U.S. DEPARTMENT OF ENERGY

SMALL BUSINESS INNOVATION RESEARCH
SOLICITATION NO. DOE/ER-0653

COVER PAGE

APPENDIX A

DOE USE ONLY

96-I

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submission."

a
Subtopic (a-d)

AMOUNT REQUESTED:
$ 72,720.44
(Not to exceed $75,000.)

A Novel Chemistry Exploration System

rotein Solutions, Inc.

6009 Highland Drive

Lake City STATE: UT ZIP: 84121 —
(Please provide extended zip code.)

CERTIFICATIONS AND QUESTIONS

ve applicant organization certifies that it is a small business and meets the definition stated in Section 2.3.

um of two-thirds of the funded research or analytical effort will be performed by the applicant organization (see
5.5).

licant small business will comply with the provisions regarding: (1) lobbying, (2) debarment, suspension, and
sponsibility matters, and (3) drug-free workplace requirements. (See Appendix E and Appendix F.) Inability to
any or all statements requires explanation.

licant small business has provided the necessary information requested in Section 3.4.4 <u>if</u> it has received more
Phase II SBIR awards in the preceding five fiscal years.

firm and/or Principal Investigator submitted proposals containing a significant amount of essentially equivalent
der other federal program solicitations, or received other federal awards containing a significant amount of
ly equivalent work? If "yes", the application must include the required information requested in Section 3.4.2.j.

all business delinquent on any Federal debt? (If "yes", please attach an explanation.)

posed project does not result in an award, does the applicant permit the government to disclose the title and
abstract of the application, and the name, address, and telephone number of the business official, to any
parties?

(See Requirements in Sec. 1.5)	**Corporate/Business Certifying Official**
Mr., Mrs., Ms., Dr.	**TYPE NAME, Indicate Mr., Mrs., Ms., Dr.**
t J. Scheer	Dr. Joseph D. Andrade
irector	**Title:** Chief Executive Officer
01)583-9301	**Telephone No.** (801)583-9301
Date: 2/12/96	**Signature** **Date:** 2/12/96

PROPRIETARY NOTICE (IF APPLICABLE, SEE SECTION 5.4)

evaluate this submission, these data shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed in whole or in
agreement is awarded to this applicant as a result of or in connection with the submission of these data, the Government shall have the right to
data to the extent provided in the funding agreement. This restriction does not limit the Government's right to use information contained in the data if
ce without restriction. The data in this submission subject to this restriction are contained on pages:

TABLE OF CONTENTS

U.S. DEPARTMENT OF ENERGY

SMALL BUSINESS INNOVATION RESEARCH PROGRAM
PHASE I - FY 1996-I
PROJECT SUMMARY

APPENDIX B

DOE USE ONLY

96-I

39
Topic No. (1-41)

a
Subtopic (a-d)

FIRM NAME, ADDRESS, TELEPHONE NUMBER:
Protein Solutions, Inc.
6009 Highland Drive
Salt Lake City, UT 84121
(801)583-9301

TITLE OF PROJECT:
A Novel Chemistry Exploration System

NAME AND TITLE OF PRINCIPAL INVESTIGATOR: Robert J. Scheer, Ph.D. Project Director

TECHNICAL ABSTRACT (Limit to space provided; use the format provided in the instructions on the reverse side.)

This Small Business Innovation Research Phase I project will study the technical feasibility and safety of a complete, quantitative chemistry exploration kit for use in high school and college chemistry classes. This series of chemistry explorations will go beyond the purely phenomenological demonstrations found in most chemistry kits to teach the concepts behind the phenomenon.

A large number of science courses taught in schools today do not involve laboratories. Although good instructors incorporate class demonstrations, hands-on homework, and various teaching aids, including computer simulations, students in such courses often accept key concepts and experimental results without discovering them for themselves. Our series will present the students and instructor with a compact, easy to use set of materials and textual explanations for discovery and incorporation of fundamental science concepts.

Research toward the development of a "household" safe, self-contained and quantitative chemistry laboratory is proposed. Although packaged like a textbook, it will contain all of the supplies and information needed to directly discover, quantify and experience key concepts related to chemistry. It is expected that such a system will be widely adopted as a supplement to chemistry textbooks of all levels of instruction, from college telecourses to junior high school classrooms.

KEY WORDS:
Laboratory, Kit, Experiment, Chemistry, Inquiry-based

ANTICIPATED RESULTS/POTENTIAL COMMERCIAL APPLICATIONS as described by the applicant. (Limit to space provided).

A conservative estimate of the classes without a laboratory is 25%, indicating a *need* in approximately 45,000 high school level chemistry classrooms. If each kit were to have enough materials for four students, then for twenty students to participate in their own research, 5 kits/class would be required (up to 225,000 kits per year.) Other markets include distance learning (telecourses), home teaching, and colleges/universities with inadequate laboratories.

D. IDENTIFICATION AND SIGNIFICANCE OF THE OPPORTUNITY

Students in the United States may receive little or no laboratory experience by the time they graduate from high school. The labless science course has become very common in chemical and physical science education. Although outstanding instructors attempt to overcome this deficiency with the use of classroom demonstrations, discovery-based homework assignments, class projects, and computer simulations, many instructors have neither the time nor the inclination to utilize these tools, particularly with the added responsibilities of instructing several classes a day over a broad range of subjects (1). Also, the rapid growth of "distance learning" – using television and video tapes to offer courses remotely over the National Information Infrastructure (internet) – is expected to produce large numbers of "science" students with little *hands-on*, laboratory experience.

At a time when there are state, regional, and national initiatives to adopt hands-on approaches to learning science (2), it becomes increasingly important that science instructors involved in labless courses have at their disposal a complete and safe laboratory teaching tool. We call one such tool, which is appropriate for use in a regular classroom, laboratory or responsible home setting, the Labless Lab®.

The name "Labless Lab®" is meant to describe a prepared laboratory system for use in a previously labless class. It will consist of a single partitioned container enclosing safety equipment (goggles, chemical resistant gloves, an absorbent working surface and a safety checklist) and 10 to 20 science exploration components (with instructions, supplies and devices). The kit will be safe, complete and ready to use (3). To provide the rigorous and quantitative results found in more complex laboratory designs using only the simple and common materials to be found in this kit, *novel experiments and experimental methods will have to be researched and developed*. This is the proposed research for this Phase I research project.

The recent recommendations for change in chemistry education (4), determined by the American Chemical Society's Division on Chemical Education 1990 Task Force, include the addition of: original problem solving, the methodology of science, experimentation in the lab, evaluation of students' ability to interpret information and analyze data, and a *reorganization of the course around the laboratory*.

United States' businesses also perceive certain general defects in the education system and have initiated skills up-grade programs, spending nearly $40 billion a year educating and training employees (5,6).

Experiments, as they are used in the classroom and classroom associated laboratories now, often follow "cookbook" formats with right or wrong "fill in the blank" answers. Comments from a beginning chemistry student include (7),

> "The labs were presented to us without any explanation of the concepts being covered. I felt like we were simply following a recipe without knowing why."

Although not directly related to pre-college education, other areas of importance include correspondence, distance learning, and TV/video delivered courses. Although some distance learning/TV-based education offerings work hard to incorporate a laboratory component, such as the University of Maine's unique course in biology (8), the very rapid growth in multi- and hyper-media and in computer, satellite, and TV based courses and even degrees, is leaving some question as to whether a "virtual education" is indeed desirable (9). Labs are either not available for these courses, or they must be scheduled during off-peak hours at a central location, defeating the purpose of a distance learning format. Nevertheless, most states, due to political and economic pressure, are rapidly increasing their distance and remote education activities. The Public Broadcasting System's adult learning service has issued a handbook on the subject (10), and the American Chemical Society is establishing an educational outreach program on the World Wide Web (11).

