National Science Foundation
Small Business Innovation Research Program

PROJECT SUMMARY

NSF AWARD NO.

NAME OF FIRM	Protein Solutions, Inc.
ADDRESS	350 West 800 North, Suite 218 Salt Lake City, UT 84103
PRINICPAL INVESTIGATOR (NAME AND TITLE)	Robert J. Scheer, Ph.D. (Res. Scientist)
TITLE OF PROJECT	The Labless Lab: Polymer Materials
TOPIC TITLE	Education and Human Resources
TOPIC NUMBER AND SUBTOPIC LETTER	25

PROJECT SUMMARY

This small business innovation research Phase II project will continue the research and development of a hands-on, personal laboratory in introductory polymer materials and engineering classes. A very large number of science and engineering courses taught in colleges and universities do not involve laboratories. 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. The only partial solution to this problem has been increasing the use of class demonstrations and computer simulations.

We propose to continue the development of a completely self contained polymer materials 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 polymer materials.

Potential Commercial Applications of the Research

We expect the product to be available in early 1997 (assuming this Phase II award). The product will be vital to the rapidly growing distance learning initiatives in most states and regions. We expect that the Labless Lab in Polymer Materials will be widely adopted as a supplement to polymer science and engineering textbooks, particularly in those courses which do not have a laboratory section or component, i.e. distance learning.

KEY WORDS TO IDENTIFY RESEARCH OR TECHNOLOGY (8 MAXIMUM)

Education, High School, University, Concepts, Textbook, Polymers, Laboratory

APPENDIX A (continued)

CERTIFICATION PAGE

Certification for Principal Investigators and Co-Principal Investigators:

I certify to the best of my knowledge that:
(1) the statements herein (excluding scientific hypotheses and scientific opinions) are true and complete, and
(2) the text and graphics herein as well as any accompanying publications or other documents, unless otherwise indicated, are the original work of the signatories or individuals working under their supervision. I agree to accept responsibility for the scientific conduct of the project and to provide the required progress reports if an award is made as a result of this application.

I understand that the willful provision of false information or concealing a material fact in this proposal or any other communication submitted to NSF is a criminal offense (U.S. Code, Title 18, Section 1001).

Name (Typed)	Signature	Date
PI/PD Robert J. Scheer	Robert J. Scheer	9/2/94
Co-PI/PD		
Co-PI/PD		
Co-PI/PD		

Certification for Authorized Company Representative

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding Federal debt status, debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPM), NSF 94-02. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U.S. Code, Title 18, Section 1001).

Debt and Debarment Certification (If answer "yes" to either, please provide explanation.)

Is the organization delinquent on any Federal debt? Yes ___ No X
Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department of agency? Yes ___ No X

Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100, 000 and for an award of a Federal loan of a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress or any employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form LLL, "Disclosure Form to Report Lobbying," in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED COMPANY REPRESENTATIVE	SIGNATURE	DATE
NAME/TITLE (TYPED) J.D. Andrade	J.D. Andrade	9/2/94
TELEPHONE NUMBER (801)596-2675	ELECTRONIC MAIL ADDRESS jdandrad@cc.utah.edu	FAX NUMBER 596-2675

(c) Synopsis of Phase I Research Results

Most students come into polymer courses with various concepts and preconceptions which lead them to conclude that the behavior and properties of polymers are counter-intuitive. It is therefore important that they fully discover and observe the properties and behavior of polymeric materials for themselves.

A very large number of science and engineering courses taught in colleges and universities today do not involve laboratories. 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.

We are developing a set of inexpensive and convenient hands-on discovery based experiments which the students can perform for themselves. Experiments are based on:

1) actual materials commonly utilized in consumer products, and
2) a set of specially developed materials which the students can utilize to directly see and experience complex concepts (1).

In both cases, the experiments and observations will utilize the students' senses for transduction and detection.

Evidence exists of considerable national interest in effective polymer education (2). The American Chemical Society's Division of Chemical Education often includes polymer related articles in its *Journal of Chemical Education* (3-9) and in its sessions at the American Chemical Society (ACS) annual meetings. The ACS also has a Polymer Education Committee which recently published *Polymers all Around You*, a booklet containing many facts and figures concerning polymers in our everyday world, as well as several hands-on polymer activities for instructors (10). The Society of Plastics Engineers (SPE) also has a standing Polymer Education Committee which recently published a series of hands-on polymer activities for the chemistry classroom (11). The Society of the Plastics Industry (SPI) is interested in polymer education as evidenced by their recent teacher publication "The Shape of Things to Come." Polymer education is also of interest to the American Institute of Chemical Engineers and the Materials Research Society (MRS).

In addition to these national organizations, several universities have developed polymer education centers which serve as clearinghouses for polymer education innovation. There is the Polymer Education Center (POLYED) at the University of Wisconsin, Steven's Point which publishes the Polymer Education Newsletter (2). Dr. J. Droske, the director of this center is a consultant to this project. Also, the Institute of Chemical Education at the Department of Chemistry at the University of Wisconsin, Madison, is active in providing a variety of educational materials for discovery based chemistry and polymer education (12).

Articles on polymer education have also appeared in mass media magazines such as *Scientific American* (13).

Commercial industry is supporting polymer education both indirectly, through support of the above societies, centers, and committees, and directly through private publications and projects. Dow-Corning Corporation, the 3M corporation and E.I. DuPont DeNemours and Company, to note only three well known examples, support the continuing polymer and chemistry education of their employees either through in house continuing education or reimbursement for university classes.

Another important area of education which this research will impact is the growing field of distance learning (14-17). The Public Broadcasting Service (PBS) has developed a new program called "Going the Distance." It will let students complete an associate of arts degree by watching courses on television, and is scheduled to start this fall at 60 colleges served by 22 PBS stations (14). Several states, including Utah, are strongly committed to the development of distance learning for secondary and post-secondary education. Governor Mike Leavitt, Utah, has stated: "I challenge you to make education an activity that is not bound by buildings, place, or space." We call this "*Education and Science without Walls.*" These education environments will require at home laboratory experiences for which the Lableless Lab™ is ideally suited.

Uniqueness: The difference between our proposed laboratory explorations and those of other, more common exercises is two-fold. The primary difference is in the required detection devices;

our laboratories require the human perceptions of sight, touch, and hearing (18); others often require costly detection equipment. This is the very difference which allows the Lableess Lab™ to be used outside the classroom (no walls), in the student's home or dorm room. The secondary difference is the use of "intelligent materials" as teaching devices (1). The students can utilize the materials developed here to directly see complex polymer concepts.

Eight primary objectives were addressed during the Phase I research project. (See Phase I Final Report.) Comments on continuing Phase II research will be addressed in the Phase II Research Objectives section.

1) Temperature Gradient Device. We tested several designs of temperature gradient devices. The heat sources were semiconductor resistors powered by an adjustable power supply. The heating substrates were aluminum plates. Surface temperatures were recorded using thermocouples, an infrared detector, and thermochromic liquid crystals (TLC's). Surface temperature gradients in the range of 30°C to 60°C were generated.

2) Homopolymer Tg. We selected several common homopolymers with Tg's in the range of -120°C to 105°C: low density polyethylene (LDPE), high density polyethylene (HDPE), polypropylene (PP) , 15% plasticized polyvinyl chloride (PVC), polyethylene terephthalate (PETE), polystyrene (PS), and unplasticized PVC.

These were chosen based on their glass transition temperatures and because they are used as common packaging materials (19-21). Students are thus able to compare common packaging materials with those samples included in the kit.

3) Plasticizer Gradient. We successfully developed a technique which directly demonstrates the effect of low molecular weight molecules on the mechanical behavior of polymeric materials. Several techniques for DOP (di-octylphthalate) plasticizer extraction of 35% plasticized PVC were tested. Gradients in plasticizer concentration from approximately 10% to 35% were obtained. These gradients demonstrate an observable difference in polymer stiffness and elasticity.

Several different experiments were performed using these samples. We utilized a "droop" test, where the sample was held rigidly along its gradient edge and thin sections of the strip were cut and allowed to drape under the force of gravity. Using this method, the sample droops more where a larger concentration of plasticizer is present and less where the sample is more rigid with less plasticizer. See figure 1. Other tests included indentation measurements and glass transition temperature measurements.

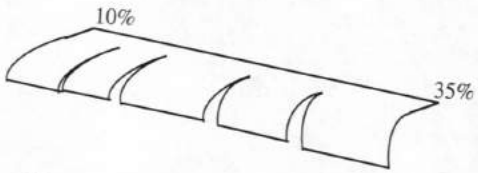


Figure 1. Schematic of "droop" test. The 10% plasticized end does not droop as much as the 35% plasticized end. This is a direct measure of the stiffness of the material sample.

4) Cross-link Gradient. We evaluated several methods to produce cross-link gradient polymers. Cross-link gradient polymers are routinely formed and utilized in gel electrophoresis analysis at the University of Utah's Center for Biopolymers at Interfaces (CBI) of which PSI is an industrial member. Two solutions with different proportions of cross-linking agent are mixed in a continuous ratio to create a greater cross-link density at one end of the gel. These samples demonstrate an observable difference in stiffness between the heavily cross-linked and the lightly cross-linked ends. Other techniques to achieve cross-linked gradients include using a photoactivatible cross-linker with preferential lighting to achieve the gradient (22-24).

Summary. The Phase I feasibility work has demonstrated 1) that we can develop the systems and materials of these 8 objectives, and 2) the intended usefulness of the materials as polymer education tools. This system of educational tools will benefit those instructors of chemistry, materials science, and polymer science who would otherwise not have the time or inclination to develop a student laboratory. They will especially benefit distance learning courses (one- and two-way tele- or video-courses). Also, the uniqueness of these exercises should make these laboratories more effective educational tools than the "recipe" and "fill-in-the-blank" laboratories sometimes found in high schools, colleges, and universities.

