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National Science Foundation
Small Business Innovation Research Program

PROJECT SUMMARY

NSF AWARD NO.

NAME OF FIRM Protein Solutions, Inc.	
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PRINICPAL INVESTIGATOR (NAME AND TITLE) Robert J. Scheer/ Research Scientist	
TITLE OF PROJECT A Labless Lab™ for Chemistry	
TOPIC TITLE Education and Human Resources	TOPIC NUMBER AND SUBTOPIC LETTER 25a

PROJECT SUMMARY

This Small Business Innovation Research Phase I project will study the technical feasibility of a novel chemistry exploration kit for use in high school and undergraduate college level chemistry classes. A large number of science and engineering courses taught in collegs and universities today do not involve laboratories, particularly "distance learning" courses via television or video. Although good instructors incorporate class demonstrations, hands-on homework, and various teaching aids, including computer simulations, the fact is that students in such courses often accept key concepts and experimental results without discovering them for themselves.

Research toward the development of a completely self-contained chemistry laboratory is proposed. Although packaged like a textbook, it will contain within it all of the materials, equipment, and information needed to directly discover and experience key concepts related to chemistry.

Potential Commercial Applications of the Research

The Labless Lab™ for Chemistry is expected to be adopted as a textbook supplement for courses in high school and university level chemistry which do not have an intrinsic laboratory component. This product will be particularly useful in distance or remote learning applications, involving, video, TV, and computer based delivery.

KEY WORDS TO IDENTIFY RESEARCH OR TECHNOLOGY (8 MAXIMUM)
Education, High School, University, Concepts, Textbook, Laboratory, Chemistry

D. OPPORTUNITY AND SIGNIFICANCE

High school students in many science courses in the United States receive little or no laboratory experience in such courses. The labless science course has become a very common feature in intermediate 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 may not have the time or inclination to utilize these tools, particularly with the added responsibilities of instructing several classes a day over a broad range of subjects. Also, the rapid growth of "distance learning" – using television and video tapes to offer courses remotely – is producing large numbers of "science" students with little hands-on, laboratory experience.

Many chemistry teachers who perform demonstrations are "... not making the connection between the demonstration or activity and a particular content objective," and "... the teachers may not know enough to understand the risk" (1). At a time when there are local, 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 complete and safe laboratory teaching tools, we call it the Labless Lab™.

The recent recommendations for change in chemistry education (3), determined by the American Chemical Society's Division on Chemical Education 1990 Task Force, include the addition of: novel problem solving, the methodology of science, experimentation in the lab, evaluation of students on their ability to interpret information and analyze data, and a reorganization of the course around the laboratory. The Task Force's report will be available in late 1994 (3), and is expected to significantly affect the chemistry curriculum.

American businesses 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 (4).

Undergraduate college students, particularly those enrolled in large sections of the science core courses of physics, chemistry and biology, often find themselves in a laboratory whose objectives are not coordinated with the classroom lecture. Even with classroom coordination, these laboratories often do not instill a fundamental understanding of basic concepts. They are often "cookbook" laboratories with right or wrong "fill in the blank" answers. Labs are also not generally available for correspondence, distance learning, or 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 (5), the very rapid growth in multi- and hyper media and in computer, satellite, and TV based courses and even degrees, it is leaving some question as to whether a "virtual education" is indeed desirable (6). Nevertheless, most states, including our own, due to political and economic pressure are rapidly increasing their distance and remote education activities. The Public Broadcasting System's adult learning service has even issued a handbook on the subject (7).

Although there is indeed a science education materials industry (8), the products of that industry are generally directed towards elementary and junior high school age groups and to science novelties and curiosities for adults. Also, with few exceptions, science museums and science centers have not been well integrated into high school and undergraduate education and the "hands on" activities and experiences available in such institutions rarely go beyond a superficial discovery and awareness. It is also interesting to note that such institutions usually under-represent chemistry topics and activities.

supplement to existing chemistry texts, particularly in those courses where no laboratories exist, are perceived as inadequate or too expensive, or in distance learning environments.