It is apparent that there is a need for <u>small, inexpensive, completely self contained personal laboratories</u> which are safe and can supplement existing textbooks. Many complex concepts can be safely observed, quantified and assimilated by experimentation with properly designed simple materials. Good models are the *Explorabook : A science museum in a book* (12), *The Most Amazing Pop-up Science Book* (13) and *Earthsearch: A kid's geography museum in a book* (14). We suggest the reviewers examine a copy of one or more of these books in preparation for their review of this proposal.

If our national goal is to produce a public with the knowledge to make informed decisions on matters of science, industry and the environment, then it is important that students are presented with a positive and lasting science experience early in their education. This is accomplished by giving these new chemists a practical look at how chemistry works and affects their everyday lives. An emphasis on this type of discovery-based learning is taking hold, but its implementation has been slow due to several factors including: lack of teacher preparation time, safety issues, cost limitations, laboratory expenses, and a general resistance to change. The Labless Lab® in Chemistry addresses all five of these impediments to chemistry education.

This proposal is relevant to the program emphasis of the 1994 National Critical Technologies study (15), which states that the general public and scientific professionals in particular, must have awareness and appreciation, and preferably a strong working knowledge of the concepts, principles, and limitations of chemistry. Our Labless Lab® in Chemistry will incorporate activities and experiments related to improving math/computational skills, energy/Earth conservation, and communication skills. But the most important contribution this project will make in National Critical Technologies, is helping to produce individuals who have a real, rather than solely a virtual, background in chemistry.

E. BACKGROUND, TECHNICAL APPROACH, AND POTENTIAL USES

Background

One job of the chemistry educator is to "enable" the public to understand how chemistry affects our lives and how it can improve our lives. An innovative series of 26 half-hour segments entitled "The World of Chemistry" featuring nobel laureate Dr. Roald Hoffman and noted chemistry demonstrator, Dr. Donald Showalter (UW-Stevens Point), aired on many PBS stations and is available on video (16). During this series, Hoffman and Showalter create a unique learning environment where chemistry comes alive. They demonstrate how chemistry is part of our everyday lives. Shows like this can help chemistry instructors *initiate student interest* in chemistry.

While demonstrations(videos) can be exciting, they lack individual involvement. (In the case of demonstrations, their set up can be time consuming.) This lack of involvement leaves the student without a *personal experience* or understanding. The step required to make chemistry "real," is left to the laboratory where each student is allowed to "try" chemistry. Unfortunately, without adequate laboratory space and equipment, or the time required to develop inquiry-based laboratories, this step ("personal exploration") is often bypassed in favor of videos or demonstrations. But it is this critical step, the *personal exploration*, that leads to the *retention* of chemistry knowledge (17-19).

Other than the "microscaling" of experiments (a valuable environmental achievement), chemistry teaching laboratories have not changed much over the past 40 to 50 years. The ability of a student to reproduce known values is still taken as evidence of "understanding" the scientific principles involved. We hope to shift the laboratory paradigm from that of well known but highly structured "recipe" laboratories, with "fill in the blank" lab reports, to one of *investigative* problem solving where the concepts can be appreciated and understood. This method, sometimes called "constructivist" or "inquiry-based" learning, allows students great flexibility in answering their laboratory questions.

An example of just such a constructivist chemistry laboratory was presented at both the 1994 and the 1995 Annual National Science Teacher's Association (NSTA) meetings in Anaheim, California and Philadelphia, PA, respectively. The presentation, by P. Clough and L. Clark who are chemistry instructors in a Wisconsin high school, described how students were given a set of starting chemicals (reactants) and were then asked to determine the outcome or products. Students had to think, organize and persevere to complete the exercise, thus developing good science

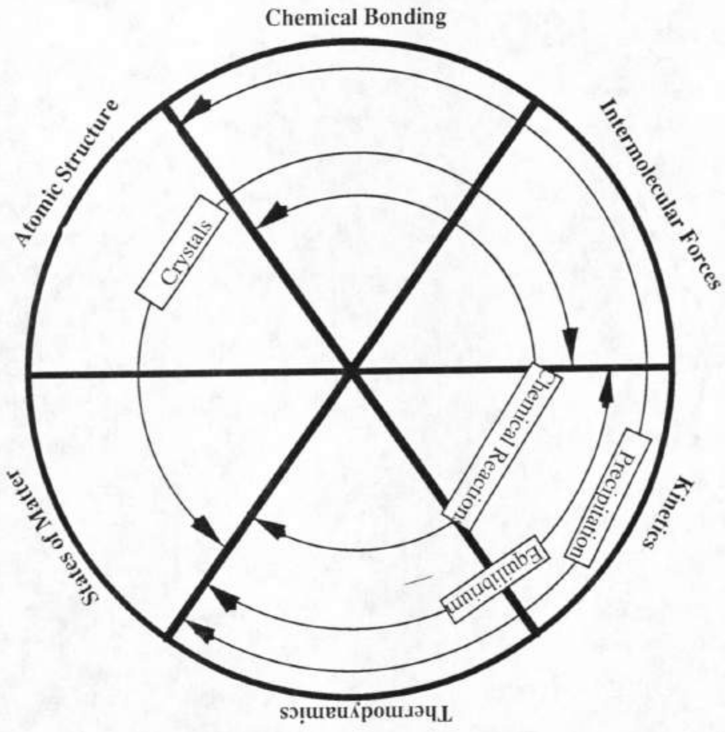

Figure 1. The "Concept Wheel" demonstrates the interrelatedness of each subtopic (written inside the circle) to each major concept (written outside the circle).

electrolytes. All of these can be found among the average household kitchen/bathroom cleaning and personal care items and pose no particular new dangers. Emphasis will be placed on **safety and responsible use of these everyday items**, and should increase the safety conscious use of these materials in the course of everyday activities. Suitably accurate lab equipment/devices will be constructed from common kitchen and office supplies. The lab will be supplied with simple and inexpensive devices for determining mass, density, temperature, volume, etc.

At the conclusion of Phase I we will have established the feasibility of a Labless Lab® in Chemistry. The materials, equipment, and procedures developed during the early part of Phase I will be evaluated during the fall/winter of 1996-7 by INVERNESS Research Associates and the Center for Integrated Science Education*. Other evaluators will include

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* See attached letters in appendix concerning Consultation arrangements.

investigation techniques as well as learning the concepts of chemical reactions, gas production, heat production, precipitation, etc.

Another inquiry-based learning system has been developed by Dr. S.L. Seager, Professor of Chemistry at Weber State University in Ogden, UT. He has developed a laboratory for first year chemistry students based on inquiry. His laboratory follows the path of exploration, invention/discovery, and application.

Dr. Art Ellis, chemistry professor at the University of Wisconsin–Madison has led a team of chemistry and materials science professors to develop a system of teaching freshman chemistry utilizing solid state materials (i.e. familiar objects) in an inquiry-based format (6). The results of their efforts, *Teaching General Chemistry: A Materials Science Companion*, is utilized by several colleges and universities including Reed College, Portland, OR and Purdue University, West Lafayette, IN (21).

The disadvantage of these laboratories has been the increased time commitment required of the lab instructors. Our safe, simple and complete Labless Lab® exploration system minimizes the need for instructors to use valuable time gathering equipment and chemicals and designing the laboratory experiments, thus providing the time for the instructor to work directly with the students.

