An Inquiry/Technology Based Approach to Introductory Chemistry

Summary

For many years we have been concerned about the instructional effectiveness of the general chemistry course taken primarily by freshman science majors. We, like many other faculty members involved in this course, have become increasingly alarmed by the lack of motivation of our students, their refusal to read the textbook, their poor performance on tests, and shoddy attendance in our classes. While some may argue that the root of these ills can be found in the quality of available textbooks, instructors, or the nature of our students; we believe the lack of engagement on the part of our students may be the result of a traditional teacher centered instructional approach. Chemical education research has shown that a student centered inquiry-based instructional approach develops more positive attitudes towards learning, increases student understanding of concepts and improves the ability to use scientific processes. Currently, however, there is not a complete set of learning materials that support such an approach in a practical manner. To address this, we propose to develop a set of materials that supports an inquiry-based instructional strategy called the learning cycle approach.

The Traditional Approach to General Chemistry

At the present time General Chemistry is taught in Colleges and Universities in a fairly uniformed way. As represented in Figure 1, this teacher centered instruction strategy can be seen as being divided into phases that are taken in order. First, students are assigned readings in a textbook, are expected to attend lecture where the same material is presented, and listen passively taking notes (Inform Phase). This is followed by a laboratory activity that either verifies the concepts they were already informed about in lecture (Verification Phase), or is completely unrelated to what is being covered in lecture. Then students are assigned problems from the end of the chapter in the textbook (Practice Phase). After a period of time they are given an examination to test what they have learned.

Traditional (Concept → Data)

Phases of Instruction	Goal	Activities	Questions	Data
Inform	Present Concept	Lecture / Discussion, Readings	What is the concept?	
↓ Verify Concept	Confirm the truth of concept	Laboratory, Demos	How do your observations fit the concept?	Confirm Concept with data, Provide Evidence
↓ Practice Concept	Apply, reinforce, review, extend, and understand concepts	Readings, Problem Sets, Application Questions,	Using what you know, answer the following…	
↓ Evaluate		Examinations, Quizzes		

Figure 1

We believe that this approach is less than effective for the following reasons:

- Traditional lectures presentations are not an effective method for helping students learn chemistry.
- Current textbooks are not effective learning tools for students.
- Technology plays a secondary rather than central role in instruction. The traditional approach does not allow students to develop their own understanding of chemical concepts.
- The traditional approach does not effectively address the difficulties that many students have with solving problems.

A Better Way - The Learning Cycle Approach

Research on instructional strategies has clues as to how to change our courses. An instructional strategy that is research based is a student centered inquiry-oriented approach called the learning cycle. The learning cycle approach, as represented in Figure 2, can also be seen as being divided into phases that are taken in order. First, students are exposed to data (Exploration Phase) from which concepts can be derived (Invention Phase). Students can then apply the concept to other phenomena (Application Phase). In contrast to the traditional approach, this inquiry-oriented approach is based upon data. This difference has several consequences to the role played by various instructional activities. Laboratory and other data generating activities play a more central role in introducing concepts rather than verifying concepts. Classroom discussions are focused on using data to generate concepts rather than informing students of the concepts. Textual materials are used to apply, reinforce, review, and extend concepts rather than introduce concepts. This approach encourages more active learning by students. More details about the learning cycle approach can be found in Appendix 1.

Inquiry (Data → Concept)

Phases of Instruction	Goal	Activities	Questions	Data
Explore ↓	Explore relations and patterns in data	Laboratory, Demos, MoLES, Lab Simulations, Video	What did you do? What did you observe?	Gathering Data
Invent Concept ↓	Develop and understand concepts with teacher/peers	Lecture / Discussion	What does it mean?	Explaining Data
Apply Concept ↓	Apply, reinforce, review, extend, and understand concepts	Readings, Problem Sets, Application Questions, Verification Laboratory	Using what you know, answer the following…	Using Data, Provide Evidence
Evaluate		Examinations, Quizzes		

Figure 2

However, for this approach to be viable, a much greater source of data generating activities must be available to the instructor. Instructional technology offers a source of these activities.

Technology is the Key to Implementation

Although technology is beginning to make inroads into General Chemistry instruction, it has done little to change its nature. For the most part, technology is being used to supplement traditional instruction or to replicate traditional methods. We propose to use technology in a more central role

This project will develop a set of learning tools that will be informed by theoretical and research based principles and that take advantage of the instructional technologies available to most modern colleges and universities. The proposed activities and materials, in addition to supporting all the concepts commonly presented in a two-semester course, will be flexible and can be used in a variety of instructional strategies.

The Tools

Here is description of the materials we propose to develop.

Computer-Based Concept Development Resources: These are computer-based resources that allow students to generate data from which a chemistry concept can be invented or to explore the application of the concept. These resources will allow students to explore chemical concepts at the macroscopic, submicroscopic and symbolic levels, and to analyze and interpret data in a virtual laboratory. Accompanying the resources would be an Activity Manual(s) that would direct student inquires into chemical phenomena and contain their observations and responses to questions. These inquires could be used as pre-lecture, during lecture, or post-lecture activities. There are three types of resources:

MoLE (molecular level laboratory experiments): These are Web accessible, computer-based simulation activities that mirror the procedures and the instructional strategy of guided inquiry sensory-level laboratory activities. The computer window of the activity is divided into submicroscopic (atomic/molecular) representations, a symbolic (graphical representation) and a macroscopic representation. See the example for the gas law MoLE activity. Students can use the simulation to generate data to support a submicroscopic representation of a concept. With each MoLE activity an activity guide is included to assist the student in collecting, analyzing and interpreting the data. This component is design for greater flexibility to allow the instructor greater range of implementation strategies, including a computer laboratory setting; as an independent homework assignment; and in a lecture/group discussion setting. As in the case of the guided inquiry laboratory activities the MoLE activities should be used to introduce the concept. (See Appendix 4 for Gas Law example.)

Video demonstrations: Video demonstrations are macroscopic demonstrations of chemical phenomenon. Students will be able to collect qualitative and/or quantitative data and with the aid of an activity guide assist the student in collecting, analyzing and interpreting the data. The activity guide will also include paper and pencil inquiry activities for individual and cooperative group investigations. These simulations can be viewed on the Web, in groups, during a lecture/discussion class, or as an assignment to be completed before or following lecture.

Laboratory Simulations: Laboratory simulations will have a virtual laboratory feel, and allow students to investigate a concept at the macroscopic level. Some of the Laboratory Simulations will include submicroscopic views to encourage linking between levels. Students will be able to collect qualitative and/or quantitative data and with the aid of an activity guide assist the student in collecting, analyzing and interpreting the data. The activity guide will also include paper and pencil inquiry activities for individual and cooperative group investigations. These simulations can be viewed on the Web, in groups, during a lecture/discussion class, or as an assignment to be completed before or following lecture.

PreLecture Explorations: A PLE is a web-based exercise that students do before they attend a lecture. It is platform independent and can contain static images, video and/or animations. It usually consists of 5 – 7 questions that require only 10 – 15 minutes of the student's time to complete. Upon submission of the PLE, students receive an expert's response to the same questions for comparison. The instructor can access student responses and use them to customize their lecture, to address specific students' misconceptions, to assess students' prerequisite knowledge, and to generate charts and graphs that can be used to invent concepts.

Guided and Open Inquiry Laboratory Resources: We are recommending the use of the *Inquiries into Chemistry* Laboratory Manual by Michael R. Abraham and Michael J Pavelich as the laboratory manual for this project. This laboratory manual uses an inquiry approach based on the Learning Cycle. The guided inquiry activities in this laboratory manual lead the student to collect data that can be used to support the invention of a major concept. Each laboratory activity consists of the following sections: a problem statement that focuses students on the eventual conceptual outcome of the activity; a data collection section that guides the students to generate data that will support the concept necessary to eventually invent/derive the concept; a data analysis section that helps students organize the data in a way that facilitates conceptual invention; and an interpretation section that offers the opportunity for students to identify the concept and can be used as the base for the concept invention discussion that will occur in lecture. The intended use of the guided inquiry laboratory activities is as an introduction to the concepts to be invented and therefore must occur prior to any lecture coverage of the same materials. (See Appendix 3 for Gas Law example.)

The Abraham and Pavelich laboratory manual also includes descriptions of chemical systems that students can use to further investigate using an Open-Inquiry format. The student is expected to develop a problem statement, to design and carry out a laboratory investigation to solve the problem. (See Appendix 3 for Gas Law example.)

WebText: We envision using a Web-based reference source as an alternative to the traditional textbook. The entries from the WebText will summarize and define the concept/terms developed/invented in class. The entries consist of a terse exposition of the content with any supporting graphical, tabular, or mathematical relationships, formulas, and equations associated with the particular concept. Bold-faced key words will be linked to related concept/terms in the WebText. Links will also be provided to the instructional tools used in class to invent the particular concept and to the associated problem-solving tutorials. Supporting graphics and figures will play a central role in the discussion of the concept. Real world applications and chemical applications of the concept will also appear here. The WebText will use linear computer animations and QuickTime movies to provide dynamic representation of the concept. The course instructor will define the Scope and Sequence of the course from a collection of learning objectives that are associated with a list of Concepts/Topics (see Appendix 2). The instructor can further customize the list of Concepts/Topics by adding their own learning objectives and associated activities for each of the Tools (i.e., MoLE, Video Demonstrations, Problems, etc.)