The learning objectives of the Labless Lab™ in Chemistry are summarized in Table 1 which is divided into six major concepts of introductory general chemistry. Each concept is divided up into several subtopics, typical of introductory chemistry texts. This idea is well represented by the "concept wheel" of Figure 1. For simplicity, only four major concepts and four subtopics are shown. The major topics each make up one slice of the circle, and inside the circle are drawn the subtopics. Arcs of influence are drawn inside the circle to indicate which major concepts are covered by which subtopics.

Finally, each subtopic is explored using the activities listed in the second column of Table 1 (12). The numbers of these activities correspond to the activities which appear on the activity matrix in Figure 2. To assemble this matrix please cut along the dotted lines. Now, place the page with the subtopics listing on top of the page with the activity listing. To use the matrix. Move the open slit down the page until you reveal the subtopic that you wish to explore, then, indicated by X's next to the subtopic will be list of suitable activities. By using both the concept wheel and the activity matrix, the instructor can quickly determine a suitable activity for the chosen major concept or subtopic.

Table 1. Introductory Physical Science Concepts (13)

Major Theme and Subtopics	Activity Numbers
States of Matter:	
Density	2,3,11,18,19
Phase Changes	13,17
Gases	6,17
Metals	2,5,7,8,11,18
Crystals	13
Aqueous Solution Chemistry	2,3,4,5,6,7,9,10,13,17,18,19,20
Atomic Structure (General Experiment # 1):	
Electromagnetics	2
Metals	2,5,7,8,11,18
Crystals	12
Oxidation/ Reduction	5,6,7,8
Acid/Base Chemistry	4,7,9,10
pH	4,7,9,10

We feel strongly that there is a growing appreciation and an evolving need for chemistry kits which are coupled with high school and beginning undergraduate chemistry courses which do not have an intrinsic laboratory component. There is a need for <u>small, inexpensive, completely self contained personal laboratories</u> which can supplement existing textbooks. A good model is the *Explorabook* (9), "a science museum in a book" – available in nearly every bookstore in the nation.

Many complex concepts can be observed and assimilated by experimentation with properly designed materials. We propose the development of materials and specimens designed specifically for <u>teaching purposes</u>.

Nearly 3,000 colleges and universities in the United States teach a wide variety of science and technical courses; in addition, over 20,000 high schools all offer various chemistry, physics and biology courses to their students. In total, over three million students participate in a chemistry course each year. These range from simple physical science taught at the ninth grade level to quantum mechanics at the graduate school level. Of these, approximately one million students are participating, many for the first and *only* time, in an introductory chemistry class. It is important that these students are left with a positive and lasting experience. This can be 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: instructor time, cost limitations, laboratory expenses, and resistance to change. The Labless Lab™ in Chemistry addresses all three of these impediments to chemistry education.

This proposal is relevant to the program emphasis of the 1994 National Critical Technologies study (10), 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 applied molecular biology, materials synthesis and processing, pollution minimization and remediation, and electricity supply. 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.

PSI already has considerable experience in the Labless Lab™ concept. We are now working on a Phase I NSF SBIR, the Labless Lab™ for Polymer Science. There the focus is on sets of materials and experiments to facilitate the direct experiencing and understanding of many unique concepts and characteristics of macromolecules and polymeric materials. As a result of this work and our own experience in the teaching of chemistry at the high school (J. Andrade), the community college (R. Scheer), and university levels (R. Scheer, J. Andrade), we have become convinced that most of freshman chemistry can be experienced using a minimal apparatus, Labless Lab™ approach.

E. BACKGROUND, APPROACH, AND BENEFITS

1. <u>Background and Proposed Research</u>:

Say "chemistry" to someone and they immediately think of complicated equations, white lab coats, gas burners, and fuming chemicals. Chemistry is feared by most of our society. How can something so ubiquitous be so alien? The job of the chemistry educator is to "enable" us 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 noble laureate Roald Hoffman and noted chemistry demonstrator, Dr. Donald

Chemical Bonding (General Experiment # 21):

Metals	2,5,7,8,11,18
Crystals	12
Chemical Reactions	4,5,6,8,9,10,11,12,14,15
Oxidation/Reduction	5,6,7,8
Aqueous Solution Chemistry	2,3,4,5,6,7,9,10,13,17,18,19,20
Gas Formations	4,6,9,17
Precipitation	3,4,9,13
Acid/Base Chemistry	4,7,9,10