To define the learning objectives of the Labless Lab® in Chemistry (summarized in Tables 1 and 2), we exhaustively reviewed both chemistry curricula and major chemistry textbooks (21). Each major learning objective or concept is divided up into several subtopics, typical of introductory chemistry texts. This idea is well represented by the "concept wheel" of Figure 1. The six major topics each make up one slice of the circle, and inside the circle are drawn example subtopic arcs. These arcs of influence are drawn inside the circle to indicate which major concepts are covered by which subtopics. For simplicity, only four subtopics are shown on the concept wheel, (all 15 will be covered by the explorations.) See Table 2 for a list of all subtopics.

Innovativeness and Originality

Several publishers and manufacturers provide laboratory supplements to existing texts. These supplements usually consist of text which describes the experiments and lists the materials required for the lessons. Other supplements or kits which do contain materials required for the experiments are focused on only one or two concepts (i.e. acid/base chemistry, or ion exchange reactions); additional kits must be purchased to complete the series. These kits are relatively expensive and as a result are often used by the instructor only for demonstration purposes.

We propose to create a supplement which contains the supplies and explanation necessary to free students and instructors to explore the possible *reasons* for an outcome. These will arise out of new experiments and novel ways of preparing and presenting the experiments. Indeed, creating these *novel ways* is the primary research focus of this project. The Labless Lab® will free the instructor from having to gather the required chemicals and equipment for each set of experiments since the students will each have their own complete set. This freedom will allow the instructor more time to interact with the students and the time to develop an inquiry-based laboratory/classroom. In this environment of student exploration, the laboratory or investigation could supplant (but never eliminate) the classroom lecture setting. Our Labless Lab® in Chemistry will describe the laboratory procedures and provide the means for students and teachers to realize all of the major concepts of chemistry, with the versatility to encourage new explorations.

Technical Approach

Using simple procedures, "safe" household chemicals, and simple apparatus, we propose to develop, characterize, and produce novel explorations suitable for the direct observation of a range of phenomena related to chemistry. The explorations and fundamental concepts are considered in a matrix model, where the concept is "integrated" into several observations/experiments and each experiment "integrates" several concepts. See Tables 1 and 2. This supplement will be flexible enough to complement any one year introductory chemistry course regardless of the text used.

During the Phase I research period we will select the chemicals and materials and develop necessary devices to perform the explorations. Needed chemicals will include oxidants, ion exchange salts, acids, bases, gases, hydrate salts, metals, polymers, polar/nonpolar liquids, and

Table 1. Activity matrix showing the 23 proposed explorations (numbered) along the horizontal axis and the subtopics of introductory chemistry along the vertical axis.

Exploration/ Fundamental Concept	Density	Phase Changes	Gases	Metals	Crystals	Chemical Reactions	Exothermic/Endothermic	Equilibrium	Oxidation/Reduction	Aqueous Solution Chemistry	Gas Formation	Precipitation	Acid/Base Chemistry	Intermolecular Forces	Chemical Bonding
(25) LCT Calorimetry						×				×				×	×
(24) Construction of a Battery						×			×					×	×
(23) Dehydration of Hydrate Salts						×		×						×	×
(20) Conductivity Tester															
(19) Crystallization of Salts					×							×		×	×
(18) Crystallography		×			×									×	×
(17) Stoiciometry/Continuous Variations						×					×	×		×	×
(16) Ionic and Polar Bonding								×				×		×	×
(15) Electrochemcial Metal Series					×	×		×	×	×				×	×
(14) Gases and Pressure	×		×								×			×	×
(13) Chromatography															
(12) Hot Packs: Heating System		×				×		×				×		×	×
(11) Polar and Hydrogen Bonding	×					×						×		×	×
(10) Polymers															
(9) Kinetics						×								×	×
(8) Colligative Properties		×												×	×
(7) Titration of Acids/Bases						×		×	×	×			×	×	×
(6) Acid/Base Indicators						×			×	×			×	×	×
(5) Ice Calorimetry		×						×						×	
(4) Advanced Measurement	×		×	×	×			×	×				×	×	×
(3) Simple Measurement	×	×				×	×			×	×	×		×	×
(2) Introduction to Measurement	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×
(1) Lab Safety	×	×	×	×	×	×	×	×	×	×	×	×	×	×	×

Table 2. Introductory Physical/Chemical Science Concepts and their corresponding Exploration Numbers (21)

Major Theme and Subtopics	Exploration Numbers
Safe/Accurate Laboratory Practices (Experiment # 1):	
States of Matter:	
Density	2, 3, 4
Phase Changes	5, 8, 12, 18, 19
Gases	14
Metals	15, 18, 19
Crystals	12, 16, 18, 19
Atomic Structure:	
Electromagnetics	15
Metals	15, 18, 19
Crystals	12,16, 18, 19
Oxidation/ Reduction	6, 7, 15, 24
Acid/Base Chemistry	6, 7
Chemical Bonding:	
Metals	15, 18, 19
Crystals	12, 16, 18, 19
Chemical Reactions	6, 7, 9, 11, 12, 15, 17, 23, 24
Oxidation/Reduction	6, 7, 15, 24
Aqueous Solution Chemistry	6, 7, 8, 9, 11, 12, 16, 19, 25
Gas Formations	7, 9, 14
Precipitation	11, 12, 16, 17, 19
Acid/Base Chemistry	6, 7
Intermolecular Forces:	
Phase Changes	5, 8, 12, 18, 19
Gases	14
Metals	15, 18, 19
Crystals	12,16, 18, 19
Chemical Reactions	6, 7, 9, 11, 12, 15, 17, 23, 24
Aqueous Solution Chemistry	6, 7, 15, 24
Precipitation	11, 12, 16, 17, 19
Thermodynamics:	
Chemical Reactions	6, 7, 9, 11, 12, 15, 17, 23, 24
Exothermic/Endothermic	5, 7, 12, 15, 16, 23
Equilibrium	7, 10, 12, 15, 17, 25
Aqueous Solution Chemistry	6, 7, 15, 25
Gas Formation	14, 17, 25
Precipitation	11, 12, 16, 17, 19
Acid/Base Chemistry	6, 7, 17
Kinetics:	
Chemical Reactions	6, 7, 9, 11, 12, 15, 17, 23, 24
Exothermic/Endothermic	5, 7, 12, 15, 16, 23
Equilibrium	7, 10, 12, 15, 17, 25
Aqueous Solution Chemistry	6, 7, 15, 25
Gas Formation	14, 17, 25
Precipitation	11, 12, 16, 17, 19

Phase II research will include the study of more complex chemistry questions as well as the development and incorporation of a software component (for molecular modeling and safe visualization of dangerous procedures.) During Phase II we will address the question of how to quantify the student's senses so they will be able to answer the questions, "How bright is the light? What is the temperature of that material? What is the mass of that object?" Other Phase II extensions will include rewrites of the explorations to establish quantifiable results and the addition of further explorations as suggested by review committees. We will convert the typical phenomenological results of these explorations to quantifiable results, "real numbers". During Phase II and on into Phase III we will scale up the production of the materials and equipment in a cost-effective manner and provide the further materials needed for a comprehensive Labless Lab® in Chemistry. The Labless Lab® in Chemistry will be produced, packaged along with appropriate written materials and given wide commercial distribution during Phase III.

G. PHASE I WORK PLAN:

Design and Development of Explorations

To alter these explorations from their current status (that of producing phenomenological results) to an advanced status producing quantifiable results will require extensive research and development. During the Phase I research period we will examine the following explorations (as listed in table 1) to determine if they can produce easily measured quantifiable results.

1. *Safe Chemical Laboratory Practices.* Important issues to be addressed include personal safety, safety of others and environmental safety. We will compile proven systems of safety from university, high school, industry, and college lab instructors. Our set of explorations will begin with the review and practice of these safety issues. We will incorporate safety reminders throughout each exploration. A sample safety explanation is in the appendix.