The concept and practice of the Lableess Lab™ in Polymer Materials is being favorably received at national conferences. Dr. Joe Andrade, PSI's President and Chief Scientific Officer, presented a paper on intelligent materials for teaching at the Second International Conference on Intelligent Materials, June 1994 in Williamsburg, Virginia (1). Dr. Rob Scheer, project director Protein Solutions, Inc., met with several key polymer and science textbook companies, as well as distributors of student laboratory equipment at the 1994 National Science Teachers Association (NSTA) Conference in Anaheim California. We have been invited to attend both the National Educators Workshop, November 1994 in Gaithersburg, Maryland and the 1994 NSTA regional meeting in Las Vegas, Nevada. Both invitations are to present our research on the Lableess Lab™ in Polymer Materials to chemistry and science instructors at the high school and undergraduate levels.

We expect the Lableess Lab™ in Polymer Materials to be available in early to middle 1997 (assuming this Phase II award). We expect this product to be of national and international interest in the many chemistry, materials, and polymer science courses currently lacking individual laboratory experience, and for it to be widely adopted as a supplement to the more conventional polymer science and engineering textbooks, particularly in those courses which do not have a laboratory section or component.

References -

See Reference section at end of paper (1-38)

(d) Phase II Research Objectives

The goal of a laboratory is (39)

- •To excite interest and enthusiasm for the processes of scientific investigation.
- •To develop an appreciation for the science of measurement.
- •To develop an awareness of practical methods for dealing with real systems.
- •To develop an ability to plan and design experimental procedures
- •To interpret instructions and analyze data to solve a problem.
- •To accurately report observations and derive conclusions.
- •To clearly communicate scientific results.
- •To learn to safely handle and dispose of chemical substances.

By developing explorations which can be performed without expensive equipment, we hope to bring the student closer to the material being studied; thereby, discovering for themselves, the desired concept.

These explorations are matched with the introductory polymer concepts which they support in Table 1. The vertical column lists the most common introductory polymer concepts; the horizontal row lists the objectives intended for the Lableess Lab™ in Polymer Materials.

Lableess Lab™ components/objectives -

1) Temperature Gradient: The feasibility of this objective was established during the Phase I portion of this research. During the Phase II portion of this research we will modify the heating system to allow for portable battery operation as well as an AC based power supply. Further modification of device geometry is also necessary to generate a more *linear* gradient. The issues of temperature gradient reproducibility, equipment safety, and reduced cost of materials will also be addressed.

5) Copolymer Gradients. Two comonomer gradients were produced by pouring one type of partially cured monomer into a second partially cured monomer of lesser density. Two different gradient systems were prepared and evaluated: polymethyl methacrylate/polyhexyl methacrylate (PMMA/PHMA) and polymethyl methacrylate/ polyhydroxyethyl methacrylate (PMMA/PHEMA). The PMMA/PHMA gradients exhibited a gradient in room temperature (23°C) stiffness; the PMMA end with a Tg of 105° was rigid and the PHMA end with a Tg of -35°C was soft. This gradient demonstrates the effect of sidechain bulk and mobility on the backbone chain stiffness and bulk polymer stiffness. The PMMA/PHEMA gradients exhibited a water absorption gradient. At equilibrium in water, the PMMA end kept its original shape and was rigid and collapsed while the PHEMA end swelled and became flexible. This gradient demonstrates the effect of sidechain hydrophilicity and hydrophobicity on water absorption.

6) Ionic Responsive Polymers. The research performed on polymers responsive to solution ion concentration is based on the work of Allan Hoffman a consultant to this proposed Phase II research (25), Sung Wan Kim, et al (26), Yoshihito Osada, et al (27), Toyoichi Tanaka (28-30) and others (31). Current literature describes acrylamide/acid copolymer gels which have an ionizable group. Once the polymer chain has been ionized the hydrogel will react to external electric fields by collapsing and forcing out the absorbed water. Another ionic responsive polymer, sodium polyacrylate, is a common material used in "super absorbent" diapers. During our tests, this polymer rapidly absorbed up to 500 times its dry mass of water. If the pH or ionic content of the polymer gel was adjusted away from neutral, the gel collapsed. These behaviors demonstrate the hydrophilicity and hydrophobicity of a polymer network.

7) Temperature Responsive Polymers. Poly(N-isopropyl acrylamide) was chosen as the temperature responsive polymer. At temperatures below 32°C the polymer is soluble in water. When placed on the temperature gradient device described above, the polymer responded by precipitating or "clouding" at temperatures above 32°C (32-34). These samples demonstrate the effect of temperature on cohesive energy density and how cohesive energy density affects solubility. The concepts of upper and lower critical solution temperature (LCST) are directly experienced

8) Surface Property Gradient. Wettability gradients were generated on samples of polystyrene using an oxygen plasma field (35-38). The gradients were formed by placing a plasma barrier/mask along one half of the polystyrene surface and plasma treating the entire sample for 20 seconds. See Figure 2. During wettability measurements the treated end was completely wetted with a thin film of water, and the untreated end allowed water to bead up considerably. Other measures of wettability included a capillary effect along the length of the treated surfaces. The treated end allowed water to wick up approximately two centimeters while the untreated end only allowed the water to wick up approximately 0.5 centimeters. These samples demonstrate dipole-dipole bonding and the difference between bulk and surface properties of a material.

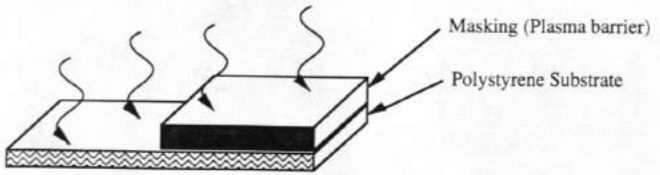


Figure 2. Schematic of polystyrene substrate with mask (barrier) to prevent surface modification from the plasma treatment. The wavy lines represent the impact of ionized gases and UV radiation.

Table 1. Lableѕs Lab™ Material Explorations versus Introductory Polymer Concepts.

Material System and Concept	Molecular Weight and Distribution	Morphology(Crystallinity)	Intermolecular Forces	Cohesive Energy Density/Solubility	Polymerization	Thermoset/Thermoplastic	Glass Transition	Time-Temp Superposition/Viscosity	Entropy	Stearic Hindrance	Macromolecular Effects	Surface/Bulk Properties	Processing	Additives/Fillers	Optical Properties
Temperature Responsive Polymer			X							X	X				X
Ionic Responsive Polymer			X							X	X				X
Tg Homopolymers			X				X			X					
Heat Shrink Material		X	X					X		X			X		
Composites												X	X	X	
Surface Gradient												X			
Voight-Maxwell Models			X			X	X	X		X	X				
Shape Memory Polymer		X	X				X		X	X	X				
Crosslink Density Study	X		X			X					X		X		
Elastomer		X	X			X			X		X				
Polymerization Procedure	X				X					X	X		X	X	
Spherulite Gradient		X				X	X	X	X		X		X		X
Crosslink Gradient	X		X		X	X	X			X	X				
Plasticizer Gradient	X		X	X			X				X		X	X	
Copolymer gradient			X		X		X								

2) *Homopolymer Tg*: The feasibility of this objective was established during the Phase I portion of this research. During the Phase II portion of this research we will address the issues of reproducibility of material properties and scaling up the size of the samples.

3) *Plasticizer Gradient*: The feasibility of this objective was established during the Phase I portion of this research. During the Phase II portion of this research we will address the issues of reproducibility and gradient bounds. We will determine the most efficient way of making large numbers of gradient samples with controlled properties.

4) *Cross-link Gradient*: The feasibility study of this objective was begun during the Phase I portion of the research. During the Phase II portion of this research we will examine the use of a photoactivatible crosslinking agent and an optical gradient for generation of a cross-link gradient. Other study will include determining the proper bounds on the gradient properties. The bounds should be such that both ends are distinctly different, both by sight and touch.

5) *Copolymer Gradient:* This material system was partially developed during the Phase I research and work will continue with expected supplemental funding, and into Phase II. The systems tested during the Phase I of this research were step gradients; we are continuing research in this area to generate a more continuous gradient.

6) *Ionic Responsive Polymer:* The material systems of sodium polyacrylate and polyacrylamide were tested during Phase I. We will develop and test other systems including polymer gels being considered for prosthetic muscles, during Phase II (25-30). Poly(Vinyl Alcohol) hydrogels have demonstrated marked volume change in response to changes in solvent ion content and external electric fields and are being developed for possible use as substitute muscular tissue (40-42).

7) *Temperature Responsive Polymers*: The feasibility of this objective was completed during the Phase I portion of the research. During Phase II we will determine reproducibility of solubility temperature and the most economical solution concentration.

8) *Surface Property Gradient*: The feasibility of this objective was largely completed during Phase I. During Phase II we will continue studies to determine the most efficient surface treatment times, and the surface chemistry stability after treatment.

9) *Shape Memory Polymer*: Japanese researchers have utilized a polymer which behaves in a similar fashion to the popular shape memory metal Nitinol (43). The polymer is poly(norbornene) (PNB). Figure 3 shows the chemical structure of the monomer and polymer.

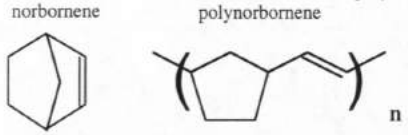


Figure 3. Chemical structure of the norbornene monomer and polynorbornene .