Intermolecular Forces (General Experiment # 21):

Phase Changes	13,17
Gases	6,17
Metals	2,5,7,8,11,18
Crystals	13
Chemical Reactions	4,5,6,8,9,10,11,12,14,15
Aqueous Solution Chemistry	2,3,4,5,6,7,9,10,13,17,18,19,20
Precipitation	3,4,9,13

Thermodynamics:

Chemical Reactions	4,5,6,8,9,10,11,12,14,15
Exothermic/Endothermic	4,9,11,12,14,15
Equilibrium	10
Catalysts	6
Aqueous Solution Chemistry	2,3,4,5,6,7,9,10,13,17,18,19,20
Gas Formation	4,6,9,17
Precipitation	3,4,9,13
Acid/Base Chemistry	4,7,9,10

Kinetics:

Chemical Reactions	4,5,6,8,9,10,11,12,14,15
Exothermic/Endothermic	4,9,11,12,14,15
Equilibrium	10
Catalysts	6
Aqueous Solution Chemistry	2,3,4,5,6,7,9,10,13,17,18,19,20
Gas Formation	4,6,9,17
Precipitation	3,4,9,13

Showalter, recently aired on many PBS stations and is available on video (11). During this series, Hoffman and Showalter create an environment where chemistry comes alive for each of us. Shows like this help chemistry instructors initiate student interest in chemistry. Demonstrations can be exciting but their set up can be time consuming and may leave the student without a personal experience. The next step, that of making 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 gather the proper materials for "kitchen" chemistry laboratories, this step is often bypassed in favor of videos or demonstrations. But it is this second step, the personal exploration, that leads to the *retention* of chemistry knowledge.

Other than microscaling of the experiments, 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 these well known but highly structured "recipe" laboratories, with "fill in the blank" lab reports, to one of *investigative* problem solving where the problem can be appreciated and understood. This method, sometimes called "constructivist" or "inquiry based" learning, allows the student great flexibility in solving their laboratory questions. An example of just such a constructivist chemistry laboratory was presented at the 1994 Annual National Science Teacher's Association meeting in Anaheim, California by P. Clough and L. Clark, chemistry instructors in Wisconsin. The student is given a set of starting chemicals (reactants) and is asked to determine the outcome or products. First, a list of five possible reactions is generated through brainstorming and some instructor guidance. The students are then free to perform the reaction in as many ways as necessary and gather as much information about the materials as possible. Students must think, organize, and persevere successfully to complete the exercise. They learn about stoichiometry, gas formation, solubility, reaction rates, equilibrium, reduction/oxidation reactions, and good science investigation techniques.

S.L. Seager, Professor of Chemistry at Weber State University in Ogden, UT, has developed a laboratory for first year chemistry students based on inquiry. His laboratory consists exploration, invention/discovery, and application. The students develop their own questions and answers. The disadvantage of this type of learning is the increased time commitment required of the instructor.

Our simple and complete Labless Lab™ exploration system minimizes the need for instructors to utilize valuable time gathering equipment and chemicals and designing the laboratory, thus providing the time for them to work directly with the students.

We propose 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. Where possible, materials and chemicals commonly utilized in consumer products will be employed, and sets of special materials and simple equipment will be designed and developed to directly observe complex concepts. The experiments and observations will utilize only the student's senses for transduction and detection.

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 materials, equipment, and information needed to directly discover and experience key concepts related to chemistry. Bulk packaging of the materials may be appropriate for high school level courses where a single set of materials could be used for several sections of the same class. We expect that the Labless Lab™ in Chemistry will be widely adopted as a