2. *Introduction to Measurement.* The explorations described here require the measurement of mass, volume, temperature and pH. Measurement accuracy, significant figures and repeatability will be discussed and emphasized through examples and exercises in this exploration and reinforced through out each exploration.

3. *Simple Measurement.* We will design a simple mass measurement device using a pencil, ruler, paper clips, BB's and double-sided tape. Other measurement devices to be included are a TLC (thermochromic liquid crystal) thermometer for temperature measurement, pipettes for volume and density measurement, and pH paper for pH measurement. Exercises in this exploration will include practice measuring mass, temperature, volume and pH. It is recognized that these devices do not offer the accuracy of standard lab equipment, but they will offer the students a chance to record numerical data and perform meaningful calculations.

4. *Advanced Measurement.* We will design explorations centered around determining density, energy/enthalpy changes, solubility, and ionic content. For example, we may have the student build a simple device for measuring liquid density (hydrometer) from pipettes and wood screws. The accuracy of such a device is expected to be within 1% for specific gravities between 0.95 and 1.05. The density of solid materials can be determined using the mass measurement device and the volumetric measurement device. Densities near that of water can be measured using various water solutions such as NaCl/water and alcohol/water solutions of different ratios.

5. *Ice calorimetry and "Coffee Cup" calorimetry.* Using the heat of fusion and the heat capacity of water, one can measure the amount of energy given off from an exothermic reaction by determining the mass/temperature of ice/water before and after the event. Using a 150ml sample of water and a TLC thermometer, the heat change can be measured to within 1.5 kilojoules.

several chemistry instructors from our junior high teacher network†. Thus we will have the benefit of rigorous field testing of the concepts and prototype of this Phase I project prior to the completion of the project report and submission of the Phase II application.

Potential Uses and Commercial Potential

There are over 10 million students in high school grades 10-12, with a student/teacher ratio of 20 to 1 (24). Each student will participate in an average of one year of chemistry, thus accounting for approximately 180,000 high school chemistry classes being taught each year. Many of these classes have inadequate or absent laboratory facilities due either to lack of time or funds. Motivated and prepared instructors can prepare class demonstrations and show instructional videos, such as "The World of Chemistry"(16), to enhance classroom learning, but these do not provide the thorough understanding gained through the experience of doing chemistry. A conservative estimate of the classes without a laboratory is 25%, indicating a *need* for approximately 45,000 high school level chemistry classroom kits. If each kit were to have enough materials for four students, then for twenty students to participate in their own research, 5 kits/class would be required (up to 225,000 kits per year.) Other markets include distance learning (telecourses), home teaching, and colleges/universities with inadequate laboratories.

Protein Solutions, Inc. now has three products in the science education market: Night Life®: Science in the Dark, a bioluminescent science kit for upper elementary and junior high students, Galaxsea®, an adult science novelty consisting of packaged bioluminescent plankton and Teacher's Kit™, a set of four science explorations involving bioluminescent phytoplankton designed for individual and classroom use. These kits are distributed through several major national catalog distributors which target science and nature stores in museum/science center gift shops. PSI is now negotiating with a group in Britain to produce and distribute the products in Britain and on the European continent.

An informal assessment indicates that the market for chemistry textbooks alone is in the range of $10 million/year for colleges and universities. If one includes the high school market this total rises to $30-40 million/year. A recent marketing survey of the college textbook market (25) indicated that there are ten major publishers who reported revenues in 1991 of $1.6 billion/year.

A typical high school/university chemistry text can be purchased for $20-50/unit. PSI's Labless Lab® in Chemistry must be priced similarly in order to be competitive.

F. PHASE I TECHNICAL OBJECTIVES

We are proposing the development of a completely self contained chemistry laboratory which, although packaged like a textbook, will contain within it all of the supplies, devices, and information needed to directly discover and experience key chemistry concepts. It will include a set of hands-on, discovery-based experiments which the students can perform for themselves, enabling them to experience, utilize, understand, and apply the major concepts, themes, and topics of "first year" chemistry. Common consumer products will be employed as the supplies and devices (3). Experiments which are designed for inquiry, discovery and quantification of complex concepts will be designed. The experiments and observations will utilize both the students' senses and simple measurement devices for detection and quantification of data.

The objective of the Phase I research project is to convert the major concepts, principles, and themes of basic chemistry at both the high school and university levels (now in a written format) to a hands-on format, i.e. to design the experiments. By carefully reviewing modern chemistry textbooks, current reports, and leading discussions with educators, those concepts, principles, and themes have become one dimension of the matrix given in Table 1. The second dimension of the matrix in Table 1 includes experiments, activities, and projects enabling the student to *experience and discover* the major concepts, principles, and themes (21,22). Refinements will be made to this table as suggested by upcoming conferences, reviewer comments and task force reports.

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† A consortium of 27 junior high school instructors from around the country, recently established to evaluate a physical science laboratory under development at Protein Solutions, Inc.

6. *Acid and Base Indicators found in the Kitchen.* Many vegetable extracts indicate pH change with a change in color. Red and green cabbage and other leafy vegetables exhibit this phenomenon. The reasons for color change will be discussed and the student will calibrate their indicator color to a known pH value. This lab will include discussion and exploration of what pH and pOH mean and the discovery of other possible indicators.

7. *Titration of Acid/Base solutions.* Using included weak acid/base solutions of known concentration, students will determine the molar concentration of unknown samples.

8. *Colligative Properties.* The task here is to design an exploration to teach the concepts of how solute concentration affects vapor pressure, osmotic pressure, boiling point and freezing point. Extensions of this exploration can include ionic charge and chemical composition. For example, how and why the same number of moles of NaCl in solution produces a different effect than $CaCl_2$.

9. *Kinetics.* Design of explorations to teach the effect of temperature, surface area and concentration on the rate of reaction. Extension to determination of reaction constants will be studied during the second phase of this research project.

10. *Polymers (LeChatelier's Principle and Entropy).* We will design an exploration centered around the use of elastic polymers as "entropy springs." Again, quantification will be an important area of development.

Stretched + Heat <===> Unstretched

11. *Polar and Hydrogen Bonding.* Design of an exploration which follows the principle of "like dissolves like". Using various oils, alcohol, water, dyes, surfactants and food coloring, students will explore hydrogen and polar bonding in liquids.

12. *Hot Packs: Heating System.* Outdoor equipment suppliers have designed a *reusable* "hot pack" which uses the latent heat of fusion in a supersaturated solution to generate a temperature increase. In addition to its use as a demonstration of the heat of fusion and supersaturation, this device can be used as a safe heat source for several explorations.

A copy of exploration 12 is included in the appendix as an example.

13. *Chromatography.* Chromatography is a common laboratory method used to separate various chemical species based on their abilities to travel through a given medium. An excellent classroom demonstration of this was developed in India (23). By using simple transport systems, i.e. sand or filter paper the student can quickly and easily see which molecules will move faster than others based on the separation of colors from drink mixes, water-soluble color markers, etc. When asked to devise their own method for separation of a given substance, the students will have to understand what causes the components of a liquid solution to separate.

14. *Gases and Pressure.* We will design a simple device, probably involving soda bottles, straws and needle-less syringes, to teach the concepts of the ideal gas law, atmospheric pressure, hydrostatic pressure and vacuum. Using relatively simple devices the students can determine the gas constant, *R*. Students will also measure and atmospheric pressure and its changes with the weather pattern by constructing a simple barometer.

15. *Electrochemical Metal Series.* A series of metal ion solutions is compared according to their ability to coat or remove metal ions from other metals in the series. Variation of metal geometry, (i.e. powder or bar, or strips, or beads) and competition between different metals will be explored. Concepts learned include electronegativity, charge, voltage and solubility.

