets huge or goes to zero? Also make sure you carefully study any drawings or reactions that accompany the problem.

Organize your approach
Once you have a really good idea of what the problem is about, you need to think about what to do next. Have you seen this type of question before? Being able to classify a problem can make it much easier to lay out a plan to solve it. You should almost always make a quick drawing of the situation or write a chemical equation describing a reaction. Label important events with circled letters. Indicate any known values, perhaps in a table or directly on your sketch. Some kinds of problems require specific layouts like a reaction table when analyzing chemical relationships. Once you've done this and have a plan of attack, its time for the next step.

Analyze the problem
Because you have already categorized the problem, it should not be too difficult to select relevant equations that apply to this type of situation. Use algebra to solve for the unknown variable in terms of what is given. Substitute in the appropriate numbers, calculate the result, and round it to an appropriate number.

Learn from your efforts
This is actually the most important part. Examine your numerical answer. Does it meet your expectations from the first step? What about the algebraic form of the result before you plugged in numbers? Does it make sense? (Try looking at the variables in it to see if the answer would change in a physically meaningful way if they were drastically increased or decreased or even became zero.) Think about how this problem compares to others you have

done. How was it similar? In what critical ways did it differ? Why was this problem even assigned? You should have learned something by doing it. Can you figure out what?

Applying GOAL

When you are looking at a problem and you don't know what to do next, remember what the letters in GOAL stand for and use that as a guide. The following questions may help you in applying the GOAL method.

G - Gather

- What is the question asking for?
- Identify the known and unknown quantities.
- Consider how the answer could vary for limiting cases. (e.g. What happens when a concentration or a mass gets huge or goes to zero?)
- Look for key phrases like "at equilibrium," or "standard conditions" for clues about relevant chemical principles.

O - Organize

- Classify the problem according to the fundamental principles that apply. (e.g. Thermodynamics, equilibrium, conservation of mass, etc.)
- Describe how you will solve the problem.
- Draw a diagram or write a chemical equation labeled with the variables assigned from the Goal step above.

A - Analyze

- Identify and show relevant fundamental equations (express chemical principles in equation form).
- Solve for the desired unknown variable (on the left of the equation) in terms of the known variables (on the right). This may require manipulating and combining several equations.
- Substitute known values, calculate a numerical answer, and round the answer to an appropriate number.

L - Learn

- Does the answer agree with the prediction in the Goal step if you were able to make a prediction?
- Are the units correct?
- Does the result have the correct sign or direction?
- How is this problem similar or different from other problems you have examined?
- Why was this problem assigned?
- If the problem were modified, how would the result change? (e.g. What if temperature and pressure conditions were significant factors?)
- What else can be learned from this problem?

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[1] ftp://ftp.ncsu.edu/pub/ncsu/beichner/RB/GOALPaper.pdf

[2] Polya, G. *How to Solve It, 2nd ed.* Princeton University Press, Princeton, NJ: 1957.