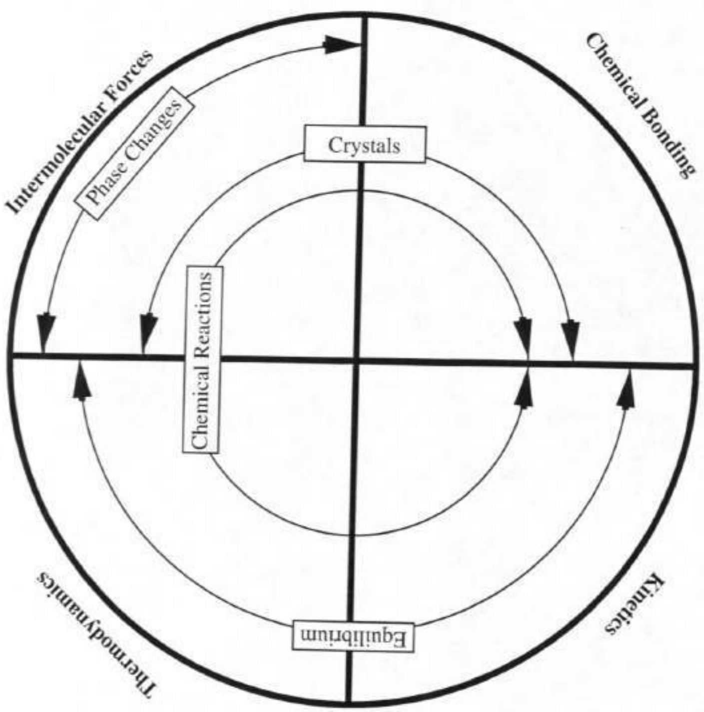

Figure 1. The "Concept Wheel" demonstrates the interrelatedness of each subtopic (written inside the circle) to each major concept (written outside the circle).

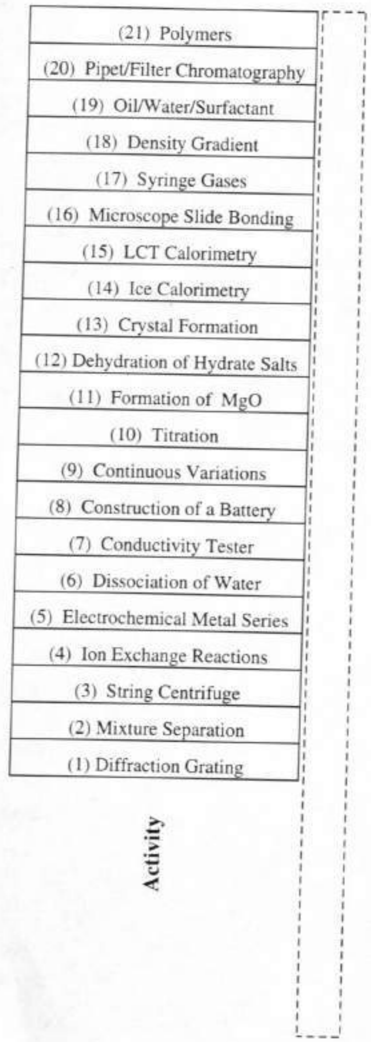

Figure 2.

1) Remove this page and the next page for ease of use.
2) Cut along dotted lines. This is your viewing window.
3) Place window with activities at the top on the second page of subtopics.
4) Choose a desired subtopic by moving the top page up and down.
5) View the subtopic on the right hand side of the page and look across to the X's which indicate appropriate activities.

Atomic structure	X																				
Magnetism		X																			
Density		X	X								X							X	X		
Phase Changes													X				X				
Gases						X											X				
Metals		X			X		X	X			X							X			
Crystals													X								
Chemical Reactions				X	X	X		X	X	X	X	X		X	X						
Exothermic/Endothermic				X					X		X	X		X	X						
Equilibrium										X											
Catalysts						X															
Oxidation/Reduction					X	X	X	X													
Aqueous Solution Chemistry		X	X	X	X	X	X		X	X			X				X	X	X	X	
Gas Formation				X		X			X								X				
Precipitation			X	X					X				X								
Acid/Base Chemistry				X			X		X	X											
pH				X			X		X	X											
Intermolecular Forces		X	X	X			X						X			X	X	X	X	X	X
Chemical Bonding				X	X	X	X												X		X

Figure 2 Continued.

2. Innovativeness and Originality:

Several publishers and manufacturers provide laboratory supplements to existing texts. These supplements are often only texts which describe the experiment and list the materials that must be acquired for the lesson. 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, if used at all, are used by the instructor for demonstration purposes or in classroom group experimental settings.