16. *Ionic and Polar bonding.* An exploration of ionic/polar bonding will be designed using several kitchen ingredients. This will require more thought and may be extended into phase II.

17. *Stoichiometry using the Method of Continuous Variations.* By varying the ratios of two reactants and observing the ratio needed for optimum reaction, the correct stoichiometric ratio is determined by the student. Various reactions will be examined to determine suitability for this set of explorations.

18. *Crystallography.* The task here is to design an experiment comparing the crystal structure of several solid state minerals and polymers. Comparison will lead to discussion of why they differ and to crystal shape, size, density and symmetry.

19. *Crystallization of Salts.* By evaporating a concentrated salt solution the student can witness the formation of typical crystal structures for various soluble salts. Examples are a saturated sodium chloride solution, which produces a cubic crystal structure upon evaporation of the water and a saturated copper (I) chloride solution which forms a hexagonal close packed structure. Variations of recrystallization techniques (temperature and evaporation rates) can be tried to determine their effect on crystal size and shape (demonstrations of kinetics and diffusion).

20. *Conductivity Tester.* A prototype of a simple and inexpensive visual conductivity meter designed to indicate "good", "poor" or "non-" conductivity of either a solid or a liquid is being designed and tested in a classroom setting for the Labless Lab® in Polymers. This should be included with the Labless Lab® in Chemistry for determination of ionic content in a liquid solution and measuring the conductivity of a metal or other solid.

Concurrent Thematic Objectives

A continuing effort to ensure safety and relevance is concurrent to development of the labs.

21. *Design Safest Reasonable Activities.* This is a review process. Each activity will be examined for safety by experienced laboratory directors, safety officials and long-time chemistry instructors. During Phase II of this grant, we will assure complete and final compliance with safety guidelines in accordance with the Consumer Product Safety Commission (CPSC) *Code of Federal Regulations*. Our CPSC representative is Mr. Louie Pain.

One such example is the general warning to be posted on the outside cover and in every document:

WARNING: THIS SET CONTAINS CHEMICALS THAT MAY BE HARMFUL IF MISUSED. READ CAUTIONS ON INDIVIDUAL CONTAINERS CAREFULLY. NOT TO BE USED BY CHILDREN EXCEPT UNDER ADULT SUPERVISION.

For the final product warning labels specific to each chemical and activity will be included on each bottle and with the literature. Copies of MSDS sheets, although not required for "consumer" amounts, will be in the hands of the school superintendent, the school safety officer, the school principal, the janitor and the instructor.

Other specific safety precautions and warnings will be incorporated under advice from Michael Kralik (industry representative and consultant for PSI on previous projects), Mojdeh Khalighi (Utah department of State Risk Management).

22. *Testing and Evaluation.* INVERNESS Research Associates, an independent educational consulting firm located in Inverness, California, has as its mission "to provide insight into the educational process -- and the efforts to reform it -- through in-depth field-based research and evaluation." They will, through participant observation, in-depth interviews, focus groups, surveys, and document reviews, evaluate the Labless Lab® in Chemistry documentation and its laboratory materials on a national level.

The Center for Integrated Science Education (CISE) will provide like services on a local and state level.

An example of just such a constructivist chemistry laboratory was presented at both the 1994 and the 1995 Annual National Science Teacher's Association (NSTA) meetings in Anaheim, California and Philadelphia, PA, respectively. The presentations by P. Clough and L. Clark, high school chemistry instructors in Wisconsin, described how students were given a set of starting chemicals (reactants) and were then asked to determine the outcome or products.

Another inquiry-based learning system has been developed by Dr. S.L. Seager, Professor of Chemistry at Weber State University in Ogden, UT. He has developed a laboratory for first year chemistry students based on inquiry. His laboratory follows the path of exploration, invention/discovery, and application.

Dr. Art Ellis, chemistry professor at the University of Wisconsin–Madison has led a team of chemistry and materials science professors to develop a system of teaching freshman chemistry utilizing solid state materials (i.e. familiar objects) in an inquiry-based format (6). The results of their efforts, *Teaching General Chemistry: A Materials Science Companion*, is utilized by several colleges and universities including Reed College, Portland, OR and Purdue University, West Lafayette, IN (21).

An innovative series of 26 half-hour segments entitled "The World of Chemistry" featuring nobel laureate Dr. Roald Hoffman and noted chemistry demonstrator, Dr. Donald Showalter (UW-Stevens Point), is available on video (16). During this series, Hoffman and Showalter create a unique learning environment where chemistry comes alive. Shows like this can help chemistry instructors *initiate student interest* in chemistry.

PSI already has considerable experience in the Labless Lab® concept. Our Labless Lab® in Polymers is a successful extension of research begun with the aid of an NSF, Phase I SBIR (January, 1994). We will introduce a prototype of this kit for evaluation at the March 1996 Annual National Science Teacher's Association (NSTA) conference in St. Louis. We hope to begin a full marketing effort of the Labless Lab® in Polymers during this conference. The Labless Lab® in polymers focuses on facilitating the direct experience and understanding of many unique concepts and characteristics of macromolecules and polymeric materials. We are working with the University of Utah's Center Integrated Science Education (CISE) on the development of a Labless Lab® in Science through Art being designed for a general education telecourse on science for non-science majors (taught by Joe Andrade).

J. KEY PERSONNEL AND BIBLIOGRAPHY

Dr. Robert Scheer, Principle Investigator, received his Ph.D. in Materials Science and Engineering in 1993. He served as the principle investigator of PSI's Labless Lab® in Polymer Materials, a completed SBIR Phase I from the National Science Foundation. This project is making rapid progress and will result in a Phase II submission about September 15, 1994. Dr. Scheer has had considerable experience in the teaching of college level chemistry, and is a part-time adjunct chemistry instructor at Salt Lake Community College. Dr. Scheer's abbreviated CV is included as the next page.

Dr. Joe Andrade is founder and Chief Scientific Officer of PSI, although he is not listed as a senior personnel participant, he does spend about 25% of his full time activities with Protein Solutions, Inc. and will be working closely with Dr. Scheer on this project. Dr. Andrade is Professor of Materials Science and of Bioengineering at the University of Utah and has taught at the University undergraduate and graduate levels for the past 25 years. He also had some experience teaching high school chemistry and biology many years ago, directs the University's Center for Integrated Science Education and is heavily involved with jr. high and high school teachers locally. He is also involved in the development and conduction of inservice courses for local teachers and in the revision of the state core science curriculum.

Bibliography

Please see the list of references at the end of this proposal.

Preliminary Work for Phase II

The development of the following are seen as long term projects requiring more effort than available during the Phase I research period.

23. *Dehydration of Hydrate Salts.* This is a classical experiment to determine the hydration coefficient of a salt, and an excellent method for investigating stoichiometry. See example. This will require refinement of chemistry and technique for use with relatively cool heat sources and crude mass balances.

24. *Construction of a Battery.* The concept of reduction/oxidation, ion exchange reactions, conductivity, and electric potential can be discovered by building a simple electro-voltaic cell. Models for implementation of this procedure have already been established. These typically involve the metals and ions of Cu/Pb/Fe/Ni/Sn/Ag/Zn/Mg. A cell with wide applicability to these related concepts will be developed using "safe" metals and ions.

25. *LCT Calorimetry.* To test for an energy change during mixing, a procedure of reading temperature change from a LCT thermometer is used.

26. *Development of Software Component.* We will establish connections with software publishers through our involvement with the Journal of Chemical Education: Software editor, Dr. John Moore, one of our Labless Lab® in Polymers consultants. Our goal in Phase II is to incorporate a software component into this lab. Software development during Phase II will primarily be done through subcontracting.