Problem Solving Resources: This is an interactive feature that can be used to help students develop problem-solving skills. Each tutorial consists of three prototype questions that are randomly sequenced. In the tutorial the student views the first question and is given three choices of how to interact with the problem. The 'Show Me' function presents the student with a detailed presentation that parses the information in a step-by-step approach similar to a teacher doing a sample problem at the board. The Show Me feature will include an audio overlay during the step-by-step presentation. The 'HELP! Me' function presents the student with an interactive parsed approach to solving the same problem. Input from the student is evaluated by the computer as the student progresses through the problem. The 'Watch Me' function presents the student with an input box where the student is expected to enter the answer to the problem. The computer evaluates the answer. Incorrect answers are compared to a set of answers that exist as a result of predictable errors. If a match occurs the student receives some feedback and asked to try again. If the answer does not match a correct answer or a known incorrect answer the student is given the choice to return to the 'HELP! Me' or 'Show Me' functions. If the answer is correct the student can exit the Tutorial and proceed to the Computerized Problem Sets (see following). If the student uses the 'Show Me' functions, the program moves them to a second question that only has the 'Watch Me' and the 'HELP! Me' functions available. If the student uses the 'HELP! Me' function, the program moves them to a second question that only has the 'Watch Me' and the 'Show Me' functions available. If the student successfully answers the second problem correctly they can exit the Tutorial. If the student cannot correctly answer the question they are automatically moved to the 'HELP Me' presentation after which they will be moved to the third and final problem in the Tutorial. In the third problem they only have the option of the entering an answer to the question. If the student is still unsuccessful they are directed to find assistance from an instructor. At anytime the student may return to the 'Show Me' or 'HELP! Me' function of previous questions to review their work.

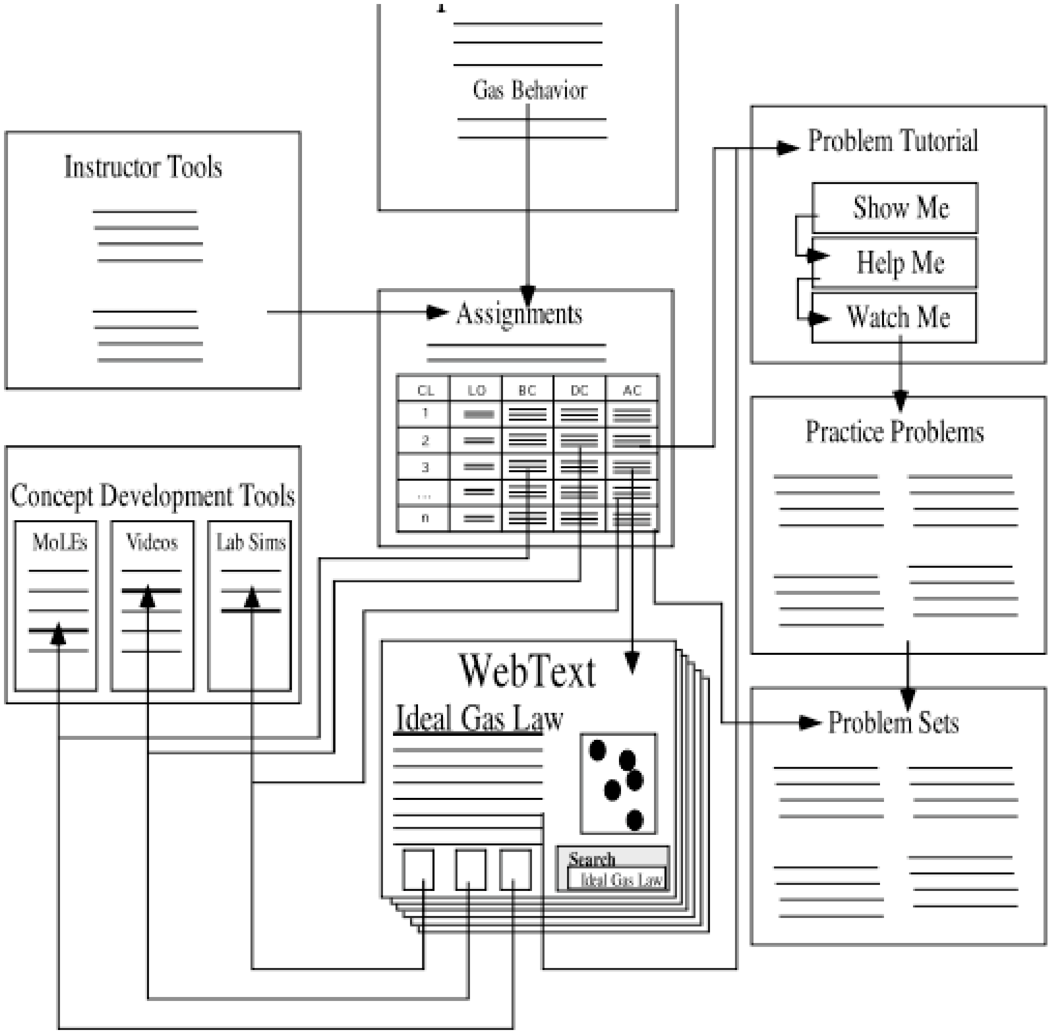
Students who successfully complete the Problem Solving Tutorial will be able to access collections of additional problems associated with the particular concept. These problems would reside on a WedCT or WebCT like server and have a number of features. Questions would be individualized to each student by using randomly generated numbers. Different chemical species could be used in a fixed problem stem. The questions could be computer graded with facility for feedback. The instructor would be able to control the number of submissions and specify deadlines for submission. Finally, grades could be added to computer grade book. This resource could also be used to generate problem sets, quizzes, and exam questions.

Administrative Structure

We envision a flexible, web based delivery system that organizes and integrates the tools we propose to develop around a student-centered assignment page. The instructor defines the content to be taught by generating an assignment page for each unit of instruction. The assignment page would be organized around class meetings (lectures/recitation/discussion and laboratory) and would prescribe the activities to be completed by the student. Specific tools will allow the instructor to easily and quickly build the assignment page for each unit.

Figure 3 illustrates the central nature of the Assignment page and the structure of the proposed web site. The panels, surrounding the Assignment page represent the tools from which the instructor has selected as activities for the students to complete. The student simply clicks on a link on the assignment page to access any particular resource or activity the instructor has assigned to be completed before, during or after class.

Students enter the web site on a topics page that will list the topics of the course as identified by the instructor. From that page they can click on the topic they are interested in (eg Gas Behavior) to access the instructor generated assignment page.



Gas Behavior
Instructor Tools
Assignments
CL
LO
BC
DC
AC
1
2
3
...
n
Problem Tutorial
Show Me
Help Me
Watch Me
Practice Problems
Concept Development Tools
MoLEs
Videos
Lab Sims
WebText
Ideal Gas Law
Search
Ideal Gas Law
Problem Sets

Figure 3

Figure 4 and Figure 5 are sample class and laboratory assignment pages that an instructor might generate for the Gas Law Unit. It is presented as one of many possible examples that an instructor might produce using the Instructor Tools.

Class	Learning Objectives	Before Class	During Class	After Class
1	(LO: Describe measuring gas pressures using barometers and manometers. Relate pressure units.)	View Video Demonstrations (Collapsing Can) respond to challenge questions	Discuss Collapsing Can view Cartesian Diver video and respond to questions in groups, discuss barometers and manometers	Webtext assignment, measuring pressure problem tutorial and practice problems
2	(LO: Apply the ideal gas law to relate and calculate values for pressure, volume, temperature, and amount of a gas.)	View Video Demonstrations (Boyle's Law, Charles' Law, Gay-Lussac Law) collect data respond to challenge questions	Use student data to invent the Ideal Gas law, group problem solving using ideal gas law	WebText assignment, Ideal Gas Law tutorial and practice problems
3	(LO: Apply the ideal gas law to relate and calculate values for pressure, volume, temperature, and amount of a gas.)	View Video Demonstration (Burning Candle)	Group activity application of the Ideal Gas Law to the burning candle experiment, gas density, gas stoichiometry	WebText assignment, Ideal Gas Law Tutorial and practice problems. Problem Set on LO's from Lectures 1 - 3
4	(LO: Apply Dalton's Law of partial pressure to calculate the pressure of combined gases and to calculate the partial pressures of gases in mixtures.)	Dalton's Law Video Demonstration	Continue gas stoichiometry and Dalton's Law	WebText assignment, Dalton's Law Tutorial and practice problems.
5	(LO: Describe gases in terms of KMT)	Ideal Gas Law MoLE guided-inquiry activity	Group activity to analyze data collected from MoLE activity, plan an open-ended activity	Do open-ended MoLE activity, WebText, KMT Problem tutorial and practice problems
6	(LO: Relate MW and speeds of molecules using Graham's law and Real Gases.)	Video Demonstration of Graham's Law	Group activity to analyze data collected from Graham's Law and discuss Real Gases	WebText, Graham's Law and Real Gases Problem tutorial and practice problems. Problem Set on LO's from Lectures 1 – 6.