This polymer was developed in the France around 1979 by CdF Chimie Inc. and marketed in the United States as a means for absorbing hydrocarbon spills (44,45). In addition to its remarkable ability to absorb oils and fuels, this polymer demonstrates a shape memory effect that is triggered at its glass transition temperature, 37°C (46). When polynorbornene (PNB) is cast, its molecular chains are set in place. Upon heating above its molding temperature, 70°C, the molecules of PNB become mobile and the polymer itself can be molded to almost any shape. If the polymer is held in that shape while cooling, the molded shape will be retained indefinitely. The polymer can be plastically deformed at room temperature, but once the polymer is heated above it Tg, the material will return to its original as cast shape; the polymer molecules remember their original shape. See

11) *Composites Gradient* : Polymer composites are primarily used to save money during processing (inert fillers) and to improve materials properties (second phase particles and fibers). We will include several types of materials for the student to make their own polymer composites. The properties of the individual materials can be tested and compared to the properties of the composite material. Through adjustment of the component ratios, many properties can be developed.

12) *Spherulite Gradient*: Polyethylene oxide (PEO) crystallizes at approximately 50°C to form spherulites. The size of the crystals depends on the cooling rate. An example of how this phenomena might be demonstrated would be to place a melted sample on the temperature gradient, and observe how the equilibrium temperature affects the size of the crystals. Diffusion calculations relate diffusion temperature with diffusion rate.

13) *Cross-link Density Study*: Cross-linked polyvinyl alcohol and polyvinyl acetate are well known classroom demonstrations (5). These are often used as a "tease" to generate student interest in science and polymer chemistry but without explanation of the chemical principles involved. Using variations of this experiment including cross-linking gradients and inquisitive explorations of the chemical processes, the student will both enjoy and learn the science of cross-linking.

14) *Elastomers*: Often called an "entropy spring," rubber bands and balloons have been used to demonstrate how entropy, internal energy and free energy are related. As the elastomer is stretched, it gives off energy (temperature increases), as it is relaxed, energy is removed from the environment (temperature decreases). The temperature changes are minor, however, and can only be felt when placed on a sensitive part of the skin. We will develop a polymer geometry which enables a more dramatic temperature change to be sensed. The student is encouraged to attempt several simple and safe tests to explain the stretching and energy change behavior of elastomeric materials.

15) *Heat Shrink Materials*: The objective of this research is to provide several polymer materials which contract or expand during heating. Some will do so reversibly, others will shrink irreversibly. When explored, these materials will demonstrate the effects of glass transition and polymer chain orientation on mechanical properties.

16) *Polymerization*: We will utilize an aqueous redox polymerization (probably hydroxyethylmethacrylate (HEMA)) to demonstrate the formation of long polymer chains from short monomer molecules. As well as the actual chemical demonstration, we will utilize a common macroscopic physical polymerization involving paperclips and marbles. This exploration demonstrates how increased energy or temperature (more shaking) and collisions (more marbles) can increase the reaction rate.

17) *Other material ideas*: 1) A study of molecular weight distribution possibly using several samples of a single polymer of various molecular weights. 2) A study of gel permeation chromatography (GPC), this will tie in well with objective 4 cross-link gradient. 3) In conjunction with protein research continuing at Protein Solutions, Inc. a study of biopolymers could be included.

18) *Curriculum Development*: Our goal is to match several well-known polymer texts with a Lableess Lab™ exploration. Although the concepts learned through these exercises were drawn from the most popular introductory polymer texts (19,21,49-54), we will work to completely match the explorations to a specific chapter and page number for each of the best selling texts. See example in Table 2. We also will develop our own manual – Polymer Concepts and Principles: A Handbook for the Lableess Lab™ in Polymer Materials.

figure 4. Recent research has centered around developing PNB and its shape memory ability for medical implant use (47,48).

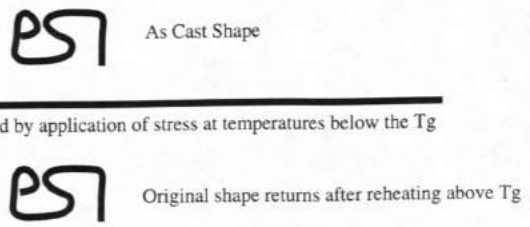


Figure 4. Demonstration of how shape memory polymer, polynorbornene, will reform into original shape. The polymer sample is cast into the word "PSI". At room temperature the polymer can be stretched or bent to "erase" the word. The polymer will retain this shape until heating above its Tg when the polymer will return to its original shape.

10) Voight-Maxwell Models: These models are shown schematically in Figure 5. They are a model of the viscoelasticity demonstrated by polymeric materials. Using springs as springs and syringes as "dashpots", the student will be able to customize a Voight-Maxwell model to match the particular behavior of a polymer sample. The elements will be attached to each other with snap connections which will allow both tensile and compressive stress. By adjusting the elements' orientation and the spring constant or dashpot constant, one can compare both strain rate and modulus of real polymers with the polymer models. Use of a spring scale for force measurements will assist this exploration.

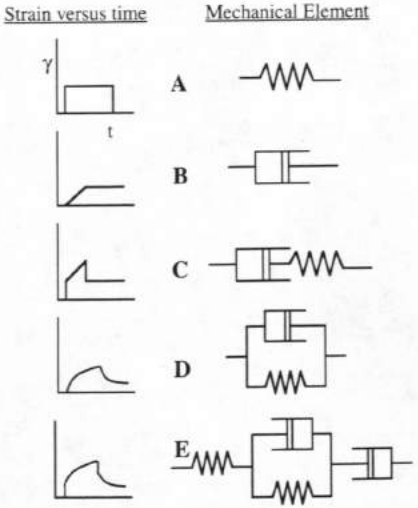


Figure 5. "A" is an elastic element (spring), "B" is a Newtonian fluid (dashpot), "C" is a Maxwell element, "D" is a Voight element, and "E" is Voight-Maxwell element.

Table 2. Example of an exploration being matched and correlated to specific concepts and chapters in a polymer text book.

Spherulite Gradient

Observation #1:	Melting Point §11.4 **
Elevated temperature properties	Viscosity §9.13, p.207

19) Prototype Assembly: The object will be to aesthetically present the exploration materials, equipment, and curriculum guide. Safety will be emphasized. Safe and efficient packaging will be designed in consultation with Wild Goose™, Inc., a local company that manufactures and distributes science kits to the elementary student and teacher (55). Our kits and components will also be evaluated by the Utah State Department of Education safety specialist and science curriculum specialist.

20) Prototype Evaluation: The object will be to use the explorations in the classroom and encourage expert critiquing by qualified instructors and professors. See advisory board.

(e) Phase II Research Plan

In this section we will discuss the Phase II research objectives in more detail.

** We will also point out those objectives which we are considering for another line of products we call Technurios™. Those materials which are unique and novel enough to elicit general public interest may be developed as individual products, Technurios™, in addition to their use in the Lableѕs Lab™ (56).

1) Temperature Gradient: We will measure reproducibility of the current and future designs. Design and building of a temperature gradient which utilizes a portable energy source as well as an AC based power supply will proceed. Cost of materials and equipment as well as safety will be of primary concern.

2) Homopolymer Tg: Homopolymers with wide ranging Tg's have been selected. We will confirm Tg estimates and their affect on mechanical properties for each polymer selected. Reproducibility of materials properties will be maximized and cost will be minimized during Phase II. This will be an excellent opportunity for the student to utilize the temperature gradient included with the Lableѕs Lab™ to observe the effect of different temperatures on the polymers' properties and behavior.

3) Plasticizer Gradient: DOP plasticized PVC gradients were made and tested. During Phase II we will determine if scaling up to larger samples will affect the material properties, as well as determine the most suitable gradient boundaries for establishing a linear stiffness gradient. In consultation with Drs. John Nairn and Jules Magda, both polymer characterization specialists, we will develop direct correlations between the sample's droop angle and hardness and the polymer's Tg and elastic modulus. This will be an opportunity for the student to utilize the temperature gradient to observe the effect of different temperatures on the gradient polymer's properties and behavior.

4) Cross-link Gradient: During Phase II we will examine the use of a photoactivatible crosslinking agent and an optical gradient for generation of a cross-link gradient and make several such gradients to measure reproducibility. Other studies will include determining the proper bounds on the gradient properties and minimizing costs of the required materials. The bounds should be such that both ends are distinctly different in both the sight and touch.

5) Copolymer Gradient: During Phase I the comonomer gradients were formed by mixing partially polymerized monomers and placing the more dense monomer on the top to force a diffusion mixing. Phase II research will create a more uniform gradient and simplify the mixing procedure. We learned during the Phase I research that isocompositional copolymers will demonstrate the desired range of behaviors. During Phase II we will blend these ranges of properties within a single sample. We will mix the partially cured monomers with a gradient pumping system. See Figure 6. This system of generating a gradient will produce a more uniform and linear gradient of materials properties. We will use computer control to develop a reproducible pattern of gradient gels. We propose to develop a program to incrementally adjust pumping rates to produce the most useful, readily observable gradient properties.

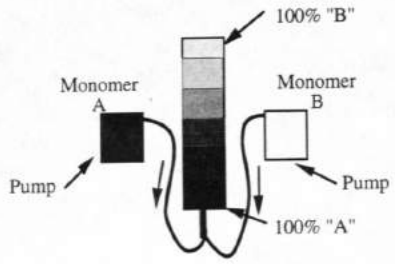


Figure 6. Schematic of proposed monomer pumping system. The pump for monomer "B" will begin transferring the less dense fluid; pump "A" will then begin to transfer the more dense monomer. During final stages only pump "A" is transferring monomer.

Explorations utilizing these samples include water swelling and mechanical stiffness measurements, similar to the characterization studies performed for the evaluation of these polymer gradients. Both of these involve no sophisticated equipment other than the human senses of sight and touch. They plainly demonstrate the effect of sidechain chemistry on the mechanical and chemical behavior of the polymer system. This will also be an excellent opportunity for the student to utilize the temperature gradient included with the Lableess Lab™ to observe the effect of different temperatures on each portion of the copolymer gradient's properties and behavior.