We recently had the opportunity to attend the April 1994 National Science Teachers Association Meeting in Anaheim, and the American Chemical Society April 1994 meeting in San Diego. These are the two major national meetings where chemistry based educational materials, textbooks, and laboratories are exhibited and discussed. In perusing the exhibits and in discussions with textbook publishers and kit manufacturers represented there, we could find little resembling our proposed Labless Lab™ in Chemistry. In approaching the subject however, we found considerable interest in such a kit.

We propose to create a type of text supplement – one which frees the students' to explore the possible reasons for an outcome. These will arise out of new experiments and novel ways of preparing and presenting the experiments. This lab will free the instructor from gathering 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 develop an inquiry based laboratory/classroom. In this environment of student exploration, the laboratory or investigation can supplant the classroom. Our Labless Lab™ in Chemistry will describe procedures and provide the means for the student to realize all of the major concepts of chemistry, with the versatility to encourage new explorations.

3. Expected Results:

Using simple procedures, "safe" 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. This supplement will be flexible enough to integrate into any one year introductory chemistry course regardless of the text used.

We will select chemicals and materials, and develop necessary equipment, to perform the explorations. Needed chemicals will include oxidants, ion exchange salts, acids, bases, gases, hydrate salts, metals, polymers, polar/nonpolar liquids, and electrolytes. Particular emphasis will be placed on safety and responsible use. Necessary equipment will include inexpensive but suitably accurate balance, centrifuge, heat source, electric potential source, chemical separation, specific gravity, filter, vacuum/pressure source, volumetric measurement , and reaction vessels.

We expect that 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 tested during the spring of 1995 in an introductory chemistry course at Salt Lake Community College, offered and taught by Dr. Rob Scheer. 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.

Phase II will expand these efforts to incorporate the full range of chemical science concepts and topics. 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 Lableess Lab™ in Chemistry. The Labless Lab™ in Chemistry will be published, assembled, and given wide commercial distribution during Phase III.

F. PHASE I RESEARCH OBJECTIVES

Our general objective is to elucidate and summarize major concepts, principles, and themes of basic chemistry at both the high school and university levels. By careful review of modern textbooks, current reports, and discussions with leading educators, those concepts, principles, and themes become one dimension in the matrix given in Figures 1 and 2. The second dimension of the matrix in Figure 2 includes experiments, activities, and projects to enable the student to experience and discover the major concepts, principles, and themes (13,14).

The research objectives of this Phase I proposal are summarized in Table 2. Each category is divided into several tasks and assignments. The estimated project schedule is noted.

Table 2. Summary of Phase I Research Objectives

Category / Task	Assignment
Classroom Requirements: (Largely completed)	
1. Compilation of Major First Year Chemistry Themes	Scheer
2. Correlation of Class and Textbook Topics to Themes	Scheer
3. Selection of Proper Activities for each Topic	Scheer
Exploration Design: (1st-4th months)	
4. Ice Calorimetry	Scheer
5. Pipet Chromatography	Dryden
6. Simple Balance	Scheer and Dryden
7. Electrochemical Metal Series	Scheer and chemist
8. Polymers	Scheer
9. Continuous Variations	Scheer and chemist
10. Crystal Formation	Scheer and chemist
11. Conductivity Tester	Dryden and Pungor
Safety and Testing: (Throughout)	
12. Design safest reasonable activities	Scheer and Dryden
13. Testing in Classroom setting	Scheer and chemist
Preliminary Work for Phase II: (5th-6th months)	
14. Safe Heat Source	Scheer and Pungor
15. Dehydration of Hydrate Salts	Scheer
16. Construction of a Battery	Pungor and chemist
17. LCT Calorimetry	Scheer

G. PHASE I RESEARCH PLAN:

Objectives 1 - 3 were largely completed in preparation for this proposal. Further refinement and development of the concept wheel and activity matrix will be pursued based on instructor comments and new findings.

1. *Compilation of First Year Chemistry Themes.* Most of the work for this objective was already completed for the writing of this proposal. Refinements will be made as suggested by upcoming conferences and task force reports.