Figure 4

Lab	Learning Objectives	Before Laboratory	During Laboratory	After Laboratory
1	(LO: Apply the ideal gas law to relate and calculate values for pressure, volume, temperature, and amount of a gas.)		Your Lab Instructor will assign you one of the activities from your lab manual (E.1.A, B, C: Gas Relationships)	Complete Laboratory Report
2	(LO: Describe gases in terms of KMT)		Print out the laboratory experiment: Guided-inquiry activity (Do pages 1 - 8) using Gas Law MoLE	Complete Laboratory Report
3	(LO: Apply the ideal gas law to relate and calculate values for pressure, volume, temperature, and amount of a gas.) (LO: Apply the ideal gas law to relate and calculate values for pressure, volume, temperature, and amount of a gas.)		Pick one of the systems from the open-inquiry experiments from E. Gas Systems	Pick one of the systems from page 9 of Guided-inquiry activity using Gas Law MoLE

Figure 5

Using the Instructor Tools the assignment page can be quickly generated. The instructor enters the number of class days need to present the contents of the unit, selects or provides the specific learning objectives and identifies the class day(s) the particular objective will be covered. The instructor then selects the resources from Concept Development Tools, Web Text, Problem Tutorials and Problem Sets to be used before, during and after class.

How This New Project Will Improve Instruction in the General Chemistry Course

A number of observations can be made regarding current effectiveness of instruction in introductory chemistry, what changes are needed, and how our project addresses these needs.

> Students undercut our efforts by not reading the assigned material in the textbook; not attending the class lectures; dry-labing their experiments, copying the solutions of the problems from a solution manual, or from fraternity files; and miserably failing the examinations.

Observation #1: Current textbooks are not effective learning tools for students.

Textbooks try to serve two functions simultaneously: a stand alone, complete instructional tool, and a reference tool. Consequently current textbooks do neither very well. As an instructional tool textbooks, by their very nature, are didactic and teacher centered. Most students trying to use the textbook as an instructional tool are either confused or under the false impression that simply reading the assigned material will result in their understand the concepts and their ability to do problem assignments. Many of our students do not read their textbook at all.

Many students do use the textbook as a reference for problem solving, to pick up concepts they did not understand in lecture, and to review for examinations. However as a reference tool current textbooks are wordy and not well organized.

- Textbooks should emphasize their role as a reference.

Our 'Text' will exist on the Internet but will function as a reference tool that focuses on the application phase that follows concept invention in lecture.

Observation #2: Lectures are not an effective method for helping students learn chemistry.

A didactic instructional strategy is the norm in introductory chemistry classes despite the advantages of a more active, student centered instructional strategy. Most chemistry professors use the traditional lecture method to deliver information and “cover” material. Many professors believe that if you present the material in a clear well-organized manner, students will learn. Unfortunately students are generally so passive in a lecture classroom they do not get involved in the learning process.

Inquiry instructional strategies have been shown to have advantages over traditional instructional strategies in attitudes, motivation, and concept and process learning. Inquiry is recognized by numerous professional organizations and funding agencies as the preferred strategy for science teaching. In spite of this, a paucity of available inquiry-oriented instructional materials has resulted in little or no change in how chemistry is taught.

The tools we propose to develop can be used in a wide variety of instructional strategies, including inquiry. The MoLE Simulations, video demonstrations and macroscopic laboratory simulations could be used to introduce a topic in a lecture setting. These tools could also be used as explorations in a laboratory setting by students using guided-inquiry instructions. These tools could also be the basis of challenge questions posed to students to address particular ideas.

Observation #3: Most instructional materials can be used in a limited range of instructional settings.

Most instructional materials have prescribed instructional strategies either implicit or explicit in their use. In spite of what the curriculum developer might consider is the best instructional approach most instructors would insist on personalizing their instruction given curriculum materials flexible enough to do so. Even if you agree that inquiry instructional strategies are superior there are many variations in the implementation in any one teacher's classroom.

- Instructional materials that are flexible and can be used in a wide variety of instruction settings are needed.

Our instructional materials can be used in a wide variety of instructional settings, including; lecture, lecture supplements, homework assignments, computer laboratory, as either group or individual activities, and to introduce or verify concepts.

Observation #4: Technology plays a secondary role in instruction.

Although technology through the use of CD-ROMs has begun to be used to help students develop visualization of particulate nature of matter (PNM) phenomenon they are typically used as ancillary materials and play a secondary role in instruction. Furthermore the computer resources are designed to fit into an instructional strategy that is fundamentally didactic.

- More technology-based activities need to be developed that can be used as a central focus of instruction.

The Computer based Concept Development Resources will allow students to visualize chemistry models at the atomic, macroscopic and symbolic levels. Guided-inquiry activities will be used in concert with the software to help students explore and invent fundamental chemical concepts.

Observation #5: There is a paucity of instructional materials that can be used to introduce concepts.

At the present time new concepts are commonly introduced through the use of assigned readings, didactic lecture, or lecture demonstrations. In rare instances new concepts may be introduced in laboratory. Technology offers a way to easily and quickly generate reproducible data, within the context of a real experiment, to support concept development.

The Computer Based Concept Development Resources are designed to be used to introduce concepts by providing a source of data that students can use in support of conceptual invention.

Observation #6: Materials that allow visualization at the particulate level of matter are limited.

In recent year the use of computer animations to illustrate particulate nature of matter phenomenon have been on the increase. However, these materials are not particularly interactive and students have difficulty linking particulate behavior of matter with macroscopic behavior/properties.

The MoLE simulations, a component of the Computer Based Concept Development Resources, are designed as interactive explorations of chemical phenomenon that can be viewed simultaneously at the macroscopic, submicroscopic and symbolic levels.

Observation #7: Students are poor problem solvers.

Students come to our lectures to listen, take notes, and watch the instructor do the problems. They (instructor as well as the student) then believe they can now do the problems themselves. But when given an examination they get low grades. They do not do assigned problems, and fail miserable at trying to explain what we consider basic chemical concepts. Too often problem-solving is taught in isolation of the concepts upon which the problem is based. A stronger link between the conceptual ideas and the problem-solving strategies is needed.

A common complaint from students is that we are not working enough sample problems in class. Students do not see the problems as the culmination of their understanding of the material but as proof of their understanding of the concept. Reality strikes when the instructor wants to get at the proof of a student's understanding of a concept by asking a slightly different question. Students see this 'new' problem as "unfair" or "tricky".

- A more active, student-centered, investigative approach that is technology based can help students develop superior problem-solving abilities.

The MoLE, Video Demonstrations and the Macroscopic Laboratory Demonstrations can be used as a source of problems and as a basis for linking problem-solving to conceptual understanding.

The Problem Solving Tutorials and the Computerized Problem Sets will take advantage of technology and inquiry activities to deliver a more interactive and systematic approach to problem solving.

Observation #8: Students exhibit poor conceptual understanding of chemistry.

While students can solve plug and chug $PV = nRT$ problems, they cannot correctly represent what a sample of helium gas looks like in a picture diagram when it is cooled from 25°C to 5°C. Most students can correctly calculate the pH of a 0.0010 M HCl solution. However, they are not successful when asked to estimate the pH when 10 mL of HCl at pH = 2 are mixed with 10 mL of HCl at pH = 6. Problems that cannot be solved by the use of an equation or problems that require a written explanation are considered to be conceptual problems. Research has shown that students who have better conceptual understanding are better problem solvers. Instructors who adopt a strong conceptual understanding approach to teaching and learning use instructional strategies and materials that require students to organize and make sense of data, predict outcomes, and explain observations to their peers. Instructors who incorporate the particulate nature of matter representation of chemical processes in their teaching provide students with an alternative method for understanding chemistry. A conceptual change approach to teaching has been shown to be a powerful basis for problem solving. Students who have a strong conceptual understanding are able to solve more sophisticated multiple concept problems.

- Materials that require more active, student-centered, investigative approach can help students develop superior conceptual understanding.

We envision our tools can be utilized in a more active, student-centered classroom; such as cooperative learning, peer lead team learning, supplemental instruction and other active learning strategies.

The Key Differences With Our Approach

In summary, we believe the key distinguishing features of the materials we propose to develop are as follows.

Use of Technology: Presently, the use of technology in general chemistry is ancillary in nature, peripheral to the central role of instruction, used as examples and illustrations, and supporting a didactic approach to instruction. In our approach the technology will play a more centralized role in instruction. It will replace the textbook in introducing concepts, by serving as a source of data from which concepts and principles can be invented. These computer-based materials will be student centered and interactive. Another strength of the components of this technology will be their ability to be used in a variety of different instructional approaches, including a computer laboratory setting; as an independent homework assignment; and in a lecture/group discussion setting.