In general, Phase II research will center around turning these relatively common, well known explorations into experiments which will produce quantifiable results found in most conventional chemistry laboratories. It is recognized that without the electronic enhanced sensor equipment found in the well-equipped chemistry laboratory, the results here will not be as *accurate* as those found in a chemistry laboratory. This is not to say that the results are "bad."

H. PHASE I PROJECT DESCRIPTION

The principle objectives of this phase I research project are to advance the usefulness of several chemistry explorations from phenomenological results to quantitative results utilizing several novel measurement devices. These include mass measurement (#3), specific gravity and density measurement (#4), calorimetry (#5), pH (#'s 6 and 7), kinetics (#8), pressure (#14) and others to be developed during the phase II portion of this lab.

Our estimated timeline for completion of each of these sections is shown on the Gantt chart which follows, see figure 2.

I. RELATED RESEARCH

Much of the related research described in this section has been reviewed in the background section and commercial potential sections above.

An important area of research exists in the area of distance learning/TV-based education. For example, the University of Maine offers a unique course in biology (8) which incorporates a laboratory into a distance learning format. The Public Broadcasting System's adult learning service has issued a handbook on the subject of distance learning (10), but there is little discussion of the incorporation of laboratories into science courses offered over long distances.

In the area of traditional classroom settings, chemistry teaching laboratories have not changed much over the past 40 to 50 years. The ability of a student to reproduce known values is still taken as evidence of "understanding" the scientific principles involved. The Labless Lab® will change the laboratory paradigm from that of well known but highly structured "recipe" laboratories, to one of *investigative* problem solving where the concepts can be appreciated and understood.

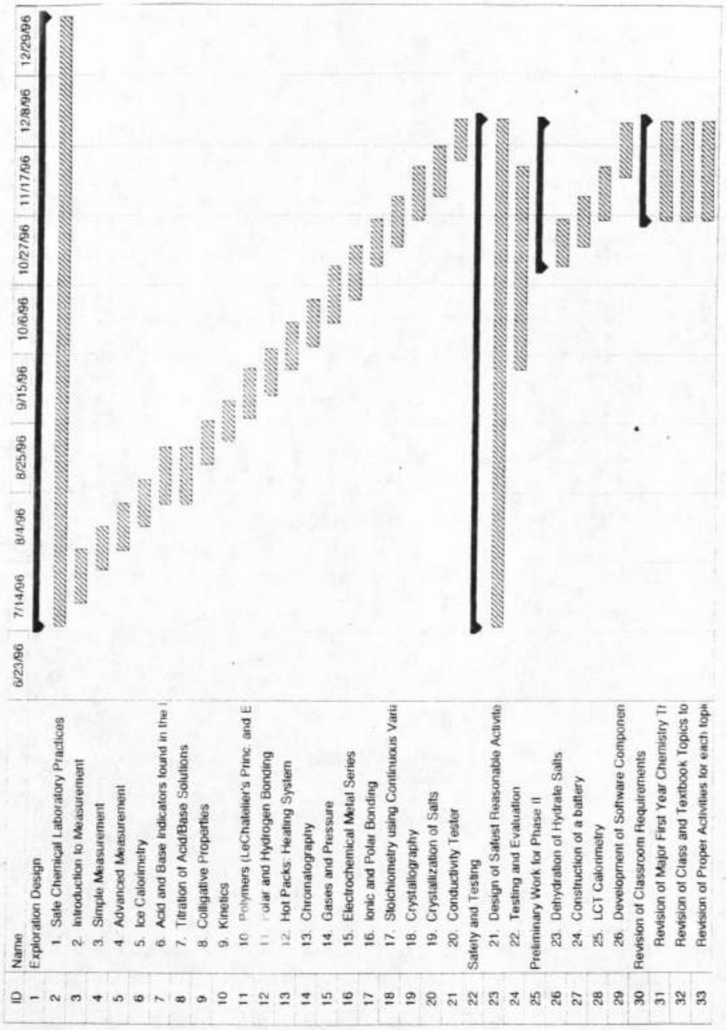

Figure 2. Gantt chart outlining project milestones. Numbered explorations correspond to numbers in Section G of this proposal (Phase I Work Plan.)

K. EQUIPMENT, INSTRUMENTATION, COMPUTERS, AND FACILITIES

PSI's laboratories and office are located in the University Research Park at 391 Chipeta Way. The labs are adjacent to the University of Utah's Center for Integrated Science Education (CISE) with whom PSI has a synergistic relationship. Cooperation between CISE and PSI has produced workshops and science exhibits. PSI's facilities include about 150 square feet of office space and 600 square feet of laboratory and production space. Research and development equipment includes spectrophotometers, ovens, measuring electronics, Macintosh and IBM computers with appropriate sensor and monitoring interfaces, optical microscopes, and other general routine laboratory equipment.

PSI is a member of the Center for Biopolymers at Interfaces at the University of Utah, a University/Industry/State consortium. As a member, PSI has priority access to equipment, laboratories, and technical personnel in the Center, including specialized analytical facilities, specialized material testing facilities, and materials production and fabrication equipment.

L. CONSULTANTS AND SUBCONTRACTS

INVERNESS Research Associates will serve as a consultant for evaluation of these explorations at a national level. An agreed upon fee for services is shown in the budget.

The Center for Integrated Science Education will serve as a consultant for evaluation if these explorations at a local and state level. An agreed upon fee for services is shown in the budget.

No subcontracts are included with this proposal.

M. SIMILAR GRANT APPLICATIONS, PROPOSALS, OR AWARDS

An NSF Phase I SBIR entitled, "A Quantitative, Modular Exploration System for Chemistry" was submitted in June of 1995. Dr. Scheer's role as the principle investigator for this proposal would be approximately 3 months. (Our proposal was submitted on June 15, 1995. Its outcome is not known. If funded, its tentative effective dates are from 3/96–9/96.) This proposal was submitted under topic "Education and Human Resources, Topic 25(a)."

The proposal to NSF emphasizes development of a chemistry exploration set for college students, while this DOE proposal emphasizes development of a chemistry exploration for pre-college students. We estimate approximately 60% funding overlap.

N. BUDGET

Senior Personnel: Dr. Robert J. Scheer, Principle Investigator. Dr. Joe Andrade, advisor to the project, his experience and expertise will be invaluable to us (Dr. Andrade will donate his time to this project.) Mr. Roshen Koshy, an experienced lab technician working at Protein Solutions, Inc.

Travel: Travel, room and board, and registration for the 1997 NSTA annual convention in New Orleans, LA. Here we will disseminate information concerning our findings.

Materials and Supplies: Chemicals, labware, and disposable supplies.

Publication, Documentation, Dissemination: Printing costs for evaluation copies of lab instructions.

Consultant Services: Dawn Huntwork of INVERNESS Research Associates will direct the national evaluation. Mary McDonald of the Center for Integrated Science Education will direct the local and state evaluation.

Other: Miscellaneous fees for chemical testing and toxicity studies at local private testing laboratories.

O. PRIOR PHASE II AWARDS

Protein Solutions, Inc. has not received more than 15 Phase II awards in the past 5 fiscal years.