2. *Correlation of Class and Textbook Topics to Themes.* The typical textbook categorizes its topics into the major themes; a consistent and widely applicable correlation of these topics will be finalized in the form of a concept wheel.

3. *Selection of Proper Activities for each Topic.* As outlined in the activity matrix of Figure 2, selected activities and explorations will be emphasized for certain chemistry topics.

Objectives 4 - 11 are demonstrations either already in use or currently being developed. They are expected to require refinement and adaptation to suit the needs of the Labless Lab™.

4. *Ice calorimetry.* Using the heat of fusion of ice, one can measure the amount of energy given off from an exothermic reaction by determining the mass of ice before and after the event.

5. *Pipet/Filter paper chromatography.* Chromatography is a common laboratory method used to separate various chemical species based on their abilities to travel through a given medium. By using simple transport systems, i.e. sand, filter paper, or alumina powder/beads, 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 or anything contained in the Labless Lab™ or elsewhere. An example of this experiment has recently been utilized as a demonstration in India (15).

6. *Simple Balance.* Design and testing of a simple, inexpensive, and reasonably accurate weighing balance.

7. *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.

8. *Polymers.* Polymer surface are used to directly observe, via contact angles, chemical bonding and attraction. They will demonstrate covalent bonding, Van der Waals forces, hydrogen bonding and molecular orientation. Polymer systems which lend themselves to these demonstrations include the methacrylates and polyacrylonitrile. These are being developed for the Labless Lab™ in Polymer Materials.

9. *Method of Continuous Variations.* By varying the ratios of two reactants and determining the ratio needed for optimum reaction, the correct stoichiometric ratio is determined. Because most experiments will be dealing with the microscale, the difference between optimum and nonequilibrium reaction ratios may not be decipherable. Various precipitate reactions will be examined to determine suitability.

10. *Crystal Formation.* By evaporating a concentrated salt solution the student can witness typical crystal structures for various soluble salts. An example might be a sodium chloride solution, which produces a cubic crystal structure upon evaporation. Variations of recrystallization techniques can be tried to determine their effect on crystal size and shape.

11. *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 Polymer Materials.

Objectives 12 and 13 will be ongoing. A goal of the Labless Lab™ is to promote safety student satisfaction.

12. *Design safest Reasonable activities.* This is more of a review process. Each activity will be examined for safety and where possible, less toxic/hazardous materials will be implemented.

13. *Testing in Classroom Setting.* During the spring quarter of 1995, R. Scheer will teach an introductory level chemistry class at Salt Lake Community College. During this time frame, activities already developed will be implemented where appropriate for the given lesson. Student trials will determine, ease of use, safety, and, learning effectiveness.

Objectives 14 - 17 are activities and devices which will require further thought. It is expected that by the end of the Phase I of this project, we will have begun design work on these objectives.

14. *Heat Source.* Many chemistry kits utilize an open flame (usually alcohol) heat source, others utilize a compressed gas fuel. Both of these systems are considered hazardous and may result in severe burns from the flame or explosions due to build up of inflammable vapors. We propose the development of an electrical heating source to avoid use of flammable liquids or gases.

15. *Dehydraion of Hydrate Salts.* This is a classical experiment to determine hydration coefficient of a salt, and an excellent method for investigating stoichiometry. This will require refinement due to less accurate weighing capabilities and cooler heat sources than usually utilized for dehydration.

$$CuSO_4{\cdot}3H_2O \longrightarrow CuSO_4 + 3H_2O$$

16. *Construction of a Battery.* The concept of reduction/oxidation, ion exchange reactions, conductivity, and electric potential can be discovered by building a simple electric cell. Models for implementation of this procedure have already been established. (these 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.

17. *LCT Calorimetry.* Tests must be performed here to determine if the temperature rise is large enough to be indicated on conventional liquid crystal thermometers. Otherwise, different reaction systems or unique thermometers will have to be developed.

H. COMMERCIAL POTENTIAL

There are over 10 million students in high school grades 10-12, with a student/teacher ratio of 20 to 1 (16). 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"(11), to enhance classroom learning, but these do not provide the thorough understanding gained through the experience of doing chemistry. We anticipate a *need* for approximately 100,000 high school level chemistry classroom kits each year with enough materials available for a class of twenty students to participate in their own research (up to 2 million individual kits per year.) Other markets include distance learning (telecourses), home teaching, and colleges/universities with inadequate laboratories.