Laboratory: In so far as the laboratory is coordinated with the rest of the course its traditional role has been to generate data to verify or confirm concepts previously introduced in the textbook and/or lecture. In this project the use of an inquiry approach in laboratory is compatible with the other elements of this project as a source of student generated data that is used to invent concepts. An additional feature will be a number of parallel macroscopic and computer-based virtual submicroscopic laboratory experiments that are designed to help students link the sensory, particulate and symbolic levels of understanding.

WebText: The traditional textbook has played a central role and carried the major burden of instruction. Our project would replace the traditional textbook with a Web-based text (WebText). The WebText will play a different role of instruction, that of applying, reinforcing, extending and reviewing the conceptual content of the course. The WebText would not be used to introduce conceptual content; a role that now would be played by other technology based tools and the laboratory. The WebText is essentially a database from which the instructor can define the Scope and Sequence of the course, and subsequently the student, can access information important to the content being studied. The instructor will be able to add supplementary entries of their own to the WebText database and the students will have a measure of control over the path they use to move through the information using links. Due to the nature of the database structure of the WebText, revisions and corrections can be done conveniently and easily when necessary. Although we do not think it would be necessary, instructors who are uncomfortable with the WebText as the only source of text-based instruction could adopt a traditional text (either new or used) to supplement their course.

Problem Solving: In the traditional textbook most problems are organized by subtopics (learning objectives) at the end of the Chapter. The problems in the WebText will be linked to the learning objectives that are chosen/defined by the instructor. To access the problems in the WebText students will be routed through a tutorial that will allow a more intelligent and systematic tutoring strategy. Students can bypass the tutorial by proving they can solve a particular problem, but if unsuccessful they will be interactively guided through the process. Once the student completes the tutorial they will be exposed to a collection of problems, similar to problems that appear at the end of the chapter in the traditional text, to practice problem solving for the particular learning objective. After problem solving in several learning objectives, a new problem set containing randomly generated problems from several learning objectives can be accessed. The engine used to generate these problem sets will also be able to generate examination questions. Instructor who feel the need for additional problems, and worked out problem examples could adopt the Schaum's Outline as a supplement.

Appendices

1. Research Base for the Project
1. Proposed Content for the Project
   a. Topics
   a. Sub Topics
   c. Learning Objectives
1. Sample Macroscopic Laboratory (Gas Laws)
   a. Guided Inquiry Lab (E-1A, B and C)
   a. Open Inquiry Lab (E. Gas systems)
1. Parallel Submicroscopic Laboratory (using MoLE Simulation)
   a. Guided Inquiry Lab
   a. Open Inquiry Lab

1. Research Base for the Project

<u>The Learning Cycle Approach:</u> The learning cycle approach is an inquiry-based instructional strategy derived from constructivist ideas of the nature of science (Bodner, 1986), and the developmental theory of Jean Piaget (Piaget, 1970). Instruction is divided into three phases. First, in the exploration phase (E), students are given experience with the concept to be developed. Second, in the conceptual invention phase (I), the student and/or teacher derives the concept from the data. Third, the application phase (A) gives the student the opportunity to explore the usefulness and application of the concept.

There are several characteristics which, when used in combination, establish the learning cycle approach as a distinct instructional strategy. The most important of these is the presence of three phases of instruction in a specific sequence, E-->I-->A. This sequence has a number of logical consequences. The exploration phase coming first implies that the information exposed by the learning activity will be used inductively by students during the invention phase.

There has been a large amount of research concerning the Learning Cycle Approach since its origins in the 1960's. Most of the research supporting the Learning Cycle Approach is discussed in detail in Lawson, Abraham, & Renner (1989).

The theoretical justification for the learning cycle approach can be found in the history and philosophy of science and in the psychology of learning, especially the developmental psychology of Jean Piaget. Although Piaget's theories are too complex to discuss in detail here, a brief consideration of one aspect of his ideas is provided to clarify how the learning cycle approach is consistent with these ideas.

According to Piaget, human beings have mental structures that interact with the environment. We assimilate or transform information from our environment into our existing mental structures. Our mental structures operate on the assimilated information and transform it in a process of accommodating to it. Thus, information from the environment transforms our mental structures, while at the same time our mental structures transform the information. This change is driven and controlled by the process of disequilibration. When our mental structures have accommodated to the assimilated information, we are in a state of equilibrium and have reached an 'accord of thought with things' (Piaget 1963, p. 8). In accommodating the information, however, the altered mental structure can become disequilibrated with related existing mental structures. The new structure must be organized with respect to the old structures to develop a new equilibrated organization. In other words, we must bring the 'accord of thought with itself' (Piaget 1963, p. 8).

If learning spontaneously occurs through a process of assimilation accommodation and organization, then instruction could take advantage by sequencing instructional activities to be compatible. In order to facilitate assimilation, instructional activities should expose the learner to a segment of the environment that demonstrates the information to be accommodated. This should be followed by activities that help the learner to accommodate to the information. Finally, in order to organize the accommodated information, activities should be developed that help the learner to see the relation between the new information and other previously learned information. The parallels between Piaget's functioning model, the Learning Cycle Approach, and the activities of this project are illustrated in the following table.

Piaget's Functioning Model	Learning Cycle Teaching Model	Project Activities and Materials
Assimilation	Exploration	Data Collection & Analysis
Accommodation	Concept Invention	Conclusions and/or Interpretation
Organization	Application	Application Activities

Bodner, G. M. (1986). Constructivism: A theory of knowledge. *Journal of Chemical Education*, *63*(10), 873-878.

Piaget, J. (1970). *Structuralism* (Chaninah Maschler, Trans.). New York: Harper and Row.

Piaget, J. (1963). *The origins of intelligence in children*. New York: Norton.

Lawson, A. E. (1995). *Science teaching and the development of thinking*. Belmont, CA: Wadsworth Publishing Company.

Lawson, A. E., Abraham, M. R., & Renner, J. W. (1989). *A theory of instruction: Using the learning cycle to teach science concepts and thinking skills [Monograph, Number One]*. Kansas State University, Manhattan, Ks: National Association for Research in Science Teaching.

Cooperative Groups: Cooperative, collaborative, and/or group learning activities have been shown to have many advantages over more individual learning modes (Johnson & Johnson, 1975, 1979; Johnson, 1976). We have suggested how group learning and data pooling can be structured by the teacher into our activities and materials.

Johnson, D. W. and R. T. Johnson (1975). Learning together and alone: Cooperation, competition and individualization. Englewood Cliffs, New Jersey, Prentice Hall.

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Linking Levels of Understanding: Chemistry has many special instructional problems that should be taken into account when instructional materials are developed and implemented in classroom settings. A critical issue in instruction is the interrelationships of the three levels of representation of most chemistry concepts; the sensory, particulate, and symbolic levels (Gabel, Samuel et al. 1987; Kozma & Russell, et al., 1996). Sensory information derived from a chemical process is explained by chemists in terms of particles (atomic and molecular behavior), which is then translated into symbols or formulas. The particulate nature of matter (PNM) is the very essence of theoretical chemistry. Atomic and molecular behavior is an abstract construct that is used to explain most chemical concepts. We know that students have difficulty understanding concepts at the particulate level and with linking these three levels of understanding. This is a frequent source of student misconceptions (Novick and Nussbaum 1981; Osborne, Cosgrove et al. 1982; Shepherd and

Renner 1982; Mitchell and Gunstone 1984; Griffiths and Preston 1989; Peterson, Treagust et al. 1989; Haidar and Abraham 1991; Abraham, Williamson et al. 1994). Instructional materials designed to aid the visualization of PNM using computer-generated, interactive, dynamic representations of atomic level behavior have been shown to be effective (Williamson and Abraham, 1995; & Abraham and Aldamash, 1996). These kinds of materials will form the base of the proposed curriculum.

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2. Proposed Content for the Project
(Scope and Sequence)

The scope and sequence of the proposed project is not unusual. It follows the path of many available general chemistry texts. What we feel is innovative about the proposed curriculum is the tools that we will develop and how they offer a fully integrated teaching and learning package. As such the following proposed topics is not rigid. The authors are open to additions and subtractions to suit the needs of potential users.

a. Topics

Chemistry I
Unit 1 - Basic Concepts, Atoms, Molecules, & Ions -
Unit 2 - Stoichiometry -
Unit 3 - Thermochemistry -
Unit 4 - Atomic Structure & Periodicity -
Unit 5 - Molecular Structure & Bonding -
Unit 6 - Properties of Gases -
Unit 7 - Properties of Liquids, Solids, & Solutions -
Unit 8 - Organic Chemistry

Chemistry II
Unit I - Kinetics -
Unit II - Equilibrium -
Unit III - Acid/Base -
Unit IV - Aqueous Equilibrium -
Unit V - Chemical Thermodynamics -
Unit VI - Electrochemistry -
Unit VII - Nuclear Chemistry -
Unit VIII - Coordination Chemistry -

b. Sub Topics

Chemistry I
Unit 1 - Basic Concepts, Atoms, Molecules, & Ions -
- Metric Measurement and Conversions
- Significant Figures
- Basic Periodicity
- Basic Atomic Theory
- Formulas and Nomenclature of Simple Compounds