6) Ionic Responsive Polymer: Hydrophilic polymer gels absorb water and swell; hydrophobic polymer gels expel water and collapse. By reversibly switching a polymer's characteristics from hydrophilic to hydrophobic we can control the amount of water uptake and its dimensions. Research to utilize this phenomenon for drug delivery is ongoing at the Center for Controlled Chemical Delivery at the University of Utah. In consultation with Center faculty and students, we are developing a polymer system that demonstrates the effect of hydrophilicity and hydrophobicity on water absorption. Currently, we are concentrating on systems which utilize switching in response to changes in temperature, electric field, pH, and ion content.

Polymer gel networks which form as the result of hydrogen or ionic bonding can often be disturbed with the use of an electric field. An example of this phenomena is described by Kim, et al (26). They describe how the network polymer of Poly(ethyloxazoline) (PEOx) and Poly(methacrylic acid) (PMAA), dissolves under the influence of an electric current as a function of pH. Recent papers have covered topics concerning converting chemical energy into mechanical energy (40-42). For example, Osada of Hokkaido University in Japan has a strong interest in developing materials for artificial muscles.

Superabsorbant polyacrylates are the subject of a recent article in *Trends in Polymers Science*. These polymers are used in everything from diapers to planting soil to educational demonstrations (57-59). They absorb water in large quantities (up to 800 times the mass of the polymer).

10) Voight-Maxwell Models: These models are used to help understand and predict the viscoelastic properties of real polymers. By designing a set of modular spring-dashpot systems, the Lableess Lab™ will allow the student to quantitatively model an actual polymer sample. See figure 7.

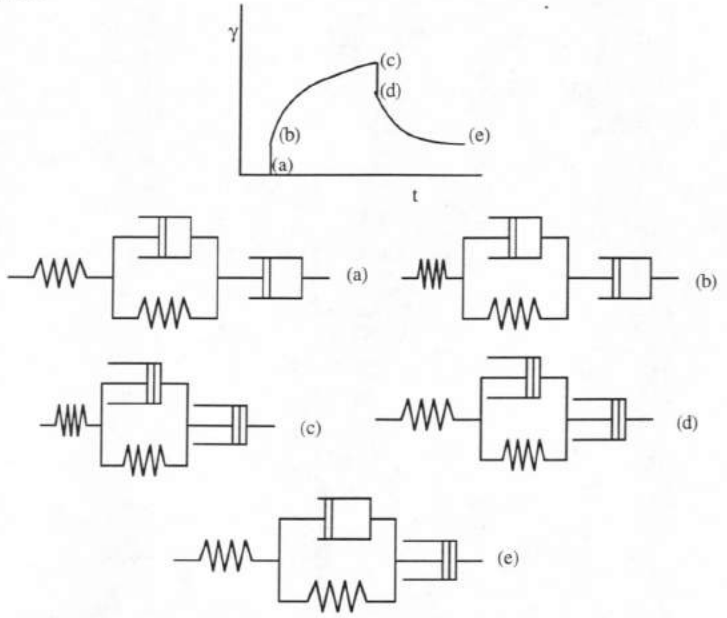


Figure 7. The Voight -Maxwell model at varying degrees of strain. The strain versus time curve is similar to the viscoelastic strain behavior exhibited by actual polymers.

By modular attachment of these elements (snap connectors allowing both tension and compression), and through the use of varying degrees of stiffness in the springs and viscosity in the dashpots, the student can model the properties of a specific polymer sample supplied to them. During Phase II research we will study ways to adjust the spring constant and viscosity of the syringes being used for this exploration. The requirements will be that through controlled selection of desired properties and simple adjustment of those properties, the student could model the time-strain behavior of a real polymer sample.

11) Composite Gradient: We will develop several different shapes of second phases to be combined with the primary phase of either a moldable putty or simply taping together a sandwich of second phases. Possible shapes include, rods, spheres, and fibers of various sizes and lengths. By placing fibers longitudinally, the student can enhance the properties in the longitudinal direction but may lower the properties in another direction. To explore other options, the student can simply place a layer of fibers in another direction, or possibly use an entirely different type of filler. See figure 8. This exploration leaves open many avenues for exploration and expansion of knowledge not only of polymers and composites, but for mechanics and physics. For example, by using a spring scale the student will measure the deformation load of different composites and calculate the effect of the different types of fillers on the modulus and strength of the material.

Explorations for these polymer samples include studying the effects of temperature, pH, and electric field on polymer swelling and solubility. By studying how each of these environmental factors affect the polymer, hypotheses can be formulated relating changes in outside conditions to the chemistry of the polymer chain.

** This is a material which we are considering for development into a Technurio™. The concept of electrically driven motility is one which stimulates the imagination. Imagine a material configured such that when an electric current is passed through it, it will flip over or "walk" across a table or desktop. Such behavior has been demonstrated by Osada and Ross-Murphy (42).

7) Temperature Responsive Polymers: During Phase II we will study the effects of solution concentration to determine the most efficient use of polymer material for this exploration. This will be an excellent opportunity for the student to utilize the temperature gradient to observe the effect of different temperatures on the polymer solution's properties and behavior.

** This is a material which we are considering for development into a Technurio™. The poly(N-isopropylmethacrylamide) could be packaged in a colored water solution for distribution as a novelty. When the solution reaches a temperature of 32°C or greater it will cloud or precipitate, at temperatures less than 32°C the solution is clear and appears as colored water. The "ghost" in the solution can be made to appear simply by holding the container in one's hand and allowing it to reach body temperature, 32°C. Several people could participate in a timed contest to see who had the ability to raise the solution's temperature the fastest (56).

8) Surface Property Gradient: During Phase II we will establish several surface tests including sessile drop, capillarity, and peel-tape tests. By placing either water drops or tape samples on different parts of the gradient surface, the qualitative difference between each portion of the surface can be measured. These tests provide different approaches to the same question of what has happened to the polymer surface.

9) Shape Memory Polymer: When polynorbornene (PNB) is cast, its molecular chains are set in place. Upon heating above its molding temperature, 70°C, the molecules of PNB become mobile and the polymer itself can be molded to almost any shape. If the polymer is held in that shape while cooling, the molded shape will be retained indefinitely. The polymer can be plastically deformed at room temperature, but once the polymer is heated above it Tg, the material will return to its original as cast shape. In effect the polymer molecules remember their original shape.

Polynorbornene although well characterized, has had little published concerning the explanation for it shape memory effect. The information available indicates that the high chain stiffness caused by the pentane group coupled with the tangling of the polymer chains leads to the shape recovery. When above its molding temperature, approximately 70°C, the PNB chains are free to move around each other due to their high energy state. At this temperature we can imagine the chains as extensively intertwinned limp strings. As the temperature decreases, the molecular motion slows and the chains are "locked" in place by strong interchain Van der Waals forces. In this plastic state, below 70°C, the polymer can be deformed; chain movement occurs by rotating bonds and stretching bonds. Finally, as the polymer is heated above its Tg, 37°C, the chains recover their strain by rotating back to their preferred orientation programmed at the original 70°C forming temperature.

We propose using PNB as a demonstration of strong intermolecular Van der Waals forces, polymer chain stiffness, and the effect of Tg on mechanical properties.

Our research will center around developing a suitable custom casting process and identifying the specific polymer chain conformational changes which lead to the shape memory effect.

** This is a material which we are considering for development into a Technurio™. A Japanese company, Maruyoshi Co., Ltd., distributes a similar novelty product in Japan. We will develop our own unique or custom shapes, similar to nitinol samples used for education purposes (43,56).

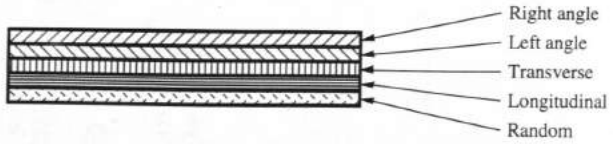


Figure 8. Schematic diagram of different direction composite layers.

12) Spherulite Gradient: During Phase II we will develop a set of explorations with a spherulite forming polymer, probably poly(ethylene oxide) PEO. The explorations will teach the student about the phenomena of diffusion, molecular kinetics, crystallization, and light polarization to name a few. Variables will include diffusion temperature, heating rate, ambient conditions, impurities, and melting substrate. This exploration will be a perfect use for the temperature gradient to demonstrate the effect of different crystallization temperatures. When the polymer melt is placed on a cooling substrate, the polymer molecules begin slowing their rotations and vibrations. During this cooling it is energetically favorable for the polymer molecules to line up with each other; while lining up the molecules will form a macroscopic sphere or circle depending on the melt geometry. This spherulite is visible with the naked eye, and its image can be enhanced by using crossed polarizers and a magnifying glass, which will be included with the lab.

The formation of the spherulites over time is depicted in figure 9, for different cooling temperatures.

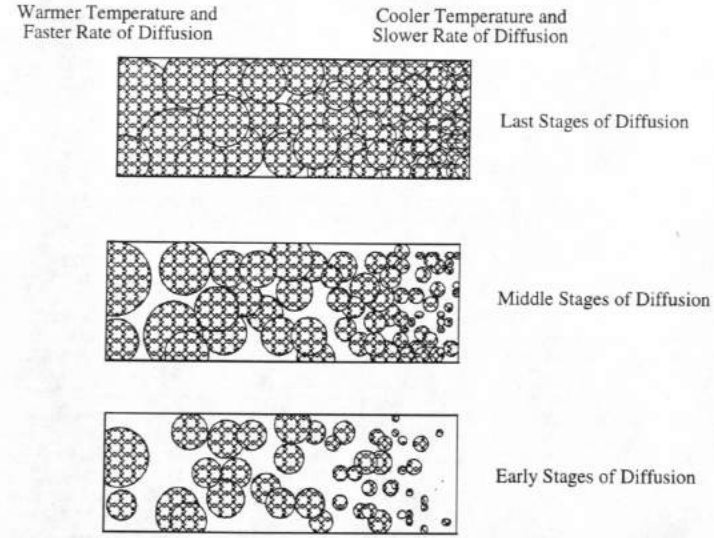


Figure 9. A schematic diagram of polyethylene oxide spherulites. This depicts the condition after melting with slow cooling. The right hand side was cooled quickly and the left hand side was cooled slowly.

appropriate for a given topic. In most cases a concept will be covered by multiple explorations. Also, each exploration may incorporate several polymer concepts. For example the concept of time and temperature superposition is covered by the spherulite gradient, the elastomer, the Voight-Maxwell models, and the Tg homopolymers, while the temperature responsive polymer objective covers cohesive energy density (CED), macromolecular effects, steric hindrance, and optical properties. See table 1.