Protein Solutions, Inc. now has two products in the science education market: Night Life™: Science in the Dark, a bioluminescent science kit for upper elementary and junior high students and Galaxsea™, an adult science novelty containing bioluminescent plankton. Teachers' versions of Night Life™ are also available. This kit is distributed through several major national catalog distributors which target science and nature stores in museum/science center gift shops. PSI has concluded a major marketing agreement with a Florida distributor and the producer of the unique catalog *Living and Natural Wonders.* PSI is now negotiating with a group in Britain to produce and distribute the products in Britain and on the European continent. A recent marketing survey of the college textbook market (17) indicated that there are ten major publishers using revenues in 1991 of $1.6 Billion/year. The very major textbook area, colleges and universities, is the basic sciences of which chemistry and biology are the two largest components. Although we have not yet had the opportunity to do a comprehensive market survey, our informal assessment indicates that the market in chemistry alone is in the range of $10 Million/year for colleges and universities. The high school market is expected to be in the range of $20-30 Million/year. Since a typical high school/university chemistry text delves even in larger volume purchases in the range of $20-50/unit, Labless Lab™ in Chemistry must be in a comparable price range.

We are targeting our existing Labless Lab™ activity, the Labless Lab™ in Polymer Science, to retail in roughly the $50-75/unit range, which is also the upper end of the range for textbooks in the subject. Since many colleges and universities already charge laboratory fees in the range of $25 to an excess of $200 per term for laboratory intensive courses, a price for the Labless Lab™ one to three times that of the textbook price appears to be reasonable.

At first glance one might think that it would be impossible to profitably produce Labless Labs™ given such economics. The *Explorabook* (9) has demonstrated dramatically that this can indeed be done. We have not even begun to address the international marketing implications of these efforts. There is a growing realization in many parts of the world, and particularly in Japan, that a more hands-on and experience-based approach to education is needed. We have already received inquiries from Korea and Japan regarding our Labless Lab™ in Polymer Science. We frankly anticipate no problem in developing interest and capital to develop our concepts and prototypes through Phase III and into profitable commercial production and distribution.

I. PRINCIPLE INVESTIGATOR

Dr. Robert Scheer, Principle Investigator, received his Ph.D. in materials science and engineering in 1993. He is Principle Investigator of PSI's Labless Lab™ in Polymer Materials, an ongoing 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. A letter from his Department Chair attesting to the fact that he is a part-time, non-permanent employee, and thus cannot submit research grants through Salt Lake Community College is included here in accord with NSF's PI instructions regarding eligibility (pp. 4-5 of the 1994 SBIR Solicitation). 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 conduct of inservice courses for local teachers and in the revision of the state core science curriculum.

J. CONSULTANTS AND SUBCONTRACTS

There will be no formal consultants nor any subcontracts.

K. EQUIPMENT, INSTRUMENTATION, COMPUTERS, AND FACILITIES

PSI's laboratories and office are located in the Northgate Business Center near downtown Salt Lake City, 350 West 800 North. These facilities include about 250 square feet of office space and 1100 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.

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Born: March 26, 1967 Residence: 31 N. L Street #106, SLC, UT 84103. (801)363-2319

EDUCATION

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

B.S. in Mechanical Engineering, 1989, Duke University, Durham, NC. GPA 3.76. 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.
Scholastic Societies: Tau Beta Pi and Pi Tau Sigma.

COMPUTER SKILLS

Systems: DOS, UNIX
Languages: FORTRAN and True Basic (BASIC).
Software: Autocad, Claris Cad, Excel, and Lotus 123.
Applications (test equipment): MTS, Instron, DSC.