Unit 2 - Stoichiometry -
- Molar Masses
- Chemical Equations
- Mass and Molar and Molecular Reaction Relationships
- Molar Concentration

Unit 3 - Thermochemistry -
- Calorimetry
- Enthalpy in Physical and Chemical Change
- Hess' Law

Enthalpies of Formation
Bond Energies
Unit 4 - Atomic Structure & Periodicity -
Light
Line Spectra
Energy Levels
Quantum Numbers
Electron Configuration
Orbitals
Periodicity
Unit 5 - Molecular Structure & Bonding -
Polarity
Simple Bonding Types
Lewis Structures
Molecular Geometry
Unit 6 - Properties of Gases -
Pressure
Ideal Gas Law (Boyle's Law, Charles' Law, Gay Lussac, Avogadro)
Gas Density
Molar Mass
Gas Stoichiometry
Dalton's Law
KMT
Graham's Law
Real Gases
Unit 7 - Properties of Liquids, Solids, & Solutions -
Phase Change
Intermolecular Bonding
Solutions
Unit 8 - Organic Chemistry
Simple Nomenclature
Functional Groups
Isomerism

Chemistry II
Unit I - Kinetics -
Collision Theory
Rates, Rate Laws, and Rate Constants
Half Life
Reaction Profiles
Catalysts
Activation Energy
Temperature Effects
Mechanisms
Unit II - Equilibrium -
Law of Mass Action
Equilibrium Stoichiometry
Le Chatelier's Principle
Unit III - Acid/Base -

pH
Acid/Base Theories
Strong Acids
Weak Acids
A/B Salts
Polyprotic Acids

Unit IV - Aqueous Equilibrium -
Buffers
A/B Neutralization/Titration
Solubility Product

Unit V - Chemical Thermodynamics -
Enthalpy
Entropy
Gibbs Equation
Free Energy and Equilibrium and Temperature

Unit VI - Electrochemistry -
Balance Redox Equations
Voltaic Cells
Standard Potentials
Electrical Potential, Equilibrium, and Free Energy
Non Standard Conditions
Electrolytic Cells

Unit VII - Nuclear Chemistry -
Subatomic Particles
Predict Stability
Balanced Nuclear Equations
Half-Life & Dating
Nuclear Energetics

Unit VIII - Coordination Chemistry -
Transition Metals
Coordination Compounds
Isomerism
Magnetic and Color Properties

c. Learning Objectives:

Chemistry I
Unit 1 - Basic Concepts, Atoms, Molecules, & Ions -
1.1. Convert units (e.g., length, mass, volume, temperature) within a unit system
1.2. Convert units (e.g. length, mass, volume, temperature) between unit systems.
1.3. Combine measurements to calculate properties (e.g. density).
1.4. Express measured and calculated quantities in exponential form.
1.5. Express measured quantities in the proper number of significant figures.
1.6. Express calculated quantities in the proper number of significant figures.
1.7. Trace the historical development of theories of matter.
1.8. State the name and symbol for the elements and their ions.
1.9. Characterize the important subatomic particles.
1.10. Determine the subatomic structure of atoms, ions, and isotopes. Use $^{A}{}_{Z}X$ charge notation.
1.11. Characterize the various parts of the periodic table.

1.12. Name and write formulas for simple compounds.

Unit 2 - Stoichiometry -
2.1. Determine atomic weights from isotope abundance.
2.2. Relate formula weights and moles to weights and numbers of particles in a chemical formula.
2.3. Determine the % composition of compounds.
2.4. Determine molecular formulas from experimental analysis data.
2.5. Write and balance simple chemical equations.
2.6. Relate numbers of moles, grams, and particles in a chemical equation. (including limiting reagents)
2.7. Determine and use molar concentration units.
2.8. Use the $M_AV_A = M_BV_B$ relationship to do dilution determinations.

Unit 3 - Thermochemistry -
3.1. Utilize and convert different forms of energy.
3.2. Determine the heat produced by a chemical or physical process from experimental data (calorimetry).
3.3. Determine the heat produced during changes in state from experimental data.
3.4. Given a thermochemical equation, calculate ΔH for a given amount of reactant or product.
3.5. Apply Hess' Laws to determine ΔH for reactions.
3.6. Apply standard ΔH_f to determine ΔH_{rxn} of reactions.
3.7. Use bond energies to predict ΔH_{rxn}.

Unit 4 - Atomic Structure & Periodicity -
4.1. Relate color, □, speed, and energy of light being released or absorbed by atoms.
4.2. Interpret the line spectrum of an atom in terms of quantum mechanics.
4.3. Describe the location and nature of electrons in an atom or ion in terms of: (a) quantum numbers, (b) energy level diagrams, (c) electron configuration, and (d) orbital shape.
4.4. Relate the periodic table to electron configurations.
4.5. Predict trends; similarities, and differences of physical and chemical properties of elements using the periodic table and electron configuration. (e.g. ionization energy, radius, formulas, reactivity)

Unit 5 - Molecular Structure & Bonding -
5.1. Predict the relative polarity and ionic/covalent character of bonds and molecules.
5.2. Identify simple bonding types.
5.3. Draw Lewis structures of ions and molecules.
5.4. Identify resonance structures for molecules.
5.5. Determine the geometric arrangement of atoms in a molecule.
5.6. Predict the types of orbitals (including hybrids) involved in bonding and resulting bond types (sigma, pi).

Unit 6 - Properties of Gases -
6.1. Describe measuring gas pressures using barometers and manometers. Relate pressure units.
6.2. Apply the ideal gas law to relate and calculate values for pressure, volume, temperature, and amount of a gas.
6.3. Apply Dalton's Law of partial pressure to calculate the pressure of combined gases and to calculate the partial pressures of gases in mixtures.
6.4. Describe gases in terms of KMT.

6.5. Relate MW and speeds of molecules using Graham's law.
6.6. Distinguish between ideal and real gases.

Unit 7 - Properties of Liquids, Solids, & Solutions -
7.1. Use KMT to explain the general properties of liquids and solids and to explain phase changes.
7.2. Classify intermolecular bonds and predict relative properties of chemical substances.
7.3. Describe the structure and properties of liquids.
7.4. Describe the structure and properties of solids.
7.5. Interpret phase diagrams.
7.6. Identify the composition of a solution.
7.7. Characterize the dissolving process. Characterize hydrolysis.
7.8. Predict products of precipitation reactions.
7.9. Characterize solutions as strong electrolytes, weak electrolytes, and nonelectrolytes.

Unit 8 - Organic Chemistry
8.1. Describe the bonds associated with organic molecules.
8.2. Use IUPAC system to name simple organic compounds.
8.3. Identify types of organic molecules according to functional group.
8.4. Characterize the simple reactions of organic molecules.
8.5. Identify isomers of simple organic compounds.
8.6. Characterize the formation of polymers.

Chemistry II
Unit I - Kinetics -
1.1. Express and compare rates of chemical reactions in terms of the concentration changes of the reactants and products (or factors proportional to concentration) per unit time.
1.2. Use collision theory to explain how chemical reactions occur and how rates are affected.
1.3. From experimental kinetics data, derive the rate law, order, and rate constant for a chemical reaction.
1.4. For a zero, first or second order reaction, determine the exact rate constant and half-life for a chemical reaction from time/concentration data.
1.5. From a reaction profile, determine ΔH & E_a for a chemical reaction. [Readings 16.6 Problem 62]
1.6. Explain the role of catalysts, what they are, how they work, and how they affect a reaction profile.
1.7. From kinetic data, determine the relationship between E_a, k, and the temperature of both catalyzed and uncatalyzed chemical reactions.
1.8. Determine the relationship between the rate law and the mechanism of a simple chemical reaction.

Unit II - Equilibrium -
2.1. Characterize chemical reactions in terms of reversibility and relative concentrations of reactants and products.
2.2. Determine equilibrium expressions for homogeneous and heterogeneous chemical reactions from stoichiometry.
2.3. Determine the stoichiometric relationship between initial and equilibrium concentrations of reactants and products.
2.4. Determine the relationship between Kold and Knew when a chemical reaction is reversed or

multiplied by a constant factor of n.
2.5. Determine the relationship between KC and KP for a chemical reaction involving gaseous components.
2.6. Determine value for K from equilibrium concentrations of reactants and products in a chemical reaction.
2.7. Determine the equilibrium concentrations of reactants and products of a chemical reaction from initial concentrations and value of K.
2.8. Determine if equilibrium has been reached in a chemical reaction; determine the direction the reaction will shift if equilibrium has not been reached.
2.9. Use Le Châtelier's Principle to predict the direction a reaction at equilibrium will shift as a result of changes in concentration, pressure/volume, and temperature as it approaches a new equilibrium.