In addition to matching the objectives to their textbook application and writing our own Lableess Lab™ curriculum guide, we will determine the best modeling and simulation parameters for the matching concepts and objectives. Drs. Nairn and Magda, both polymer characterization specialists, will assist during this portion of Phase II. Table 3 is an example of the type of chart we envision. We call it the periodic table of polymer concepts. During Phase II we will expand this chart to include all of the concepts and explorations shown in table 1.

19) Prototype Assembly: In consultation with scientific packaging and safety experts, we will assemble the materials, equipment, and instructions necessary for the student to safely and quickly find the materials necessary for each exploration.

20) Prototype Evaluation: The Lableess Lab prototypes will be sent for evaluation to a few prominent polymer instructors. Dr. Allan Hoffman, Dr. Jules Magda, Dr. Ferdinand Rodriguez, Dr. Charles Carraher, Dr. John Nairn, and Dr. John Droske have agreed to serve as consultants. See attached letters in budget section. This evaluation procedure will accompany our presentations at national conferences as a portion of the dissemination procedure

The principle investigator will attend the annual meetings of the American Chemical Society (Division of Chemical Education), National Science Teachers Association, and the National Educators Workshop. (At least two seminars, presentations, or posters each year) in an effort to determine necessary modifications for complete instructor/student satisfaction and effectiveness.

In his speech one year ago to the students of Rose-Hulman Institute of Technology, Dr. Collens discussed the use of computer based education systems and how their use can provide students with more direct experience and feedback, engaging students more actively in the learning process. He states that, "University life in the first half of the 21st century will be much different that the last half of the 20th century. ... Powerful computing technology will merge with advances in the cognitive sciences to release the real power of computers in instruction." (60) Certainly these advances must be accompanied by parallel advances in the laboratory teaching method. Already several manufacturers have developed virtual reality laboratories for computer use; we feel that the integration of real reality labs with computer instruction will benefit the student and the instructor.

(f) Commercial Potential (Summary)

A recent article in *The Futurist* describes the educational institution of the future as one without walls (61). It states, "In the future, technologies will allow learning to take place virtually everywhere." At a site called "the plug-in school" teachers could check out learning modules, such as the Lableess Lab ™ in Polymer Materials, for a particular lesson. We will package our explorations in both individual formats and in class size formats.

A recent issue of POLYED discussed the development of a set of video lessons on introductory polymer science (62). During a discussion with the video series designer and instructor, Dr. Richard Stein, the possibility of utilizing the Lableess Lab™ personal laboratory was encouraged.

Dow-Corning Corporation, 3M Corporation, and E.I. Dupont DeNemours and Company, to note only three well known examples, support continuing polymer and chemistry education. During a recent discussion Tom Tucker, the supervisor of technical education at 3M, suggested that the Lableess Lab™ in Polymer Materials could be of interest to many of the 8000 students that participate in continuing education classes offered on site each year. With $15 billion in sales and 10,000 professional employees, the 3M Corporation alone represents a large market.

13) Cross-link Density Study: A common cross-linking demonstration will be modified to allow the student to generate a cross-linking gradient. Poly(vinyl alcohol) (PVA) and poly(vinyl acetate) (PVAc) can be cross-linked at room temperature by mixing their water solutions with a water solution of sodium tetraborate. During student explorations, adjustments can include the concentration of tetraborate ion in solution, the concentration of (PVA) or (PVAc) in solution, and the amount of filler materials added. Figure 10 shows the expected chemical reaction. Trapped water in between the cross-linked chains gives the polymer its characteristic gel-like quality.

As the concentration of tetraborate ions [$B_4O_7^-$] for several cross-linking explorations is varied, the student can estimate the cross-linking density (number of bonds per chain) and its effect on the gel state of the polymer. There will be a critical cross-link density where the polymer will form the gel state and where it will stay in its liquid state.

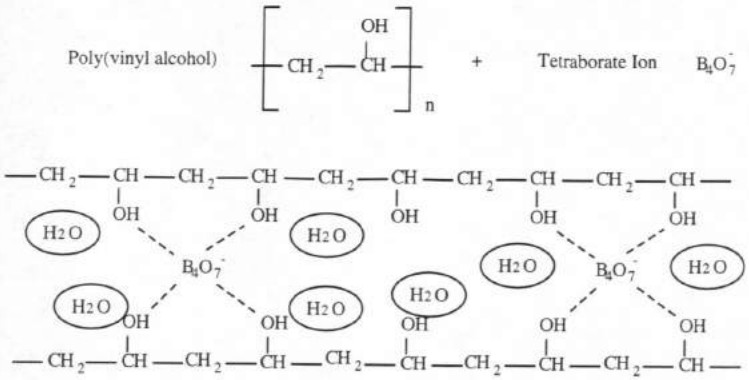


Figure 10. Cross-linking due to dipole-dipole attraction. Both the number of cross-links and the number of water molecules trapped in between the cross-links strongly affect the mechanical properties of the polymer gel..

14) Elastomers: Elastic polymers act like mechanical springs and will recover to their original length after repeated strains. When the polymer molecules are stretched, the decrease in entropy causes the polymer system to give off energy as heat.

The equation for free energy is $\Delta G = \Delta H - T\Delta S$. During stretching ΔS is less than zero, during contraction ΔS is greater than zero, T is always greater than zero, and ΔH is zero for an ideal elastomer. (This case holds if the strain or stretching of the polymer chains is very fast.) If ΔG is greater than zero, the reaction gives off heat, if ΔG is less than zero the reaction absorbs heat.

According to LeChatelier's principle, an external addition of energy (heating) should then cause the polymer molecules to recoil or recover their elastic strain, and an external removal of heat (cooling) should cause the polymer molecules to stretch or increase their strain. See equilibrium equations for free energy below.

Coiled, random chains (high entropy) <=> Stretched, parallel chains (low entropy) + heat

15) Heat Shrink Materials: Similar to the behavior of elastomeric polymers are a category of polymers called "heat shrink". Except that when *these* polymers contract during heating above their Tg they remain in their contracted state unless heated above their melting point. Their

Table 3. "Periodic Table" of Polymer Science. An example of how polymer concepts can be related to Labless Lab™ explorations with simple scaling equations.

Material System and Concept	Copolymer Gradient	Plasticizer Gradient	Crosslink Gradient	Spherulite Gradient
Molecular Weight and Distribution			$E \propto M.W.$	
Morphology (Crystallinity)				$r = Dt$
Intermolecular Forces		$\Delta G^{im} = G_{12} - (G_1 - G_2)$	$F \propto \frac{1}{d}$	
Cohesive Energy Density/Solubility		$\Delta H^m \propto (\delta_1 - \delta_2)$		
Polymerization	$f(1-F)/F = r_2 - (f^2/F)r_1$		$x = \frac{k_p[M] - k_{sp}[M_\cdot]}{v_i}$	

contraction is irreversible at room temperature. Figure 11 depicts a heat shrink polymer in its room temperature and its heated states.

Figure 11. Polymer "A" is in its expanded state. Upon heating the polymer will contract as in diagram "B".

During explorations of this polymer the student will measure dimensional changes and volumetric changes to determine preferential shrinking directions or reduction of free space. Variables include temperature, heating rate, and initial conditions. During Phase II we will establish suggested parameters for each of these variables and relate them to the observable changes in the polymer sample. Scaling equations can be used to calculate specific parameters of the polymer including its modulus, Tg, Tm, free volume, and processing procedure.

16) Polymerization: We will utilize an aqueous redox polymerization (probably hydroxyethylmethacrylate (HEMA)) to demonstrate the formation of long polymer chains from short monomer molecules. The kinetics of chemical reactions will be explored including the effects of temperature and concentration on polymerization rate and polymer chain length. As well as the actual chemical demonstration we will utilize a common macroscopic physical polymerization involving paperclips and marbles. By placing several hundred *slightly unbent* paperclips (monomers) in a box and shaking the box, some of the clips will connect (polymerize). These explorations demonstrate how increased energy or temperature (more shaking) and collisions (more marbles) can increase the reaction rate and affect the chain length.

17) Other material ideas: 1) A study of molecular weight distribution possibly using several samples of a single polymer of various molecular weights. 2) A study of gel permeation chromatography (GPC), this will tie in well with objective 4 cross-link gradient. 3) In conjunction with protein research continuing at Protein Solutions, Inc. a study of biopolymers could be included.

18) Curriculum Development: We will consult with several leading polymer text authors and instructors for assistance in the development of the laboratory curriculum. Those who have agreed to consult include Dr. Ferdinand Rodriguez of Cornell University, Dr. John Droske, Professor of Chemistry and Director of POLYED at the University of Wisconsin-Stevens Point, Dr. Jules J. Magda, Professor of Chemical Engineering at the University of Utah, Dr. Allan Hoffman, Professor of Chemical and Bioengineering at the University of Washington, and Dr. John Nairn, Professor of Materials Science and Engineering at the University of Utah.

During Phase II research we will confirm that each essential concept of introductory polymer science is covered by at least one of the Labless Lab™'s explorations. We will match specific explorations with the concepts listed in the most widely used introductory polymer texts as well as the syllabi from the instructors who have written and used them. With this information, any instructor of polymer science will be able to quickly determine which explorations will be

(Commercial Potential continued)

A survey of several popular polymer science introductory textbook authors revealed approximate sales of 10,000 to 15,000 books each year (19,21,49-54). If the Lableess Lab™ were to accompany these texts, we could expect similar sales figures once major distributors were contacted.