P. REFERENCES/NOTES/BIBLIOGRAPHY

1. Kelter, P. "Are Our Demonstration-Base Workshops Doing More Harm than Good?" *J. Chem. Educ.* 71 (1994) 109.

2. Project 2061 report in *Science for all Americans* by F.J. Rutherford and A. Ahlgren.

3. Anticipated List of Chemicals and Supplies:

Thermometer
pH paper
Filter Paper
Misc. Cups/containers
Pipettes
Marker
Pencils
Rulers
Paper Clips
Paper Towels
Goggles

Toothpicks
Wire
Spectrographic Film
Cylinder and Plunger
Double Sided Tape
Volumetric measuring cup
Heat Solution™ packet
Isopropyl Alcohol
Fizzing Antacid Tablets
Baking Powder
Baking Soda

Vinegar
Chalk
Cotton
Food Coloring
3% Hydrogen Peroxide
Salt
Sugar
Quartz
Pyrite
Chewable Antacid Tablets
Bubble Solution
Craft Sticks

4. Lloyd, B.W.; Spencer, J.N. "New Directions for General Chemistry," *J. Chem. Educ.* 71 (1994) 206.

5. Editorial Column "Education: An Industrial Imperative," *J. Chem. Educ.* 71 (1994) 179.

6. Ellis, Arthur B. "Treating Students and Industry as Customers," *Chemtech.* March (1995) 15.

7. Salt Lake Community College, CHEM 123, taught by the PI during Summer 1995.

8. Office of the President, University of Maine, Orono, Maine.

9. Winner, L. "The Virtually Educated," *Technology Review.* (MIT Press) May/June (1994) 66.

10. PBS Adult Learning Service, *Going the Distance: A Handbook for Developing Distance Degree Programs.* Alexandria, VA. 1994.

11. American Chemical Society, *A Foundation for the Future: American Chemical Society Annual Report, 1994.* Washington, DC. 1995.

Related Web Pages:

http://rampages.onramp.net/~jaldr/chemtchr.html	(precollege curriculum)
http://tigerched.clemson.edu/	(evaluation techniques)
http://www.anachem.umu.se/elcs/pointers.html	(general)
http://putwest.boces.org/standards11.html#Science	(Benchmarks 2061)
http://www.aaas.org/project2061/2061main.htm	(Benchmarks 2061)
http://www.nas.edu/new/science-standards.html	(National Science Education Standards)
gopher://gopher.chs.iron.k12.us:70/1D-1%3A16207%3AK-6	(Utah elementary science standards)
gopher://gopher.chs.iron.k12.us:70/1D-1%3A16209%3AScience	(Utah secondary science standards)

12. Cassidy, J. *Explorabook.* Klutz Press: Palo Alto, CA. 1991.

13. Young, Jay. *The Most Amazing Pop-up Science Book*. Science Museum: London. 1994?.
14. Cassidy, J. *Earthsearch* Klutz Press: Palo Alto, CA. 1993.
15. National Science Foundation, SBIR Program Solicitation, p. 2.
16. *The World of Chemistry, Video Series*. Produced by University of Wisconsin and the Educational Film Center: Madison, Wisconsin. 1990.
17. Landisk, C.R., et. al. "Curriculum Planning Conference." *J. Chem. Educ.* 71 (1994) 454.
18. Ashford, P.C. "The Science-Kit Advantage." *Science Scope*. March (1995) 75.
19. DuPont Communications Team. Fun with Science. Dupont Ponchartrain Works: Kinston, NC. (1994)
20. Listing of 20 Activities to be developed for the Labless Lab® in Chemistry

1) Safe Chemical Laboratory Practices
2) Intr[illegible]tion to Measurement
3) Si[illegible]easurement
4) A[illegible]d Measurement
5) I[illegible]imetry
6) A[illegible] Base Indicators
7) Titr[illegible]on
8) Colligative Properties
9) Kinetics
10) Polymers
11) Polar and Hydrogen Bonding
12) Hot Packs: Heating System
13) Chromatography
14) Gases and Pressure
15) Electrochemical Metal Series
16) Ionic and Polar Bonding
17) Stoichiometry
18) Crystallography
19) Crystallization of Salts
20) Conductivity Tester
23) Dehydration of Hydrate Salts
24) Construction of a Battery
25) LCT Calorimetry

21. (All of the following chemistry textbooks and lab manuals were evaluated for their content and topics)

Amend, et al. *General, Organic, and Biological Chemistry*. Saunders. 1993.
Bell, J.A. *Chemical Explorations*. D.C. Heath. 1993.
Brady, J.E.; Holum, J.R. *Chemistry: The Study of Matter and its Changes*. Wiley. 1993.
Chemistry in Context: Applying Chemistry to Society. American Chemical Society. 1990.
Ellis, A.B., et al. *Teaching General Chemistry: A Mat'ls Science Companion*. ACS. 1993.
General Chemistry (117-119) Laboratory Manual. University of Utah. 1993.
Korchin, F.G. *Science and the Marketplace*. Tiger Publications. 1992.
Kotz, J.C. et al. *The Chemical World: Concepts and Applications*. Saunders. 1994.
Kotz, J.C.; Purcell, K.F. *Chemistry and Chemical Reactivity*. Saunders. 1991.
Masterson, W.L.; Hurley, C.N. *Chemistry: Principles and Reactions*. Saunders. 1989.
Milio, F.R. et al. *Experiments in General Chemistry*. Saunders. 1991.
Shakhashari, B.Z. *Chemical Demonstrations: A Handbook for Teachers of Chemistry*, vol. 1-4. U. of Wisconsin. 1992.
Smoot, R.C. et al. *Chemistry*. Macmillan. 1993.
Snyder, C.H. *The Extraordinary Chemistry of Ordinary Things*. Wiley. 1992.
Summerlin, L.R.; Ealy, J.L. *Chemical Demonstrations: A Sourcebook for Teachers* . ACS. 1988.

22. Selvaratnam, M. "Coherent, Concise, and Principle-based Organization of Chemical Knowledge." *J. Chem. Educ.* 70 (1993) 824.
23. Lalitha, N. "Chromatographic Separation of Plant Pigments Using Sand as the Adsorbant," *J. Chem. Educ.* 71 (1994) 432.
24. Schwartz, B.B. *The American Physical Society News*. May 1994.
25. *Educational Marketeer*. August 10, 1992.
McDonald, M.; Thorimbert, K.; Andrade, J.D. "The Science Education Market." report to the State Centers of Excellence Program (801-538-8770), July 1992; Center for Integrated Science Education.

THE UNIVERSITY OF UTAH

Center for Integrated Science Education (CISE)

2480 MEB, Salt Lake City, Utah 84112
(801) 581-4171

February 5, 1996

Robert J. Scheer, Ph.D.
Project Director
Protein Solutions, Inc.
P.O. Box 58093
Salt Lake City, Utah 84158-0093

Dear Dr. Scheer,

The Center for Integrated Science Education (CISE) at the University of Utah is pleased to collaborate with Protein Solutions' "A Novel Chemistry Exploration System" project. CISE is committed to provide junior and high school students enhanced science learning opportunities, particularly in the physical and chemical sciences.

CISE will work closely with Protein Solutions by establishing a content review committee of scientists from the region, and by coordinating test sites with local school districts and the State Office of Education. CISE will assure that the key concepts will be aligned with the *National Science Standards* and *Benchmarks for Science Literacy*.

CISE's partnership with Protein Solutions provides an innovative opportunity to better prepare our students with the scientific knowledge necessary to make informed public decisions in their future. Thank you for this opportunity.

Sincerely,

Mary L. McDonald, Program Coordinator
Center for Integrated Science Education

Department of Bioengineering
2480 Merrill Engineering Building
Salt Lake City, Utah 84112
(801) 581-8528
FAX: (801) 585-5361

INVERNESS
RESEARCH
ASSOCIATES

Post Office Box 313
Inverness CA 94937
PHONE: 415 669-7156
FAX: 415 669-7186

February 12, 1996

Rob Scheer
Protein Solutions
P.O. Box 58093
Salt Lake City, UT 84158-0093

Dear Mr. Scheer,

This memo serves as a letter of commitment to serve as the evaluator on your chemistry education project "*A Novel Chemistry Exploration System*." I and the Inverness Research Associates team have many years of experience in the area of science and math education evaluation, both in the formal and informal domains. We have conducted many classroom studies of curricular materials, including kit-based ones; we have extensive experience in developing studies which involve working intensively with teachers and students, as well as considering the perspectives of "outside experts" in the field of study.