Unit III - Acid/Base -
3.1. Relate $[H^+]$, $[OH^-]$, and K_W in an aqueous solution.
3.2. Determine the pH and/or pOH of an aqueous solution from the $[H^+]$ (or $[OH^-]$) and v.
3.3 Define acids and bases in terms of Arrhenius, and Brönsted-Lowry theories.
3.4. Recognize and construct conjugates of acids or bases.
3.5. Determine the $[H^+]$, $[OH^-]$, pH and/or pOH of a strong acid or strong base solution.
3.6. Determine and relate equilibrium concentrations, $[H^+]$, $[OH^-]$, pH and/or pOH with K_a values for weak acids (also, same for K_b values for weak bases).
3.7. Determine the $[H^+]$, $[OH^-]$, pH and/or pOH for weak acids or weak bases from initial concentrations.
3.8. Construct an ordered list of strongest to weakest (or v.v.) for acids or bases.
3.9. Determine the K_b for a weak base, given the K_a value of its conjugate acid (v.v.).
3.10. Determine the $[H^+]$, $[OH^-]$, pH and/or pOH of a salt solution.
3.11. Qualitatively determine the acidic, basic, or neutral properties of a salt.
3.12. Identify acids and bases using Lewis theory.
3.13. Determine the $[H^+]$, $[OH^-]$, pH and/or pOH of weak and strong polyprotic acids.

Unit IV - Aqueous Equilibrium -
4.1. Define and make buffer solutions from (1) a weak acid and its conjugate base, (2) a weak base and its conjugate acid, (3) a weak acid and a strong base, and (4) a weak base and a strong acid.
4.2. Determine the pH of a buffer solution from concentrations and v.v.
4.3. Make a buffer with a specific pH. [Readings 19.1 Problems 23,25]
4.4. Determine the conjugate pair best suited to make a buffer of desired pH.
4.5. Analyze a strong acid/strong base titration (including polyprotic) (determine end point location and entire pH curve, including pH at beginning, pH at end point, and pH at all other points).
4.6. Analyze a titration of a weak acid or base with a strong base or acid (determine end point location and entire pH curve, including pH at beginning, pH at end point, and pH at all other points).
4.7. Determine the K_{SP} equilibrium expression for a partially soluble salt.
4.8. Determine the K_{SP} value, given the solubility of a salt (v.v.).
4.9. Determine the effect of a common ion on the solubility of a partially soluble salt.

Unit V - Chemical Thermodynamics -
5.1. Apply Hess' Laws to thermodynamic quantities.
5.2. Determine $\Delta H°$ for a chemical reaction from $\Delta H_f°$ values of reactants and products.
5.3. Predict the qualitative change in enthalpy for various chemical reactions.
5.4. Predict and compare the qualitative change in entropy for various chemical reactions and

physical processes.
5.5. Determine $\Delta S°$ for a chemical reaction from $S°$ values of reactants and products.
5.6. Determine $\Delta G°$ for a chemical reaction from the Gibbs equation.
5.7. Determine $\Delta G°$ for a chemical reaction from $\Delta G_f°$ values of reactants and products.
5.8. Determine ΔG for a chemical reaction from $\Delta G°$ and the reaction quotient, Q.
5.9. Predict whether a chemical reaction, as written, is spontaneous, non-spontaneous, or at equilibrium.
5.10. Calculate the standard free energy for a chemical reaction from the equilibrium constant (v.v.).
5.11. Determine the equilibrium temperature, $T_{e,}$ for a chemical reaction from $\Delta H°$ and $\Delta S°$ (v.v.).

Unit VI - Electrochemistry -
6.1. Assign oxidation numbers (oxidation states) to individual elements in a chemical compound or complex ion.
6.2. Recognize redox reactions; distinguish from reactions not involving oxidation/reduction.
6.3. Stoichiometrically balance both half-reactions and cell reactions involving redox.
6.4. Draw a diagram of a voltaic (galvanic, spontaneous) cell and explain how it works, predicting changes that will occur during discharge.
6.5. Define and identify anode, cathode, oxidation process, reduction process, oxidizing agent, and reducing agent for a redox reaction.
6.6. Calculate E° for a chemical reaction using a standard reduction potential table.
6.7. Predict the products of a redox reaction.
6.8. Calculate and relate values of E°, $\Delta G°$, and K for an oxidation-reduction reaction.
6.9. Calculate E for a redox reaction under non-standard conditions of constituent concentrations and/or pressures.
6.10. Draw a diagram of an electrolytic (non-spontaneous) cell and explain how it works, predicting changes that will occur during operation.
6.11. Construct a line notation for an electrochemical cell from information concerning the anode, cathode, oxidation process, reduction process, oxidizing agent, and/or reducing agent (v.v.).
6.12. Relate the amount of product(s) produced and/or reactant consumed in an electrolytic cell to the current used, time involved, and moles of electrons associated with the corresponding half-reaction.

Unit VII - Nuclear Chemistry -
7.1. Identify the number of protons and neutrons found in the nucleus of any atom.
7.2. Identify the symbols representing various subatomic particles.
7.3. Using N and Z relationships for individual nuclides, predict stability/instability (non-radioactivity/radioactivity).
7.4. Write balanced equations for nuclear reactions including decay, transmutation, fission, & fusion.
7.5. Identify missing nuclear particles in a nuclear reaction.
7.6. Determine the half-life, beginning amount, final amount, or elapsed time in a radioactive decay reaction.
7.7. Use radioactive (e.g. carbon-14) dating techniques to calculate the age of a substance.
7.8. Determine the mass defect, binding energy, and binding energy per nucleon for a nuclear particle.
7.9. Determine the energy absorbed or released in a nuclear reaction.

Unit VIII - Coordination Chemistry -
8.1. Determine the electronic configurations of transition metals and metal ions.
8.2. Recognize and identify coordination compounds and their components.

8.3. Determine oxidation number, coordination number, orbitals used in bonding, and geometry of the central metal atom in coordination compounds and complexes.
8.4. Describe the bonding effects of polydentate ligands.
8.5. Given their formulas, name coordination compounds and complexes (and v.v.).
8.6. Recognize, describe, and identify structural isomers (coordination & linkage) and stereoisomers (geometrical and optical) of coordination complexes.
8.7. Explain spin state and the magnetic and color properties of transition elements.
8.8. Relate and predict electronic structure, field strength (Δ), spin state, and magnetic and color properties of coordination complexes in octahedral, tetrahedral, and square planar environments.
8.9. Relate and predict electronic structure, field strength (Δ), spin state, and magnetic and color properties of coordination complexes based on ligand strength.

3. Sample Macroscopic Laboratory (Gas Laws)

Gas Pressure and Volume Relationships
Exp. E-1A

Name________________________________ Lab Section______________________

Lab Partner___________________________

Problem Statement: How are the pressure and volume of a gas sample related?

I. Data Collection:

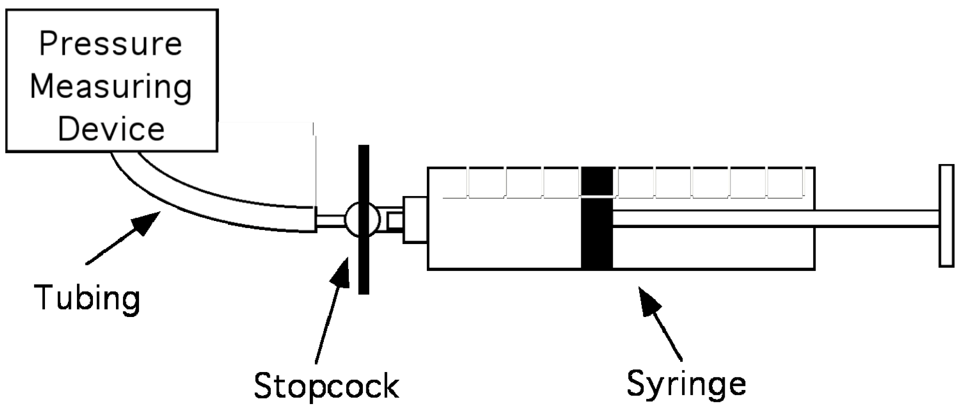

Figure A

A. Obtain a pressure measuring device as indicated by your lab instructor. Obtain a 60 mL syringe, fill it with air, and connect the syringe to the gas measuring device as indicated in figure A. Test your apparatus for gas leaks. If you can't eliminate all leaks, see your lab instructor.

B. If necessary, calibrate your gas measuring device as indicated by your lab instructor. Fill your syringe to the largest volume mark on the syringe and reconnect it to the gas measuring device. What is the pressure of the trapped air in the syringe? Explain.

C. Depress the plunger of the syringe and describe the system. Is the pressure of the trapped air greater or less than atmospheric pressure? Explain.

D. Release the plunger of the syringe. Adjust the plunger to the 60 mL mark. Record the pressure reading of the trapped air in the following table. Compress the trapped air by pushing on the plunger. Note the volume of the trapped air, close the stopcock to trap the pressure, and then note the pressure reading on the pressure device. Record these data in the following table. Take volume and pressure readings for a total of ten compressions down to as small a syringe volume as is practical. Obtain atmospheric pressure. Record these values in the following table.

Atmospheric pressure=__________torr at_______________(time),_____________(date)

Pressure Reading	Syringe Volume

II. Data Analysis:

A. If necessary, calculate the total pressure of the trapped air for each reading and record it in the following table. Show how you calculate this pressure for your first reading in the space below.