EXPERIENCE

Principle Investigator
Protein Solutions, Inc. Salt Lake City, UT. 1994 - present. Directed research for the design and implementation of novel science education materials (polymer and chemistry orientation). (36,000/yr)

Research Assistant
University of Utah, Salt Lake City, UT. 1989 - 1994. 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. (10,500/yr)

Instructor/Tutor
University of Utah and Salt Lake Community College, Salt Lake City, UT. 1991 - present. Planned, instructed, and graded for undergraduate physical science classes. (10,000/yr)

Engineering Technician
Sandia National Laboratory, Albuquerque, NM. Summer, 1989. Designed engineering experiments for failure analysis of ceramic materials, and extensively researched current experimental techniques for determining material fracture toughness. (22,400/yr)

Engineering Technician
Sandia National Laboratory, Albuquerque, NM. Summer, 1988. Designed engineering experiments for strength testing of brittle materials, and performed CAD. Interacted with diverse engineering disciplines on a major research project. (22,400/yr)

AFFILIATIONS

American Society for Mechanical Engineers
ASM International
The Minerals, Metals, and Materials Society
American Physical Society
The Center for Biopolymers at Interfaces
National Science Teachers Association
American Chemical Society

PUBLICATIONS

Scheer, R.J. and J.A. Nairn. "Variational Mechanics Analysis of Stresses and Failure Analysis in Microdrop Debond Specimens." *Composites Engineering*, Vol. 2, No. 8, pp. 641-654, 1992.

Scheer, R.J. Ph.D. Dissertation. "An Energy Based Analysis of Fiber-Matrix Adhesion." University of Utah, 1993.

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., 1994, in press.

L. CURRENT AND PENDING SUPPORT OF PRINCIPAL INVESTIGATOR AND SENIOR PERSONNEL

Robert J. Scheer:

1. Current Support:

NSF Phase I SBIR, The Labless Lab™ in Polymer Materials (ends 8/15/94) Phase II will be submitted by 9/15/94.

2. Pending Support:

1) Department of Energy SBIR, Luminescent Films based on Photoproteins (7/1/94 - 1/1/95) two man months.

2) NSF STTR, Direct Reading, Quantitative Biosensors for ATP-Dependent Processes (7/1/94 - 6/30/95) two man months

3) NIH SBIR, Direct Reading, Quantitative Bioluminescent Biosensors, (10/1/94 - 4/1/95) one man month.

As PSI's sponsored R & D volume increases several Ph.D. level research personnel will be attracted and hired, although Dr. Scheer will serve as principle investigator and primary supervisor and scientist for these projects, the more routine scientific and engineering activities and tasks will be delegated to these new staff researchers. Dr. Scheer will retain a minimum of one man month of direct involvement with each of the projects for which he is serving as principle investigator.

M. EQUIVALENT PROPOSALS TO OTHER FEDERAL AGENCIES

None.

N. BUDGET

See Appendix D, NSF form 1030.

O. PRIOR PHASE II AWARDS

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

P. REFERENCES/NOTES

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

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

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

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

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

8. 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.

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

10. National Science Foundation, SBIR Program Solicitation, p. 2.

11. *The World of Chemistry, Video Series.* Produced by University of Wisconsin and the Educational Film Center: Madison, Wisconsin. 1990.

12. Listing of 21 Activities to be developed for the Labless Lab™ in Chemistry

1) Diffraction grating
2) Separation of mixtures
3) String centrifuge
4) Ion exchange reactions
5) Electrochemical series
6) Dissociation of Water
7) Conductivity tester
8) Construction of a battery
9) Method of continuous variations
10) Acid base titration experiment:
11) Formation of MgO
12) Dehydration of hydrate salt experimen
13) Salt crystal formation
14) Ice calorimetry
15) Use of liquid crystal thermometer
16) Microscope slide bonding
17) Gas in a syringe
18) Density gradient (alcohol/water/sugar ratios)
19) Oil/water/surfactant combinations
20) Pipet/Filter paper chromatography

21) Use of polymers

13. (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.

14. Selvaratnam, M. "Coherent, Concise, and Principle-based Organization of Chemical Knowledge." *J. Chem. Educ.* 70 (1993) 824.

15. Lalitha, N. "Chromatographic Separation of Plant Pigments Using Sand as the Adsorbant," *J. Chem. Educ.* 71 (1994) 432.

16. Schwartz, B.B. *The American Physical Society News*. May 1994.

17. *Educational Marketeer*. August 10, 1992.