I feel that Inverness Research can contribute significantly to the development and evaluation of this project; we look forward to working with you.

Sincerely,

Mark St. John

Mark St. John

Robert J. Scheer
P.O. Box 80 3
Salt Lake City, UT 84158-0093
(801)583-9301
e-mail <rob.scheer@m.cc.utah.edu>

EDUCATION

Ph.D. in Materials Science and Engineering, December 1993, University of Utah, Salt Lake City, UT.
Dissertation emphasis: Mechanical, interfacial, and surface study of composite materials.

B.S. in Mechanical Engineering, May 1989, Duke University, Durham, NC.
Emphasis: Fracture mechanics and failure analysis of polymeric materials.

UNIVERSITY HONORS

National Science Foundation Fellow, University of Utah Graduate Research Fellow,
Dean's List Duke University, Academic All American, Duke University Magna Cum Laude

EXPERIENCE

Project Director
Protein Solutions, Inc. Salt Lake City, UT. 1994 - present. Directed research for the design and implementation of novel science education materials.

Instructor
Salt Lake Community College, Salt Lake City, UT. 1993 - present. Planned, instructed, and graded for undergraduate physical science and engineering classes.

Research Assistant
University of Utah, Salt Lake City, UT. 1989 - 1993. Tested mechanical properties of polymers and composites, studied surfaces and interfaces, tested adhesive bonds on the microscopic scale, and developed stress analyses related to materials testing and bimaterial interfaces.

Engineering Technician
Sandia National Laboratory, Albuquerque, NM. Summers, 1988-1989. Designed engineering experiments for failure analysis of ceramic materials, and extensively researched current experimental techniques for determining material fracture toughness.

AFFILIATIONS

American Society for Mechanical Engineers
ASM International
The Minerals, Metals, and Materials Society
American Physical Society
The American Chemical Society, Division of Chem. Ed.
National Science Teachers Association
Utah Science Teachers Association
American Society for Engineering Educators

PUBLICATIONS

Andrade, J.D. and R.J. Scheer. "Applying 'Intelligent' Materials for Materials Education: The Labless Lab™." *Proc., 2nd Annual Conference on Intelligent Materials*, Tech. Publ. Co.: PA, 1994.

Scheer, R.J. and J.D. Andrade. "Applying Intelligent Materials to Materials Education." *Journal of Intelligent Materials*, 1995.

Scheer, R.J. "A Labless Lab® Approach to Materials Education using Intelligent Materials." Proceedings, American Society for Engineering Educators, 1995 Annual Conven. 1995.

Exploration #12:
Measuring "The Heat Solution™" using Coffee Cup Calorimetry

The Heat Solution™ hand warmer device utilizes a chemical "activity" to generate a temperature increase.

You are to determine the nature of this chemical "activity".

Materials supplied:

Heat Solution™ packet
1 20 oz. styrofoam cup with lid
1 12 oz. styrofoam cup with lid
thermometer
goggles
mass balance (the one you've made)
tongs/tweezers
100 ml volumetric measuring cup
Thermodynamic Chart (listed below)

Other required materials:

Vessel with boiling water
Timepiece

Procedure:

1) Don your safety goggles.
2) Heat your vessel of water to boiling.
3) Place the Heat Solution™ packet in boiling water using tongs.
4) After ten minutes, remove the vessel from the heat source and gently remove the packet from the hot water using the tongs.
5) Allow the packet to cool for at least 30 minutes or until it reaches room temperature (cool to touch).
6) Carefully dry the packet and measure and record its mass.
7) If the packet should accidentally activate (turn white and feel solid), repeat steps 2 through 5.
8) Add 150 ml of cool water to the 12 oz. styrofoam cup.
9) Place the 12 oz. cup in the empty 20 oz. cup
10) Gently submerge the packet in the 150 ml of water.
11) Measure and record the time and temperature of the water in the cup.
12) Measure and record the temperature every five minutes until it does not change between readings.
13) Activate the packet by "clicking" the metal disk.
14) Quickly cover both of the cups with their plastic lids.
15) Measure and record the temperature every two minutes until it reaches a maximum (3 readings in a row).
16) Remove the packet, dry it, and measure and record its mass.

You now have all of the data required to answer the following questions:

I. Is the chemical "activity" exothermic or endothermic?
II. Is the "activity" reversible?
III. What is the specific heat (joules/g) of the "activity"? (To answer, do the following four items.)
1) Calculate the difference between the temperature of the water just before activation and the plateau temperature. This is ΔT.
2) Add the mass of the water (148 grams) to the mass of the packet. This is the total mass.
3) Multiply the total mass by the change in temperature (ΔT) by the specific heat of water (4.184 J/g•°C). This is the total heat generated.
4) Divide the total heat generated by the mass of the packet. This is the specific heat generated.

IV. Use the information you know about the specific heat and the temperature to determine which one of the following chemicals and activity are involved in the temperature increase?

THERMODYNAMIC CHART

Chemical Name/Specific Heat	Heat of Solution	Heat of Fusion	Melting Point
Sodium chloride	67 J/g	517 J/g	800°C
Sodium acetate	208 J/g	≈364 J/g	324°C
Sodium hydroxide	1072 J/g	209 J/g	322°C
Potassium acetate	151 J/g	≈275 J/g	292°C
Calcium chloride	185 J/g	230 J/g	782°C
Potassium bromide	181 J/g	176 J/g	742°C

WARNING: THIS SET CONTAINS CHEMICALS THAT MAY BE HARMFUL IF MISUSED. READ CAUTIONS ON INDIVIDUAL CONTAINERS CAREFULLY. NOT TO BE USED BY CHILDREN EXCEPT UNDER ADULT SUPERVISION.

Important safety issues.

1. Always perform explorations with the aid of an adult partner or supervisor. Never work alone.
1. You are required to wear splash goggles in all chemical laboratories.
2. Learn the following emergency procedures:
   Call 911 in case of emergency.
   If you feel dizzy or sick, stop what you are doing and leave the room.
3. Wear appropriate clothing (no shorts, short skirts, or short sleeve shirts or tank tops) and shoes (no open toed sandals); confine long hair.
4. Do not eat, drink or smoke in your lab area.
5. When mixing or heating chemicals, point the container away from individuals.
6. Clean up all spills immediately by covering the spill with the appropriate clean-up materials listed below:
   Paper Towel, Chemisorb, resealable plastic bags
7. Dispose of chemicals as properly described in each exploration.
8. Only those experiments included in this instruction manual should be used.
9. Chemicals should be mixed only in the proportions and by the methods prescribed in the instructions.

Please sign the following agreement:

I have read carefully and understand all of the safety rules contained on this sheet and in the laboratory manual or laboratory handouts required for this course. I recognized that it is my responsibility to obey them faithfully.

I realized that all chemicals are potentially dangerous; therefore I will exercise care in handling them. If I am unsure of the potential hazards of any chemical, I will discuss this with my instructor prior to using the chemical in question.

I understand that I am required to wear approved chemical splash goggles <u>AT ALL TIMES</u> while I am in the laboratory. I also understand the dangers involved in wearing all types of contact lenses in the chemical lab. If I elect to wear contact lenses in the laboratory, I will assume all responsibility for damages caused by wearing them in the lab.

I further understand that I am permitted to work on these explorations only when accompanied by a lab partner or supervisor.

____
Name Signature Date

____

____

____
School Address

____
School Phone Number

____
Instructor Name