B. Calculate the total volume of the trapped air for each reading and record it in the following table. Show how you calculated this volume for your first reading. (Hint: treat the volume in the tubing and the pressure measuring device as a cylinder, $V = \pi r^2 l$.)

Data Table

Pressure	Total Volume
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________

C. What patterns are shown in these data? It might be helpful to graph the data. Try to come up with an algebraic equation that expresses the pattern you found.

III. Interpretation and Conclusions:

A. How are the pressure and volume of a gas sample related?

B. Mental Model - Draw a picture(s) that explains how the pressure and volume of a gas sample are related at the level of atoms and molecules and that illustrates the observations you made in the experiment. In words, explain how your picture(s) illustrate(s) this relationship.

Gas Pressure and Temperature Relationships
Exp. E-1B

Name________________________________ Lab Section______________________

Lab Partner___________________________

Problem Statement: How are the pressure and temperature of a gas sample related?

I. Data Collection:

A. Obtain a pressure measuring device as indicated by your lab instructor. Assemble a 125 mL Erlenmeyer flask with thermometer, tubing, and a 1000 mL beaker as shown in figure A. Connect this via a three way stopcock to the pressure measuring device and test for gas leaks. If you can't eliminate all leaks, see your lab instructor.

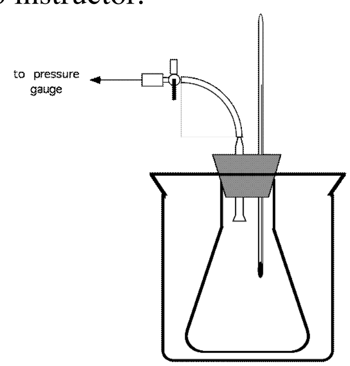

Figure A

B. If necessary, calibrate your gas measuring device as indicated by your lab instructor. Using a ring and wire gauze, support the 1000 mL beaker so that a gas burner can be used to heat the beaker. Using a clamp, suspend the flask in the beaker so that only its neck is above the beaker rim and does not touch the sides or bottom of the beaker.

Fill the beaker with tap water to about 1 1/2 cm from the rim. Be careful to **not** get any water into the flask.

Adjust the stopcock so that the flask is vented to the outside. Using a gas burner, heat the water to a temperature of 80-85˚ C using a second thermometer dipped directly into the water. The water should be constantly stirred during the heating process. The thermometer can be used, but care must be taken to not break the fragile thermometer.

When the temperature reaches 80-85˚ C, remove the heat. When the thermometer measuring the air temperature inside the flask reaches a maximum, adjust the stopcock to connect the flask to the pressure measuring device while closing the vent to the outside. While continuing to gently stir the water, allow the temperature to drop about 5˚ C.

C. Record the temperature and pressure reading in the following table. Allow the temperature to cool approximately another 5˚ C while continuing to stir the water. Record the temperature of the gas sample and the pressure reading in the following table. Using the procedure outlined above continue to record readings at approximately 5˚ C intervals until a temperature of about 15˚ C is reached.

Notes:

1. If the system leaks at any time, the experiment must be restarted

2. Cooling can be hastened by adding small amounts of ice to the water. However, to insure the temperature of the gas sample has been equalized, stir for at least 3 minutes after the ice has disappeared before taking readings.

3. Excess water can be removed from the beaker. However, the water level should be at most 3 cm from the rim.

II. Data Analysis:

A. If necessary, calculate the total pressure of the trapped air for each reading and record it in the following table. Show how you calculated this pressure for your first reading in the space below. Obtain atmospheric pressure. Record these values in the following table.

Atmospheric pressure=_________torr at______________(time),____________(date)

Data Table

Pressure Reading	Temperature (˚ C)	Pressure of Trapped Gas
___________	___________	_________________
___________	___________	_________________
___________	___________	_________________
___________	___________	_________________
___________	___________	_________________
___________	___________	_________________
___________	___________	_________________
___________	___________	_________________
___________	___________	_________________
___________	___________	_________________

B. What patterns are shown in these data? It might be helpful to graph the data. Try to come up with an algebraic equation that expresses the pattern you found.

C. (Optional) Estimate the temperature of a gas when the pressure is reduced to zero. Discuss the significance of this temperature.

III. Interpretation and Conclusions:

A. How are the pressure and temperature of a gas sample related?

B. Mental Model - Draw a picture(s) that explains how the pressure and temperature of a gas sample are related at the level of atoms and molecules and that illustrates the observations you made in the experiment. In words, explain how your picture(s) illustrate(s) this relationship.

Gas Volume and Temperature Relationships
Exp. E-1C

Name________________________________ Lab Section_______________________

Lab Partner___________________________

Problem Statement: How are the volume and temperature of a gas sample related?

I. Data Collection:

A. Using a ring and wire gauze, support a 1000 mL beaker so that a gas burner can be used to heat the beaker. Obtain a graduated J-tube filled with oil such that an air sample is trapped in its closed end. Suspending the J-tube with a thermometer clamp in the 1000 mL beaker filled with tap water so that the air trapped in the short end of the tube is well below the surface of the water (see figure A). Suspend a thermometer with another thermometer clamp in the water so that it is next to the air trapped in the short end. Make sure that the J-tube is arranged so that its graduations can be easily read.

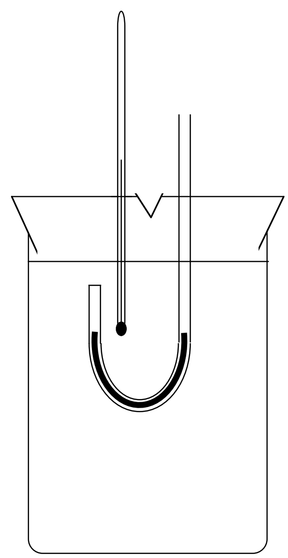

Figure A

B. Read the temperature of the water and the volume of the trapped air in the J-tube. In the space below show how you calculated the volume of the trapped air from reading the graduations from the J-tube Record your temperature and volume readings in the following table.

C. Using a gas burner, heat the water to a temperature of 75-80˚ C. The water should be constantly stirred during the heating process. When the temperature reaches 75-80˚ C, remove the heat. Allow the temperature of the trapped air to equalize with the water temperature by continuing to gently stir the water and allowing the temperature to drop about 5˚ C. At that point read the temperature and volume of the trapped air and record these values in the following table. Using the procedure outlined above continue to record readings at approximately 5˚ C intervals until a temperature of about 15˚ C is reached.

Notes:

1. Cooling can be hastened by adding small amounts of ice to the water. However, to insure the temperature of the trapped air has been equalized, stir for at least 3 minutes after the ice has disappeared before taking readings.

2. Excess water can be removed from the beaker. However, make sure the J-tube remains submerged well below the water level.

Data Table

Temperature	Volume
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________

II. Data Analysis:

A. What patterns are shown in these data? It might be helpful to graph the data. Try to come up with an algebraic equation that expresses the pattern you found.

B. (Optional) Estimate the temperature of a gas when the volume is reduced to zero. Discuss the significance of this temperature.

III. Interpretation and Conclusions:

A. How are the volume and temperature of a gas sample related?

B. Mental Model - Draw a picture(s) that explains how the volume and temperature of a gas sample are related at the level of atoms and molecules and that illustrates the observations you made in the experiment. In words, explain how your picture(s) illustrate(s) this relationship.

E. GAS SYSTEMS
Open Inquiry Laboratory

System 1

Investigate and compare the behavior of gases other than air. Possibilities include oxygen (can be generated by heating potassium chlorate with a pinch or manganese dioxide as a catalyst), or carbon dioxide (can be generated by adding dilute acid to calcium carbonate). **CAUTION!!!** When diluting acids extreme care must be taken not to allow the acid to come into contact with your skin or clothes. Also add acid to water, *not vice versa*, when diluting.

System 2

Investigate and compare the vapor pressures of pure liquids with combinations of these liquids. See your instructor for suggested liquids.

System 3

Investigate the relationship between the amount of gas and its pressure at constant temperature and volume.

System 4

Investigate and compare the vapor pressures of liquids using different sized flasks.

System 5

Investigate and compare the vapor pressures of pure liquids with solutions of those liquids containing measured amounts of dissolved solid chemicals.

System 6

Investigate the relationship between the density of air and temperature. (Hint: Derive an equation relating the change in mass of air at different temperatures at constant pressure and volume.)

System 7

Investigate the molecular weight of gases from the mass of a measured volume. CO_2 and CH_4 are examples.

System 8

Investigate any other gas system or investigate a modification of any of the above systems. For safety reasons, discuss your system with the lab instructor before proceeding.

4. **Parallel Submicroscopic Laboratory**
MoLE Gas Laws Activities

To begin this assignment you must be able to log on to the Internet using Internet Explorer (Microsoft) 4.5 or higher. If you do not have the current version of the browser, go to http://www.microsoft.com/downloads and follow the instructions on the page. You will need Internet Explorer for your particular operating system. If you have any difficulties contact your instructor.