The distance learning market is expanding at a fast pace. Several national organizations exist to facilitate distance learning capabilities. The United States Distance Learning Center (USDLA), which publishes *ed at a distance*, and the National Distance Learning Center (NDLC) are two examples. A recent article in the journal *Teleconference* describes a preliminary market analysis of distance learning service needs. Several recommendations were identified including the need for "experiential learning," a need our Lableess Lab™ could satisfy. We are consulting with the Virtual University community concerning their needs and the application of the Lableess Lab™ for their offered courses. The PBS's definitive guide to distance learning, *Going the Distance* (14), discusses major issues related to developing a distance learning program, and points out the special needs of the distance taught laboratory sciences.

TeleCons, a newspaper for interactive telecommunications, recently reported that sales in the teleconferencing industry (both video and audio) would top $3.6 billion in 1994, up from $2.3 billion in 1993, and $1.8 billion in 1992. They also reported over 15,000 two-way interactive videoconferencing rooms operational in North America by the end of 1993, up from nearly 6,000 at the end of 1992 (63).

There is growing interest in the concept of the virtual university, the university without walls. In a sense this was pioneered by the Open University of London and by the National Technological University located in Fort Collins, Colorado. The discussion and interest has picked up dramatically in recent years. President Dr. Warren Baker of California Polytechnic University in San Luis Obispo has been an ardent spokesperson for the virtual university, as has Governor Michael Leavitt of the State of Utah. There has even been talk of international virtual universities and long distance learning (65-67).

As these virtual activities develop there will be greater and greater need for mechanisms by which *real* interactive, experiential, education can be achieved. That is exactly where our Lableess Lab™ concept and project fits in. In spite of all the interest in software, CD ROM, and other technologically-based learning materials, conventional textbooks remain the mainstay of education. Textbooks are now a nearly $3 billion market at the elementary and high school level, and nearly $3 billion at the college level, and these markets are increasing at roughly 5% per year, particularly at the college level (68).

An article in the March 1994 issue of *Ed Journal*, surveys the use of telecommunications in K-12 classrooms. The computer and its networking capabilities are a much sought after tool; current limitations on hardware availability seem to be the most quoted barrier to further expansion of computer usage in the K-12 classroom (64). The ACS is encouraging high school and college science departments to include polymer components into their chemistry curriculums. We propose developing a specialized, abbreviated Lableess Lab™ in Polymer Materials with a chemistry emphasis for this application. This kit would be a small component of the larger Lableess Lab™ in Polymer Materials and our planned kit for a Lableess Lab™ in Chemistry.

PSI is now working on a preliminary marketing plan and Phase III strategy for this evolving product. The Phase III financing mechanism and the marketing plan will be presented in detail in Appendix 2 to this proposal, Commercial Potential, which will be submitted approximately November 15, no later than 90 days following the submission of the technical Phase II proposal, i.e., this document.

The marketing plan will include an alliance with one or more major textbook publishers, and/or an alliance with one or more major software/simulation/CD ROM publishers, and/or an alliance with one of the major laboratory equipment and supply firms. Our goal is to have the Lableess Lab™ marketed, together with existing textbooks, in college and university bookstores throughout the nation, and eventually the world. We also expect that it will be marketed through those computer, educational, and related supply outlets which tend to feature computer, video, and tele-based educational materials. We further expect it to be marketed through the normal science supply/kit mechanism, the major source of materials and equipment for traditional college and university laboratories. In addition, the Technurios™ which will be developed and sold independently of the main kits, will be marketed through science and education-related gift shops,

CONSULTANT'S INFORMATION

Dr. John Droske directs the Poly-Ed Information Center at the University of Wisconsin, Stephen's Point. Poly-Ed is an organization of polymer scientists and engineers derived primarily from among the membership of the American Chemical Society Divisions of Polymer Chemistry and Polymeric Materials: Science and Engineering. This group has been very influential in increasing polymer awareness and content in chemistry courses, including the publication of a wide range of articles and materials in the *Journal of Chemical Education*. Poly-Ed sponsors a variety of projects related to enhanced polymer education. Poly-Ed provided a grant to Dr. J.D. Andrade, Professor of Materials Science at the University of Utah, for an initial feasibility study on the Lableess Lab™ in Polymer Science. It was this initial feasibility study that led to the successful Phase I proposal and thus to this Phase II application. Dr. Droske's experience with Poly-Ed and his knowledge of the polymer science education field will be invaluable in helping us assess the efficacy and effectiveness of the Lableess Lab™ for Polymer Materials.

Dr. Allan Hoffman is Professor of Chemical Engineering and Bioengineering at the University of Washington and is a pioneer in the development of materials for bioengineering and medical diagnostic applications. Although he has immense experience and background in all areas of polymer science and engineering, his activities in the last 10 years dealing with the development of "intelligent" materials for drug delivery and diagnostic applications is of particular interest and relevance to this Phase II application. Dr. Hoffman has worked extensively with thermally responsive polymers, with pH and ionically responsive polymers, and in addition has wide experience in teaching polymer science and engineering at the university level. His insight, critique, and suggestions will be extremely important.

Dr. Ferdinand Rodriguez is Professor of Chemical Engineering at Cornell University and author of one of the most successful and well known polymer science textbooks, *Principles of Polymer Systems* (46). Now in its third edition, the Rodriguez textbook is generally recognized as one of the classic polymer textbooks and is widely used throughout the field. In addition Dr. Rodriguez has been particularly interested in and effective in developing hands-on demonstrations of polymer concepts and principles. His series of papers in the *Journal of Chemical Education*, and the laboratory experiments and manuals which he has produced, form the mainstay of much of experimental polymer science in the university environment. We are pleased and honored to have Dr. Rodriguez join us as an advisor on this project. His interest in and emphasis on engineering applications of polymers will also provide a polymer technology component to the Lableess Lab™, enhancing its relevance in engineering and technology circles.

Dr. John Nairn is Professor of Materials Science and Engineering at the University of Utah and teaches the graduate polymer science courses together with Dr. Richard Boyd and others in the Department. Dr. Nairn is an expert on composite materials and has paid particular attention in his polymer science courses to developing simulation software to help illustrate and model important polymer concepts and principles. He will be especially helpful in providing the educational materials and analysis to take the Lableess Lab™ experiments from what might appear to be simple demonstrations of phenomena or concepts to the next plateau of quantitative analysis, modeling, equation and relationship development, and full understanding and predictability. Dr. Nairn was Dr. Rob Scheer's thesis advisor from 1989 to 1993. During those years Dr.'s Nairn and Scheer developed a close working relationship which continues today with a soon to be published paper based on Dr. Scheer's Ph.D. research. Dr. Nairn recently returned from a Fulbright Fellowship to the Imperial College of London for advanced study of polymer composite materials.

Dr. J. Magda, Associate Professor of Chemical Engineering and Materials Science at the University of Utah, is an expert on polymers in solutions, including the dimensions, shapes, and conformations of polymer chains in solution. He deal with such topics as viscosity, light scattering, and polymer processing. Dr. Magda has also taught the basic undergraduate polymer science and engineering course a number of times, as have Drs. Nairn and Andrade.

catalog sales and museum and science center gift shops, and related mechanisms with which we are now familiar as the result of the marketing of our bioluminescence science educational products, Galaxsea™ and Night-Life™.

Regarding the funding for Phase III:

1) We anticipate an appropriate mix of equity investment targeted to the production, marketing, and commercial development of this specific project.

2) A contract with one or more distributors or customers for specific numbers of Lableess Lab™: Polymer Materials kits to be produced and shipped in 1997 and 1998 (69).

3) Continued investment by PSI's principals and existing shareholders as it is clear that the Lableess Lab™ line will be PSI's major source of revenues in the 1996 -1999 time frame. PSI is now planning a small, initial public offering in 1997 or 1998 which would provide the financial resources to expand the Lableess Lab™ line of products, the Technurios™ derived from those products, and several new science education products. Our goal is that by the end of the current decade we will be recognized internationally as the source of personal kits and experiments for a wide range of science and engineering college and university courses and for high school courses as well.

PSI is deeply committed to continuing the development, full-scale marketing, and the expansion of the Lableess Lab™ in Polymer Materials, and further Lableess Lab™ products.

(g) Principal Investigator and Senior Personnel

Dr. Robert Scheer, Principle Investigator, received his Ph.D. in materials science and engineering in 1993. He is Principle Investigator of PSI's Lableess Lab™ in Polymer Materials, an SBIR Phase I from the National Science Foundation. Dr. Scheer has had considerable experience in the teaching of college level chemistry, and is maintaining a part-time adjunct chemistry instructor position at Salt Lake Community College. This minimal classroom involvement is important in order to keep up with current student concerns and to work with students on their needs for a personal laboratory. This experience is very important to the development of the Lableess Lab™. 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 (page 2 of 13 in Part III - SBIR PHASE II Process of NSF 94-81 (new)).

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 junior 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. Joe regularly teaches Materials Science and Engineering 519, the basic undergraduate polymer course. It was his experience and examination of the needs of this course that lead to the Lableess Lab™ in Polymer Materials.

(h) Consultants and Subcontracts

Consultants as described above for evaluation of prototypes and curriculum development. Formal consultants are Dr. John Droske, University of Wisconsin-Stevens Point (Director, POLYED National Information Center for Polymer Education), Dr. Allan Hoffman, University of Washington, Dr. John Nairn, University of Utah, Dr. Charles Carraher, Florida Atlantic University, Dr. Jules Magda, University of Utah, and Dr. Ferdinand Rodriguez, Cornell University. See letters of agreement as submitted with budget.