Once the browser is running, type the following address into the location-input line near the top of the Internet Explorer window:

(see referenced web site)

This will load the Gas Simulation. Once you have the simulation is running your screen will look like what is shown in left hand section of Figure I. below.

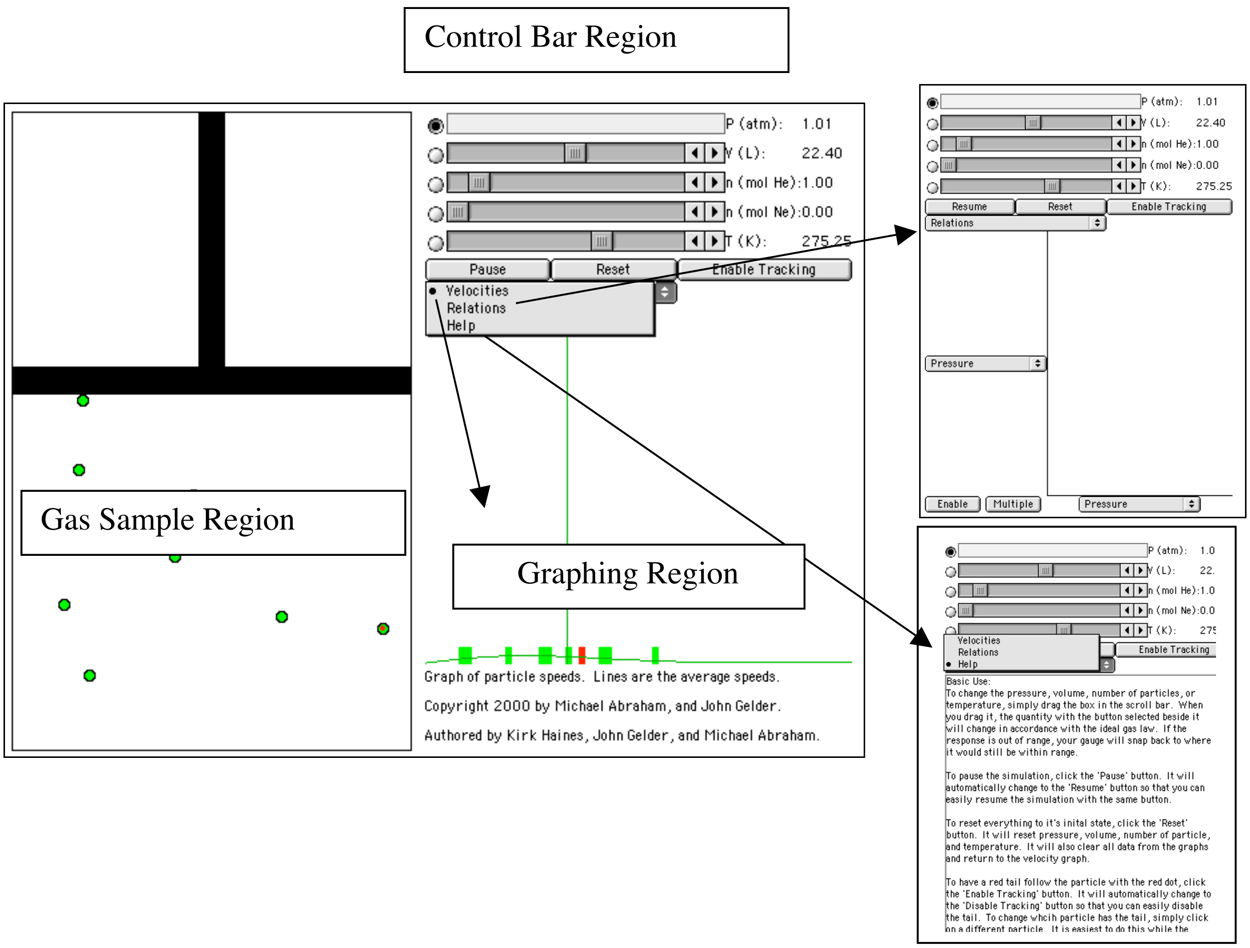

Figure I.

There are three important regions that require some discussion. The Gas Sample Region has the most activity. It is a container with a plunger. To explore the behavior of the gas sample you can change the variables located in the Control Bar Region. The Control Bar Region shows five scrollbars: pressure (in units of atmospheres), volume (in units of liters), mol of gas (one for He gas and the other for Ne gas), and temperature (in units of Kelvins). To the left of each scrollbar is a radio button. When selected, that particular variable (called the dependent variable) is calculated based on the value of the other four variables. In the default mode the pressure scrollbar's radio button is selected so the pressure of the gas sample is calculated.

As a simple exploration try moving each of the scrollbars and observe the effect on the gas sample. These effects will be addressed in more detail in this experiment.

There are three buttons immediately below the Control Bar Region. The Pause button will suspend the motion in the gas sample, the Reset button returns the program to the default conditions, and the Enable Tracking button turns a red tracking line on and off.

Below the Pause Button is a fourth button different from the previous three in that it is a dropdown menu. Clicking and holding the mouse button will reveal three choices: Velocities (default); Relations (graphing); and Help.

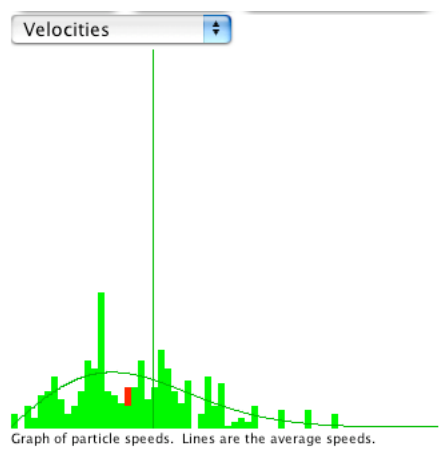

Figure II.

The default mode is Velocities. The Velocity Distribution Region shows a plot of the velocity distribution in the gas sample (see Figure II.). The y-axis of this plot represents the number of particles. The x-axis represents the range of velocities starting at zero. The bars in this plot represent the velocities of the particles in the Gas Sample Region. As the velocities of the particles change, the plot is redrawn. The smooth curved line in the plot represents the ideal distribution of the velocities for the gas sample. The vertical line represents the average (root-mean-square average) velocity of the sample. Observe the behavior of this region while changing each of the variables in the Control Bar Region. In the Gas Sample Region, one of the particles is labeled with a red dot. This same particle is identified in red in the velocity distribution plot. If you click on the enable tracking button, you can follow the path of the particle. The length of the tail represents a fixed unit of time, and consequently can be used as a measure of the velocity of the particle. If you pause the motion of the particles, you can click on different particles to get a measure of their velocity.

A second choice from the drop down menu is the Relations view. This choice reveals an x,y graph with a dropdown menu on each axis. Selecting the dropdown menu on either axis provides a list of the variables shown in the Control Bar Region. The two buttons, Enable and Multiple are used when plotting pairs of variables. If you select pressure for the y-axis and volume for the x-axis, and the click on “Enable,” these same variables are activated in the Control Bar Region. By scrolling the volume slide bar in the Control Bar Region you will trace out a plot that will look similar to Figure III.

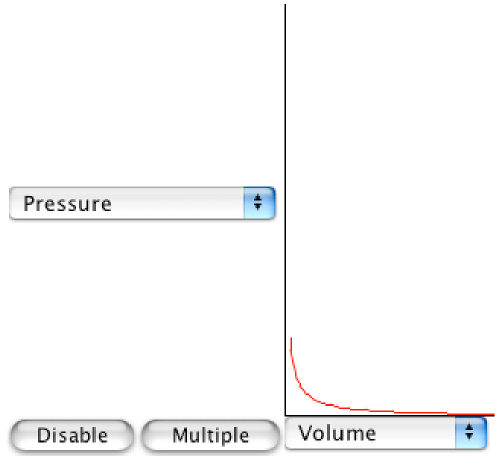

Figure III.

The Multiple Button allows two or more plots to be superimposed. Select Pressure and Volume as the variable to be plotted on your graph. Then click on the Multiple button and adjust the temperature to 400 K. Click on the Enable button and scroll the Volume slide bar. Click on the Disable button and change the temperature to 200 K. Click on the Enable button and scroll the Volume slide bar. Repeat this process for the minimum temperature. You will see a graph that looks similar to Figure IV.

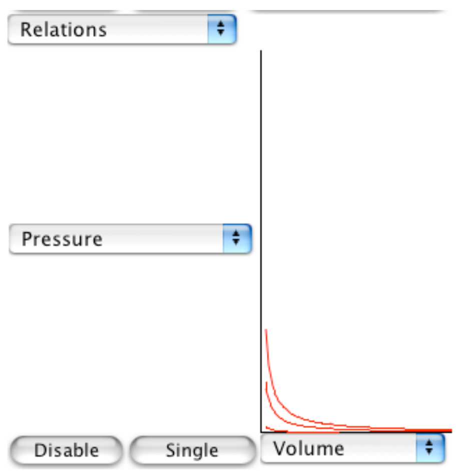

Figure IV.

Got the hang of it? If you have any questions check with another student in the class, your instructor.