Dr. Charles Carraher is Dean of the College of Science at Florida Atlantic University and is co-author of one of the most well-known and widely distributed polymer science textbooks, *Polymer Chemistry: An Introduction* (49), this book is considered the bestseller among basic undergraduate polymer science texts. He too has been heavily involved in effective undergraduate polymer education, including the development of hands-on, experiential, laboratory components. He is the co-chair of the Polymer Education Committee and on the board and founder of the Intersocietal Polymer Education Committee. His experience and insight will be vital to testing and enhancing the Lableess Lab™ in Polymer Science.

(i) 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, a plasma chamber, ovens, measuring electronics, Macintosh and IBM computers with appropriate sensor and monitoring interfaces, optical microscopes, and other general routine laboratory equipment.

PSI is an industrial 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.

(j) Current and Pending Support of Principal Investigator and Senior Personnel

Robert J. Scheer:

1. Current Support:

1) NSF Phase I SBIR, The Lableess Lab™ in Polymer Materials (ends 8/15/94). This proposal is the Phase II application.

2. Pending Support:

1) NSF STTR, Direct Reading, Quantitative Biosensors for ATP-Dependent Processes (9/1/94 - 8/30/95) five man months.

2) NSF Phase I SBIR, A Lableess Lab™ for Chemistry; period 1/1/95 through 6/30/95.

3) NSF Phase I SBIR, Marine Phytoplankton in Sealed Environments; period 1/1/95 through 6/30/95.

4) NSF Phase I SBIR, Sensing Nicotine in Secondary Smoke Using Bioluminescence; period 1/1/95 through 6/30/95.

5) NSF Phase I SBIR, An adjustable Thermal Gradient Surface Device for Materials and Chemical Analysis; period 1/1/95 through 6/30/95.

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.

E. REFERENCES:

1. Andrade, J.D.; Scheer, R.J. "Applying 'Intelligent' Materials for Materials Education: The Lableess Lab™", *Proceedings of the Second International Conference on Intelligent Materials*. C.A. Rogers, G.G. Williams eds. Technomic: Lancaster, PA. 1994.

2. Polyed Information Center and Polymer Education Newsletter, Prof. John Droske, Dept. of Chemistry, University of Wisconsin - SP, Stevens Point, WI 54481.

3. Allan, N.S.; McKellar, J.F. "Polymer Photooxidation." *J. Chem. Educ.* **1979**, *56*, 273.

4. Henderson, G.V.S.; Campbell, D.O.; Kuzmicz, V.; Sperlin, L.H. "Gelatin as a Physically Cross-linked Elastomer." *J. Chem. Educ.* **1985**, *62*, 269.

5. Stroebel, G.G.; Whitesell, J.A.; Kriegel, R.M. "Slime and Poly(Vinyl Alcohol) Fibers." *J. Chem. Educ.* **1993**, *70*, 893.

6. Pearce, E.M.; Wright, C.E.; Bordoloi, B.K. "Competency Based Modular Experiments in Polymer Science and Technology." *J. Chem. Educ.* **1980**, *57*, 375.

7. Sherman, B.C.; Euler, W.B., Forcé, R.R. "Polyaniline-A Conducting Polymer." *J. Chem. Educ.* **1994**, *71*, A94.

8. Seymour, R.B. "Recommended ACS Syllabus for Introductory Courses in Polymer Chemistry", *J. Chem. Educ.* **1982**, *59*, 652.

9. Mathias, L.J. "Lab for Introductory Polymer Courses", *J. Chem. Educ.* **1983**, *60*, 990.

10. Woodward, L. *Polymers All Around You.* (POLYED)Terrific Science: Middletown, OH.

11. "Solving Tommorow." Society of Plastics Engineers, Inc. Publication

12. Institute for Chemical Education, Dept. of Chemistry, University of Wisconsin - Madison, 1101 University Ave., Madison, WI 53706-1396.

13. Walker, J. "The Amateur Scientist." *Scientific American*. February **1990**, 100.

14. Toby Levine Communications, Inc. Bethesda, Maryland. *Going the Distance: A Handbook for Developing Distance Degree Programs Using Television Courses and Telecommunications Technologies*." Annenberg/CPB Project and PBS Adult Learning Service, Corporation for Public Broadcasting and Public Broadcasting Service. 1994.

15. Watkins, B.T. "Uniting North Dakota." *The Chron. of Higher Ed.* **1994**, Aug. 10, A17.

16. Frand, J. "The Academic Potential of Distance Learning." **1994**, *3*, 53.

17. Bennett, J.G. " The Need for Continuing Education." *C&EN*, **1994**, July 11, 36.

18. We are of course concerned about students who may have hearing or vision disabilities. We are considering low cost means of converting visual (optical) signals to audio for the visually handicapped. This is a part of a project with the new Utah Science/Arts Center's exhibits on "Seeing Sound" and "Hearing Light." We expect that future versions of the Lableess Lab™ can emphasize audio or visual readouts.

19. Billmeyer, F.W. *Textbook of Polymer Science*. John Wiley and Sons: New York. 1984.

39. Lloyd, B.W. *J. Chem. Educ.* **1992**, *69*, 866.

40. Okuzaki, H.; Osada, Y. "A chemomechanical Polymer Gel with Electrically Driven Motility." *Journal of Intelligent Material Systems and Structures*. **1993**, *4*, 50-53.

41. Suzuki, M.; Hirasa, O. "An Approach to Artificial Muscle Using Polymer Gels Formed by Micro-Phase Separation." *Advances in Polymer Science*. **1993**, *110*, 242-253.

42. Osada, Y.; Ross-Murphy, S.B. "Intelligent Gels." *Scientific American*. May 1993, 82-87.

43. Edmund Scientific. 1994 Scientific Products Catalog.

44. Ohm, R.F. "Polynorbornene: the Porous Polymer." *Chemtech*. March **1980**, 183-187.

45. Ohm, R.F.; Vial, T.M. "A New Synthetic Rubber Norsorex® Polynorbornene." *J. Elast. and Plastics*. **1978**, *10*, 150-162.

46. Sakurai, K.; Takahashi, T. "Strain-Induced Crystallization of Polynorbornene." *J. Appl. Polymer Sci.* **1989**, *38*, 1191-1194.

47. Echigo, S. et al. "Development of a New Transvenous Patent Ductus Arteriosus Occlusion Technique Using a Shape Memory Polymer." *ASAIO Transactions*, **1990**, *36*, M195-M198.

48. Kimura, H.; Teraoka, F. "Application of Shape Memory Polymer to Dental Materials (1) - Physical Properties" *J. Osaka, Univ. Dent. Sch.* **1986**, *26*, 59-65.

49. Cowie, J.M.G. *Polymers: Chemistry and Physics of Modern Materials*. Chapman and Hall: New York, 1991.

50. Cambell, I.M. *Introduction to Synthetic Polymers*. Oxford University Press: New York, 1994.

51. Rodriguez, F. *Principles of Polymer Systems*. McGraw-Hill: New York, 1982.

52. Boyd, R.H.; Phillips, P.J. *The Science of Polymer Molecules*. Oxford University Press: New York, 1993.

53. Munk, P. *Introduction to Macromolecular Science*. John Wiley: New York, 1989.

54. Carraher, C. *Polymer Chemistry*. Dekker: New York, 1992.

55. Cralick, Michael. Wild Goose™, Inc. Personal communication, August, 1994.

56. Protein Solution. Inc,'s interests and goals are education– our Technurios™ and other novelty products will stimulate curiosity and interest in learning more about science and technology.

57. Committee on Polymer Science and Engineering. "Polymer Science and Engineering: the Shifting Research Frontiers." *TRIP*. Vol. 2, No. 8, Aug. 1994, pp.256-258.

58. Flinn Scientific, 1994 catalog. Batavia, Il.

59. "Hydro-Grow." by Stuf, Denver, Colorado.

60. Collens, L., President, Illinois Institute of Technology. "The Future of Engineering and Science Education." *Vital Speeches of the Day*. 368-372. Delivered to Rose-Hulman Institute of Technology in Terra Haute, Indiana, September 1, 1993.

Budget Explanation Page

Permanent Equipment: Two peristaltic pumps @ $1,500: These will be used to develop linear copolymer gradients for objective 5. Carver mold press @ $1,000: this system will be used to form the polymer net shapes in objectives 2, 3, 5, 9, 11, and 15. Vacuum Oven @ $1,500: Used for analytical and heat treatment tests on polymers for objectives 1, 2, 3, 5, 7, 9, 12, 13, 15 and 16. Video microscope (PSI will match cost) @ $3,000/2 = $1,500: to quantitatively measure spherulite growth in objective 12. Microgram Balance @ $2,000: this balance will be essential for all quantitative studies including those for objectives 2,3,4,5,6,7,8,9,11,13, and 16. Equipment will be purchased over the two year grant period.

Objectives:

See Phase II Research Objectives

Travel: 1995-6 NSTA Annual and Regional conferences, 1995-6 Annual ACS Conferences, 1995-6 National Educators Workshops, also travel to consult with out of town consultants whose teaching schedules do not allow travel.

Materials and Supplies: Much of this cost will go toward raw and manufactured materials required to develop and construct the prototypes which will be disseminated to consultants for evaluation, and for participants in a summer evaluation period with selected polymer/chemistry instructors*.

Publication Costs/Documentation/Dissemination: Both publication in the *Journal of Chemical Education*, and *Journal of Intelligent Materials*. Includes estimated cost of assembling and mailing prototype kits to each of the evaluation consultants. Some of the funds will be used to run a summer workshop with selected polymer/chemistry instructors.

Consultant Services: Cost to include payment for the time, travel, and services. Formal consultants are Dr. John Droske, University of Wisconsin-Stevens Point (Director, POLYED National Information Center for Polymer Education), Dr. Allan Hoffman, University of Washington, Dr. John Nairn, University of Utah, Dr. Charles Carraher, Florida Atlantic University, Dr. Jules Magda, University of Utah, and Dr. Ferdinand Rodriguez, Cornell University. The out of state consultants will receive $1,800 each for expenses and honorarium; in state consultants will receive $900 for honorarium. All paid over the period of two years. See the following signed agreements.

* We hope to invite several local and regional high school and college instructors to a summer training program each of the two years of the grant period. The program will be designed to evaluate the value of our Lableess Lab™ and to encourage use of hands-on explorations in the high school and college science classroom. The funds for this program will come from both the Materials and Supplies and the Publication Costs/Documentation/ Dissemination budget categories.

University of Wisconsin-Stevens Point
College of Letters & Science
Department of Chemistry
Stevens Point, WI 54481-3897 (715) 346-2888
John P. Droske (715) 346-3771

August 31, 1994

Dr. Robert J. Scheer
Protein Solutions, Inc.
350 West 800 North, Suite 218
Salt Lake City, UT 84103

Dear Dr. Scheer,

Thank you for contacting me with information about your polymer education project. I would be glad to assist your efforts by serving as a consultant during Phase II in the development of your "Lableess Lab".

I have taught a lecture and lab course in polymer chemistry here at the University of Wisconsin-Stevens Point for more than ten years. Currently I am serving as the principal investigator on a large polymer education project funded by the National Science Foundation (see Droske, J. *J. Chem. Ed.* **1992,** *69*, 1014). The focus of this project is the development of polymer lecture concepts and lab experiments for inclusion in general chemistry courses. The results of this project will be published by the POLYED Center in 1995 as a volume entitled "Integrating Polymer Topics into Core Chemistry Courses".

As Director of the POLYED National Information Center for Polymer Education, I have interacted with a wide variety of polymer educators and have found that many polymer courses do not have a lab component. Your "Lableess Lab" efforts should help to enhance the hands-on learning for those polymer courses having only a lecture component.

I look forward to working with you and Professor Joe Andrade on this important effort.

Sincerely,

John P. Droske
Professor of Chemistry
Director, POLYED National Information Center for Polymer Education

FLORIDA ATLANTIC UNIVERSITY
P.O. BOX 3091
BOCA RATON, FLORIDA 33431-0991

COLLEGE OF SCIENCE
OFFICE OF THE DEAN
(407) 367-3700

September 1, 1994

Dr. Robert Scheer
Protein Solutions, Inc.
350 West 800 North, Suite 218
Salt Lake City, UT 84103

Dear Dr. Scheer,

Thank you for the information on your polymer education project. I would be pleased to serve as a polymer education consultant during the Phase II development of your "Lableless Lab." As you are aware, I am co-author of a textbook "Polymer Chemistry: An Introduction" that holds a major market share. Further, I am co-chair (with John Droske) of the Polymer Education Committee and on the board and a founder of the Intersocietal Polymer Education Committee. I have also had a long history of teaching polymers at the introductory levels.

I look forward to working with you and Professor Joe Andrade on this important project.

Thank you.

Yours truly,

Charles E. Carraher, Dean
College of Science

/yw

CORNELL
UNIVERSITY

School of Chemical Engineering

Dr. Robert J. Scheer
Protein Solutions, Inc.
350 West 800 North, Suite 218
Salt Lake City, UT 84103

August 25, 1994

Dear Dr. Scheer:

Thank you for the information on your polymer education project. I would be very happy to serve as an education consultant during the Phase II development of your Lableless Lab™ in Polymer Materials. I have been teaching polymer courses for the past 35 years and I am the author of the textbook *Principles of Polymer Systems*. I certainly hope you will be able to establish the modular laboratory which you have described to me.

Sincerely,

Ferdinand Rodriguez,
Professor

SALT LAKE COMMUNITY COLLEGE

4600 South Redwood Road / P.O. Box 30808 / Salt Lake City, Utah 84130-0808
Telephone (801) 957-4111 FAX (801) 957-4444

Dr. Donald Senich
National Science Foundation
4201 Wilson Blvd.
Arlington, Va. 22230

May 16, 1994

Dear Dr. Senich:

Dr. Robert J. Scheer is currently teaching chemistry classes on a part-time basis for us. As an adjunct faculty member he is not eligible to submit research proposals or receive research grants as an agent of Salt Lake Community College.

If you have any questions please let me know.

Sincerely,

Davis V. Ballard
Division Chair
Math/Physical Science

University of Washington
Center for Bioengineering, FL-20
Seattle, WA. 98195

Phone: 206-543-9423 Fax: 206-543-6124

September 3, 1994

Dr. Robert J. Scheer
Protein Solutions, Inc.
350 W. 800 N.
Suite 218
Salt Lake City, UT 84103

Dear Dr. Scheer,

Thank you for the information on your polymer education project. I am happy to serve as a consultant to you on the development of your Labless Lab in Polymer Materials during the Phase II development of this project. I taught my first polymer course in 1958, and have been teaching polymer courses for over 33 years. I have spent most of my career doing research on polymers, as well. I look forward to working with you and Dr. Joe Andrade on your interesting and challenging goals.

Sincerely yours,

Allan S. Hoffman
Professor

Protein Solutions, Inc. (PSI)
Science Education Innovators

Dr. J.D. Andrade
Protein Solutions, Inc.
350 West 800 North, Suite 218
Salt Lake City, UT 84103

September 6, 1994

Dear Joe,

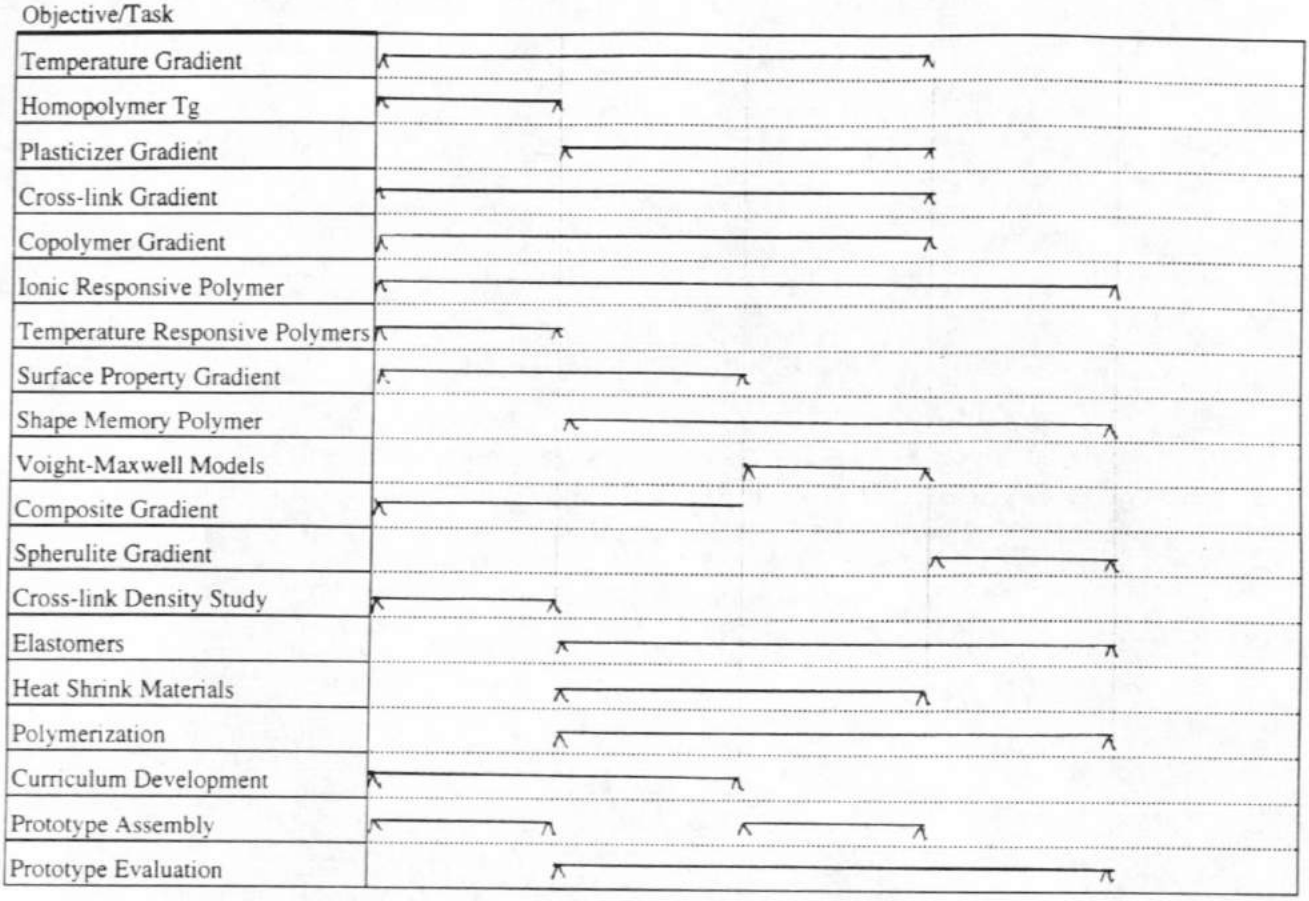
I agree to continue serving as principal investigator on our Labless Lab™ in Polymer Materials project for the duration of Phase II funding, if received, at the rate of $45,000 per year. I expect to be working at a time commitment of one-half time (i.e. 12 man-months over a period of two years.)

Sincerely,

Rob

Robert J. Scheer

Appendix 1. Milestone Chart



Months:	**0**	**6**	**12**	**18**	**24**
Effort:					Cumulative
Key Personnel	5	5	5	5	20
Consultant	0	1/5	1/10	1/10	2/5
Subcontracts	0	0	0	0	0
Estimated Expenditures:					
Key Personnel	19,750	19,750	19,750	19,750	79,000
Consultants	0	4,500	2,250	2,250	9,000
Subcontracts	0	0	0	0	0
Perm. Equipment	5,000	2,000	2,000	0	9,000